CHAPTER 19

APPLICATIONS OF GEOPHYSICAL DATA SETS TO RESOLVE ECOSYSTEM CHALLENGES

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Introduction

Satellite Remote Sensing (SRS) datasets are often used in empirical or semi-analytical validated models, either to extrapolate regional datasets in space or to generate derived geo-physical products. A simple example for this can be the summation of thermal signals from different wavelengths for generation of SST. In a similar way, some of the most useful and relevant environmental properties in fisheries research such as sea surface salinity (SSS), Wind Speed (WS) and Wind Direction (WD), sea surface height (SSH), chlorophyll-a (Chl-a) and Chl-a derived primary production (PP) are available online as processed and unprocessed geo-physical datasets. These datasets can be used to advantage in various fisheries research and management programmes. A few such case studies are illustrated in this section:

SRS chlorophyll data providing cues on fish stock variability

Variations between years in the seasonal cycle of SRS Chl-a have been implicated in fluctuations in fish stock variability (Platt *et al.,* 2003). In this section, we describe the results of an analysis of Chl-a with Indian oil sardine in the coastal waters of India. Fishing effort in the coastal waters of India changed little in the period 1998-2006, with 238,772 fishing craft in 2005 (CMFRI 2005) in comparison with 239,000 craft in 1997 (Sathiadhas, 2006). Thus, the variability in sardine landings during the study period, despite steady fishing effort, indicates that other factors such as environment or food to the sardines are involved. A correlation analysis between available environmental factors (SST, sea bottom temperature, surface salinity, surface dissolved oxygen, bottom dissolved oxygen, pH, nutrients, chlorophyll, zooplankton, rainfall, multivariate El Niño Southern Oscillation index, coastal upwelling index, and derived SST) and sardine catch from the study area emphasised the high significance of chlorophyll compared with other environmental factors in explaining the variability in sardine catch (Krishnakumar and Bhat, 2008). Using their fine branchial apparatus, sardines feed predominantly on phytoplankton and zooplankton. In a given area, Chl-a is a good index of the food availability to sardines. Summer surface Chl-a from the study area lies in the range 0.1 to 5 mg/m^3, and can be very high, from 5 to 10 mg/m^3, during bloom periods. Given the wide dynamic range of chlorophyll concentration in the coastal waters of southwest India and the dominant role of chlorophyll as a determinant of variability in sardine stocks, it seems likely that much will be gained in studying this link in detail.

Algal bloom in the study area often occurs during upwelling. Upwelling in the waters of the southwest coast of India (5 to 15^0 N latitude) and the variability in local physical parameters drives changes in the chlorophyll concentration (Smitha *et al.,* 2008). Physical processes affect not only the magnitude of the plankton biomass, but also its species composition (Huntsman *et al.,* 1981), which may in turn affect larval fish feeding and survival (Lasker 1975; Simpson 1987). According to the Hjort-Cushing match-mismatch hypothesis (Hjort 1914; Cushing 1974; 1990), the survival rate of fish larvae is a function of the match between timing of hatching of eggs and initiation of spring phytoplankton bloom. The advent of SRS provides information at the appropriate temporal and spatial scales for testing this hypothesis (Platt *et al.,* 2007). With SRS, it is possible to characterize the spring bloom objectively based on the timing of initiation, amplitude and duration. The statistical moments of all of these properties, and their inter-annual variation, can be calculated and the results used to analyze the effect of ecosystem fluctuations on exploited fish stocks (Platt *et al.,* 2003).

The case study presented below deals with the interannual variability of Indian oil sardine (*Sardinella longiceps*) stock in the southwest coastal waters of India and its relationship with the phytoplankton bloom characteristics computed from SRS, with a view to explain larval survival and interannual variability at the synoptic scale (Grinson *et al.,* 2012). The life cycle of sardines includes an active breeding season from May to September. This coincides with the high chlorophyll concentration seen during May to September every year.Thus, we find a probable connection between the life history of sardines and phytoplankton bloom dynamics. This supports the finding that the fish itself times its breeding and adjusts its migration to exploit the productive southwest monsoon period. In this study, magnitude of the bloom during initiation month is selected for characterization of bloom, which naturally falls in the month of May every year. May is the most critical month for sardines because both bloom initiation and the beginning of sardines' active breeding phase occur during this month. A delay in the initiation of bloom in the area results in a delay in the onset of suitable conditions for survival of sardine larvae (Grinson *et al.,* 2012).

Reef Health Advisories Using SRS Derived SST

Globally, there are several instances of mass coral bleaching incidents leading to heavy reef mortality (Krishnan *et al.,* 2011). The application of SRS provides synoptic views of the global oceans in near-real-time for monitoring the reef areas (Liu *et al.,* 2003; Bahuguna *et al.,* 2008; Mahendra *et al.,* 2010). SST during night time is an important parameter for assessment of the thermal conditions inducing the bleaching. SRS provides SST information during day and night routinely, facilitating the development of a coral reef bleaching warning system to generate early warning advisories/ bulletins in near realtime. The estimation of monthly maximum mean using night time SST climatology retrieved using NOAA, AVHRR is used for generating reef health advisories to eliminate the effect of solar glare and reduce the variation in SST caused by the heating during day time. Threshold hotspot (HS) and daily heating week (DHW) values for a region are calculated the advisory (Mohanty *et al.*, 2013). Depending on the intensity of HS and DHW there can be advisories such as 'no stress'; 'watch'; 'warning' and 'alert levels-I & II' which progressively indicate the severity of a potential bleaching event. Based on this study INCOIS offers reef stress advisories to alert the reef managers to take appropriate measures to reduce the damage caused to reefs during bleaching events.

SRS Data for Cyclone Tracks Creating Productive Fishing Grounds

Even though cyclones are devastating, there are some positive effects of cyclones on the fishery. Study of the effect of tropical cyclones on biological processes has gained momentum in the recent past. In thermally-stratified coastal waters, cyclones trigger the breaking up of nutrient-depleted surface waters and bring in nutrient-rich sub-surface waters inducing sudden algal blooms and enhancing the regional scale PP. The effect of physical forcings on PP, its variation and associated hydrography in the southwestern Bay of Bengal during the southwest monsoon (July) and post-cyclone period (November) of 1999 was studied by Madhu *et al.,* (2002). In the post cyclone period, the combined effects of well-mixed coastal waters and freshwater injection from the land runoff associated with the cyclone brought nutrients to the mixed layer, which enhanced PP. Potentially, such enhancement of PP results in improving the regional fishery. But cyclone tracks alone will not provide the information on enhanced PP. SRS is able to detect the environmental changes caused by tropical cyclones. Geo-physical data sets from SRS are useful in such studies for indicating possible productive fishing grounds after a lag following the cyclone (Rao *et al.*, 2006).

Demarcation of Ecological Provinces in Support of an Ecosystem Approach to Fisheries Management

Globally, the ecosystem approach to fisheries management (EAFM) is preferred as a basis for sustainable management of fish stock (Garcia *et al.,* 2003). In this context, it is useful to have a spatial structure for global oceans defined on the basis of ecological provinces rather than geo-political considerations. There are various approaches for classifying the global oceans into ecological provinces (Ekman 1953; Margelef 1961; Yentsch and Garside 1986; Cushing 1989; Fanning 1992; Sathyendranath *et al.,* 1995). The classification by Longhurst *et al.*, (1995) is the most comprehensive, identifying some 50 biogeochemical provinces globally (Longhurst *et al.,* 1995). Some other methodologies require huge data sets for demarcating ecological provinces (Hooker *et al.,* 2000; Li *et al.,* 2004; Alvain *et al.*, 2005; Sherman *et al.,* 2011). But there is lack of *in situ* data to suppport these approaches. As oceanic realms are dynamic, there are logistic issues in sampling. Consequently, SRS data are very useful to clasification protocols. PP derived from SRS can be a very useful input as PP provinces subsume many oceanographic forcing mechanisms on synoptic scales (Platt and Sathyendranath 2008). These ecological provinces are useful in fisheries management as the physical processes and the ecosystems in each province support characteristic fisheries different from those in nearby provinces (Stuart *et al.,* 2011). Beyond static partitioning, there is a further goal for dynamic bio-geography at regional scales that would incorporate complexities of a dynamic marine environment and their effect on the phytoplankton. SRS will be an invaluable source of inputs in case of such partitioning. Changes in spatial extent of the ecological provinces arising from temporal variations in physical forcing can be captured in a SRS climatology of ocean colour.

Coupling Modelled and SRS Data for Effective Fishery Management

So far in this chapter, we have discussed the usage of environmental data sets from models and SRS for various aspects in fisheries research and management. But lack of environmental time series data sets pointed to the need for more data. Coupled with SRS, numerical modelling is an alternative tool to generate environmental and biological datasets, which can help to mitigate problems arising from data gaps.

Trophic Modelling Using SRS Data as an Ecosystem Approach To Fisheries Management

Trophic levels in the marine ecosystem are similar to those in terrestrial systems starting with primary producers and ending in scavengers. But, the trophic structure in marine systems is web like, rather than a linear food chain. Fishing often alters the ecosystem structure. Trophic webs will respond differently to fishing depending on whether the target species is a predator or prey species. Single-species fish stock-assessment models ignore food web interactions. Ecosystem based fish stock assessement is offered as another option. EAFM models often resort to SRS-based PP as an input for forcing at the base of the food web to investigate energy transfers and biomass in an ecosystem without fishing, from lower to upper trophic levels (Chassot *et al.,* 2011).

Generating Potential Fishing Zones (PFZ) and Their Dissemination along With Ocean State Forecasts (OSF)

Identification of PFZ involves an understanding of oceanic processes and interaction of hydro-biological parameters (Desai *et al.,* 2000). The forage base and the physical gradients of temperature and Chl-a help the predatory fish to locate their prey and the same cues are used by fishermen. A number of studies have examined the use of SRS as an aid to locate more productive fishing areas (Waluda *et al.,* 2001). Indian Remote Sensing Satellite P4 Ocean Colour Monitor (IRS P4 OCM) derived chlorophyll concentration and National Oceanographic Aerospace Administration Advanced Very High Resolution Radiometer

(NOAA AVHRR) derived SST images have been used to characterise the relationship between the biological and physical variables in coastal waters and it was observed that chlorophyll concentration and SST were inversely correlated with each other (Solanki *et al.,* 1998). The relationship between these two parameters was estimated by a clustering technique called ARNONE (NCAER, 2010) and the matching features were selected for generating integrated PFZ forecasts from the composite images on the basis of latitude and longitude (Solanki *et al.,* 2005; NCAER 2010).

Validation of studies of PFZ forecasts have shown that the forecast may lead to substantial increase in fish catch (Solanki *et al.,* 2001; 2003; Nayak *et al.,* 2003). PFZ forecasts in near-real time indicating the likely availability of fish stocks for the next 2 days are disseminated in the Indian EEZ by INCOIS to about 225 nodes for operational use (Nayak *et al.,* 2003). A significant increase in total catch by following PFZ forecasts has been documented from ANI (Grinson-George *et al.,* 2011, 2013).

Detection of Meso-Scale Features Such as Eddies and Fronts that may Indicate Productive Fishing Grounds

Oceanographic features such as eddies, currents and meanders are pervasive features in the world's oceans. These conspicuous hydrographic features influence the horizontal and vertical distributions of the chemical (e.g. nutrients), physical (e.g. SST) and biological (e.g. Chl-a) propertiesin pelagic systems (Yoder *et al.,* 1981, Seki *et al.,* 2001). Eddies have been found to be localized regions of higher PP leading to aggregation and development of forage species base communities. The presence of mesoscale eddies and their detection by the fishing fleet is an important factor in fishery performance, leading to increased catch per effort for most pelagic species (Laurs *et al.,* 1984). The influence of mesoscale processes at fronts, such as the formation of rings, meanders and streamers arising or breaking off from these dynamic current systems, has also been shown to be important in shaping the distribution of pelagic fish and shellfish (Waluda *et al.,* 2001). Studies linking the physical oceanographic processes with fish have been carried out around the major boundary currents and related mesoscale processes, such as in the fishing grounds associated with Kuroshio frontal regions (Yokouchi *et al.,* 2000), mesoscale eddies and pelagic fisheries off Hawaiian waters (Seki *et al.,* 2001), upwelling and longline fishery of Portuguese waters (Santos *et al.,* 2006), Atlantic tuna and Gulf of Mexico circulation (Block *et al.,* 2005), oceanographic conditions of spawning grounds of bluefin tuna in the NE Indian ocean (Matsuura *et al.,* 1997), bluefin and frigate tunaspawning along the Balaeric archipelago (Garcia *et al.,* 2003) and tuna exploitation near the mesoscale processes near the Sechelles (Fonteneau *et al.,* 2006).

The chlorophyll-SST based advisories depend on the surface manifestation by algal blooms and thermal fronts which result from eddies and upwelling. Using altimetry data however, one would be able to follow the evolution of feature from inception to maturation and dissipation with time. There is a time lag between physical upwelling of nutrients to the ocean surface and development of phytoplankton blooms, and subsequently the aggregation of planktivorous and piscivorous fish. Altimetry data helps to identify the fish-aggregating meso-scale features from the outset giving valuable time to forecast and exploit the consequences. Difficulties in getting cloud free imageries sometimes limits the scope of this approach. Altimetry data, especially the SSH have been useful to study the physical oceanography and mesoscale circulation. Advances in SRS altimetry are making it possible to extend the information to the coastal areas where the fishermen are most active. Inputs from the altimetry data on the mesoscale features can be used to augment the PFZ advisories and also provide data during cloud cover.

Forecasting Cyclones and Ocean State to Reduce Impacts on Coastal Fisher Folk and Resources

Apart from elucidating the areas of likelihood of fish/ shellfish distributions during the Planktonic Larval Duration (PLD) phase, the wind models used for generating wind inputs in simulation of physical process can be utilized for studying cyclone tracks. Fisheries is one of the sectors with high occupational hazard. The extent of direct mortality caused by storms at local or regional scales is severe (Gardner *et al.,* 2005; Done 1992). OSF derived as products of numerical models are provided as input to fishermen to mitigate this risk. OSF provides wave and swell height as well as period, WS as well as wind direction (WD), Tsunami and rough sea warnings and coastal current details. To ensure safe navigation and operations at sea, and to forewarn the fishermen community, INCOIS started the OSF service in 2005 by issuing forecasts seven days in advance and at three hourly intervals, with daily updates. Fishermen utilize these forecasts to guide their daily operational activities and to ensure safe navigation. Though international agencies such as National Centres for Environmental Prediction (NCEP), USA and European Centre for Medium-Range Weather Forecasts (ECMWF) and UK issue sea state forecasts based on models such as WAVEWATCH III and WAM, these forecasts are for the open ocean. The INCOIS model provide accurate location-specific forecast in the coastal waters using high resolution local bathymetry, and tuning them using observed wave measurements. Real-time and on-line validation of the forecast products is disseminated through various means by INCOIS (Nair *et al.,* 2013).

Cyclones also render coastal resources vulnerable. The ecological effects of cyclones on coral reefs have been reviewed by Harmelin-Vivien (1994). Tropical storms cause severe damage to the reefs; their impacts include the removal of reef matrix, scouring and fragmentation (Rogers *et al.,* 1991; Done 1992), deposition of loosened material onto beaches above sea level or transporting it into deeper sub-reef environments (Done 1992). The reefs in Andaman and Nicobar Islands (ANI) suffered severe damage following a tropical cyclone in the Bay of Bengal off Myanmar coast during13–17 March 2011 (Krishnan *et. al.,* 2012). The investigation exposed the vulnerability of the reefs to oceanographic features which generally remain unnoticed unless they directly affect the life or the property of coastal inhabitants. The wind tracks of cyclone were generated using weather research and forecasting (WRF) models which clearly indicated the passage of cyclone where reefs suffered damage.

Estimation of Potential Fishery Resources of an Exclusive Economic Zone (EEZ) for Fishing Fleet Management

Global marine fish production increased from less than 20 million tons per year in early 1950's to average around 90 million tons per year during the last decade. If the unreported and discarded catches are also taken into account, the global catches will be around 120 million tons per year (Zeller *et al.,* 2005). The general trend in shortfall from traditional fishing grounds in the EEZ's of developed countries is compensated by the increasing exploitation of resources in developing countries. The United Nations Convention on the Law of the Sea (UNCLOS) bestows the coastal states with the right to exploitation and responsibility for management of fishery resources of their EEZs. Observations are of paramount importance for managing the resources, and there is a need to establish acccurate catch data collection systems. Fish captured are considered to reflect fish abundance in coastal waters. From marine fish catch data, we can estimate the potential harvestable fish by plotting the catch effort curve, and estimate the maximum sustainable yield (MSY). But, mere post-mortem analysis of landed fish may lead to imperfect estimates as fish catch data without geotags of catching locations may not provide samples representative of the stock in the sea. Therefore, an estimate of harvestable fish based on *in situ* water productivity, taking into account the tropho-dynamics in the EEZ may afford very useful complimentary information.

Chlorophyll, which is an index of algal biomass (ML^{-3}) present in a water column (L) is a prerequisite for primary production and subsequent fish production ($ML^{-2}T^{-1}$) which is the annual rate of production of fish biomass per unit area of sea bed. The importance of the potential link between PP and fish was understood decades ago (Ryther 1969), but the advent of SRS Chl-a and modelled PP data sets now available on global and meso-scale prompted policy planners to utilize this for estimation of fishery potential in the EEZ. Past studies relied on *in situ* datasets resulting from different sampling and processing methods and were generally characterized by low spatio temporal sampling coverage. SRS Chl-a data are now basic to cross-trophic-level analyses of ecosystem production, structure, and function because of the easy and free availability of a wide-ranging, high resolution, and consistent sampling framework (Platt *et al.,* 2007) at a reliable accuracy.

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