Proceedings of the Seminar on

REMOTE SENSING IN MARINE RESOURCES

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Edited by

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Foreword

The Space Research Programme in India is applications oriented and the decision to launch an Indian Remote Sensing Satellite IRS-1, in 1986, is a major step forward. India is a vast country, full of resources and it has been recognised that for the management of these resources timely information is an important factor. Space based remote sensing technique promises such timeliness and for a National Natural Resources Management System (NNRMS) it is envisaged to have a hybrid information system consisting of an optimum mix of remote sensing based system as well as conventional systems.

Marine resources development, specifically, Fisheries development is one of the major areas demanding immediate attention. In this field work carried out in other countries have shown that remote sensing can be successfully used in mapping and monitoring of ocean features like thermal fronts, eddies, upwelling, concentration of sediments and biomass. For locating probable areas in the ocean having fish schools such information is very useful. With this in view and for learning the use of remote sensing in marine fish resources a project was carried out in the early seventies, the UNDP/FAO/GOI Pelagic Fisheries Project.

When a decision was taken to plan for an Indian Remote Sensing Satellite, in 1979, a decision was also taken to conduct Joint Experiments with the actual users so as to provide data for optimising the sensor parameters for the IRS as well as jointly develop the operational methodology for different remote sensing applications in the country. One such Joint Experimental Project for Marine Resources and Fisheries Survey has been conducted, in a comprehensive manner, jointly by Central Marine Fisheries Research Institute (CMFRI) of the ICAR, Fishery Survey of India (FSI) of the Ministry of Agriculture and the Space Applications Centre (SAC) of ISRO. The present seminar is planned to discuss and review the results of this joint experiment to help in planning the future work for the utilisation of the IRS-1 data.

The results presented in this proceedings bring out the techniques and methodologies developed for the primary sea truth data collection and extraction and mapping of biological parameters from airborne and spaceborne sensors. Efforts have been made in the difficult area of developing models for atmospheric correction of Nimbus-7 Coastal Zone Color Scanner (CZCS) data to retrieve the phytoplankton pigment. Apart from the CZCS sensor, which is optimised for ocean colour sensing, efforts were also made in the use of Landsat satellite data, which is basically designed for earth resources survey, for fish resources survey.

It is hoped that a long term plan, mutually worked out by all agencies concerned with Marine Resources Survey, will evolve out of these efforts.

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Preface

The seminar proceedings on the role of Remote Sensing in Marine Resources is the outcome of the collaborative efforts between Indian Space Research Organisation, Indian Council of Agricultural Research and Ministry of Agriculture, as one of the projects under Joint Experiment Programme (JEP) (1979-1984). The objectives of this programme were to address the spaceborne sensor requirements under Indian Remote Sensing Programme for the application of detection and mapping locations of marine living resources and also to develop methodologies for the extraction of information related to marine living resources survey from remotely sensed data.

Seminar proceedings in all contain nine papers. These papers essentially cover the following topics in terms of our understanding about the role of remote sensing in marine resources survey:-

1. Biological productivity of the Indian Ocean, developments in fisheries technology and scope of remote sensing techniques in marine fish resources survey.

2. Methods in estimating the optical parameters and their relationship with oceanic/biological parameters.

3. Ocean colour mapping from airborne and spaceborne sensors

There are three overview papers which cover a detailed discussion on biological productivity of the Indian Ocean, role of remote sensing in fish resources survey and the scope of Indian Remote Sensing Programme in marine living resources. A detailed understanding of optical processes in remote sensing of ocean colour, relationship between optical and oceanic/biological parameters has been brought out using sea truth data collected during the period preceding South West monsoon i.e. October, November and December 1981 and November 1982 in oceanic waters off Cochin. This area is well known for the occurrence and abundance of pelagic shoals of **oil sardine** and **mackerel.** Role of airborne sensors and spaceborne sensors on **Landsat** and **Nimbus-7** satellites, have been discussed in detail towards extraction of information related to fish resources survey.

We are extremely grateful to Director, Space Applications Centre (SAC/ISRO) and Director General, Indian Council of Agricultural Research (ICAR) for their keen interest and support to this programme. Thanks are due to Shri D.S. Kamat, the then Programme Manager, JEP., Prof. P.D. Bhavsar, Associate Director, SAC and Chairman, RSA, SAC and Dr. Baldev Sahai, Associate Director, IRS-Utilisation Programme and Head, Aerial Surveys Ground Truth and Photointerpretation Division, SAC for their guidance and encouragement. Our sincere thanks to colleagues at SAC, Mrs. V. Sudha, Dr. M.B. Potdar and Dr. P.C. Pandey for their support extended to us in many ways. Thanks are also due to Assistant Director of Cochin base, Fishery Survey of India (FSI), Skippers and crew members of **Meena Sachatak, Meena Utpadak** (FSI Vessels), **Cadalmin I & IX** (CMFRI Vessels). NRSA's flight crew and ground truth team's efforts are also thankfully acknowledged. We would like to thank Shri K.H. Bharadiya and Shri R.V. Nair for drawings, Shri K.M. Bhavsar for photographic support and Shri Naresh Bhatnagar for secretarial assistance.

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BIOLOGICAL PRODUCTIVITY OF THE INDIAN OCEAN

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Introduction

India has a long coast line of nearly 6,000 km with the Andaman and Nicobar Islands and the Laccadive Archipelago lying beyond her shores. The geographical position of India with the peninsular portion extending deep into the central part of the Indian Ocean gives her a locational advantage in marine fishing activities. At present though India contributes about 40% of the fish landings of the Indian Ocean, when viewed against the world production of 76 million tonnes of marine fish, her share is only 1.6 million tonnes representing less than 2%. A quarter of a million persons are actively engaged in actual fishing producing annual landings valued at Rs. 650 crores. The industry also provides employment to over 2 million persons. There are about 19000 mechanised crafts which land 35% of the total production. Over 400 crores rupees worth of sea food is exported to different countries annually.

Studies made during the International Indian Ocean Expedition as well as those conducted in the bordering countries reveal that there are several areas in the Indian Ocean which are exceptionally rich in nutrients,chlorophyll, organic production and zooplankton biomass. Consequently these areas could sustain large stocks of fish.

The Indian Ocean has an area of about 75 million square kilometers including Antarctica and some of the adjacent seas, as against 106 million sq km for the Atlantic and 180 million sq km for the Pacific Ocean. The shallow water areas form about 3.1 million sq km in the Indian Ocean. The shelf areas vary in width as well as in surface contour.

The West Coast of India, Ceylon and Pakistan have prominent shelves, whereas on the East Coast the shelves are narrow. The continental shelf area of India between 0 and 50 m depth is estimated at 1,91,972 km^2 and between 0 and 200 m depth at 4,52,060 km^2. The average width of the shelf from the shore-base varies from 32 km off the coast of Andhra Pradesh to 174 km off the coast of Maharashtra. In view of the declaration of 200 miles limit the Exclusive Economic Zone has a total area of 2.02 million sq km.

It is estimated that the rate of primary production on the east coast of India is at 0.63 $gC/m^2/day$ on the shelf and 0.19 $gC/m^2/day$ outside the shelf; the mean value within 50 m depth on the west coast is 1.24 $gC/m^2/day$, the daily rate of production for the rest of the west coast shelf being 0.47 $gC/m^2/day$ and for the oligotrophic regions outside the shelf 0.19 $gC/m^2/day$.

Fishery Potential of the Indian Ocean

The fish landings in the Indian Ocean and the development during the last twenty-five years as compared to the Atlantic and Pacific Oceans present a poor comparison both in the progress and also in the yield ratio in terms of primary production.

It has already been indicated that with an annual net organic production of 3.9×10^9 tonnes for about two-third area of the Indian Ocean, the relative productivity of this area is in no way less than that of the rest of the world oceans. The yield ratio of carbon production as well as the estimated potential yield derived from the results of exploratory surveys indicate that the Indian Ocean can possibly support an annual sustainable yield of 11 million tonnes of fish. The continental shelf area in the Indian Ocean with an area of 3.1 million km^2 accounts for one seventh of the total fish production in the Indian Ocean.

The phytoplankton production for this area has been calculated, as 283 x 10^6 tonnes of carbon. This would be equivalent to 12 x 10^9 tonnes of phytoplankton by wet weight which can sustain an yield of 5 million tonnes which is more than the current production from the Indian Ocean.

According to the Indicative World Plan estimates, the world marine fish of currently exploited species with known techniques in areas already fished may amount to some 120 million tonnes by the end of the century. But the living resources of the sea are not limitless and higher yields will be possible only by envisaging utilisation of unconventional resources or aquaculture. The maximum yield in terms of carbon (which forms about 10% of the wet weight) is only 0.4% of the net primary production in the coastal areas and in the oceanic areas considerably less. When viewed in this light India and the Indian Ocean countries have a challenging task to bridge the gap between the present yield and the possible production. According to some experts an output of 20 million tonnes of fish per annum from the Indian Ocean towards the close of this century is a possibility if planned efforts are put in. It is here the utility of remote sensing technology comes in.

About 40% of the total exploitable stock from the Indian Ocean and adjacent seas could be expected from the Exclusive Economic Zone of the Indian Seas. Some estimates put the potential harvest at 4.5 million tonnes of fish from EEZ which is about three times the present yield. The fish biomass estimated from phytoplankton biomass will amount to 7 million tonnes, that is 0.06% of the wet weight of phytoplankton. Considering the conventional resources and their scope for further expansion of the harvestable stock and non-conventional resources (tunas, horse mackerel, flying fish, myctophids, gonostomatids, deep water prawns and crabs, cephalopods and molluscs) an yield of 5 million tonnes from the EEZ of India is a very reasonable estimate.

Chlorophyll, Primary Production & Relationship with Fishery

Chlorophyll measurements are indicative of bioproductivity of the sea. Sea surface chlorophyll has been considered to be significant in the food relations of oceanic fish resources such as tunas since a steady state relationship is possible between the forage of tunas and the chlorophyll through the food chain. This can be measured either by ***in situ*** or ***in vivo*** methods and recently by remote sensing. In a recent study off Cochin under the Joint Experiment Program between the Space Applications Centre (ISRO), Fishery Survey of India (Ministry of Agriculture) and Central Marine Fisheries Research Institute (ICAR), it was observed that a chlorophyll value of 6.4 mg/m^3 during October followed by a sharp fall during November (1.7 mg/m^3) and December (1.4 mg/m^3) when compared with the available fish catch rate data in the study area for the period from 1977-'81 showed that the mean monthly fish catch rate for October, November and December was directly proportional to the mean quantity of chlorophyll. This suggests that mapping of chlorophyll distribution either from airborne sensors optimised for ocean colour sensing or satellite scanners combined with 'sea truth' measurements will facilitate in better understanding of the resource potential and also the management of the fishery resources.

In the above study it was also found that a non-linear relationship exists between chlorophyll and resource availability which follows a characteristic 'S' shaped growth curve. There is an initial period of slow growth which eventually stabilises below a certain ceiling level. At a certain level it is observed that although there is a marginal increase in chlorophyll-a the fish catch shows an almost twofold increase. It is felt that it would be necessary to conduct synoptic studies of chlorophyll from space platform along with conventional measurements from the sea in order to develop appropriate algorithms so that the chlorophyll estimations can be used as an effective tool in forecasting the fishery resource.

The chlorophyll scanning experiments conducted by aircraft survey in 1980-81 in the Cochin area have shown extreme patchiness in the distribution of chlorophyll from 0.5 mg/m^3 to about 9 mg/m^3. Chlorophyll-a and pheopigments in many areas of the Arabian sea as observed during IIOE is 15 to 25 mg/m^2 for the water column (integrated value). Hence it can be concluded that chlorophyll values for water columns approximating to 15 mg/m^2 can sustain an yield of over 250 kg/ha/year of fish inclusive of both demersal and pelagic resources. Perhaps this could be tested as a sort of general guideline in the estimation of resources based on chlorophyll data for a larger area in future studies involving the application of remote sensing technology of chlorophyll scanning in intensely fished waters on our coasts.

Oceanic features such as chlorophyll distribution, ocean temperature, current boundaries, ocean fronts and slicks can be detected in satellite imagery. Scientifically planned data acquisition on these parameters useful for understanding the seasonal availability and areas of concentration of oceanic fishes such as skipjack and young yellowfin tunas, is an urgent necessity. Further, the use of satellite as a tool for studying migratory patterns of tunas using telemetric tags should also be further explored.

Remote Sensing of Sea Surface Temperature (SST) from multispectral infrared satellite observations offer wide opportunity to deduce the movement of tunas and other pelagic fishes which are largely depending on the variations in SST. Several investigations have been conducted earlier to understand the relation between the variations in sea surface temperature and availability of tunas. Based on the surface isotherms, 'thermal equator' has been identified and the movements of the latter have been studied in relation to the fishing ground of yellowfin tunas in the Indian Ocean. In the tropical areas, localised differences in the sea surface temperature also may help to locate areas of current boundaries, upwelling etc. where forage of tunas accumulate. High surface temperature gradients where the optimum temperature zones are narrow are the places of concentration of albacore and southern bluefin tunas. Most of the species of tunas respond directly to the temperature which forms the lower limit. It has recently been indicated that the 15°C, 20°C and 23°C isotherms are the lower normal boundary of occurrence of albacore, skipjack and yellowfin tunas respectively. As stated earlier, the mapping of the pattern of sea surface temperature by remote sensing from multichannel infrared and microwave satellite observations could be made use of for understanding the distribution and quantification of oceanic pelagics in the Exclusive Economic Zone of India.

It is hoped that the technology of remote sensing will enable locating the movement of fish shoals and their quantification in a more precise manner for better harvesting and management in future.

MARINE FISHERY RESOURCES SURVEY AND ROLE OF SATELLITE REMOTE SENSING IN THE ASSESSMENT OF PELAGIC FISHERY RESOURCES IN INDIA

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Introduction

Marine fishery resources survey as a scheme for providing protein rich food and augmenting fish production was initiated by Govt. of India in 1946 as post war development programme by establishing a deep sea fishing station at Bombay. The deep sea fishing station along with a number of offshore fishing stations at various places began undertaking exploratory fishing along the Indian coast deploying vessels of different sizes but of limited survey capabilities. These were subsequently reorganised under Exploratory Fisheries Project with its headquarters at Bombay in 1974. Consequent to declaration of 200 n.miles Exclusive Economic Zone in 1977, Govt. of India acquired a number of sophisticated vessels with capabilities to conduct survey of pelagic/midwater and demersal resources. In order to carry out systematic survey of the Exclusive Economic Zone fishery resources, during 1984 Govt. of India have reorganised the institution as "Fishery Survey of India" with six zonal bases, viz. Veraval, Malpe, Cochin, Madras, Visakhapatnam and Port Blair.

For taking sound policy decisions and for optimum utilisation, knowledge of fishery resources, its composition, magnitude in time and space is essential. Planned and systematic survey could provide these basic data required for proper management of the fishery resources. Fishery Survey of India through its survey work all along the Indian coast and around groups of islands has established the demersal trawling as a viable commercial/industrial fishing method for exploiting demersal fish and prawn resources. The organisation has also been adopting diversified fishing viz. pelagic/midwater trawling, purse seining, long lining and squid jigging so as to assess the resources at surface, sub-surface and mid levels of sea column. These technologies are being transferred to fishing industry by providing in-vessel and on the job training to the deep sea fishing operatives.

In addition to conducting exploratory fishing and realising the importance of remote sensing of fishery resources especially in the case of pelagic resources, a Joint Experiment Programme on marine fisheries was drawn up during late seventies. It is being executed by the collaborating agencies, Space Applications Centre, Fishery Survey of India and Central Marine Fisheries Research Institute. In this paper an attempt has been made to present the status of marine fishery resources, its survey and role of remote sensing in surveying and managing the resources.

Marine Fishery Resources

Present Status

India has a cost line of about 7500 km including that of its island territories. The continental shelf reckoned at about 183 m depth is approximately 4,42,000 sq km of which about 70% of the area is along West coast. The shelf is generally

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broad along west coast with a maximum width of 340 km off North of Bombay and minimum of 50 km along South Kerala cost. The continental shelf along East coast is relatively narrow and its width varies from a maximum of 180 km off Balasore and 80 km off Point Calimere. The average width along East and West coast may be placed at about 40 and 75 km respectively. The estimated area within the Indian Exclusive Economic Zone is about 2.02 million sq km, 0.86 million sq km (42.5%) along the West coast including Lakshadweep, 0.56 million sq km (27.80%) along the East coast and 0.60 million sq km (29.70%) around Andaman and Nicobar groups of islands (Figure 1).

Resource Composition

India stood 8th in the world in fish production during 1982 with a total of 2.35 million tonnes. As per the provisional estimates an increase of 8% has been recorded during 1983 bringing the total fish production to 2.52 million tonnes (Anon, 1984). The marine fish component has been about 1.3 to 1.4 million tonnes as could be seen from Table 1.

The West coast on an average contributed to 71% of the catches and East coast share has been around 29%. However the present fish production in the country is mainly from the area within 75 m depth.

The marine fish production during the period of past six years from 1977 to 1982 is analysed in terms of its major components demersal and pelagic and depicted in Figure 2. It may be seen that the present share of demersal fish production is comparatively higher (51.2%) than that of pelagic (48.8%). However, with intensive fishing on continental shelf area and further exploitation of pelagic resources in the Exclusive Economic Zone, future may change the pattern and hopefully see a rise in the latter mainly by way of increased landings of tuna and tuna like fishes. The East and West coasts have contrast in the pattern of the two components of marine fishery resources. East coast has been landing more demersal fish (55.9%) compared to its 44.1% pelagic fish landings whereas West coast witnessed 51.6% pelagic and 48.4% demersal fish landings during the period.

Composition of Pelagic Resources

The annual average production of 6,59,369 tonnes of pelagic fish is made up of oil sardine, mackerel, Bombay duck, lesser sardines, ribbon fishes, tuna, carangids, Anchoviella, seer fish, Chirocentrus, Trissocles, Hilsa, other clupeids and other pelagic fishes (Table 2). The aggregate percentage composition of these varieties constituting pelagic fisheries for the period of six years, in India is presented in Figure 3. The maximum contribution to the pelagic fish production is by oil sardine (25.6%), followed by Bombay duck (16.6%) and mackerel and ribbon fish (8,9 and 8.8% respectively). Rest of the varieties ranged between 0.68% (other pelagic fish) and 7.93% (other clupeids).

Distributional Pattern of Major Pelagic Fisheries

Some of the pelagic fisheries have well defined geographical distribution range with marginal increase and decrease from year to year in this range. Figure 4 shows the schematic distributional pattern of these fisheries. The oil sardine and mackerel fisheries coincide in the geographical range and season along the West coast extending from South Kerala to South Maharashtra coast. The Bombay duck fishery, though the species has discontinuous distribution, on West coast extends from South Maharashtra coast to Gujarat coast. It is also present in lesser quantities along upper East coast.

Fluctuations and Migratory Patterns of Pelagic Resources

Among the exploited pelagic fishery resources, a few show unpredictable fluctuations in their year to year landings. To name such resources, oil sardine and mackerel should serve typical examples. Figure 5 shows the variations in the oil sardine landings during different years (1962-1982). Where the fluctuations in the landings are wide and remarkable, the reasons for such variations could not be assigned with certainty. In all probability the success or failure of the fishery are connected with 0-year class individuals, spawning (in turn rainfall) and survival rate (Chidambaram, 1950 and Antony Raja, 1969). Some workers link better fishery with occurrance of *Fragillaria oceanics*, a prominent food item of oil sardine, in blooms (Nair and Subrahmanyan, 1955).

Most of the species supporting pelagic fisheries exhibit shoaling behaviour.The shoals differ in shape and magnitude, so also the shoaling pattern, not only among different species but in the same species. Mobility of the pelagic resources could be judged from the speed of the oil sardine shoals approximating to 5 km/hr (Balan, 1962) and other groups of pelagic fishes like tuna which move at greater speed than the oil sardine shoals.

Resources Survey and Estimates

Demersal Resources Survey

The fishery resources potential based on various direct and indirect methods have been worked out by several workers from time to time, in respect of different sections of the seas around India and for country as a whole. The exploitable yield from the Indian continental shelf has been estimated to be in the range of 2.3 to 2.6 million tonnes based on productivity and fish yield per unit area (Prasad et al, 1970, Jones and Banerji, 1973 and Antony Raja, 1974). George et al (1977) have estimated a potential yield of 4.5 million tonnes, of which 2.5 million tonnes is anticipated from inshore waters (upto 50 m depth) and 1.5 million tonnes from offshore waters upto continental shelf edge and slope. The share of West coast is estimated to about 2.5 million tonnes, East coast 1.4 million tonnes and the seas around Andaman and Lakshadweep groups of islands 0.16 and 0.09 million tonnes respectively. Among different constituents, the pelagic group's potential is placed as 2.1 million tonnes, demersal fishes 1.4 million tonnes, crustaceans 0.3 million tonnes and the cephalopods 0.2 million tonnes. These estimates were made considering the average annual growth rate of fish production, organic productivity and current fish yield from unit area.

The results of the organised survey carried out by Fishery Survey of India during 1948-1974, indicated potential yield of 0.61 million tonnes within 40 fm depth (Joseph, 1974 and Joseph et al, 1975). The organisations's further unique work carried out by deploying identical vessels and using standardised gear for demersal resources all along the Indian coast from 1970-1980 as reported by Joseph (1980), placed the potential yield at 1.7 million tonnes of which 1.06 million tonnes to come from West coast and rest 0.64 tonnes from East coast. The exploration carried out by the Fishery Survey of India vessels in seas around Andamans shows a standing stock of 45000 tonnes of demersal fish (Sudarsan, 1978). Antony Raja (1980) on the basis of tertiary production has estimated the potential yield at 10,39,000 tonnes comprising 8,23,000 tonnes from the present area of exploitation and 2,16,000 tonnes from the areas beyond and upto continental shelf edge in the Bay of Bengal region.

The Indo-Polish industrial fishery survey carried out by Fishery Survey of India chartered vessel M.T. **Murena** projects the resources to the tune of 1.48 lakhs tonnes along North West coast, about 86% of which constitute the group of columnar fishes (Anon, 1979 and Bapat et al, 1982). Among the columnar fishes, *Megalopsis cordyla*, pomfrets and ribbon fishes were obtained in high quantities. Subsequently the results of the operation of **Matsya Nireekshani** along Gujarat coast under World Bank aided project, show the potential yield of demersal fish as 1.34 lakhs tonnes (Anon, 1983).

Recent surveys conducted by large vessels belonging to this organisation indicate rich resources of Indian drift fish - *Psenes indicus*, Bulls eye - *Priacanthus* spp., Black ruff - *Centrolophus niger* from waters upto 450 m depth along East coast as well as West coast of India. The deep sea prawns and lobster resources in significant magnitude along Kerala-Karnataka coast and lower East coast from the depth range 150-450m have also been discovered during the course of survey (Joseph, 1984). New and potentially rich fishing grounds for the resources like perches, carangids and nemipterids in Wadge Bank, Barracuda, perches and pomfrets in the Gulf of Mannar, and mackerel and pomfret along Andhra Pradesh coast have been also located (Somvanshi and Bhar, 1984 and Ninan et al, 1984).

It may be concluded from the foregoing discussions that fairly good picture of the demersal fishery resources within 40 fm depth is made available through the surveys carried out, various left out segments and continental shelf and edge are being explored by Fishery Survey of India and the results are partially published and rest would be on hand in coming years.

Pelagic Fishery Resources Survey

Besides the pelagic fishery resources survey carried out by Fishery Survey of India from few of its bases in past, the earstwhile UNDP/FAO Pelagic Fisheries Project undertook investigations on the pelagic resources along South West coast during 1972-76 (Anon, 1976). The average magnitude of sardine and mackerel on standing stock is estimated to be of the order of about 4,00,000 and 3,00,000 tonnes respectively. Besides, all along the South West coast is "shallow water mix" comprising Scads, Silver bellies and *Ambassis* spp. having 60,000 tonnes potential. Beyond this belt and within 40 m depth, dominant species are the white baits (5,00,000 tonnes) and cat fish and ribbon fish (average stock of 2,00,000 tonnes). Indian ocean has potential of 510-785 thousand tonnes of tuna and tuna like fishes (Silas and Pillai, 1982).

Recent surveys conducted in different sections of the Indian coast by large vessels belonging to Fishery Survey of India resorting to pelagic/midwater trawling, purse seining and long lining have revealed potentially rich resources. The purse seine survey by the vessel **Matsya Varshini** along Gujarat coast has indicated existance of little tuna and frigate mackerel in sizeable quantities. A catch upto 12 tonnes of little tuna was obtained from the above region whereas off Deogarh along Maharashtra coast about 30 tonnes of oil sardine was pursed by the vessel. Dense and frequent shoals were observed along North West coast mainly between 20-40 fm depth during the course of survey. During 1983-84, the vessel conducting the survey along Kerala - Karnataka coast located several shoals of sardine, mackerel, carangids and little tuna between 20-50 fm depth and caught shoals yielding 15 and 14 tonnes of mackerel and oil sardine respectively. Of the 34 sets made, 20 were successful netting 75 tonnes of catch comprising mackerel (34.6%), sardines (18.4%), tuna (8.9%), carangids (11.7%) and others (26.4%). Little tuna shoals of having an estimated weight of 30 tonnes were recorded off Malpe in 40-50 fm depth during May 1984. During February 1985, non-conventional variety, Rainbow runner - *Elagatis bipinnulatus* was caught to the extent of 7 tonnes along with 4 tonnes of carangids, seer fish, Elacate etc., off Muttam (Cape Comorin).

The purse seine survey carried out by **Matsya Darshini** along Orissa - West Bengal coast has exhibited presence upto 65 m depth and recorded predominance of fish forming subsurface shoals.

Tuna and tuna like fishes are being explored from oceanic waters by resorting to long lining from the vessel **Matsya Sugundhi** along South West coast, Bay of Bengal and around Andaman islands. Promising results on pelagic resources of tuna, tuna like fishes and sharks have been obtained since 1981. Tuna comprising yellowfin, skipjack and big eye formed 10% of the catches along South West coast (7°N to 15°N), whereas in equatorial waters (3°S to 6°N), and the Bay of Bengal regions the tuna contributed to 21 and 37% of the catches respectively.

Thus it appears that much remains to be done in the field of pelagic fisheries especially in context of oceanic fisheries. The present pace of exploration for pelagic resources on the continental shelf and upto Exclusive Economic Zone limit needs to be accelerated through acquisition and deployment of large vessels having capabilities of conducting purse seining, long lining, pole and line fishing and midwater trawling. Also, the space technology applications in this regards could be of immense help.

Remote Sensing

Role of Remote Sensing in Assessing Pelagic Fishery Resources

Remote sensing of marine fishery resources is a comparatively recent development in India. The FAO/UNDP Pelagic Fisheries Project had undertaken a few aerial surveys mainly to locate concentration of shoals in photographic form during 1972-74 (Anon, 1975). However, an integrated and systematic attempt involving multi-disciplinary agencies in remote sensing of the fishery resources commenced only with commencement of Joint Experiment Programme in 1980. During the period of the Joint Experiment Programme studies, through their multipronged approach of aerial surveys, ship board experiments and data collection, and fish sampling, some of the basic problems have been solved, relationship between plankton concentration and fish availability is attempted (Narain et al, 1983). Similar attempt has been made to relate tuna catch and plankton concentration while ocean colour mapping by National Aeronautics Space Administration (NASA, 1984). Simultaneously, attempts were on to explore the possibility of using very simple devices which would give an idea about the turbidity of water and plankton concentration *vice versa* fourth-coming crop of fish viz., Forel-Ule and Secchi disc. It has been observed that the spectral signatures data in respect of visible and invisible bands and indirect measurements of chlorophyll-a contents by QSM could give more accurate results. In fact the studies have revealed three spectral channels centered at 445,520/550 and 670 nm will be quite useful in ocean colour sensing. While the sea truth data collection and fish exploration would continue to quantify ocean colour and establish relationship between primary, secondary and tertiary production levels, the data acquired through IRS-1A could be assimilated for understanding various aspects of pelagic fishery. Landsat data has been used in mapping blooms of blue-green algae in Baltic sea (Ulbricht, 1978).

Though the nature and magnitude of some of the pelagic fisheries is partially known, there are some constraints in direct assessment of the resources mainly due to mobility of the resources and greater time involved in collection of resources data. Moreover, the exploited pelagic fisheries are mostly from traditional/artisnal sector and large scale mechanisation and modernisation of the fleet for exploitation of resources in Exclusive Economic Zone will require long lead time. The remote sensing techniques may therefore play vital role in management of the marine fish resources.

Future Prospects

Once the technique is perfected and relationships between various levels of production viz., primary, secondary and tertiary are established, the remotely sensed data could be utilised for (i) studying migratory patterns of the pelagic fish, (ii) preparation of spatial distribution of chlorophyll-a, charts and fishery forecasting, and (iii) eco-system modelling. These informations could be of considerable use in designing and actual conduct of exploratory fishing.

While there is a need for proper assessment and appraisal of exploited pelagic fishery resources, it is essential that new pelagic fish resources and fishing grounds in the extended areas in Exclusive Economic Zone are located for increasing fish production of the country. The satellite data could be used for better understanding migratory patterns of fish especially in our case, the tuna and tuna like fishes, which are fast moving resources to be shared by different countries in their respective Exclusive Economic Zones as well as adjoining areas, if available. Thus the various types of movements (i) regular seasonal migrations, (ii) movements related to growth and development of fish and (iii) dispersions related to environmental factors, will be better understood through the data to be acquired through satellite. The fishery forecasting at certain intervals in respect of individual pelagic fisheries and eco-system modelling and simulations should also become possible eventually.

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Table 1

Annual marine fish landings during 1977-82 (in '000 tonnes).

Year	West coast		East coast		Total
1977	923.22	(73.28%)	336.56	(26.72%)	1259.78
1978	1042.27	(74.26%)	361.34	(25.84%)	1403.61
1979	970.76	(69.92%)	417.62	(30.08%)	1388.38
1980	857.52	(68.61%)	392.32	(31.39%)	1249.84
1981	972.64	(70.56%)	405.82	(29.44%)	1378.46
1982	979.50	(68.95%)	441.12	(31.05%)	1420.62
TOTAL/ AVG.	957.65	(70.93%)	392.47	(29.07%)	1350.12

Source: CMFRI Annual Reports.

Table 2

Annual average pelagic fish landings during 1977-82

Species/Group	Average quantity (tonnes)	Percentage
Oil sardine	169040	25.63
Lesser sardine	61907	9.38
Bombay duck	109422	16.59
Mackerel	58472	8.86
Ribbon fish	57446	8.71
Tuna	15937	2.41
Carangids	34017	5.16
Anchoviella	41075	6.23
Seer fish	26364	4.00
Chirocentrus	9629	1.46
Thrissocles	12307	1.87
Other clupeids	52300	7.93
Other pelagic fish	4500	0.68
Hilsa	6953	1.05
Total	659369	100.00

Source: CMFRI Annual Reports

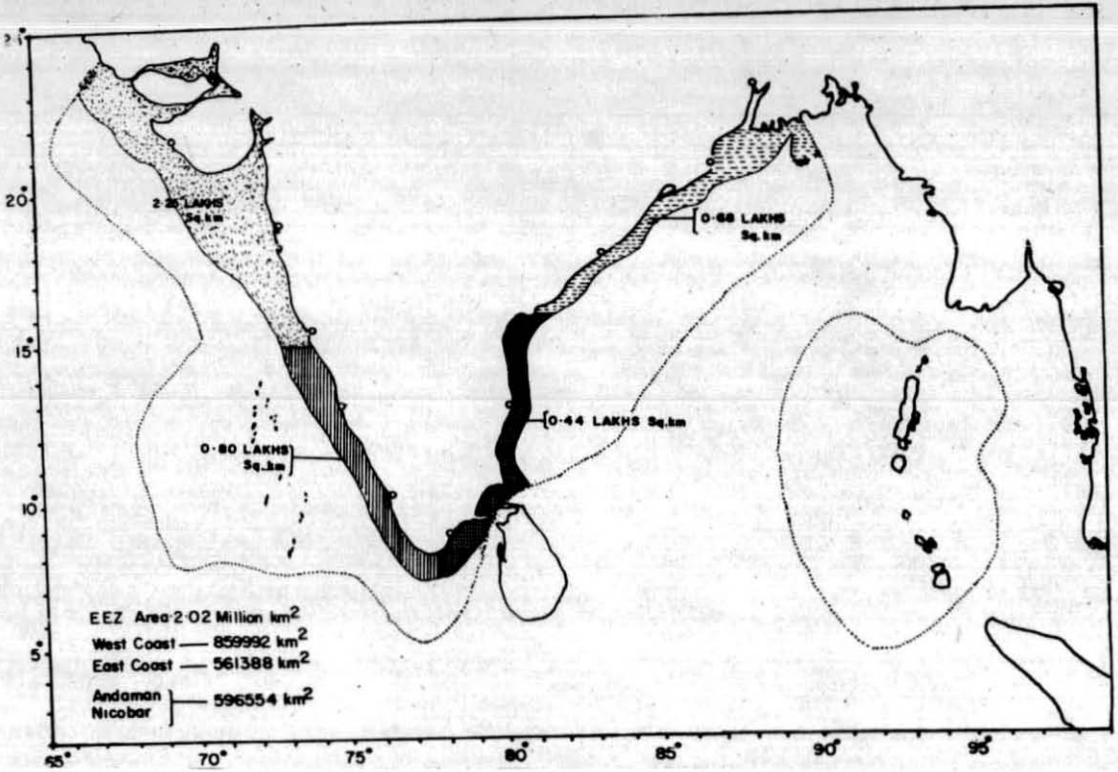

Fig. 1 Indian EEZ and continental shelf area

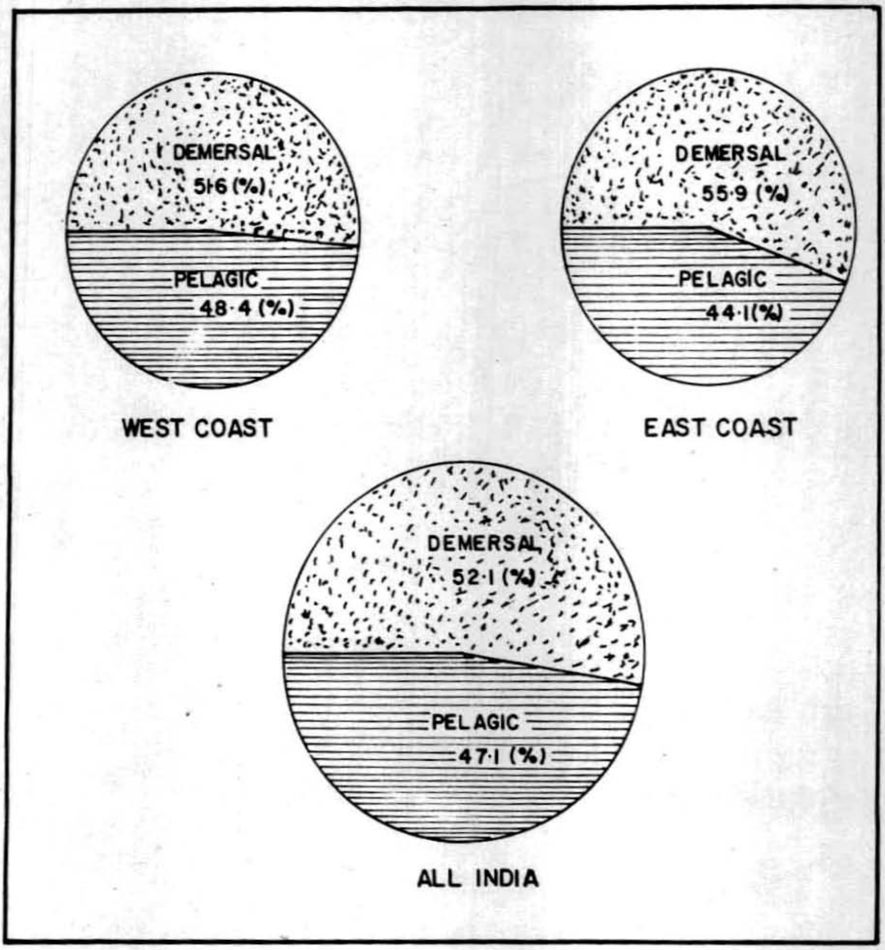

Fig. 2 Composition of marine fish landings

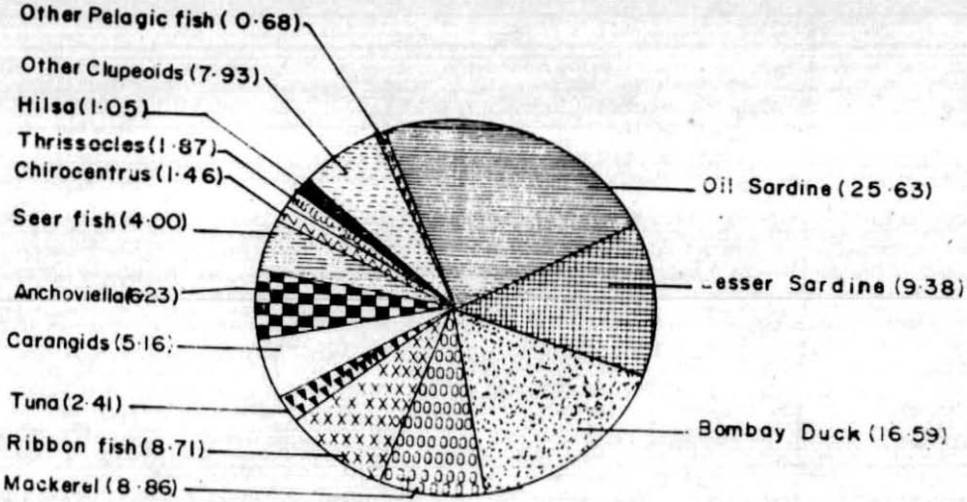

Fig. 3 Composition of pelagic fishery resources (%)

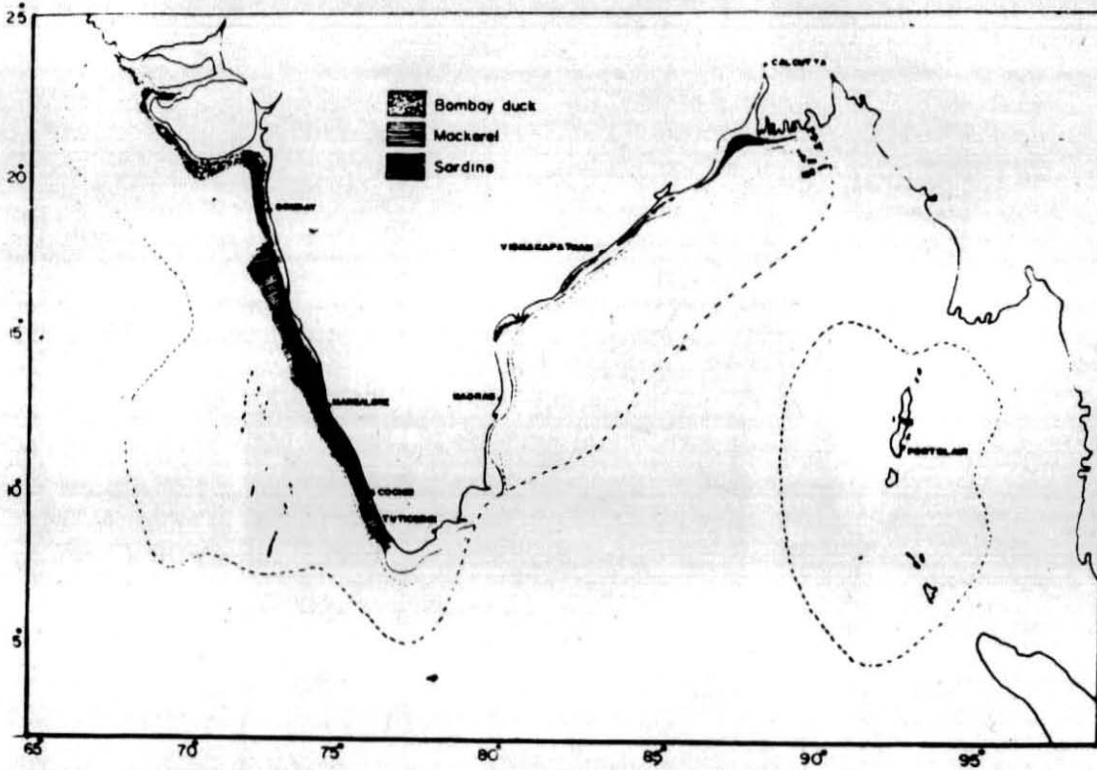

Fig. 4 Schematic distribution pattern of major pelagic fisheries

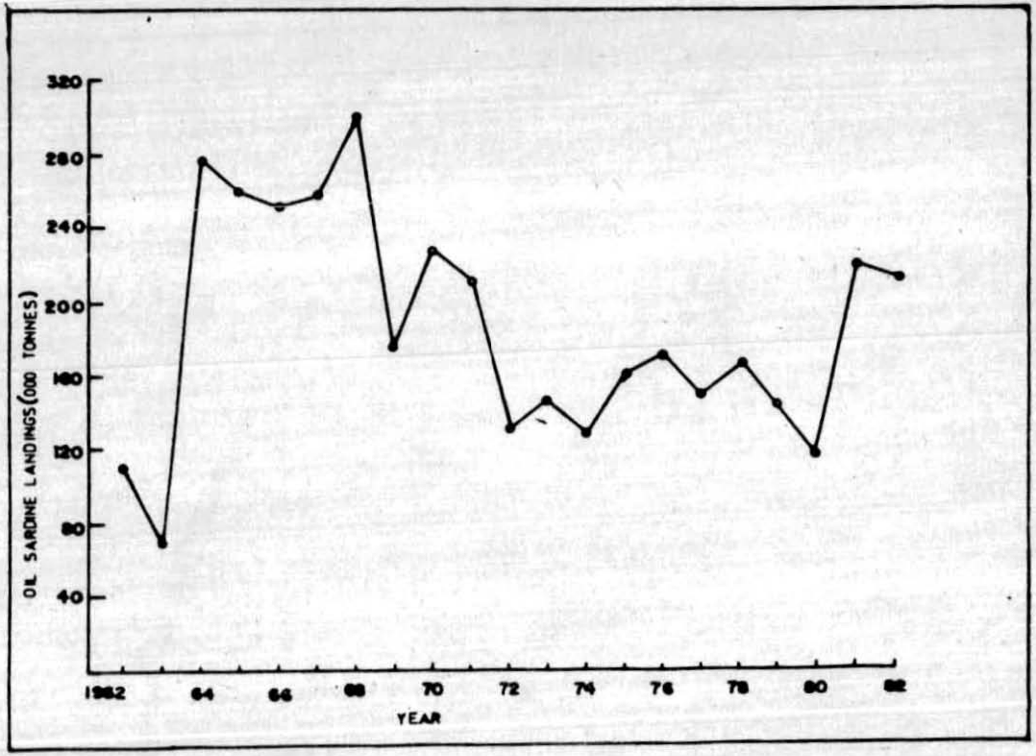

Fig. 5 Fluctuations in oil sardine landings during 1962-82

SCOPE OF INDIAN REMOTE SENSING PROGRAMME IN MARINE LIVING RESOURCES SURVEY

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Introduction

The Joint Experiment Programme (JEP) was formulated in 1979 between the Indian Space Research Organisation and various user agencies and Departments of Government of India. One of the experiments was the survey of fish resources using remote sensing techniques.

The main objectives of the experiment were to identify suitable sensor parameters such as optimum spectral bands, sensitivity, spatial resolution in the context of the Indian Remote Sensing Satellite (IRS) programme for fish resources survey and to develop methodologies to extract relevant information from remotely sensed data for resource estimation and modeling. Experiments were conducted in 1981 and 1982 to acquire data from airborne sensors, spaceborne sensors and to correlate them with the sea truth data collected synchronously.

The various scientific papers in this proceedings details out the user needs, the infrastructural facilities available in the country for data acquisition and analysis, the techniques developed to analyse field data, airborne sensor data and spaceborne sensor data and the results obtained for estimating and mapping of chlorophyll concentration.

This note discusses the future programmes of the Department of Space (DOS) and what needs to be done jointly between DOS and user agencies to achieve the main goal of locating the movement of fish shoals and their quantification in a precise manner for better harvesting and management in future. In this context the requirements given in the paper on 'Biological Productivity of the Indian Ocean' by Dr. Silas et al appearing elsewhere in this proceeding and the report of the Task Force on 'Remote Sensing in Oceanography, Marine Resources Management and Coastal Studies', August 1984, prepared under the National Natural Resources Management System (NNRMS) are kept in mind while making the observations.

State of the Art Technology and Future Programmes in the Country

The main sensor that needs to be developed for this purpose is the one similar to that of 'Coastal Zone Color Scanner' (CZCS) of NASA which has six narrow spectral bands in visible, near IR and thermal infrared region, very high sensitivity and coarser resolution. The auxiliary information from microwave altimeter, passive microwave sensors and thermal sensors to obtain information on topography of sea, ocean currents, sea state, salinity, sea surface temperature etc., will also help in modeling the precise location of fish shoals and estimation of fish resources. Since this is a dynamic phenomena enough repetivity and statistics is required to arrive at specific conclusions. Therefore, there is a need to conduct investigative experiments for few more years to arrive at an understanding of the migratory patterns of fish schools and quantification of fish resources through mapping of chlorophyll concentration.

We are presently in the stage of designing an operational satellite similar to that of Landsat sensitivity. The IRS-1A system will have the spectral bands and sensitivity characteristics as shown in Table 1 in which for comparison purposes the characteristics of Landsat sensors and CZCS sensors are also given.

Table 1

Table 1(a)

Comparison of IRS and Landsat sensors w.r.t. their sensitivity

Bands	Gain settings (G_1 through G_4) in $mw/cm^2/sr/\mu$ (Saturation values)				
	IRS				Landsat
	G_1	G_2	G_3	G_4	
1	33	27	17	11	24.2
2	33	27	17	11	19
3	30	23	17	10	17.5
4	20	16	14	10	15

Table 1(b)

Spectral bands for IRS, Nimbus-7 CZCS and Landsat TM/MSS

Bands	IRS-1A (µm)	CZCS(µm)	TM(µ m)	MSS(µ m)
1	0.45-0.52	0.43-0.45	0.45-0.52	-
2	0.52-0.59	0.51-0.53	0.52-0.60	0.5-0.6
3	0.6-0.68	0.54-0.56	0.63-0.69	0.6-0.7
4	0.77-0.86	0.66-0.68	0.76-0.90	0.7-0.8
5	-	0.70-0.80	1.55-1.75	0.8-1.1
6	-	10.50-12.50	10.40-12.5	-
7	-	-	2.08-2.35	-

Under IRS Utilisation Programme the use of IRS, SPOT and Landsat MSS & TM data are planned. However, it is to be kept in mind that these sensors will have wider spectral bands, much lesser sensitivity and very high data rates due to their high resolution capability. This will reduce the accuracy of chlorophyll estimation and will increase the cost of survey. Further, time of data acquisition (around 10 AM) is not conducive to ocean surveys due to sun glint problems.

DOS had flown two sets of passive microwave sensors on board Bhaskara system and methodologies for estimating sea surface state were developed. However, the frequencies used were not suitable for sea surface temperature estimation and salinity studies. INSAT-1 satellite has thermal sensor and can be used for obtaining sea surface temperature contours. INSAT-2 satellite systems are planned with higher resolution and will be better for such applications.

DOS has plans to collaborate with European Space Agency (ESA) to receive the ERS-1 satellite data which has an altimeter, a scatterometer, a synthetic aperture radar and an infrared sensor.

DOS has a Microwave Remote Sensing Programme under which passive and active microwave sensors for airborne and spaceborne sensing are under development. An airborne Ocean Colour Radiometer also is available with National Remote Sensing Agency (NRSA).

It appears from the above that there are ample opportunities to conduct detailed experiments to meet the user needs in this area. Parallely efforts are required to bermade to define and execute a suitable spaceborne remote sensing system for semi-operational use for Marine Resources Survey. This could be one of the IRS series of satellites. As a prelude some of the technological and methodology concepts could be tested through the use of 150 kg Rohini satellite series. One such experiment could be to try out in a limited way the CZCS type of sensor on board the 150 kg Rohini satellite.

Phasing of activities is required to first understand the utility of various remotely sensed data for modeling and later to define and execute a dedicate satellite system. The requirements have to be complemented with those projected by the Task Force on 'Remote Sensing in Oceanography, Marine Resources Management and Coastal Studies' under NNRMS.

Specific Problems to be taken up for achieving the Goal

1. Design and development of a CZCS type of sensor: A spaceborne system may be conceived with the 150 kg class Rohini satellites. Existing CCD array technology could be thought of for this work.

2. Calibration needs of spaceborne sensors for Marine Resources Survey: Special design efforts to maintain calibration of sensors on board satellites for temporal studies is needed. Sun calibration should be thought of for solving this problem.

3. Possibility of using Data Collection Platforms to work with INSAT system to acquire sea truth data with moored and drifting buoys. Special sea truth sensors like Fluorometers for **in situ** data collection coupled with DCP's will yield better temporal information on pigment concentrations upto 4-6 meters depth.

4. Design and development of sea truth equipment such as Quanta spectrometer or Spectroradiometer for under water radiance measurements in the country needs to be initiated.

5. Methodology for special data products such as chlorophyll maps with quick turn around time to feed into the Fish Resource Management System also needs to be developed.

6. Design of a suitable spaceborne remote sensing system for Marine Resources Survey has to be initiated with a view to operationally utilise remote sensing data in conjunction with conventional data for the detection and location ot fish shoals. This will involve study of sensor system selection, platform requirements, data products types, accuracy and turn

around time, satellite orbit suitable for such studies etc.

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OPTICAL PROCESSES IN REMOTE SENSING OF OCEAN COLOUR

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Abstract

The radiative transfer in the atmosphere and in water is discussed in the context of ocean colour sensing in the optical region of electromagnetic spectrum. Requirements of satellite sensor in the remote sensing of ocean colour (primarily due to phytoplankton pigment, chlorophyll-a) along with the role of apparent optical properties, namely, irradiance ratio of upwelling to downwelling irradiance and estimation of diffuse attenuation coefficient for ocean water types are discussed in detail.

Introduction

An understanding of ocean water properties and processes can be obtained more effectively through orbital remote sensing as compared to conventional ship based observations. The conventional methods lead to point measurement whereas satellite sensor with a wide area synoptic coverage aids in collecting spatial as well as temporal data. Use of appropriate algorithms along with relevant sea truth data from ship based sensors can be used to complement the data from satellite sensor. Remote sensing in optical region is found useful in understanding the spatial distribution of ocean water constituents both particulates as well as dissolved materials. Amongst these the one which has definite response in the visible region are the phytoplankton pigment (chlorophyll-a and phaeopigment-a) which impart in general a green colour to the sea water. Chlorophyll-a is the pigment present in all living plants which is responsible for photosynthesis. In the ocean this pigment is contained in microscopic free floating organisms (except Sargassam spp.) called phytoplankton which is the first link in the ocean food chain. An estimate of ocean colour provides an useful input about the primary productivity due to phytoplankton. Primary productivity estimation leads to the third level productivity i.e., fish in the ocean food chain. The requirements of a satellite sensor (operating in optical region) for oceanic regime is quite different from those designed for meteorological or land applications. The first and foremost is the strength of the apparent signal received at the satellite sensor that has information about the ocean water constituents constitutes only within 20 per cent of total signal and the remaining 80 per cent is due to the intervening atmosphere resulting from molecular scattering (Rayleigh) and scattering due to suspended dust particles-aerosols (Mie). Atmospheric correction schemes have been suggested to account for the removal of these atmospheric effects (Gordon, 1978, 1980, 1981; Gordon and Clark, 1981) so as to arrive at the upwelling subsurface radiance which contains information about the ocean water constituents, particularly, phytoplankton pigment.

In view of above, the requirement on the radiometric resolution of the sensor, dynamic range is also different for ocean applications. For example, a sensor system like Landsat MSS will provide only 2-3 levels of data in the least significant region over oceans. As regards the bandwidth it is again different from Landsat as the need is for narrow bands specifically centered at blue and green to correspond with specific phytoplankton pigment absorption and reflectivity. Coastal Zone Color Scanner (CZCS) on board Nimbus-7 is the only sensor which is optimised for ocean color sensing. In this paper an attempt has been made to discuss the various components of radiance signal received by the satellite sensor. In addition to this the optical properties of ocean and the role of apparent optical properties like irradiance ratio-R (downwelling irradiance/upwelling irradiance or radiance) and diffuse attenuation coefficient in ocean colour estimations for the ocean water types are also discussed.

Atmospheric Effects in Satellite Remote Sensing

The total radiance signal, L_T received at the satellite sensor altitude, Z results from the interaction with the solar radiation and the water. In order to understand this it is imperative to look into the propagation of sunlight through the atmosphere before it reaches the water surface and next to look into the upwelling subsurface radiance (L_{SS}) which propagates up through the water surface with a loss due to the difference in the refractive indices of water and air. This signal just emerging from the water as L_w undergoes a transmission loss t in the atmosphere before it becomes available to the remote sensor as $t.L_w$. Besides this, the total signal, L_T for a given wavelength λ received at the satellite sensor altitude, Z has the following components (Figure 1),

$$L_{Tz}(\lambda) = L_R(\lambda) + L_A(\lambda) + t(\lambda).L_W(\lambda) \qquad (1)$$

where $L_R(\lambda)$ results from scattering due to air molecules and can be further split into three sub-components which are as following;

$L_R(1)$, the one which gets reflected in the atmosphere and enters directly into the sensor field of view without reaching the water surface also called as path radiance,

$L_R(2)$, the second sub-component which reaches water surface, undergoes scattering and is backscattered into sensor field of view,

$L_R(3)$, the third sub-component reaches the sensor after being scattered from the water surface and in the atmosphere.

The component $L_A(\lambda)$ resulting from scattering due to aerosols is highly unpredictable due to the variations in size and shape of suspended particles and therefore some assumptions are to be made before it becomes accountable in the atmospheric correction scheme. An atmospheric correction scheme based on clear water radiance approach (Gordon and Clark, 1981) was developed using atmospheric constituents for tropical region. This was tested using CZCS data (Orbit 5570, Dec'1, 1979) over the Arabian sea and is presented in one of the papers of this proceeding.

Amongst the various components of the total signal received by the satellite sensor, $L_w(\lambda)$ contains spectral information about the optical properties of ocean. In the satellite ocean colour sensing the main aim is to derive the spatial distribution of phytoplankton pigment from $L_w(\lambda)$. This is achieved by developing a pigment algorithm which employs an emperical approach of relating phytoplankton pigment with the inherent water leaving or upwelling radiance ratios of appropriate wavelength. Thus, there are two aims in the analysis of sensor data optimised for ocean colour sensing, namely, to develop an atmospheric correction algorithm so as to extract the inherent water leaving or upwelling radiance in different spectral channels and then to substitute it in a pigment algorithm.

Relationship of L_w with Subsurface Upwelling Radiance/Irradiance Ratio

$L_w(\lambda)$ is related to the subsurface upwelling radiance, $L_{ss}(\lambda)$ by the following Equation

$$L_w(\lambda) = L_{ss}(\lambda) . \frac{1 - \rho(\lambda)}{n^2(\lambda)} . t_{RAOZ(\lambda)} \tag{2}$$

Where, ρ is the Fresnel reflectance and n is the refractive index of sea water. t is the irradiance transmittance through the atmosphere and terms responsible are Rayleigh optical thickness (R), aerosol optical thickness (A) and Ozone optical thickness (OZ).

If the ocean were a lambertian reflector, the angular distribution of the subsurface radiance L_{ss} travelling upward can be assumed to be a constant. The upwelling irradiance E_u just below the water surface can be related to L_{ss}. Thus,

$$E_u = \pi L_{ss} \tag{3}$$

Austin (1974) has shown that for L_{ss} in the nadir direction, π has to be replaced by a factor, Q which is of the order of 5.02 - 5.2 (for natural waters) as there is a significant departure from the diffuse situation in the underwater light field.

Since the upwelling irradiance/radiance ratio is dependent on the incident radiant energy available at the water surface, it is therefore desirable to take a ratio of upwelling to downwelling irradiance i.e., reflectance R, thus,

$$R = E_u/E_d \tag{4}$$

Hence L_w can be rewritten as follows

$$L_w = R \frac{E_d}{Qn^2} (1 - \rho) \tag{5}$$

Where $R = E_u/E_d$, E_d = downwelling irradiance which can be computed from the extraterrestrial solar flux, $Q = E_u/L_{ss}$.

The water content is reflected by its colour which can be defined as being independent of changing illumination conditions by forming the ratios of the upwelling irradiance, E_u to the downwelling irradiance, E_d leading to the so called reflectance ratio R at zero depth. The spectral values of $R(\lambda)$ of the ratio R helps in defining the ocean colour.

The next step in ocean colour sensing is to understand the ocean water constituents both dissolved and particulate matter whch can be estimated from the upwelling radiance received by the satellite sensor.

Optical Properties of Ocean Water

Preisendorfer (1961) has classified the optical properties of sea into two categories; inherent properties and apparent properties. An inherent property is one that is independent of the radiance distribution; an apparent property is the one for which this is not the case. The inherent optical properties are the coefficients of attenuation, absorption and scattering as well as the volume scattering function; apparent properties are for instance, the coefficients of radiance/irradiance attenuation.

A vertical profile of beam transmittance of the water provides a rapid means of assessing the optical properties of the water column. The volume attenuation coefficient, C is related to beam transmittance, T (T is spectrally determined to understand wavelength dependence of the attenuation coefficient). Thus,

$$C = \frac{1}{l} \ln \frac{1}{T} \tag{6}$$

where, l is the path length measurement.

The volume attenuation coefficient, C is the sum of the absorption coefficient, a and the total scattering coefficient, b.Thus,

$$C = a + b \tag{7}$$

C, can be further related to linear addition of the corresponding coefficients, C for pure sea water, w for the dissolved, d and for the suspended particulate, p. Thus,

$$C = C_W + C_d + C_p = a_w + a_d + a_p + b_w + b_d + b_p \tag{8}$$

By substituting the attenuation coefficient for pure sea water, C_w, C is related to attenuation coefficient of the dissolved and suspended particulates. Thus,

$$C - C_w = a_d + a_p + b_d + b_p \approx a_d + b_p \tag{9}$$

The particulate scattering is almost independent of wavelength and hence, the major change in $(C - C_w)$ vs λ curve are due to changes in the absorption of dissolved material. The most frequently observed is the 'gelbstoffe' or yellow substance for which the absorption is pronounced in shorter wavelength.

Apart from the knowledge of above, another important estimation as part of understanding the inherent properties of water is the volume scattering function (VSF), $\beta(\theta)$, which is an essential input in radiative transfer models of remote sensing problems. By an integration of VSF over all the angles, the total scattering coefficient b can be obtained. Thus,

$$b = 2\pi \int_0^\pi \beta(\theta) \sin\theta \, d\theta \tag{10}$$

b, can be estimated from the beam transmittance along with C and leads to estimation of absorption coefficients, a for water, since

$$a = c - b \tag{11}$$

The irradiance ratio, R as discussed earlier can be computed from the absorption coefficient and backscatter coefficient, b_b where

$$b_b = 2\pi \int_{\pi/2}^{\pi} \beta(\theta) \sin\theta \, d\theta \qquad (12)$$

For given limiting conditions of radiance distribution at the air - water interface the R through radiative transfer theory can be related to the inherent optical properties of the water (Morel and Prieur, 1975);

$$R = 0.33 \, (b_b/a) \, (1 + \Delta) \qquad (13)$$

where, 0.33 is the average coefficients for varying solar altitudes. b_b and a are global backscattering and absorption coefficients respectively for the sea water under consideration (Morel, 1980). Δ is a second order term which mainly depends upon the volume scattering function and also on the radiance distribution. Prieur (1976) has shown that within an accuracy of ± 5% in the absolute values of R, Δ can be neglected and that it is almost wavelength independent in the visible part of the spectrum. The above relationship somehow is not practicable in remote sensing since it requires R in absolute units. The satellite sensor receives the upwelling radiance in different wavelength bands and only quantities proportional to the irradiance ratio, R are actually accessible. Thus R gets reduced to an apparent property of estimating ocean water constitutents. The radiance/irradiance ratio has been related with phytoplankton pigment as well as with other dissolved and particulate matter (Clark et. al., 1980, Clark, 1981). In addition to above, it is also desirable to look into the propagation of radiant flux i.e., 'penetration depth' in the water column as well as the subsurface upwelling radiance/irradiance ratio which is propagating up through the water column so as to understand the attenuation due to dissolved and particulate matter at various depths. Gordon and McCluney (1979) have estimated that penetration depth can be defined as the depth at which irradiance falls below/within e^{-1} of its value just below the surface. In other words it is the depth (also referred to as Z_{90}) above which 90 percent of the radiance contributing to L_w (the term as discussed earlier) originates in a homogeneous water column. A measurement of downwelling irradiance or upwelling radiance/irradiance between two depths in the water column leads to estimation of a coefficient defining the above and is referred to as diffuse attenuation coefficient K. If $E_d(Z)$ is the downwelling irradiance or $E_u(Z)$ as upwelling irradiance at depth Z and $E_d(0)$ or $E_u(0)$ as downwelling/upwelling irradiance respectively at just below the surface. Then,

$$E_d(Z) = E_d(0)e^{-K_Z} \qquad (14)$$

or

$$E_u(Z) = E_u(0)e^{-K_Z}$$

and

$$K_{E_d} = -\frac{1}{Z} \ln \frac{E_d(Z)}{E_d(0)} \qquad (15)$$

or

$$K_{E_u} = -\frac{1}{Z} \ln \frac{E_u(Z)}{E_u(0)}$$

Where, K_{E_d} and K_{E_u} are diffuse attenuation coefficient for downwelling and upwelling irradiance respectively.

The diffuse attenuation coefficient is an apparent optical property since its magnitude is dependent on the radiance distribution at the point of measurement (Preisendorfer, 1961). A non-analytical or emperical approach is adopted in estimating K. K is a function of wavelength and in general varies as a function of depth. Although K is an apparent property but provides a measure of light available at different depths for use in photosynthesis by phytoplankton pigment. Jerlov (1976) has classified the water types based on estimates of spectral diffuse attenuation coefficient K (λ). Similarly Smith and Baker (1978a; 1978b), have used K to define the 'bio-optical state' of natural waters. K is also used as a measure of water quality and in predicting the depth of euphotic zone (the zone which supports the plant life in ocean). A high correlation has been shown between chlorophyll concentration in the top K of phytoplankton dominated waters (Smith and Baker, 1978a). However, in the near shore waters dominated by materials of non-biogenic origin e.g. inorganic particulate matter and dissolved substances which do not covary with chlorophyll concentration, K can only be applied to an estimate of water constituents in surface layers and not for the whole column.

Austin and Petzold (1981) have developed an algorithm for deriving K of water from the ratios of upwelling radiance. In their analysis K at 490 nm and 520 nm was found to be strongly correlated with the phytoplankton pigment concentration over the first attenuation length. A K algorithm was developed using the data collected in the Arabian sea, North of Cochin (known for fisheries abundance, following South West monsoon) during October, November, December 1981 and November 1982 and results are presented in one of the papers in this proceeding.

Ocean Water Types

Morel and Prieur (1977), have classified oceans broadly into two cases; Case I (biogenic origin) and Case II (non-biogenic) waters. Case I waters are those for which the optical properties are largely determined by the presence of phytoplankton pigment and their covarying derivative products, namely, detrital particles (originating from grazing by zooplankton and natural decay) and 'gelbstoffe' or yellow substances.

Most of the open ocean waters belong to Case I. These Case I waters range from extreme condition of blue (oligotrophic waters i.e. with low productivity) to green (eutrophic waters i.e. with high productivity). These waters are the easiest to handle from remote sensing point of view, Case II waters are predominently under the influence of detrital inorganic suspended particulates resulting in relatively high scattering and presence of dissolved yellow substances which do not covary with phytoplankton pigment. Such waters are observed in shallow regions influenced by the land runoff and river discharge. A high suspended sediment load in general discolours the water and leads to high reflectance. In sum it can be concluded that detailed studies for both water types as well as intermediate cases are required to be undertaken to understand the distribution of substances both dissolved as well as particulates through an estimate of apparent optical properties as stated earlier viz., irradiance ratio R or reflectance and estimation of diffuse attenuation coefficient K.

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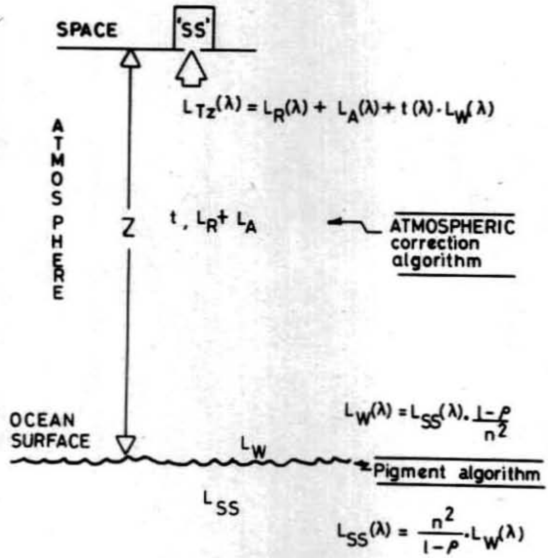

Fig. 1 Components of radiance signal received at the satellite sensor ('SS') at altitude Z

SEA TRUTH DATA COLLECTION: ESTIMATION OF DIFFUSE ATTENUATION COEFFICIENT IN OCEAN COLOUR MAPPING

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Abstract

*Phytoplankton pigments in the ocean waters are the prime synthesizers in marine food chain which in turn terminate as pelagic or benthic nekton. They perform about half of the total global photosynthesis and comprise the upper consumption and production. These are the substances that have definite spectral characteristics and thereby govern the ocean colour. Through its correlation with various biological and physical processes, the quantification of chlorophyll concentration in the ocean waters provide information which is indirectly relevant to the management of fisheries. With the help of sea truth data, an attempt has been made to develop an algorithm for estimating diffuse attenuation coefficient, K at 490 nm and 520 nm of the sea water from the ratio of inherent upwelling radiances at 443 nm and 550 nm. Since K covaries with the pigment concentration present in ocean water, it can be used as an indirect measure of chlorophyll concentration. A least squares regression has been performed for K(490) and K(520) and chlorophyll concentration. The coefficients of determination and standard error of estimate for this analysis is presented. An estimation of K is useful in understanding the optical properties of ocean water types. A colour coded K-map was generated using K algorithm for ocean waters off Cochin. The sea truth data used in the present analysis, was collected preceding SW monsoon i.e., during October, November and December, 1981 and November 1982 in coastal waters over North of Cochin in the Arabian sea, which is well known for the abundance of pelagic shoals of oil sardine **(Sardinella longiceps)** and mackerel **(Rastrelliger kanagurta)**.*

Introduction

The diffuse attenuation coefficient, K for upwelling/downwelling irradiance can be used to describe physically the optical properties of ocean waters, which makes it possible to determine marine pigment concentrations contained in the phytoplankton, (predominently chlorophyll-a). This in turn suggests the potential for obtaining rapid assessments of primary productivity over time scales required to link this productivity to commercially important fisheries. Smith and Baker (1978a) have used the spectral diffuse attenuation coefficient K(λ) for optically classifying natural waters, whose dissolved and suspended materials are primarily of biogenic in origin in terms of the chlorophyll like pigment present in these waters. Smith and Baker (1978b) have defined 'bio-optical state' as a measure of the total effect of biological meterial on the optical properties of natural waters. It is this state of ocean waters that can be remotely sensed by means of airborne/spaceborne sensors. The bio-optical state can be suitably related to the concentration of chlorophyll-a and consequently to the primary productivity. The diffuse attenuation coefficient, K for downwelling irradiance, KE_d, is readily measured at sea and is found to be highly correlated with and dependent on the chlorophyll like pigment concentration. This pigment concentration and diffuse attenuation coefficient provide a measure of the fraction of radiant energy attenuated by phytoplankton. It may also be used as an index of primary productivity, which, in turn, indirectly give an idea of available fish stock.

The diffuse attenuation coefficient may also be used as a measure of water quality. It increases with biomass and decreases with non-algal turbidity. However, increased interception of underwater light by phytoplankton pigment causes a steepening of the light gradient and thus a reduction of the vertical extent of euphotic zone. Therefore, diffuse attenuation coefficient may be used to predict the depth of the euphotic zone (Tilzer, 1983). A relationship between the diffuse attenuation coefficient for irradiance and the chlorophyll like pigment concentration has been found with spectral irradiance data of sea water.

Methodology

Diffuse attenuation coefficient, K, for upwelling radiance L, was calculated using the following Equation (Austin and Petzold, 1981),

$$K_L = -\frac{1}{L}\frac{dL}{dZ} \qquad (1)$$

with the assumption that K is a constant with depth, Z over the interval from Z_1 to Z_2, the above Equation can then be rewritten as

$$K = -\frac{1}{Z_2-Z_1}\ln\frac{L(Z_2)}{L(Z_1)} \qquad (2)$$

Smith and Baker (1978a) have shown that the total diffuse attenuation coefficient, K_T for irradiance can be used to describe the 'bio-optical state' of ocean waters and can be expressed as

$$K_T = K_w + k_c \times C + K_x \qquad (3)$$

where K_T (m^{-1}) is the total diffuse attenuation coefficient for irradiance, K_w (m^{-1}) is the diffuse attenuation for pure sea waters, k_c is the specific attenuation coefficient for irradiance due to plankton (chlorophyll-like) pigments, C (mg pigments m^{-3}) is the concentration of chlorophyll-a and phaeopigments in the water column, and K_x(m^{-1}) is the contribution due to attenuation not directly attributable to chlorophyll-like pigments.

Data Acquisition and Analysis

Surface and subsurface upwelling spectral radiance and downwelling spectral irradiance data were obtained using submersible Quanta Spectrometer (Techtum Instrument, Model **QSM-2500-UW**) at different stations with corresponding variation in depth in the coastal waters over North of Cochin during October, November and December 1981, and November 1982. Upwelling spectral radiance was measured at several depths and was used to calculate radiance ratios at different wavelengths. The resulting values were used to develop an algorithm for estimating diffuse attenuation coefficient, K. In addition to radiance measurements, data on Secchi disc depth or transparency and water samples for estimating chlorophyll-a (chl-a) concentration at various stations was collected.

Results and Discussion

78 data points were taken from different station depths during the period from October to December, 1981 and November, 1982. Values of K (λ) were computed for the wavelength 490 nm and 520 nm using Equation 2.

$\log [K_T(490) - K_w(490)]$ was plotted against

$$\log\left(\frac{L_u(443)}{L_u(550)}\right)$$

as shown in Figure 1, where K(490) is the value of total diffuse attenuation coefficient at 490 nm and $K_w(490)$ is the diffuse attenuation coefficient for pure sea water at 490 nm. A least squares fit was obtained from the total data set. Figure 1 shows 78 measured K(490) values plotted against $L_u(443)/L_u(550)$ along with the coefficients derived from the above regression analysis. Thus,

$$K(490) = 0.095\left(\frac{L_u(443)}{L_u(550)}\right)^{-1.419} + 0.022 \quad (4)$$

where diffuse attenuation coefficient for pure sea water, $K_w(490) = 0.022$ (m^{-1}). The coefficients of determination, $r^2 = 0.90$ and standard error of estimate (S y.x) = 0.11.

In Figure 2 the log of calculated values of attenuation coefficient, K_c (490) [m^{-1}] are plotted against the log of the measured values of attenuation coefficient, $K_m(490)$ [m^{-1}]. The slope of the straight line is 0.90 which shows that the value estimated from the Equation 3 closely matches with the corresponding value of K obtained from measured upwelling radiance.

A similar type of information is obtained by plotting the measured K(520) values against $L_u(443)/L_u(550)$. Figure 3 shows the plot with the coefficients derived from the above regression analysis. Thus,

$$K(520) = 0.103\left(\frac{L_u(443)}{L_u(550)}\right)^{-1.299} + 0.044 \quad (5)$$

with $r^2 = 0.95$ and S y.x = 0.13.

In Figure 4 the values of logarithm of calculated diffuse attenuation coefficient, K_c are plotted against the logarithm of measured diffuse attenuation coefficient, K_m^c values. Here the slope of the straight line is 0.97 which again shows that the estimated K values closely match with the corresponding measured values.

Relationship between Radiance Ratios

A large number of upwelling surface radiances and radiance ratios were calculated while analysing the data for developing the algorithms. An excellent correlation was found between these ratios. Figure 5 shows a plot of log $(L_u(443)/L_u(520))$ against log $(L_u(443)/L_u(550))$ for 99 points. A linear regrssion of the data yields the following relationship,

$$\frac{L_u(443)}{L_u(520)} = 0.848 \left(\frac{L_u(443)}{L_u(550)}\right)^{0.815} \tag{6}$$

with $r^2 = 0.87$ and S y.x = 0.08.

Relationship between Chlorophyll-a and Secchi Disc Depth

Figure 6 shows the relationship between chl-a and Secchi disc depth which is expressed by the Equation for vertical attenuation of light in water (Carlson, 1977),

$$I_z = I_o e^{-1(K_w + K_b)Z} \tag{7}$$

where I_z, is the light intensity at the depth at which Secchi disc disappears, I_o, is the intensity of light striking the water surface, K_w, is the coefficient for attenuation of light by water and dissolved substances. K_b, is the coefficient for attenuation of light by particulate matter and Z, is the depth at which the Secchi disc disappears. K_b is attenuation coefficient due to particulates and is mainly a function of chl-a concentration for open sea. Equation 7 can be rewritten as

$$Z = \left(\ln \frac{I_o}{I_z}\right)\left(\frac{1}{K_W + K_b}\right) \tag{8}$$

The above equation has been rearranged to a linear form as

$$\left(\frac{1}{Z}\right) \quad \left(\ln \frac{I_o}{I_z}\right) = K_w + K_b \tag{9}$$

According to the above Equation Secchi disc depth is inversely proportional to the sum of K_w and K_b. However, K_w is usually very small compared to K_b. Hence, from Equation 9 it is understood that attenuation coefficient K_b of chl-a concentration is inversely proportional to Secchi disc depth.

A plot of Secchi disc depth versus chl-a concentration given in Figure 6 was from the sea truth data over North of Cochin and shows this inverse relationship. The curve obtained is of hyperbolic nature. Figure 7 shows the plot of log-transformed ratios of Secchi disc data against chl-a concentration. The resulting Equation is

$$\ln SD = a - b \ln Chl\text{-}a$$

where SD (Secchi disc transparency) is in meters and chl-a concentration is in milligrams per cubic meter taken at various depths and in different stations. One possible explanation for this exponential relationship may be that as algal density increases, the algae concentration become increasingly light limited. In response to lower light per unit cell, more chlorophyll may be produced (Steele, 1962).

K Mapping

A colour coded K-map showing K distribution (m^{-1}) was generated using algorithm on a in-house COMTAL image processing system using Equation 4 (Figure 8). Grey values of the colour coded image after atmospheric correction of NIMBUS-7 CZCS data (Orbit 5570, Dec'1, 1979) correspond to different K values (m^{-1}). The higher grey levels in the image were flagged so as to correspond to either land/clouds. A relationship between K at 490 and 520 derived from the present data set with pigment data from sea truth is then useful in estimating pigment concentration directly from K (Figure 9). Since no synchronous sea truth data form CZCS (Orbit 5570, Dec'79) was available the chlorophyll concentration as derived from K to C relationship (Figure 9) was compared with chl-a data collected in the same area for Dec,, 15, 16, 1981. Assuming that the conditions were more or less similar during December for the year 1979 and 1981, it was found that in near shore waters chl-a value from K & C relationship was 3.0 mg m^{-3} as against the actually measured value from sea truth during December 1981 as 3.32 mg m^{-3}.

Conclusions

An algorithm for estimating diffuse attenuation, K has been developed using the data collected in ocean waters North of Cochin. The results closely match with the observations as made by Austin and Petzold (1981), employing data collected from a variety of ocean water types. The technique is useful in understanding the depth of euphotic zone which supports the plant life in the ocean. A relationship between Secchi disc depth with K is useful in employing simpler methods for estimating K on an operational basis, since K is a function of chl-a pigment concentration. By estimating K one can have an indirect estimate of chl-a concentration, which is indicative of fish stock through its conversion to other levels in the ocean food chain.

Upwelling radiance ratio after atmospheric correction could be substituted in K algorithm so as to map K values over the first attenuation length. A relationship between K at 490 nm and 520 nm with pigment concentration as shown in the present study and as well as by Austin and Petzold (1981) could then lead to estimating average chlorophyll concentration over the first attenuation length and also its distribution in euphotic zone. Apart from this it is noticed that the pigment concentration thus extracted gives a better estimate than the one obtained from the chlorophyll pigment algorithm (Gordon et. al., 1980) alone. Further details on chlorophyll mapping as derived using above mentioned pigment algorithm can be seen in another paper of this proceeding.

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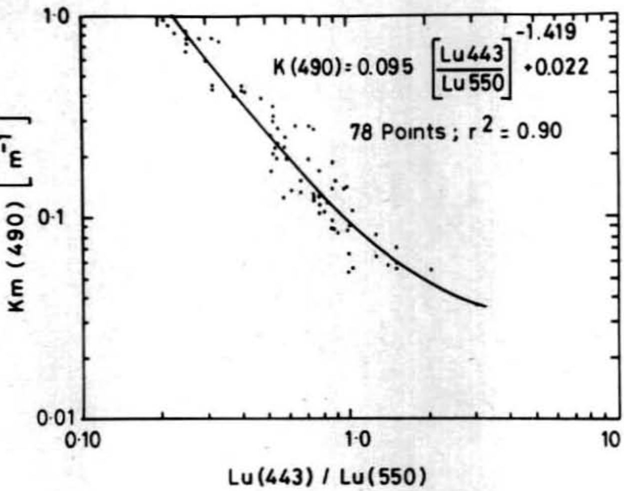

Fig. 1 Relationship between K(490) and ratio of the upwelling radiances at the ocean surface

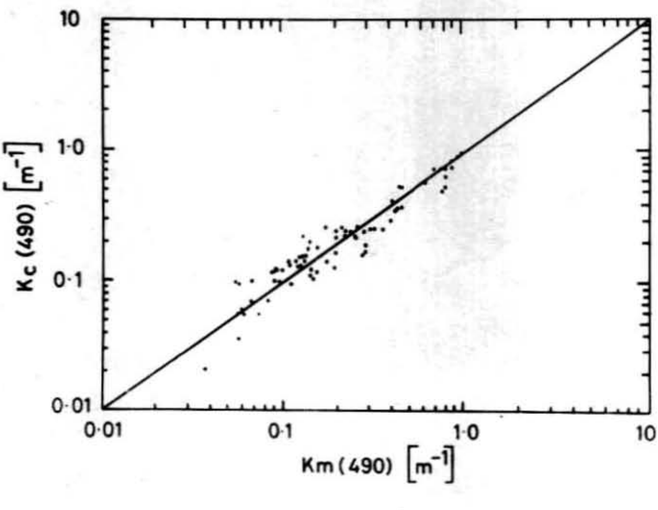

Fig. 2 Plot of calculated K(490) versus measured K(490)

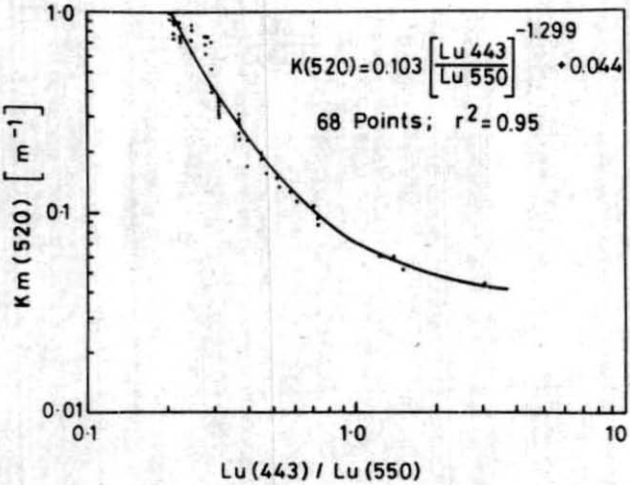

Fig. 3 Relationship between K(520) and the upwelling radiances at the ocean surface

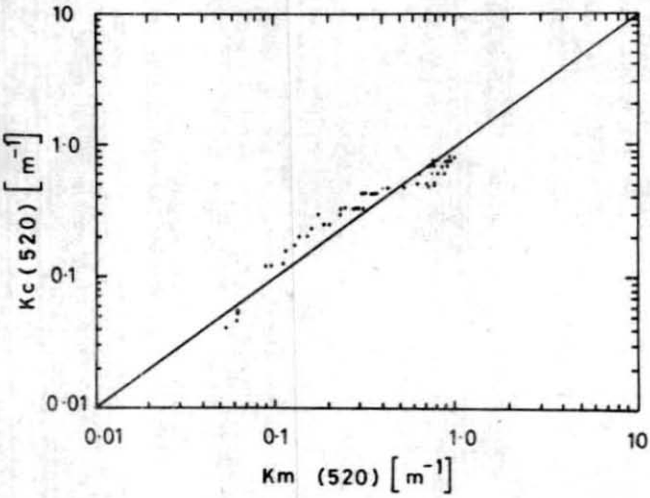

Fig. 4 Plot of calculated K(520) versus measured K(520)

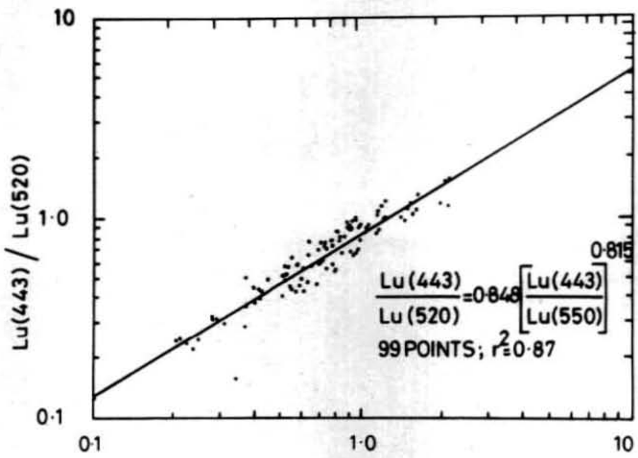

Fig. 5 Plot of the ratios of upwelling radiances

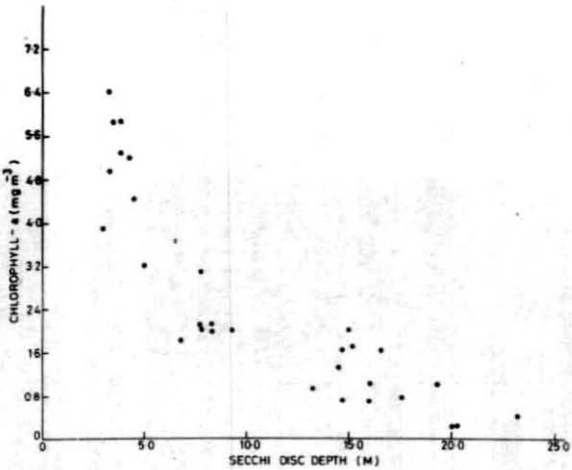

Fig. 6 Relationship between Secchi disc depth and chlorophyll-a concentration

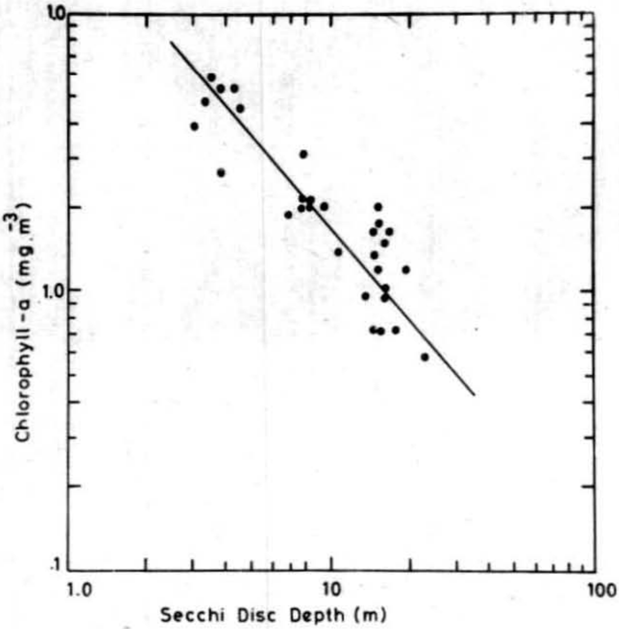

Fig. 7 Plot of log-transformed Secchi disc depth and chlorophyll-a values

Fig. 8 A colour coded K–Map showing K distribution (m^{-1}) in oceanic waters off Cochin from Nimbus–7 CZCS data (Orbit 5570, December 1, 1979)

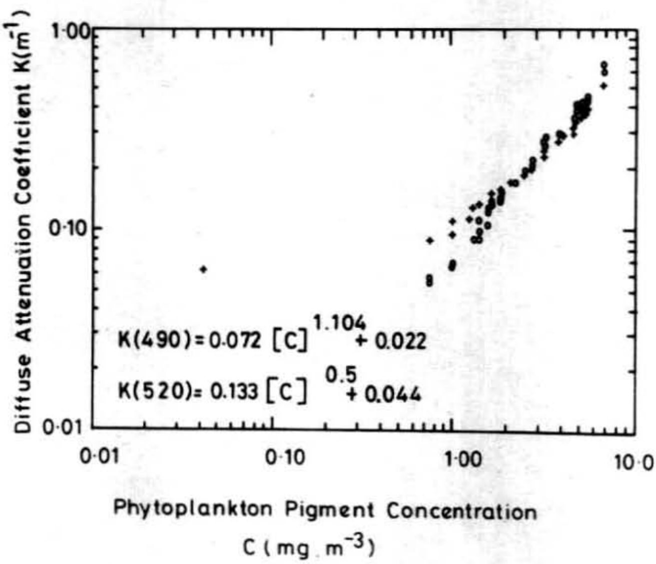

Fig. 9 Relationship between the diffuse attenuation coefficients K(490) and K(520) with phytoplankton pigment - C (chlorophyll-a) values

OCEANOGRAPHIC PARAMETERS AND THEIR RELATIONSHIP TO FISH CATCH ESTIMATION: A CASE STUDY IN COASTAL WATERS NORTH OF COCHIN DURING 1981

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Abstract

*Coastal waters in the North of Cochin was selected for the present study. This area is well known for the occurrence and abundance of fish schools of oil sardine (**Sardinella longiceps**) and mackerel (**Rastrelliger kanagurta**) following the period after SW monsoon in the Indian Ocean. Oceanographic data on parameters like, chlorophyll-a, particulate matter, dissolved oxygen, temperature and salinity was collected during October, November and December, 1981 at various ocean depths to look into spatial and temporal aspects. Since the colour of the ocean in terms of chlorophyll-a (present in phytoplankton) provides an useful input about the primary productivity, an attempt was made at relating it with the third level productivity i.e. fish in the ocean food chain.*

Introduction

In the Indian Ocean, hydrobiologically speaking two distinct periods, 'May-October and 'November-April' are identified. These periods are essentially linked to the surface current changes which reverse every half yearly. The surface currents developed during the SW monsoon (May-October) are known to be much more pronounced than those of the NE monsoon (November-April) and lead to pronounced upwellings. In the Indian Ocean such areas are known to form off Somali coast, whereas weak upwellings have been reported in the Arabian sea and the Bay of Bengal. During the International Indian Ocean Expedition (IIOE) for the period 1959-65, extensive chlorophyll-a pigment estimates were made along with the primary production measurements. A strong relationship between the pigment and primary production has been observed in many areas of the sea especially in regions of nutrient enrichment like Northern Arabian sea, West coast of Africa etc. In the near shore waters of the west coast of India on an average a rate of exceeding 1 g c/m^2/day has been observed within 50m depth from the coast. It has been estimated that 1 g c/m^2/day would ultimately provide about 105 kg of both ground fish and pelagic fish (proportion of ground to pelagic fish in general is 30 per cent and 70 per cent respectively) (Prasad and Nair 1971). In order to understand and follow-up the changes in oceanic parameters viz., physical (temperature, salinity), chemical (dissolved oxygen), optical (Secchi disc depth), biological (chlorophyll-a, particulate matter) and fish catch (for the period 1977-81), a group of four research/fisheries vessels were deployed in the coastal waters over North of Cochin during October, November and December 1981.

Data Acquisition

Figure 1 shows the study area located North of Cochin Coast and vessel positions with respect to station depth viz., 10, 20, 30, 40 and 50 meters. The first sampling station was located at 10m depth in order to avoid the areas which are under active influence of land runoff and river discharge. The sampling station lie between 3 km (10m station) and 39 km (50m station). This roughly covers the waters in which most of the biological productivity takes place.

Oceanic Parameters

Data about various parameters, such as physical (temperature, salinity), chemical (dissolved oxygen), optical (Secchi disc depth, ocean colour - Forel-Ule colour scale) and biological (chlorophyll-a, particulate matter), was collected at station depths of 10, 20, 30, 40 and 50m. Oceanic parameters were estimated from water samples collected from 0 (surface),1 and 6m's. All water samples were collected with Nansen reversing bottles. Water samples were poured into 2-3 litre polyethylene screw-cap bottles. Samples for pigment estimations were kept in cool dark place. Various oceanographic parameters were estimated as per methods described in Barnes (1959) and as in Strickland and Parsons (1965 and 1968).

Oceanic parameters were analysed on samples collected from 0 (surface), 1 and 6 meters. There were two large vessels (17.5 m overall length - OAL) denoted as V1 (Meena Sachatak), V2 (meena Utpadak) and two small vessels (14.3m OAL) V3 (Cadalmin I) and V4 (Cadalmin IX). Vessel positions were kept same in all the threetime surveys.

Fish Catch Data

Two identical fishing vessels (17.5 OAL, 2000 BHP and 56.5 GRT) were deployed from Cochin to cover the coastal waters North of Cochin. These vessels were stern trawlers having six days endurance. Both the vessels were with Simrad echo-sounder for locating the ground for trawling, detection of fish school concentration and recording depth. The fish concentration and trawlable sea bed thus selected was sampled by 24m fish trawl. In order to get required horizontal opening, oval otter boards, each weighing 180 kg, were used. The net was towed in the areas having desired depth for two hours with an average trawling speed of 2.5 Knots. However, on certain occasions the fixed two hours sampling period could not be adhered to, due to the uneven nature of the sea bed, under water obstacles, catch etc. The information on fishery resources included details like catch (quantity) and its distribution with respect to area and depth belts.

Data Analysis

Oceanic Parameters

Oceanic parameters viz., chlorophyll-a (mg m^{-3}), particulate organic matter (mg/l), dissolved oxygen (ml/l), temperature (°C) and salinity (‰) was estimated /analysed from water samples collected at various stations depths and sampling depths.

Fish Catch Data

Figure 2 shows the typical index map used for plotting the fish catch data. Each degree of latitude is divided into six sections of 10 nm each and given numeric codes viz., 1,2,3,4,5 and 6 (sequenced in northward direction). Similarly each degree of longitude is divided into six sections of 10 nm each and given alpha codes viz., A,B,C,D,E and F (sequenced in eastward direction). Each grid of 10 nm x 10 nm is then referred to as sub-area. These sub-areas of 10 nm x 10 nm are with respect to the major areas by giving the co-ordinates viz., longitude and latitude for example 10 (lat.) - 76 (long.) - 1A (sub-area) etc.

Data on catch rate (kg/hr) of total fin-fish as explored by the survey vessels during 1977-81 was analysed depth-wise and presented for October, November and December (Figure 3). In the present analysis only some portions of major areas 10-75 (3E, 1F, 2F and 3F) and 10-76 (1A, 2A) were considered as these fall well within the study area. The sub-areas viz., 3E, 1F, 2F and 3F of the major areas 10-75 and 1A, 2A of 10-76 were sampled for fish abundance. The catch data was transferred on the map with respect to 10m depth interval for all the sub-areas surveyed to show the fish density (Catch, kg/hr). Above data was plotted so as to compare it with data of other oceanic parameters as mentioned earlier.

Results and Discussions

Oceanic Parameters

Figure 4 (a,b,c and d) show the data plotted for various oceanic parameters with respect to station depths viz., 10,20,30,40 and 50m for different months. Apart from chlorophyll-a, particulate matter, and Secchi disc depth, there was no significant change in other oceanic parameters viz., dissolved oxygen, temperature and salinity. This indicates that the hydrographic conditions had more or less stabilised. Figure 4a, b, c and d show the oceanographic data plotted for October, November and December which was collected for station depths viz., 10,20,30,40 and 50m. In general, it can be seen that in all the three time data an inverse relationship was observed between Secchi disc depth and chlorophyll-a (pigment) concentration (Figure 4a,b & c). The pigment shows a gradual decrease with increasing depth. Particulate matter also shows a somewhat similar pattern. Table 1, 2 and 3 show the data for various oceanographic parameters along with their standard deviation for October, November and December, 1981. During October on an average a high pigment value of about 4.8 mg m^{-3} was observed at 10 m station depth followed by a low value of about 1.4 mg m^{-3} at 50 m station depth. Similarly during November and December, the maximum value of about 2.4 mg m^{-3} and 3.3 mg m^{-3} respectively was observed at 10m followed by 0.48 and 0.96 at 50 m respectively. The magnitude of change in particulate matter (expressed as mg/l) was maximum in December between 10m and 20m station depths. In general it is seen that particulate matter also shows an inverse relationship with Secchi disc depth. Also that particulate matter shows a similar pattern i.e. it decreases with increase in station depths from 10 m to 50 m. During November data on oceanic parameters other than chlorophyll, Secchi disc depth, particulate matter could not be colleted for 50 m and similarly for December data on oceanic parameters could not be collected for 40 m depth. It is clear that apart from studying the variations in oceanographic parameters from month to month it is very important to relate these variations with respect to station depth. This helps in understanding the changes which are taking place not only in time but also in space. Using two seasons (1966 and 1967) data off Cochin during International Indian Ocean Expedition - IIOE (1959-65), Shah (1973) has shown that two distinct periods "May-October" and "November-April" are observed. He concluded that the annual variations in oceanographic parameters like chlorophyll-a, salinity, temperature, oxygen etc show a pattern which repeats year after year. Apart

Table 1

Sea truth data on oceanic parameters and their standard deviation for October 22-24, 1981

Station depth (m)	Oceanic Parameters					
	Chlorophyll-a (mg m^{-3})	Secchi disc depth (m)	Salinity (‰)	Temperature (°C)	Dissolved oxygen (ml/l)	Particulate matter (mg/l)
10	4.79±1.35	3.0±0.50	30.33±1.32	28.6±0.53	4.7±0.16	24.4±3.74
20	3.49±2.25	4.00±0.50	31.33±2.26	28.9±0.28	5.0±0.55	22.40±3.68
30	2.72±1.06	6.5±2.0	31.29±0.31	29.3±0.32	5.0±0.42	25.50±2.8
40	1.60±0.21	15.5±1.00	34.12 -	29.0 -	5.37 -	20.48±0.93
50	1.39±0.78	16.0±1.00	34.3±0.16	29.5±0.20	5.30±0.22	19.88±2.62

Table 2

Sea truth data on oceanic parameters and their standard deviation for November 27, 1981

Station depth (m)	Oceanic Parameters					
	Chlorophyll-a (mg m^{-3})	Secchi disc depth (m)	Salinity (‰)	Temperature (°C)	Dissolved oxygen (ml/l)	Particulate matter (mg/l)
10	2.42±0.65	6.0±2.0	30.53±0.16	28.9±0.05	4.01±0.08	14.01±1.24
20	0.96±0.34	15.5±1.00	30.35±0.21	28.6±0.20	4.0±0.09	14.33±1.00
30	1.15±0.32	15.0±1.0	30.89±0.25	28.72±0.09	4.08±0.09	12.44±1.19
40	0.24 -	20.1 -	29.61 -	28.7 -	-	17.40 -
50	0.48 -	20.5 -	-	-	-	-

from above observations it was seen in the present study that information about the ocean water and its constituents could easily be obtained by using simple devices like Forel-Ule colour scale (a colour comparator) and Secchi disc. Figure 5 shows that there is a clear-cut increase in ocean transparency and changes in ocean colour (essentially linked to a decrease in its constituents with time).

Fish Catch Data

The total fin-fish catch rate (kg/hr) data pooled for the period 1977-81 and corresponding to October, November and December is presented in Table 4.

Table 3

Sea truth data on oceanic parameters and their standard deviation for December 15, 16, 1981

Station depth (m)	Oceanic Parameters					
	Chlorophyll-a (mg m^{-3})	Secchi disc depth (m)	Salinity (‰)	Temperature (°C)	Dissolved oxygen (ml/l)	Particulate matter (mg/l)
10	3.32±0.76	1.5±0.50	32.60±0.07	28.8±0.52	4.00±0.25	24.05±6.39
20	0.94±0.70	5.5±1.00	32.71±0.58	28.7±0.15	4.40±0.17	17.00±6.25
30	0.63±0.43	17.00±3.00	32.40±0.31	28.6±0.15	4.70±0.27	17.1±7.3
50	0.96 -	15.5 -	32.40 -	29.0 -	4.83 -	15.1 -

Table 4

Fish catch data for October, November and December (1977-81)

Month	Catch rate	± S.e.e.*
October	83.1	±10.5
November	57.3	±11.6
December	44.7	±6.2

* Standard error of estimate

The fish catch data shows a gradual decrease with time. A plot for fish catch and pigment concentration shows a non-linear relationship (Figure 6). This follows a characteristic S-shaped growth curve. There is an initial period of slow growth which eventually stabilizes below a certain ceiling level. The term growth used here is in relation to exchange between primary producer and secondary consumer in ocean food chain. At a certain level, it is observed that although there is a marginal increase in the pigment the fish catch shows an almost two-fold increase.

Conclusions

A follow-up of changes in oceanographic parameters with respect to station depth helps in understanding their pattern in time and space. This data will provide a useful input while using in conjunction with remotely sensed data from aircraft or orbital platforms, where such a requirement becomes a pre-requisite.

Data about the ocean water and its constituents could be easily obtained by using simple devices like Forel-Ule and Secchi disc. An attempt has been successfully made in relating the fish catch with pigment concentration.

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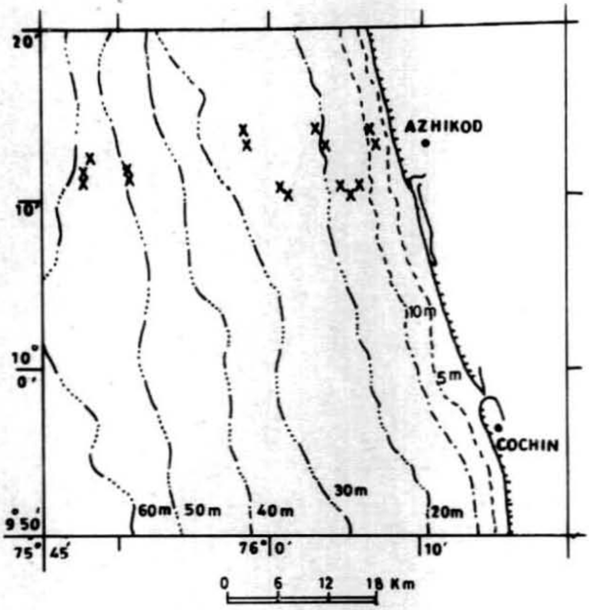


LEGEND

NAME OF THE VESSEL	VESSEL CODE	OPERATING DEPTH (m)	RUN NO
MEENA SACHATAK	V_1	40, 50	7, 8
MEENA UTPADAK	V_2	10, 30, 50	5
CADALMIN I	V_3	10, 20, 30	1, 3
CADALMIN IX	V_4	10, 20, 30	9, 10

Fig. 1 Study area showing vessel position (X) with respect to operating depth (m)

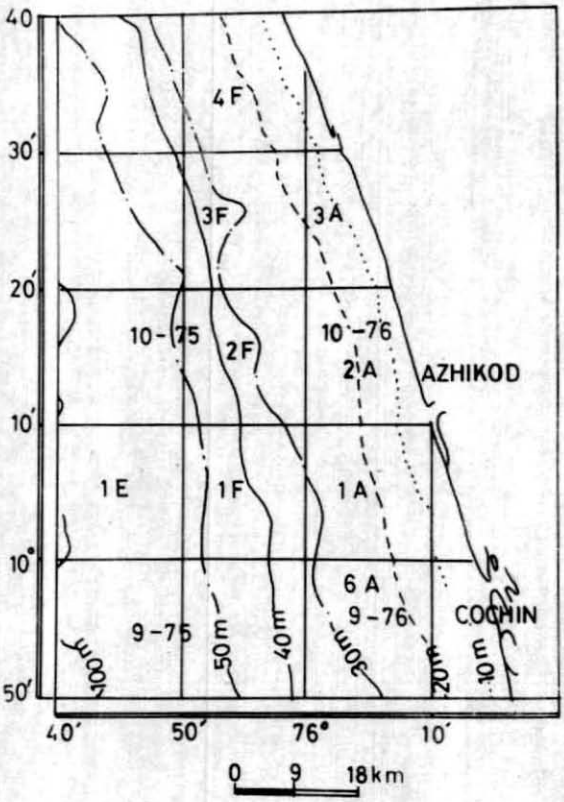


Fig. 2 Index map in respect of areas and sub areas

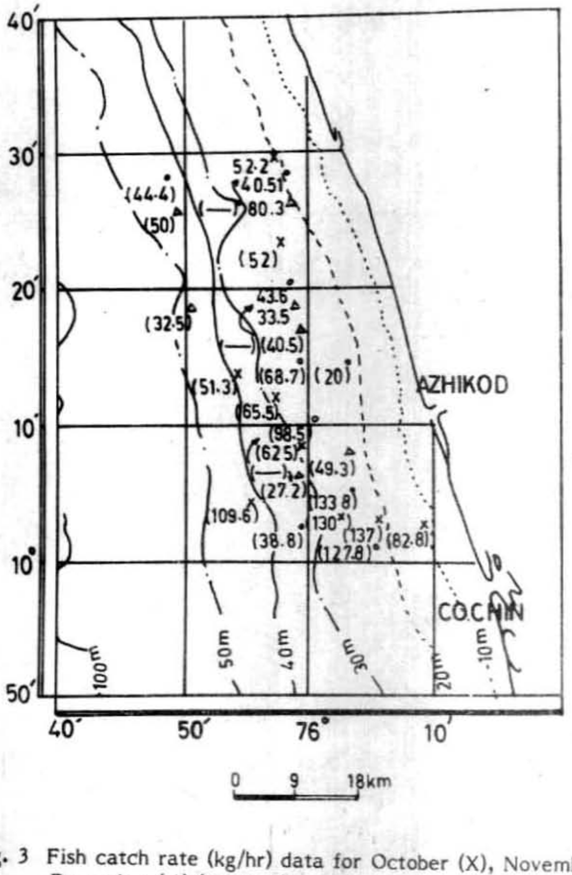


Fig. 3 Fish catch rate (kg/hr) data for October (X), November (0) and December (Δ) (1977-81)

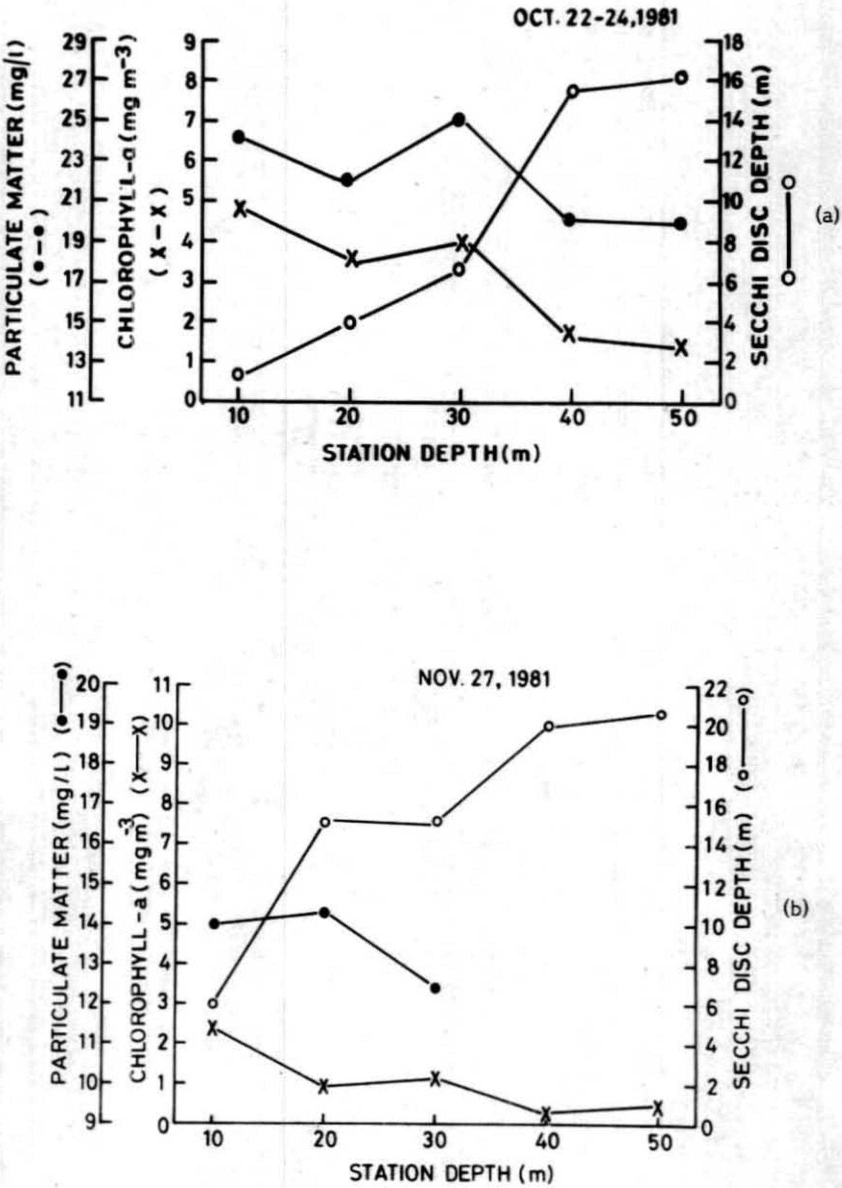
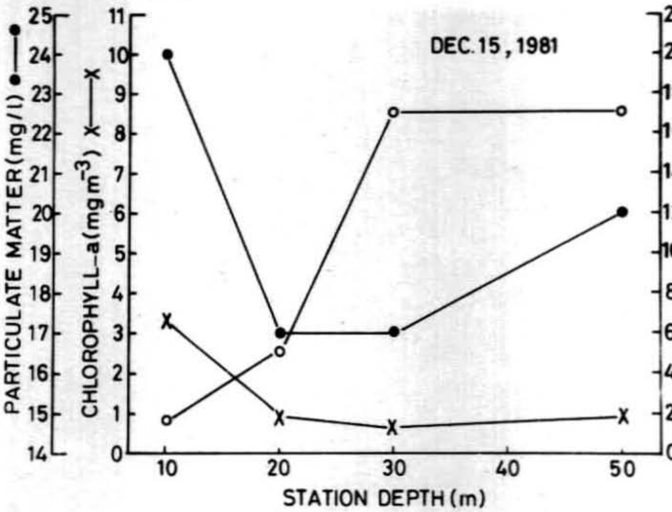
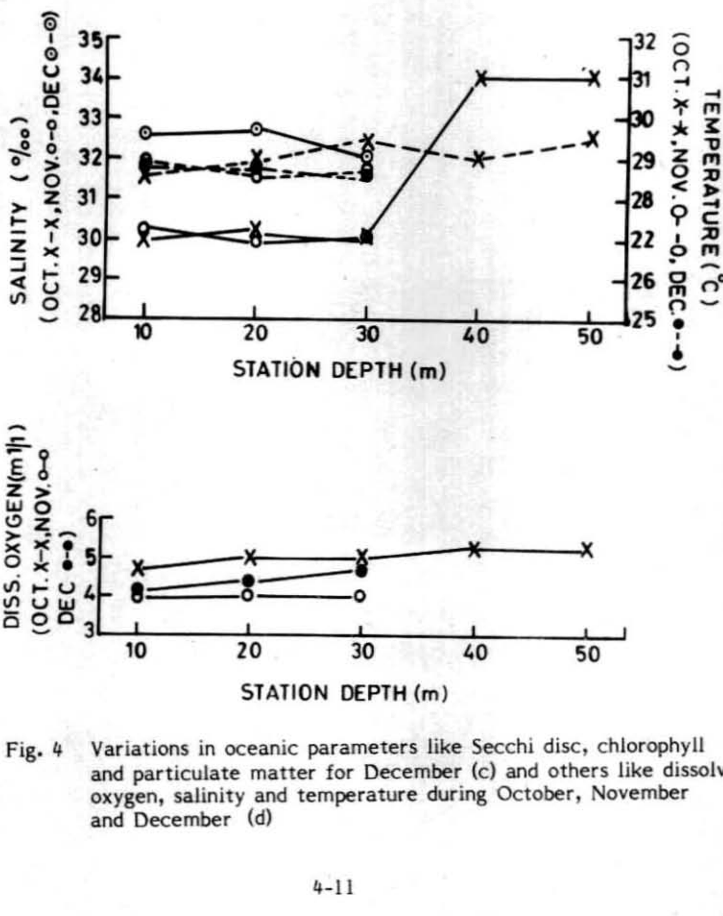


Fig. 4 Variations in oceanic parameters for October (a) and November (b)



(c)



(d)

Fig. 4 Variations in oceanic parameters like Secchi disc, chlorophyll and particulate matter for December (c) and others like dissolved oxygen, salinity and temperature during October, November and December (d)

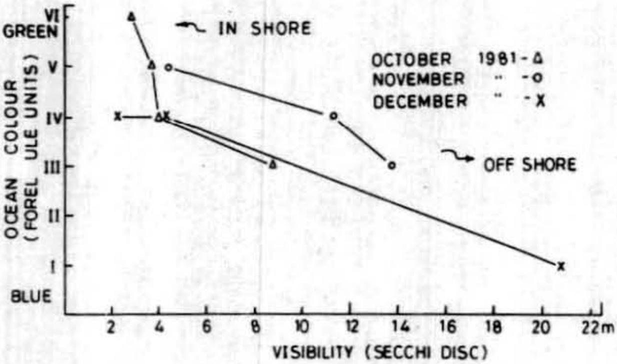


Fig. 5 Ocean colour (Forel-Ule colour scale) versus Secchi disc depth

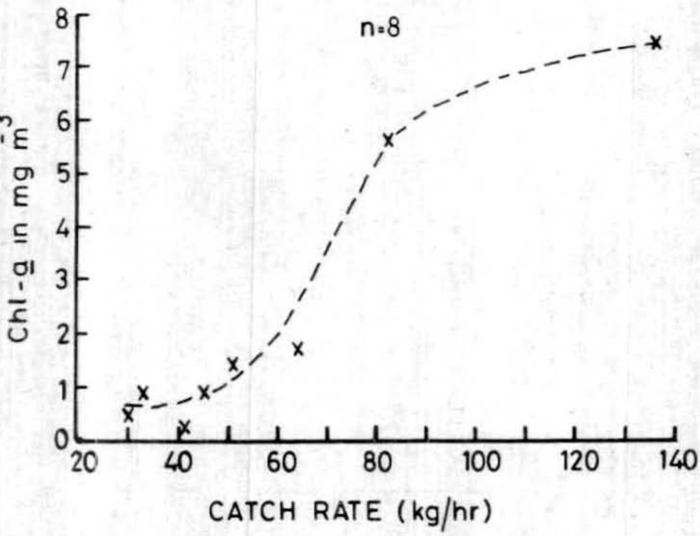


Fig. 6 Relationship between chlorophyll pigment and fish catch rate (kg/hr)

REMOTE SENSING OF OCEAN COLOUR AND TARGETING OF FISH SCHOOLS FROM AIRBORNE SENSORS

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Abstract

Remote sensing from airborne sensors has been used for studying the well known pelagic schools of oil sardine and mackerel in the Arabian sea of the Indian Ocean. A high productivity is reported in the oceanic waters off Cochin preceding SW monsoon. A remote sensing experiment was carried out in the oceanic waters over North of Cochin coast involving vessel-based sea truth data collection synchronous to aircraft overflights during October, November and December 1981. Sensors flown on board aircraft were photographic camera system and an Ocean Colour Radiometer (OCR) having spectral channels almost similar to that of Nimbus-7 CZCS sensor. Fish schools could be directly spotted equally well on all the three types of films used viz., conventional colour (Kodak 2448), colour infrared (Kodak 2443) and panchromatic black-and-white (Kodak 2402) but only during October. An indirect method of mapping spatial distribution of phytoplankton pigment (responsible for primary productivity in oceanic waters) may in turn help in estimating the fish potential through an understanding of its conversion to other trophic states in the ocean food chain. Upwelling radiance data from OCR could be suitably used in the understanding of atmospheric effects and in developing a pigment algorithm.

Introduction

The present study was aimed at studying ocean parameters directly or indirectly linked to the availability of marine fish resources. Attempts have also been made at direct spotting of fish schools and its quantification (UNDP/FAO Pelagic Fisheries Project, Progress Report 4,8 & 9, 1972-74). One of the most important ocean parameters which can be remotely sensed is chlorophyll-a pigment (present in almost all phytoplankton). The standing stock of phytoplankton can be given approximately in terms of colour of the sea. This colour of the sea can be defined by a colour index which is the ratio of upwelling radiance/irradiance to the downwelling radiance/irradiance in the blue and green region of the electromagnetic spectrum (Curran, 1972; Clarke and Ewing 1974; Hovis and

Leung, 1977; Gordon and Clark, 1980; Hojerslev, 1980; Morel, 1980). Ocean colour estimation leads to the estimation of primary productivity and finally to the third level productivity i.e. fish in the ocean food chain. During October, November and December 1981 a remote sensing experiment was carried out in coastal waters over North of Cochin using vessel-based observations and aircraft overflights. The sensors used onboard aircraft were a bank of Hasselblad 500EL/M cameras and an Ocean Colour Radiometer (OCR) having spectral channels almost similar to that of CZCS sensor on Nimbus-7 satellite. Oceanic waters over North of Cochin are well known for the occurrence and abundance of pelagic schools of oil sardine ***(Sardinella longiceps)*** and mackerel ***(Rastrelliger kanagurta).***

Data Acquisition and Analysis

Sea Truth

Figure 1 shows the sea truth stations and vessel positions with respect to their operating station depth and flight lines in the study area. Data on oceanic parameters, namely, temperature, salinity, dissolved oxygen and chlorophyll-a were collected at station depth (surface to bottom) of 10,20,30,40 and 50m. Oceanic parameters were measured on water samples collected at the surface, 1 and 6m ocean depth. Two large vessels (17.5m overall length) and two small vessels (14.3m overall length) were deployed during sea truth data collection in synchronous with aircraft flights. The vessel positions as shown in Figure 1 were kept same for all the three time surveys i.e. during October, November and December, 1981.

A bank of three Hasselblad 500EL/M cameras with three film types viz., conventional colour (Kodak 2448), colour infrared (Kodak 2443) and panchromatic black-and-white (Kodak 2402) was flown on a Dakota aircraft at 2 km altitude. Visual interpretation technique was adopted in studying the aerial photographs. Apart from the above a Ocean Colour Radiometer (OCR) was also flown on the aircraft but at different altitudes. Data from the NRSA's aircraft sensor - OCR were used to examine the aspects of atmospheric correction and developing a pigment algorithm. The OCR is a high-gain scanning radiometer optimized for ocean-colour sensing with narrow bandwidths (11-14 nm). The spectral bands of this sensor are fixed at 445, 520, 550, 600, 670 and 750 nm, with ground resolution of about 60m at 1 km flying altitude. OCR data was collected at different flying altitudes i.e., 500, 700 and 1000m and recorded on a magnetic-tape for further processing using an in-house VAX-11/780 computer system. Upwelling radiance values in different spectral channels were finally calculated using the OCR system calibration data.

Results and Discussion

It was observed that there was no significant change during the three time observations i.e. October, November and December, in oceanic parameters such as dissolved oxygen, temperature and salinity indicating that the hydrographic conditions had more or less stabilized. A significant change in chlorophyll-a (hereafter referred to as pigment) concentration was observed with the highest average value during October (about 6.4 mg m^{-3}) followed by lower values during November (about 1.7 mg m^{-3}) and December (about 1.4 mg m^{-3}).

It was observed from the study of aerial photographs that fish schools could be directly spotted equally well on all the three film types used. Figure 2 shows one such photograph. However, it was seen that these schools could be spotted only during October and were largely confined to the near shore waters.

Radiance measurements from different altitudes can be used in removing the atmospheric contribution for retrieving the water leaving radiance by extrapolation so as to achieve the zero altitude radiance (Morel 1980). A similar approach was adopted here and is shown in Figure 3 for OCR data collected over deep-blue ocean water. However, this approach could not be applied to radiance data collected in areas with higher pigment concentrations. The next step in the analysis was to develop a pigment algorithm which relates the pigment concentration to the ratios of upwelling radiances at 440 or 445, 520, 550 and 670 nm. The concept of using radiance ratios for suitable wavelengths in remote sensing of ocean colour is described by Clark et al (1970); Arvesen et al (1973); Hovis and Leung (1977); Gordon and Clark (1980); Morel (1980) and Hojerslev (1980). A pigment algorithm as described by Gordon and Clark (1980) was used here by taking ratios of OCR spectral radiances which are close to CZCS bands, namely, $R_1 = L_u 445/L_u 550$, $R_2 = L_u 445/L_u 520$, $R_3 = L_u 520/L_u 550$ and $R_4 = L_u 445/L_u 670$. The upwelling spectral radiance (L_w) as derived from within near-surface water layers has been used in most of the algorithms (Morel and Prieur 1977; Gordon and Clark, 1980). In the present study an attempt was made to relate the upwelling radiance (L_u) as derived from aircraft sensor data, directly to the surface measurement of phytoplankton pigment concentration. The log-transformed upwelling radiance ratios (R_1, R_2, R_3 and R_4), pigment concentration and their least squares regression lines are shown in Figure 4. Table 1 gives a summary of the least squares regression analysis.

Table 1

Summary of least squares regression results of the log surface chlorophyll-a and log upwelling radiance ratios

Radiance ratios	Regression coefficients $\log_{10} a$	b	Coefficients of determination r^2	Standard error of estimate S y.x
R_1	0.290	-3.953	0.544	0.584
R_2	0.291	-7.524	0.762	0.779
R_3	0.100	-1.830	0.053	-
R_4	2.742	-7.185	0.663	0.560

The coefficients of determination (r^2) value was at a maximum for R_2 ($r^2 = 0.76$) followed by R_4 ($r^2 = 0.66$), R_1 ($r^2 = 0.54$) and least in R_3 ($r^2 = 0.05$). These results approximately match those observed by Gordon and Clark (1980). The best correlation was found in 445 nm versus 520 nm although it is certainly lower than the corresponding r^2 value of 0.97 ($L_w 440/L_w 500$) and 0.94 ($L_w 440/L_w 520$) reported by Gordon and Clark (1980). One of the main reasons for the low value of r^2 in the present investigation may be due to phaeopigments which are not included in the analysis. A poor correlation in R_3 is probably due to the spectral channels being centered in closely placed spectral region i.e. at 520 and 550 nm. The pigment concentrations used here are representative of the surface to 6m depth. The regression analysis for ratio R_2 was used in mapping spatial distribution of chlorophyll-a and is presented here for a portion of flight run number-R_1 (Figure 5). The computer classified chlorophyll-a concentration and the actual surface measurements during sea truth are also shown in Figure 5.

Conclusions

Direct spotting of fish schools is possible in certain period of the fishing season but does not seem to be feasible on an operational basis. Upwelling radiance ratios derived from OCR (aircraft sensor) could be related directly to surface measurement of chlorophyll-a concentration. A high correlation ratio-R_2 (L_u 445/ L_u 520) matches the maximum (445 nm) and minimum (520 nm) absorption characteristic of chlorophyll-a. The upwelling radiance data at various flying altitude was useful in removing the atmospheric effects. Regression analysis data was effectively used in mapping the spatial distribution of chlorophyll-a pigment.

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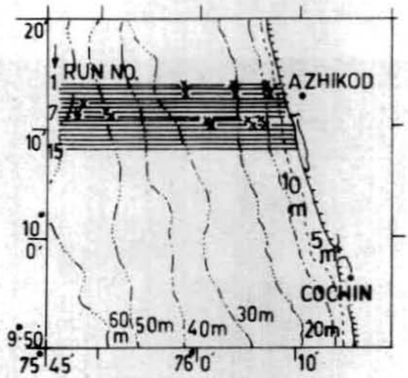

LEGEND

NAME OF THE VESSEL	VESSEL CODE	OPERATING DEPTH(m)	RUN No.
MEENA SACHATAK	V1	40,50	7.8
MEENA UTPADAK	V2	10,30,50	5
CADALMIN I	V3	10,20.30	1,3
CADALMIN IX	V4	10,20.30	9.10

0 6 12 18 km

Fig. 1 Study area showing vessel positions (X) and flight runs

Fig. 2 A panchromatic black-and-white aerial photograph showing fish schools (white patches)

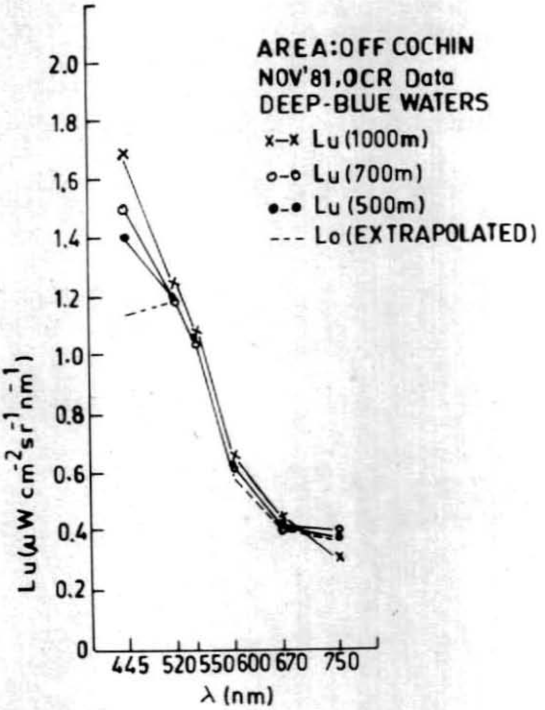

Fig. 3 Upwelling radiances measured over deep-blue waters from different flying altitudes

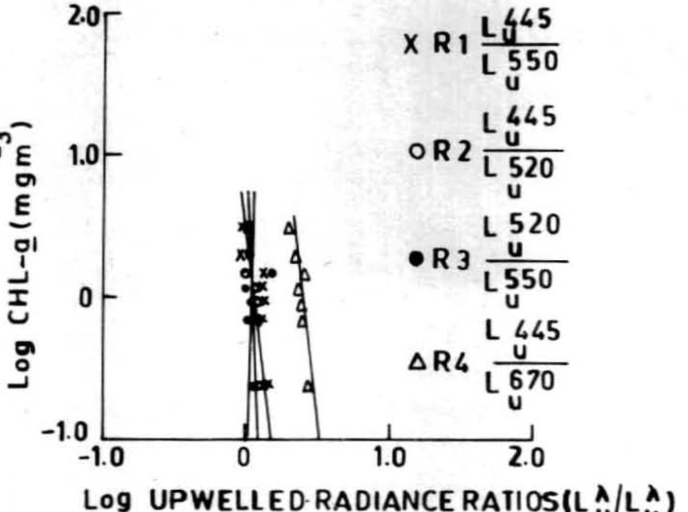

Fig. 4 Relationship between chlorophyll-a and upwelling radiance (L_u) ratios

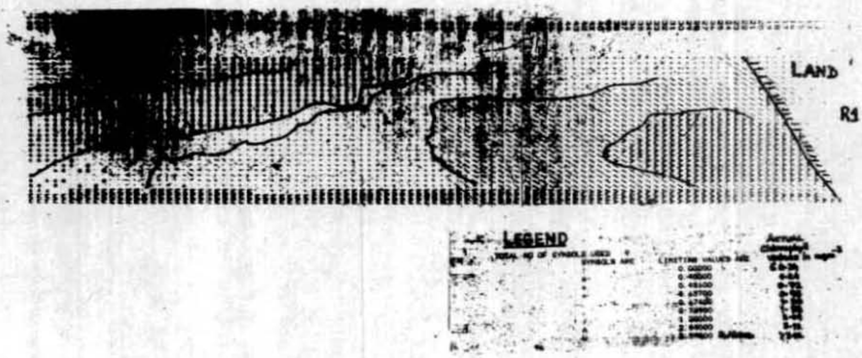

Fig. 5 Spatial distribution of chlorophyll pigment along a flight run - R_1 (OCR sensor data)

APPLICATION OF LANDSAT MSS DATA IN OCEAN COLOUR SENSING

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Abstract

Landsat MSS data off Cochin Coast was analysed and an attempt made to look into the relationship between MSS gray values and concentration of pigment/particulate matter. MSS band 4 and 5 showed the maximum gray value range as compared to band 6 and 7. A density sliced image of band 4 was generated in the form of a color coded image showing the gray levels corresponding to various pigment levels. A multiple linear regression analysis was carried out for chlorophyll/particulate matter and gray values of band 4,5,6 and 7. Regression analysis showed that chlorophyll has a high correlation with the MSS data (r^2 = 0.95) and in particular with band 4 and 5 (r^2 = 0.85). Correlation with band 6 and 7 was relatively low (r^2 = < 0.74). As against this the particulate matter showed a poor correlation with MSS band 4 and 5 (r^2 = 0.32).

Introduction

Landsat satellite is primarily designed for land applicatios but has found use to some extent in oceanographic applications as well. Gower et al (1980) showed that an increase in reflectance in MSS 4 as against those in 5,6 and 7 could be associated with increase in phytoplankton concentration. Strong (1974) has found Landsat useful in mapping algal bloom. Ulbricht (1983) reported that MSS band 4 and 5 were best suited for studying mass accumulation of blue green algae. It has also been observed that Landsat MSS data has an edge over Nimbus-7 CZCS data as regards the mapping of chlorophyll concentration above 2 μg/l (Becker et al, 1978). In the present study an attempt is made to look into the relationship between the MSS gray values and oceanic parameters like chlorophyll-a and particulate matter. In the analysis Landsat data of November 10, 1981 has been compared with the sea truth data acquired on November 27, 1981.

Data Acquisition and Analysis

Sea truth data was collected in oceanic waters over North of Cochin on November 27, 1981 at various station depths, namely, 10,20,30,40 and 50m. Three vessels namely, Cadalmin I, Cadalmin IX and Meena Sachatak were deployed for data collection (Table 1). A Landsat MSS compatible Exotech Radiometer (Model 100.A) was used on vessel to measure radiance and irradiance in four bands

Table 1

Data on location of sea truth stations (November 27, 1981)

Vessel/Station No.	Station depth (m)	Location Lat. Long.	Time (hrs)
Cadalmin (V_1)			
1	10	10°13.2'N, 76°6.9'E	9.30
2	10	10°14'N, 76°6.8'E	10.00
3	20	10°14'N, 76°3.6'E	10.40
4	20	10°13.2'N, 76°3.8'E	11.00
5	30	10°13.2'N, 75°58.6'E	11.40
6	30	10°14'N, 75°58.6'E	12.00
Meena Sachatak (V_2)			
1	40	10°10.8'N, 75°56'E	10.35
2	40	10°11.6'N, 75°56'E	11.00
3	50	10°11.6'N, 75°54'E	11.45
4	50	10°10.8'N, 75°54'E	13.15
Cadalmin IX (V_3)			
1	10	10°9.6'N, 76°07'E	9.00
2	10	10°10.4'N, 76°6.7'E	9.45
3	30	10°10.2'N, 76°01.5'E	11.00

corresponding to Landsat MSS i.e. band 4 (500-600 nm), band 5 (600-700 nm), band 6 (700-800 nm) and band 7 (800-1100 nm). Apart from above the Secchi disc visibility was also measured. Table 2 gives details of parameters collected during sea truth. Figure 1 shows the relationship between Secchi disc depth and chlorophyll pigment/particulate matter at various stations. Landsat CCT was subjected to digital analysis.

Sea Truth

Water samples from sea truth stations were analysed for estimating chlorophyll-a (mg/m^3) and particulate matter (mg/l).

Satellite Data

The first step in the digital analysis was to locate the sea truth stations on

Table 2

Sea truth data at various stations (November 27, 1981)

Vessel/Station No.	Secchi disc depth (m)	Reflectance Band 4	Reflectance Band 5	Chlorophyll (mg/m^3)	Particulate matter (mg/l)
Cadalmin I(V_1)					
1	7.75	5.60	2.35	2.08	12.83
2	7.8	5.72	3.49	3.12	13.51
3	16.0	2.4	1.62	0.72	13.50
4	15.0	3.2	1.36	1.20	15.15
5	16.0	1.82	0.79	1.52	13.0
6	16.0	1.89	0.76	0.96	13.25
Meena Sachatak (V_2)					
1	20.0	2.52	2.63	0.24	17.40
2	20.5	1.33	0.84	-	-
3	21.3	2.77	1.36	-	-
4	23.1	2.94	2.91	0.48	19.9
Cadalmin IX (V_3)					
1	4.3	3.75	2.07	1.69	14.77
2	4.3	3.03	1.87	2.77	15.35
3	13.75	-	-	0.96	11.07

the image. For this purpose thirty ground control points on the land portion of the sub image covering ocean waters off Cochin coast were chosen. A two dimensional affine transformation was used to relate image coordinates with the corresponding coordinates on the map of the study area. A window (20 pixels x 20 scan lines) around each sea truth station was taken to determine the mean gray value and its standard deviation (Table 3).

An attempt was made to look into the relationship between chlorophyll-a pigment and particulate matter with the gray values (Figures 2 and 3). A density sliced image of band 4 (Figure 4) shows distinct pattern within the sea water related to variations in pigment levels. The landmass in the image was masked to value 0. The various colour codes correspond to various pigment levels (Table 4). Singh and Cracknell (1979) have used various functional forms to correlate the sea truth data with the Landsat MSS data. A multiple linear model was used to look into the relationship of all the four MSS bands with biological parameters.

Table 3

Gray values from LANDSAT image and their standard deviation

Vessel/Station No.	Gray values			
	Band 4	Band 5	Band 6	Band 7
Cadalmin I (V_1)				
1	45.28±2.28	25.78±2.02	1.17±1.42	0.82±0.95
2	45.44±2.41	25.53±2.05	1.37±1.55	0.89±1.00
3	38.50±2.01	20.30±1.88	0.17±0.59	0.42±0.71
4	38.32±1.93	19.65±1.89	0.03±0.28	0.30±0.64
5	34.06±1.74	15.56±2.02	0.0±0.05	0.27±0.61
6	34.23±1.65	15.53±1.90	0.01±0.10	0.27±0.61
Meena Sachatak (V_2)				
1	27.62±1.40	11.17±2.29	0.0±0.0	0.26±0.64
2	27.98±1.61	11.52±2.17	0.05±0.36	0.30±0.69
3	26.53±1.69	9.69±2.39	0.0±0.0	0.15±0.44
4	28.87±1.55	10.10±2.22	0.0±0.0	0.17±0.47
Cadalmin IX (V_3)				
1	42.81±3.15	22.11±2.99	0.17±0.61	0.39±0.76
2	43.88±2.52	23.77±2.26	0.26±0.73	0.36±0.69
3	37.44±1.80	17.58±1.94	0.18±0.18	0.38±0.71

Table 4

Colour codes for Figure 4

Colour codes	Density sliced range (Band 4 gray values)	Chlorophyll concentration (mg/m^3)
Deep blue	0-22	-
Cyan	23-26	0.00-0.20
Blue	27-30	0.21-0.70
Green	31-36	0.71-1.45

(Table 4 contd.)

Colour codes	Density sliced range (Band 4 gray values)	Chlorophyll concentration (mg/m^3)
Yellow	37-40	1.46-1.96
Red	41-50	1.97-3.22

The model is,

$$X = C_o + C_1G_4 + C_2G_5 + C_3G_6 + C_4G_7$$

where C's are constants to be determined, X is pigment/particulate matter concentration and G_4 to G_7 are the gray values in MSS band 4 through 7.

The gray values of four MSS bands and biological data set were subjected to a multiple linear regression analysis. Results of the regression analysis is given in Table 5. Results of the regression analysis were also used in assigning various pigment levels in density sliced image of band 4 (Figure 4, Table 4).

Table 5

Results of the regression analysis

Physical quantity	Constant C_o	Regression coefficients Band 4 C_1	Band 5 C_2	Band 6 C_3	Band 7 C_4	Multiple correlation r^2
Chlorophyll	-4.611	0.358 (0.84)	-0.288 (0.84)	3.85 (0.73)	-7.64 (0.70)	0.95
Particulate matter	17.54	-0.327 (0.32)	0.777 (0.33)	5.72 (-0.07)	-19.62 (-0.19)	0.91

Figures in parenthesis give the correlation of the dependent variable with the corresponding independent variable.

As against pigment the particulate matter showed a poor correlation for individual MSS bands. A residual plot of measured versus calculated pigment and particulate matter is shown in Figure 5.

Results and Discussions

Sea truth data shows that there is an inverse relationship between Secchi disc depth and pigment/particulate concentration the lower is the Secchi disc depth the higher is the pigment concentration and vice versa (Figure 1). The pigment values are high at 10m depth and decline in off shore waters (Figure 1). Table 2 shows the dependence of Secchi disc depth and reflectance(Exotech Radiometer) on the concentration of chlorophyll pigment and particulate matter. It is observed that in general the reflectance in band 4 (green) is higher than in band 5 (red) with varying concentrations of pigment except at lower concentrations. Particulate matter did not show any relationship with gray values in band 4&5 which carry information about ocean colour. Table 3 shows the gray values from Landsat MSS bands at various stations. It is clear from the above table that band 4 and 5 give maximum gray level range as compared to band 6 and 7. Gray values are higher in band 4 than in band 5 and shows a gradual decrease with increasing station depth. After 40m depth not much change was observed. This indicates that the turbidity decreases in off shore and this is also confirmed from Secchi disc depth. The density sliced image of band 4 (Figure 4) shows quite distinct pattern within the oceanic waters. Regression analysis (Table 4) shows that chlorophyll concentration is highly correlated with the MSS data (Multiple correlation, $r^2 = 0.95$) and particularly with band 4 and 5 ($r^2 = 0.84$) whereas correlation with bands 6 and 7 is relatively low ($r^2 = < 0.74$). The multiple correlation value ($r^2 = 0.91$) was high for particulate matter but showed a very poor correlation with individual bands i.e. 4,5,6 and 7. It is clear that band 4 and 5 provide the most useful information about ocean colour.

Conclusions

A high correlation was observed between the phytoplankton pigment concentration and gray values of Landsat MSS band 4 and 5. Particulate matter on the contrary showed a very poor correlation with MSS gray values. Also it is clear that high concentrations of pigment can be mapped to fairly satisfactory levels in the near shore waters using Landsat MSS bands 4 and 5. Density slicing of band 4 was useful in mapping pigment levels in near shore waters.

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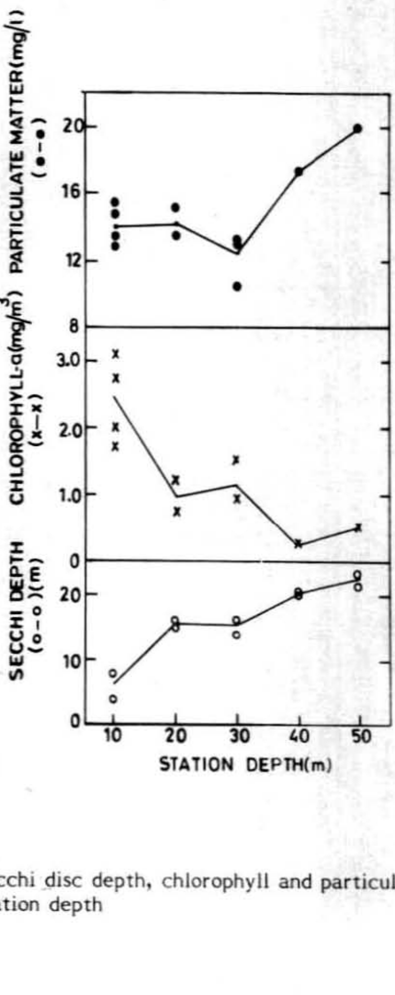

Fig. 1 Secchi disc depth, chlorophyll and particulate matter versus station depth

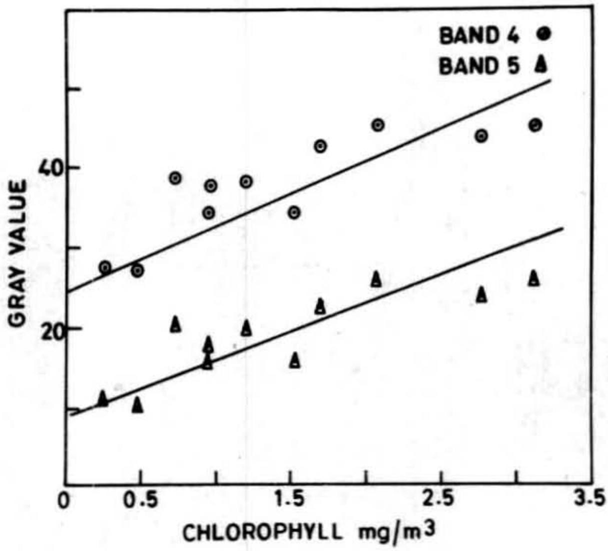

Fig. 2 Gray values (MSS band 4 and 5) versus chlorophyll-a

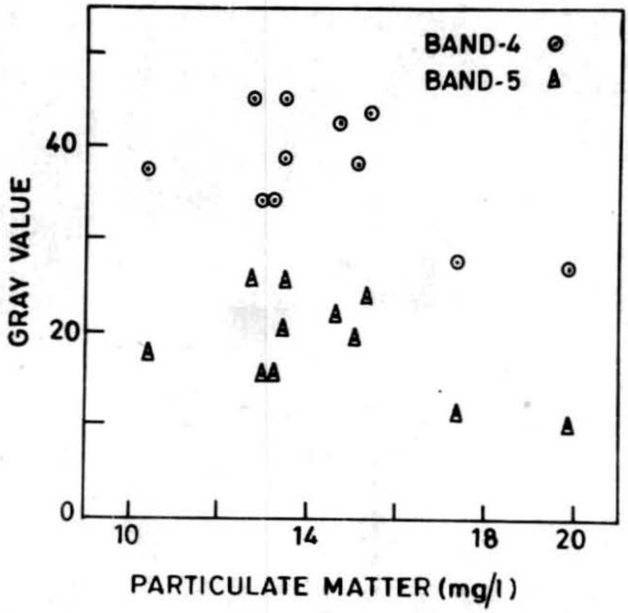

Fig. 3 Gray values (MSS band 4 and 5) versus particulate matter

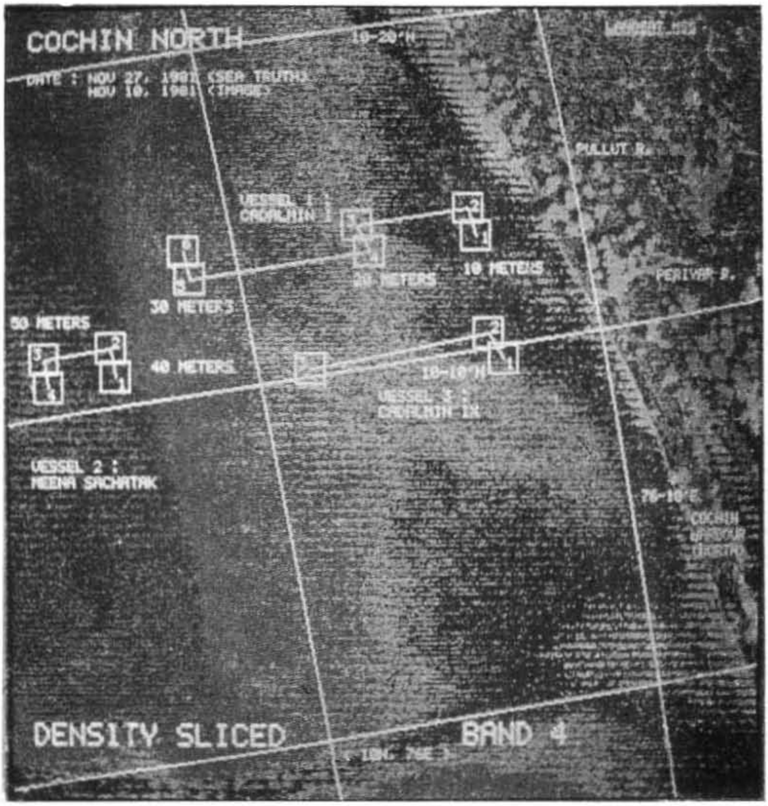

Fig. 4 Density sliced image of Landsat MSS band 4 for oceanic waters off Cochin (Path 155 Row 053, Nov., 10, 1981)

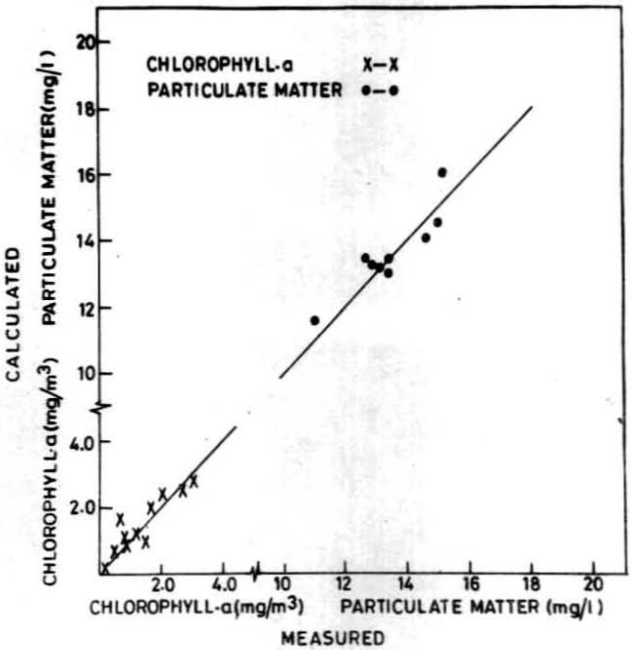

Fig. 5 Residual plot of calculated versus measured chlorophyll and particulate matter

PHYTOPLANKTON PIGMENT MAPPING FROM NIMBUS-7 CZCS DATA

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Abstract

This paper discusses about an attempt made to develop an atmospheric correction scheme using atmospheric constituents of tropical region. The same was applied to Nimbus-7 CZCS data collected over Indian Ocean. A sub image covering oceanic waters off Karwar coast was subjected to atmospheric correction in order to understand the composition of various components of the total radiance signal received at the satellite sensor. In other sub image covering oceanic waters off Cochin coast, a colour coded C-Map (chlorophyll pigment map) was generated showing spatial distribution of phytoplankton pigment.

Introduction

The Coastal Zone Colour Scanner (CZCS) on Nimbus-7 satellite launched in October 1978, is a high gain spectrometer designed to image the ocean in six coregistered spectral bands centered at 443, 520, 550, 670, 750 and 11,500 nm. Sensor channels are selected so as to help in remote determination of the near surface concentration of phytoplankton pigment in oceanic waters. The first four bands in visible have a spectral width of 20 nm and specific to properties of chlorophyll molecules while band 5 in near IR and 6 in thermal IR have spectral width of 100 and 2000 nm respectively with a ground resolution of 825 meters (0.865 m. rads.) for all the bands. An attempt has been made at developing a scheme for atmospheric correction using standard atmospheric constituents of tropical region (Gordon, 1978) and applied to CZCS data (Orbit 5570, Dec'1, 1979) over Indian Ocean. The pigment algorithm of Gordon et al (1980) was used to classify the pigment distribution in oceanic waters off Karwar and Cochin in the west coast of India.

Methodology

Atmospheric Correction Scheme

In order to use CZCS data to estimate phytoplankton pigment concentration, it is necessary to account for the scattering by the air (Rayleigh) and by microscopic particles suspended in air-aerosols (Mie). Evaluation of pigment concentration requires accurate measurements of radiance originating from or beneath the sea surface.

The total radiance signal, L_T received at the sensor aperture as a function of wavelength is composed of the three components as given below,

$$L_T(\lambda) = L_R(\lambda) + L_A(\lambda) + t_{RAOZ}(\lambda) . L_W(\lambda) \qquad (1)$$

where

$L_T(\lambda)$ = radiance viewed by the sensor

$L_R(\lambda)$ = radiance contributed by scattering due to air (Rayleigh)

$L_A(\lambda)$ = radiance contributed by aerosol scattering (Mie)

$t_{RAOZ}(\lambda). L_W(\lambda)$ = radiance backscattered from sea surface or water (L_W) and transmitted through atmosphere

$t_{RAOZ}(\lambda)$ = diffuse transmittance of the atmosphere

The contribution of $L_R(\lambda)$ and $L_A(\lambda)$ are to be evaluated from Equation 1 in order to extract the sea surface radiance. Both these parameters are wavelength dependent and are to be calculated for each of the spectral channel of CZCS sensor.

Correction for Rayleigh Scattering

Downwelling solar flux is scattered by air molecules (Rayleigh) and aerosols (Mie) in the atmosphere. A part of the solar radiation scatttered into the sensor field of view (FOV) is due to Rayleigh scattering and is computed from the following Equation,

$$L_R(\lambda) = \frac{F_O t_{OZ}(\mu)\, t_{OZ}(\mu_o)\, \tau_R(\lambda)}{\mu} \cdot$$

$$[P_R(\psi-) + P_R(\psi+).(\rho(\mu)\, t(\mu) + \rho(\mu_o)\, t(\mu_o))] \qquad (2)$$

where,

F_O = extraterrestrial solar flux

t_{OZ} = $\exp[-\tau_{OZ}(\lambda)/\mu]$ = Ozone transmittance

τ_{OZ} = ozone optical thickness

μ = $\cos\theta$ = sensor Zenith angle

μ_o = $\cos\theta_o$ = solar Zenith angle

$\tau_R(\lambda)$ = Rayleigh optical thickness

$P_R(\psi_-)$ = $3/4\,(1 + \cos^2\psi-)$ = phase function

ψ_- = scattering angle

$\rho(\mu)$ = Fresnel-reflectivity of sea water

$t(\mu)$ = diffuse transmittance in viewing direction

Detailed derivation of L_R is given in Appendix-I.

In the above Equation, the extraterrestrial solar flux for CZCS spectral channels was taken from Labs and Neckel (1970) and the values of $\tau_R(\lambda)$ and $\tau_{OZ}(\lambda)$ were used for the tropical regions (Gordon 1978). These are given in Table 1 and 2 respectively.

Table 1

Mean extraterrestrial solar flux $\overline{F_O(\lambda)}$ for the CZCS channels (Labs and Neckel, 1970)

$\overline{\lambda}$ (nm)	CZCS channel	$\overline{F_O(\lambda)}$ (μ w.cm^{-2}. nm^{-1})
440	1	182.5
520	2	186.7
550	3	186.9
670	4	153.6

Table 2

Rayleigh (τ_R) and absorbing gas (τ_{OZ}) optical thickness for CZCS channels (Gordon, 1978)

$\overline{\lambda}$ (nm)	Rayleigh optical thickness	Absorbing gas optical thickness*
440	0.2329	0.0066
520	0.1231	0.0166
550	0.0969	0.0261
670	0.0444	0.0158

*For tropical region (0°-25° latitude N & S)

Correction for Aerosol Scattering

In order to estimate the contribution of aerosol path-radiance which is added to the total signal the following assumptions were made (Gordon, 1981),

a) the normalised aerosol scattering phase function is nearly independent of wavelength, and

b) the aerosol optical thickness at a given wavelength is constant over an entire region of the image.

In that case the aerosol radiance at one wavelength will be proportional to that at another.

Hence,

$$L_A(\lambda_2) = S(\lambda_2, \lambda_1)\, L_A(\lambda_1)$$

where, $S(\lambda_2, \lambda_1)$ is a constant defined by the following,

$$S(\lambda_2, \lambda_1) \approx \varepsilon(\lambda_2, \lambda_1)\, \frac{F_O(\lambda_2)}{F_O(\lambda_1)} \quad (3)$$

where, $\varepsilon(\lambda_2, \lambda_1)$ is the ratio of aerosol optical thickness at wavelength λ_2 to that at wavelength λ_1. For λ_1 at 670 nm the L_W is assumed to be zero (Gordon and Clark, 1981). This is true for open ocean and does not apply to turbid waters near the coast because $L_W(670) \neq 0$. Then writing λ_1 as 670 and λ_2 as λ, the aerosol path radiance at wavelength λ is computed from the following (Sturm, 1983),

$$L_A(\lambda) = L_A(670)\, \frac{F_O(\lambda)\, t_{OZ}(\lambda, \mu, \mu_o)}{F_O(670)\, t_{OZ}(670, \mu, \mu_o)} \cdot \varepsilon(\lambda, 670) \quad (4)$$

where

$$\varepsilon(\lambda, 670) = \frac{\tau_A(\lambda)}{\tau_A(670)}$$

τ_A = aerosol optical thickness

Once $\varepsilon(443, 670)$ is known, $L_A(443)$ can be estimated from Equation 4. Derivation of $\varepsilon(443, 670)$ is given in Appendix-II.

The values of $t_{RAOZ}(\lambda)$, $L_R(\lambda)$ and $L_A(\lambda)$ are substituted in Equation 1, which gives $L_W(\lambda)$. Next subsurface radiance $L_{SS}(\lambda)$ is obtained from the following Equation

$$L_W(\lambda) = L_{SS}(\lambda)\, \frac{1 - \rho(\lambda)}{n^2(\lambda)}\, t_{RAOZ}(\lambda, \mu) \quad (5)$$

Pigment Algorithm

Once the subsurface radiances (L_{SS}) or water leaving radiance (L_W) have been determined in an image, then pigment algorithm as described by Gordon et al (1980) is implemented for estimating pigment concentration (C) which is as follows:

$$C = 0.504 \left(\frac{L_{443}}{L_{550}}\right)^{-1.264} \qquad (\text{for } C \leq 0.6 \text{ mg m}^{-3}) \quad (6)$$

$$C \doteq 0.843 \left(\frac{L_{520}}{L_{550}}\right)^{-3.975} \qquad (\text{for } C > 0.6 \text{ mg m}^{-3}) \qquad (7)$$

Data Analysis

Nimbus-7 CZCS data tape (Orbit 5570, Dec'1, 1979) over Indian Ocean was selected to apply the atmospheric correction algorithm as discussed earlier. Two sub images in the ocean waters off Karwar (Area-A) and Cochin (Area-B) coasts were selected in the full scene for the analysis (Figure 1).

Karwar Coast

A sub image (210 pixel x 154 scan line) was extracted from the data tape. Figure 2 a and b show the uncorrected or raw image and image corrected for Rayleigh scattering respectively. Figure 2 c shows image to which a correction for Rayleigh and aerosol scattering was applied. Table 3 shows the various components of the radiance signal for CZCS spectral channels viz., 443, 520, 550 and 670 nm. Figure 3 shows the pigment values in the study area for a few scan lines and pixels computed from the algorithm of Gordon et al (1980).

Table 3

Components of the radiance* signal received at the satellite sensor

Location		CZCS Wavelength ($\bar{\lambda}$) (nm)			
		443	520	550	670
Karwar coast	L_T	8.806	6.375	5.470	2.056
Orbit 5570	L_A	1.921	1.515	1.411	0.88
Dec., 1, 1979	L_R	5.195	2.732	2.097	0.813
	$t.L_W$	1.69	2.128	1.962	0.363
	L_W	2.03	2.396	2.197	0.396

*Radiance in μw. cm^{-2}. nm^{-1}. sr^{-1}

Cochin Coast

A sub image (250 pixel x 250 scan line) covering ocean waters off Cochin coast was selected from the CZCS image. This area is well known for the occurrence and abundance of pelagic fish schools of oil sardine and mackerel. These are known to directly feed on the phytoplankton. After application of atmospheric correction, the water leaving radiance (L_W) component from the total signal in 443 and 550 nm was used in the pigment algorithm of Gordon et al (1980) for extracting the phytoplankton pigment. As a next step, a colour coded C-Map (chlorophyll pigment map) was generated on a COMTAL image processing system in which the various gray levels correspond to the various pigment concentrations (Figure 4). The higher gray levels of the image were classified as land or cloud, whereas the lower gray levels were assigned various pigment concentrations.

Results and Discussions

In the sub image off Karwar it was observed that out of the total signal received by the satellite sensor the water leaving radiance, L_w is about 20 per cent in different CZCS channels which contains the necessary information about the ocean properties. The values of different components of radiance signal as received by the sensor matches with those reported by others (e.g., Sturm, 1979; Austin, 1981). Apart from this, a comparison of uncorrected image with corrected one shows an overall improvement in the contrast of the picture (Figures 2a, b and c). The other area off Cochin coast was used for generating a C-Map. The radiance signal in different CZCS channels after atmospheric correction was substituted in algorithm of Gordon et al (1980) to extract the pigment values.

The synchronous sea truth data for the CZCS data of December 1, 1979 was not available. However, a comparison was made between the pigment values obtained using algorithm of Gordon et al (1980), and the ones collected from vessels during December 1981 in the same area. It was observed that this algorithm appears to give an underestimation in pigment values. However, as reported earlier in one of the papers it was observed that the pigment values as obtained from K-Map gave a more realistic estimate. This is most probably due to the fact that K estimates and corresponding pigment value is representative of its distribution over the first attenuation length.

Conclusions

An atmospheric correction algorithm to account for scattering due to air molecules (Rayleigh) and suspended dust particles (Mie) has been developed to retrieve phytoplankton pigment in oceanic waters of the tropical region. The same could be applied to Nimbus-7 CZCS data collected over the Arabian Sea. The various components of the radiance signal matches well with those observed by others. A C-Map (chlorophyll pigment map) could be generated for oceanic waters off Cochin coast. However, validation of this analysis could not be done in absence of synchronous sea truth data.

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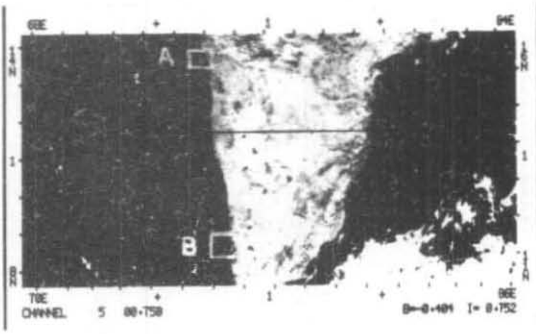

Fig. 1 Nimbus-7 CZCS image in channel 5 (Orbit 5570, December 1, 1979) showing the study areas off Karwar (A) and Cochin (B) coasts

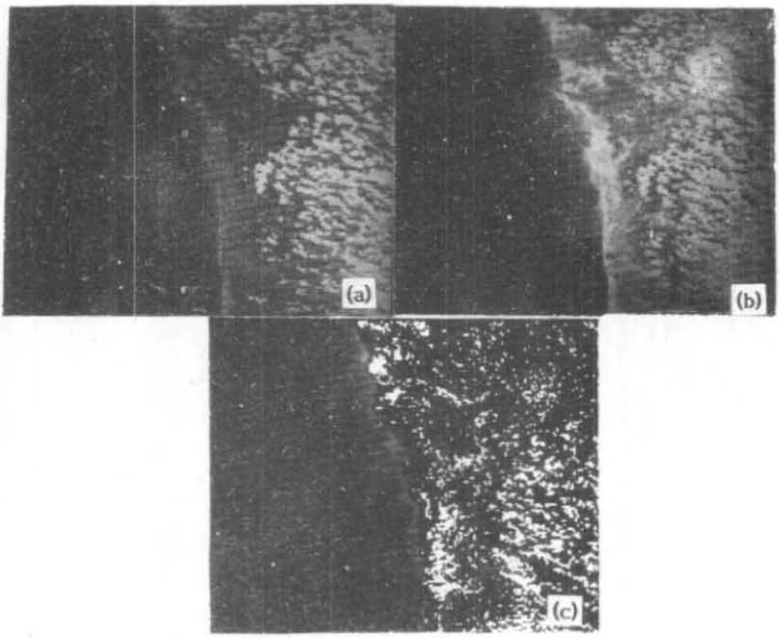

Fig. 2 Uncorrected image (a) off Karwar, corrected for Rayleigh scattering (b) and corrected for Rayleigh and aerosols (c)

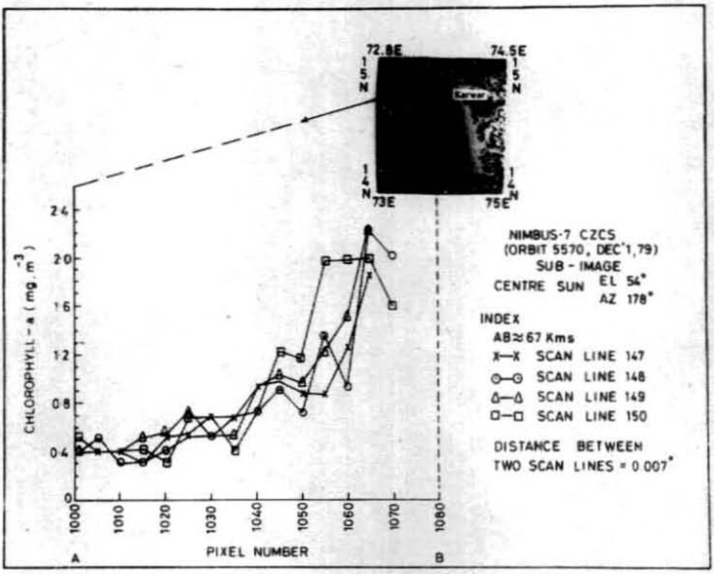

Fig. 3 Chlorophyll concentration along a few scan lines (Area : off Karwar coast)

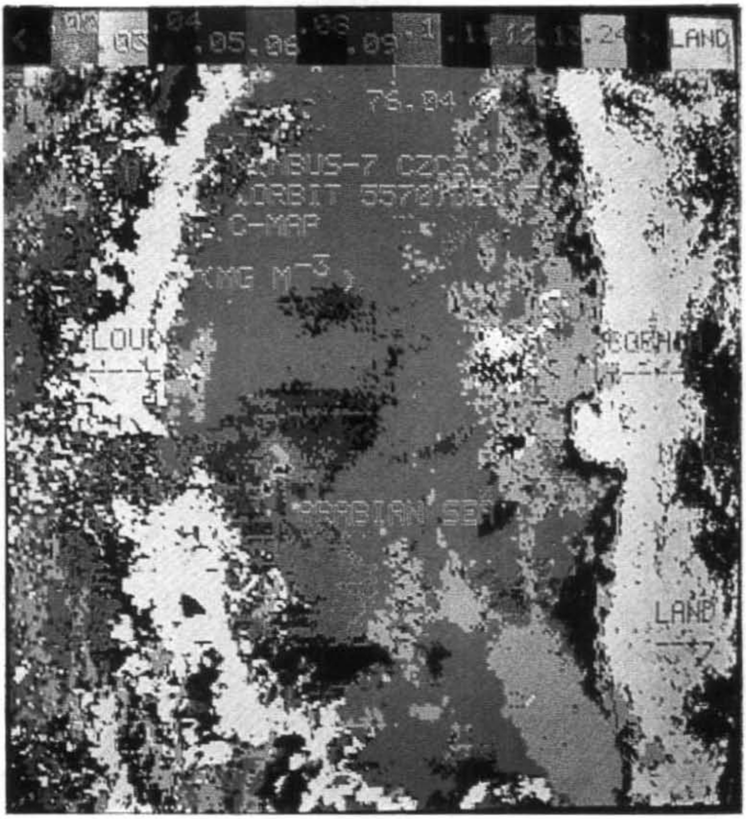

Fig. 4 A colour coded C-Map showing chlorophyll distribution (mg. m^{-3}) in oceanic waters off Cochin from Nimbus-7 CZCS data (Orbit 5570, December 1, 1979)

Appendix - I

Derivations for L_R component

Incident solar flux or irradiance is scattered by air molecules and can be explained in the following three probable ways,

$L_R(\lambda) = L_R(1) + L_R(2) + L_R(3)$

$L_R(1)$ = Direct solar flux scattered by air molecules into sensor field of view (FOV) before reaching water surface

$L_R(2)$ = Scattered solar flux reflected from water surface into FOV.

$L_R(3)$ = Reflected solar flux from water surface and scattered into FOV

$$L_R(1) = \frac{F_O t_{OZ}(\mu)\, t_{OZ}(\mu_o)\, \tau_R}{\mu} P_R(\psi_-) \quad (I.2)$$

where

τ_R = Rayleigh optical thickness

F_O = extraterrestrial solar flux

t_{OZ} = $\exp[-\tau_{OZ}(\lambda)/\mu]$ = Ozone transmittance

τ_{OZ} = Ozone optical thickness

μ = $\cos\theta$ = sensor Zenith angle

μ_o = $\cos\theta_o$ = solar Zenith angle

$P_R(\psi_-)$ = $3/4\,(1 + \cos^2\psi_-)$ is the phase function for Rayleigh scattering

ψ_- = Scattering angle

$$L_R(2) = \frac{F_O t_{OZ}(\mu)\, t_{OZ}(\mu_o)\, \tau_R}{\mu} P_R(\psi_+)\, \rho(\mu)\, t(\mu) \quad (I.3)$$

$\rho(\mu)$ = Fresnel-reflectivity of sea water

$t(\mu)$ = diffuse transmittance in viewing direction

$$L_R(3) = \frac{F_O t_{OZ}(\mu)\, t_{OZ}(\mu_o)\, \tau_R}{\mu} P_R(\psi_+)\, \rho(\mu_o)\, t(\mu_o) \quad (I.4)$$

From Equations I.1, I.2, I.3 and I.4, L_R can be rewritten as follows:

$$L_R(\lambda) = \frac{F_O t_{OZ}(\mu)\, t_{OZ}(\mu_o)\, \tau_R}{\mu} \cdot$$

$$[P_R(\psi_-) + P_R(\psi_+) \cdot (\rho(\mu)\, t(\mu) + \rho(\mu_o)\, t(\mu_o))] \quad (I.5)$$

Appendix - II

Derivations for $\varepsilon(\lambda, 670)$ as part of correction for scattering due to aerosols i.e., L_A component

A concept of clear water radiance is used to evaluate $\varepsilon(\lambda, 670)$ (Gordon and Clark, 1981). In this concept it is assumed that the subsurface radiance (L_{SS}) or water leaving radiance (L_W) in CZCS channels 2 and 3 (520 & 550 nm respectively) is constant in clear water, where phytoplankton pigment concentration (C) is low (C <0.25 mg m^{-3}), $L_{SS}(520)/L_{SS}(550) \approx 1.8$ (Sturm, 1983).

Therefore,

$$L_W(520) = 0.9\, \mu_o\, t_{RAOZ}(520, \mu_o) \frac{1 - \rho(\mu)}{n^2(520)} \cdot t_{RAOZ}(520, \mu) \qquad \text{(II.1)}$$

and

$$L_W(550) = 0.52\, \mu_o\, t_{RAOZ}(550, \mu_o) \frac{1 - \rho(\mu)}{n^2(550)}\, t_{RAOZ}(550, \mu) \qquad \text{(II.2)}$$

where

t_{RAOZ} = irradiance transmittance through the atmosphere = $e^{-(\tau_R/2)}$

ρ = Fresnel-reflectivity of sea water

n = refractive index of sea water

Having known the values of $L_W(520)$ and $L_W(550)$ from Equation II.1 and II.2, $\varepsilon(520, 670)$ and $\varepsilon(550, 670)$ were estimated from the following Equation for clear water (C <0.25 mg m^{-3}) (Gordon and Clark, 1981),

$$\varepsilon(\lambda, 670) = \frac{(L_T(\lambda) - L_R(\lambda) - L_W(\lambda))}{(L_T(670) - L_R(670) - L_W(670))} \cdot \frac{F_O(670)\, t_{OZ}(670, \mu, \mu_o)}{F_O(\lambda)\, t_{OZ}(\lambda, \mu, \mu_o)} \qquad \text{(II.3)}$$

where, λ = 520 or 550 nm.

After having estimated the values of $\varepsilon(520, 670)$ and $\varepsilon(550, 670)$ from Equation II.3, indices $\nu(520)$ and $\nu(550)$ were calculated from the following model of aerosols (Sturm, 1983) which were used for calculating $\varepsilon(443, 670)$,

$$\varepsilon(520, 670) = \left(\frac{670}{520}\right)^{\nu(520)} \qquad \text{(II.4)}$$

$$\varepsilon(550, 670) = \left(\frac{670}{550}\right)^{\nu(550)} \qquad \text{(II.5)}$$

where, $\nu(520)$ and $\nu(550)$ are known as Angstrom exponents.

$$\nu(443)' = 1/2\ (\nu(520) + \nu(550)) \qquad \text{(II.6)}$$

and

$$\varepsilon(443, 670) = \left(\frac{670}{443}\right)^{\nu(443)} \qquad \text{(II.7)}$$

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