A CONCEPT FOR ESTIMATION OF SECONDARY AND TERTIARY BIOMASS FROM PRIMARY PRODUCTION

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Global Biogeochemical Cycle

Fixation of inorganic carbon to organic carbon in the ocean is driven purely by phytoplankton. Phytoplankton carbon fixation plays an important role in maintaining the quasi steady state level of atmospheric CO_2. Relative contribution of marine primary productivity to global photosynthetic production is between 10 and 50%. Magnitude ranges from 20 to 55 Gt of C/ year (Ryther 1969, Smith et al., 1983, Walsh 1984 and Martin 1992). Ocean-atmospheric coupled climate models predict changes in the ocean circulation and hypothesize that changes in the ocean circulation will stimulate phytoplankton biomass production in the nutrient depleted areas in the open ocean (Roemmich & Wunch 1985). The effect on atmospheric CO_2 is uncertain because the relationship between the enhanced primary production and air sea exchange of CO_2 is not understood. The challenge is to study the magnitude and variability of Primary productivity, its time scales and changes in atmospheric forcing and upscale it into secondary and tertiary productivity.

Relevance to Northern Indian Ocean (NIO)

The Northern Indian Ocean (NIO) comprises a unique variety of biogeochemical provinces, including eutrophic, oligotrophic, upwelling, and oxygen-depleted zones, all within an area of relatively small geographic extent (Figure 1). Seasonally reversing winds observed in the area influence seasonal fluctuation in plankton richness, which is the resultant of enhanced nutrient supply through the process of coastal upwelling and winter cooling (Prasanna Kumar et al., 2000; de Souza et al., 1996). Enhanced nutrient supply increases

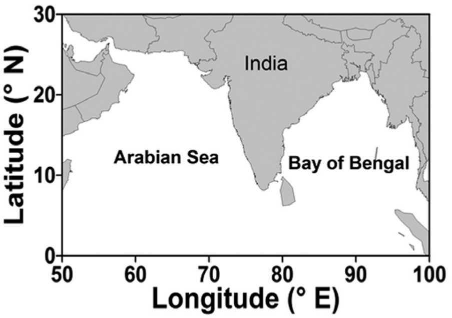

Fig. 1. Northern Indian Ocean comprising of Arabian Sea and Bay of Bengal

primary production in an alarming rate. Both secondary and tertiary production linked with primary production are found to enhance during these periods (Madhupratap et al., 2004). This factor reflects the pronounced semi-annual reversals in regional winds (the seasonal monsoons) that make this region a focus for intense study. Unlike, the seasonal cycle which have a definite periodicity, episodic events such as tropical cyclone which occurs without any periodicity also provides high nutrient supply for primary production, as a consequence of which production increases (Piontkovski and Al-Hashmi, 2014).

Estimation and integration of PP

Integrated *in-situ* column primary production (PP) will be estimated and PP will computed at biome level using *in-situ* and satellite (SRS) remote sensing data by adopting suitable mixed layer PP model. Later SRS methods will be applied for computing primary productivity to integrate at biome level.

Chlorophyll is an important indicator of the quality of aquatic ecosystems that is amenable to in situ and space borne measurement. This property can be retrieved from ocean colour data after removal of the atmospheric signal from the detected radiance. Phytoplankton blooms (indicated by rapid increase in chlorophyll concentration) and spurts in primary productivity are important for maintaining the marine organisms at higher tropic levels, but when associated with eutrophication and harmful algal blooms, as noticed in the coastal waters of India, such events are directly linked (negatively) to the quality of water. Another important measure of water quality in the coastal environment is the suspended sediment load. Together with chlorophyll concentration they determine in water light penetration, and light available for photosynthesis. Optical instruments such as spectral radiometers are able to monitor changes in chlorophyll and suspended sediment load in real time. Furthermore, such measurements can form the basis of local algorithms for application in remote sensing, allowing the results to be extrapolated to the entire study area through remote sensing. Optical methods for monitoring water quality and productivity have been established in other marine environments, for example in the USA. In India, a start in this direction has been established and operationalized by the SATCORE programme of ESSO-INCOIS.

Marine resources, especially fishery resources, have a strikingly important place of prominence in the biodiversity map of the earth. Their dynamics have very important influence; both direct as well as derived, on the wealth, health and eco-balance of many a maritime nation. Indian context to the aforementioned issue can never be overstated with a prominent chunk of future requirement of socio-economic and nutritional sustenance is centered in the marine sector. Towards establishing a scientifically deduced relationship between the marine environment and the resource availability on a realistic basis, there is a need for a focused application of established easy to surveil oceanic, geophysical and physicochemical parameters and their direct or latent influence upon the planktons which happen to be the self-replenishing source of food and nutrition for the fishery resources spread in our EEZ. The spatio-temporal fluctuations of the plankton richness which can be remotely sensed have long been established as a major factor in predicting resource richness in general and congregation and catchable availability in particular. Taking cue from these established models, paradigms can be designed to predict the resource availability from the easy to observe parameters after a thorough validation of the prediction scenarios juxtaposed with the estimated catch attributable to various fishing grounds. The change in the pattern of fishing, period of absence and the composition of fish caught per haul, when analyzed for a range of geo-spatial expanses would help refining and augmenting the existing paradigms resulting in a comprehensive prediction algorithm. Further such models would come in handy in the assessment of marine resource potentials and there periodic revalidation on a homogenous platform with a proper measure of confidence interval. ICAR-CMFRI has come up with a flag ship programme named Chlorophyll based Remote Sensing assisted Indian Fisheries Forecasting System which is operationalizing the primary productivity to biomass model and under the auspice of the Jawaharlal Nehru Science Fellowship, Govt. of India, Prof, Trevor Platt, FRS is coordinating along with Dr. Shubha Sathyendranath, the network on primary production for *in-situ* measurements and modelling the primary production in Indian EEZ.

Nutrient-Phytoplankton-Zooplankton-Detritus Model

Since the mid-20th century, several modelling studies on primary productivity have been carried out over the global ocean. Historically, through the advancement of supercomputing facility this studies have been evolved from simple zero dimensional statistical model to higher order coupled bio-physical model. The compartments of the simple first generation statistical models are expressed by a single differential equation describing the dependence of rate of change of phytoplankton with photosynthesis, respiration and grazing. The functionality of these models are greatly dependent on how efficiently it represents the mixed layer dynamics and its interactions with the euphotic zone. Now a days coupled bio-physical models are come in place and it advances the accuracy and resolution of predicted results. The efficiency of these models have significant contribution from mixed layer dynamics and it incorporates causes from horizontal and vertical advection as well. Most of these models includes phytoplankton, zooplankton, nutrients, detritus and chlorophyll as state variables.

A simple structure of these biological models comprising the sources and sinks of phytoplankton growth rate are represented by the following equation.

$$\frac{\partial P}{\partial t} = \gamma P - G_{zoo} - M_P - \pounds\ (sdet + P)\ P - W \frac{\partial P}{\partial z}$$

Where ($\frac{\partial P}{\partial t}$) represents the rate of change of phytoplankton, γp -phytoplankton growth rate as a source, G_{zoo} – grazing by zooplankton, M_P – mortality of phytoplankton, $\pounds\ (sdet + P)\ P$

represents accumulation of phytoplankton with small detritus and converted in to large detritus and W represents vertical sinking of phytoplankton. Here, first term in the right hand side acts as a source and other four terms indicates sinks of phytoplankton

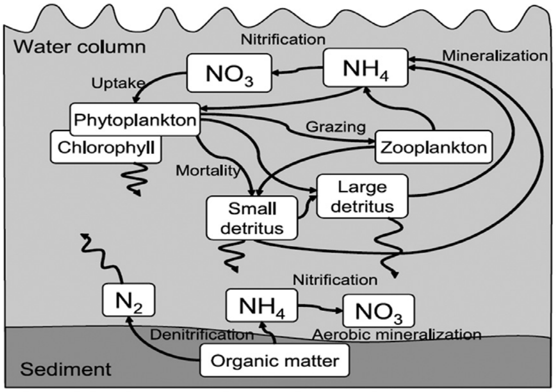

Fig. 2. Schematic representation of biological NPZD model (Figure courtesy: Fennel et al ., 2006)

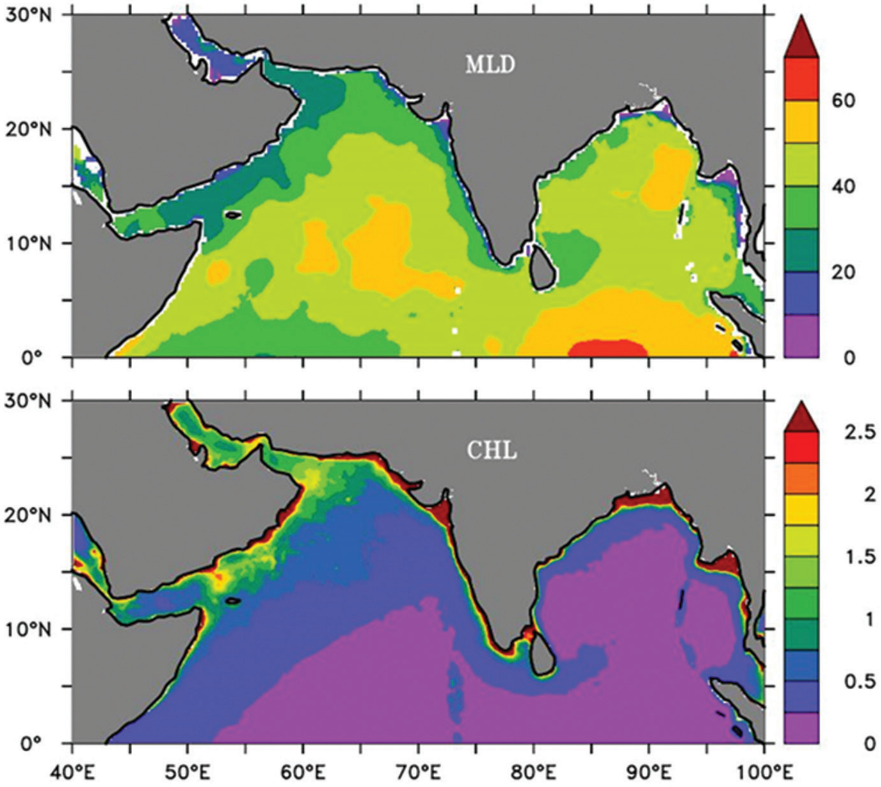

Fig. 3. Annual average of Mixed Layer Depth (MLD) in meter and annual average of Chlorophyll -a (CHL) concentration in mg/m3over the north Indian Ocean. Oceanic provinces of shallow MLD have characterized by high chlorophyll-a concentration.

A simple exercise to estimate biomass from primary productivity for conceptualizing the idea

Indian scenario on potential fish estimates

Authors	Estimated 1^0 productivity	Extrapolated fish production	Remarks
Riley, 1945 Rabinowitch 1945	375 kg C/km2 annually = 3.75 tonnes/ha	15.5 million tonnes (Indian Ocean)	8 times higher than terrestrial productivity
Steeman Nielsen & Jensen, 1967	40% for respiration from net productivity averages globally 1.2-1.5*106 tons	2 million tonnes (Indian Ocean)	Average annual production of hydrosphere similar to terrestrial productivity
Steeman Nielsen & Jensen, 1967	Eutrophic area productivity high	0.2-0.3% of fixed carbon as fish removed annually	High level of efforts in coastal waters with active fishery
Rhyther, 1959	Seasonal maxima also addressed	3 million tonnes (Indian Ocean)	Sea twice as productive as land
Schaefer, 1965	1.9*106 tons of organic carbon for all seas as average	200*106 tonnes for world oceans 40 million tonnes (Indian Ocean)	Fish production 0.03% of potential
Raghuprasad et al., 1969	Compilation of all the above	100 million tonnes (world oceans) 20 million tonnes (Indian Ocean)	0.4% of potential harvested

(All the estimates were based on primary production – Organic carbon biomass generated by the producers)

Calculation of potential estimates of fishery from primary productivity estimates for Indian Ocean basin scale (Raghu Prasad, 1969)

Average annual productivity of Indian Ocean (Anton Brunn survey)	:	3*109 tonnes of Carbon = 0.35 g C/m2
Respiration requirement	:	40% of organic production
Average net production	:	0.24 gC/m2/ day (Western Indian Ocean) 29.19 gC/m2/ day (Eestern Indian Ocean)
Area	:	29*106 km2 (Western Indian Ocean) 22*106 km2 (Eastern Indian Ocean)
Net production of carbon	:	2.3*109 (Western Indian Ocean) 1.6*109 (Eastern Indian Ocean)
Total fish yield (0.03% of net production)	:	12.6 million tonnes In 1967 the production was 2.1 million tonnes. A six fold increase in catch is possible as per the potential estimated

Estimates based on ecological efficiency

- Estimates of potential yield on annual basis is calculated and the potential biomass at the safest level (@10% ecological efficiency level)
- 23 million tons of fish from Western Indian Ocean and
- 15 million tons from Eastern Indian Ocean
- Total of 38 million tons possible from the entire Indian Ocean

Estimation of potential fish yield from zooplankton biomass

Zooplankton biomass estimated for Western Indian Ocean = 3.25*108 tonnes

Zooplankton biomass estimated for eastern Indian Ocean = 1.94*108 tonnes

At 10% ecological efficiency level

Theoretical estimate from carbon production for Western Indian Ocean = 2.3*109 tonnes

Theoretical estimate from carbon production for eastern Indian Ocean = 1.6*109 tonnes

Potential fish biomass estimated for Western Indian Ocean = 18 million tonnes

Potential fish biomass estimated for eastern Indian Ocean = 11 million tonnes

Total fish biomass estimated for Indian Ocean = 29 million tonnes

Revised estimates by different authors for Indian EEZ (million tonnes)

Mathew et al., 1989	7.46
Desai et al., 1990	3.66
Moiseev, 1971	3.59
Gulland, 1971	6.55
Prasad, 1970	5.06
Prasad & Nair, 1973	4.60
Quazim, 1976	7.36
Nair & Gopinathan, 1985	5.50

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