

## Chapter 6

### Summary and conclusions

#### 6.1 Summary

Indian coastal waters are rich in marine organisms and proper protection of their larval population are important for sustaining these organisms. But, there are certain marine organisms which are harmful and needs to be controlled. A proper demarcation of ideal sites of spawning and larval transport will help in managing the larval population. Management measures like closed area and season for the fishery will be more effective with the help of a decision support system. Numerical simulations provide a quality data base which can supplement the decision support system. The present study is an attempt in this direction and probably for the first time such study is conducted for the coastal waters of India. The broad objectives of this study are as follows:

- (i) to find out the influence of environmental parameters on the biology of the given ecosystem
- (ii) to track larval transport and biological abundance in relation to environmental variables
- (iii) to compare biological abundance and fish larval transport in three different marine ecosystems, namely, the GoK (a semi-enclosed basin), Mandovi-Zuari (estuarine system of Goa), and Mangalore coastal region (an open coast with seasonal influences)

The initiatives taken for fulfilling the objectives include the following investigations:

- (i) analysis of satellite chlorophyll data along the southwest coastal waters of India to derive a biological calender for sardine
- (ii) tracking the larval survival and establish a link between food and sardine inter-annual variability

- (iii) generating the hydrodynamic pattern of three marine ecosystems selected for the study
- (iv) identifying specific spawning locations and biology of the organisms considered in the respective regions
- (v) numerically tracking the transport of larvae released from spawning sites based on hydrodynamics of the regions, and comparison with measurements
- (vi) interpreting the data sets generated by numerical simulation studies to infer the nursery areas and seasonal importance of the larvae of marine organisms in three different marine ecosystems and
- (vii) identifying the lacunae in the study for calling upon future investigations

The tracking of sardine along the southwest coast of India is an attempt using satellite derived chlorophyll data to explain the larval survival and inter-annual variability from a synoptic scale of view [Grinson George et al., 2011]. Active breeding period in the annual biological calendar of sardine corresponds to the months with higher chlorophyll in ambient waters. Chlorophyll biomass during bloom initiation month can be a precursor to the sardine biomass for the year. But, lack of continuous larval data sets on sardine larval abundance is a major lacuna in developing a model for prediction of sardine biomass along the southwest coast of India.

Further, efforts are taken to illustrate the significance of using the physical factors like wind, tides, current speed and ocean colour in defining fish and shell fish larval transport. Numerical modelling is used for explaining the bio-physical link involved in fish and shell fish larval transport in the coastal waters. They also corroborate the earlier suggestions on larval abundance, but explain further the bio-physical mechanisms controlling the larval abundance in a synoptic scale.

Variation in sardine abundance could be attributed to variability in the physical parameters such as upwelling, Mean Sea Level (MSL), temperature, wind stress, rainfall and monsoon conditions [Longhurst and Wooster, 1990; Krishnakumar and Bhat, 2008]. However, such indicators are not a direct trophic link to sardines. The important factors responsible

for the offshore-inshore migration appear to be the strength and duration in the upwelling bloom which brings about variations in physicochemical and biological properties of the coastal waters. But, a phase lag between upwelling and intense production has been reported in earlier studies in this region [Kumar et al., 2008]. Hence, chlorophyll concentration in coastal waters is the most important factor for establishing a trophic link that summarizes the above physical and chemical processes. An early spawning and a time lag in the development of food (through a break in monsoon or upwelling) would be detrimental to sardine recruitment. Consequently, chlorophyll concentration during the bloom initiation month substantially explains the interannual variability in sardine landings. The spatial and temporal variations in the intensity of chlorophyll in the coastal waters is proportionally reflected in the sardine abundance of the respective area.

Biological data sets from various sources and numerical simulation of particle tracking helped in identifying the major spawning sites of fishes in the GoK. Fish larval transport studies in the GoK shows that particle transport modelling can be an effective tool and decision support system in identifying the locations that are potential nursery areas for fish larvae. Management measures like demarcation of closed areas and closed seasons can be implemented in the GoK based on this tool. The spawning sites may vary with seasons, but the dispersal of larvae ensures that larvae reach nursery grounds in the GoK rather than getting dispersed in the gulf mouth. The fish larval abundance or aggregation during different seasons suggests the priority areas of likelihood of larval retention. Presently, regulations are enforced only in the Marine National Park and Marine Sanctuary areas in the southern gulf, which is also an area of maximum particle retention, as seen in the modelling studies. Thus, the model demonstrates quantitatively a definite pattern on redistribution of fish larvae in the southern gulf, leading to more abundant fish populations. Hitherto, a significant percentage of particles  $\geq 30\%$  are retained at two other locations *viz.*, areas beyond the three eddies inside the gulf and upper north-western boundary of the gulf which are not regulated for fishing. This stipulates the necessity of enforcement of fishing regulations in these areas during pre-monsoon and southwest monsoon seasons (Figure 5.2) for ensuring sustained fishery in the region.

Mangalore fishing ground is also rich in fish. The aggregation of fish larvae in the fishing ground is due to the prevailing currents in the Mangalore region. The sampling experiments conducted earlier [Rivonker et al., 1990] indicate the abundance of rich fishery, and the numerical simulations also substantiate this finding. The temporal variation in fish and their biological cycle may be attributed to the seasonal changes. Upwelling plays a major role in deciding the biology, as we have discussed in the case of Indian oil sardine (Chapter 3), which is evident from the larval samplings along the Mangalore coast. But, eggs and larvae are present throughout the year with varying abundance which is also common for a diverse tropical fishery existing here. Therefore, the drift and aggregation of larvae from offshore and north boundaries of the Mangalore domain is likely to increase fish abundance in the Mangalore region as evident from the numerical simulations.

The importance of barnacle larval transport study is to identify the seasons and spawning sites of bioinvasive barnacles in the coastal waters of Goa. Surveys indicated a similar abundance pattern which was not shown by the models. The barnacle population abundance is contributed by spawning sites outside the estuary and the sites contributing to the barnacle larval abundance varies from season to season. Spawning sites found on the north of the estuary is significant during all seasons, except post-monsoon. The barnacle larval population in the estuary is well mixed. The spawning sites from north and south of the estuary are contributing to the larval abundance. Larvae traverse as far as 78 km along the coastal waters with a minimum dispersal of 3 to 5 km. Barnacle larval abundance is higher during post-monsoon season as large quantities of larvae are supplied from spawning sites located south of the estuary. This is further strengthened by the wind pattern during the season. Unlike a pelagic open offshore larval pool for barnacles in Californian coast [Pineda, 2000], the acorn barnacle larvae in the Mandovi-Zuari estuarine system is concentrated only in the nearshore waters and estuarine mouth as seen in the observations and numerical experiments. Larval abundance in the estuary significantly increases with the tidal amplitudes as larvae are pushed into the estuary during the flood currents.

## 6.2 Importance of the study and future perspective

Analysis of remotely sensed chlorophyll data provided a putative trophic link for explaining variation in sardine catches along the waters of the southwest coast of India. However, this information has to be coupled with other appropriate biological data for forecasting fish distribution. Thus, satellite chlorophyll alone in its present state cannot be an alternative to *in situ* chlorophyll. The absolute chlorophyll present in *Case-2* waters often gets challenged by the turbidity contributed by other optical constituents. It is the judicious application of both satellite and observed data that will help in deducing the correct picture. There are many developments in the building of trophic models of aquatic ecosystems [Hall and Mainprize, 2004]. There is potential for phytoplankton data to serve in future as a surrogate for sardine biomass. Usually, investigations in fisheries biology lack time series environmental or other biological data sets [Longhurst and Wooster, 1990; Madhupratap et al., 1994]. The combination of satellite data sets with fisheries data can lead to robust conclusions. Time series data for a long period will be required to confirm and determine the large-scale fluctuations in abundance, population crashes and subsequent revival of this major pelagic fishery in the southwest coast of India.

Numerical simulation is an attempt to supplement the existing decision support systems to enable the right demarcation of nursery areas for fishes. Similarly, the technique can be extended to identify the potential spread of bio-invasive obnoxious species like barnacle thus helping in deciding the place of ballast water release and infrastructure development and related activities. The biological relevance of numerical modelling and remote-sensing is restricted to few operational activities in fisheries. Potential fishing zone advisory is the major activity of this kind in India. The findings of this thesis signifies the usage of numerical modelling and remote-sensing in fisheries management. Aggregation pattern of fish larvae and an estuarine larval pool for barnacles may be seen as a manifestation of physical processes which could supplement the other ongoing biological investigations. There are numerous possibilities of improving the model by addition of biological features like predation, mortality and behaviour. The present study invokes the idea that the demarcation of marine protected areas should be based on the rationale

that areas of maximum likelihood of retention of ichthyoplankton will be a better fisheries management strategy, imbibing the concepts of an ecosystem-based spatially structured approach. Being a complex study involving a lot of uncertainties, the role of coastal processes in fish and shell fish production and dynamics deserves further investigation with a better time series sampling of early life stages in marine organisms.

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# **Appendix A**

## **Abbreviations**

- RS-GIS - Remote Sensing and Geographical Information System
- NE - North East
- SW - South West
- WCI - West Coast of India
- PLD - Pelagic Larval Duration
- SeaWiFS - Sea-viewing Wide Field of view Sensor
- NASA - National Aeronautics and Space Administration
- WLR - Water Level Recorder
- AWS - Autonomous Weather Station
- RCM - Recording Current Meter
- ICMAM - Integrated Coastal and Marine Area Management
- COP - Captain of Ports
- HT - Heron Tranter
- HD - Hydrodynamics
- DHI - Danish Hydraulic Institute
- ADI - Alternating Direction Implicit
- DS - Double Sweep
- UTM - Universal Transverse Mercator

- CFL - Courant-Friedrichs-Lewy
- WNW - West North West
- SSW - South South West
- NNE - North North East
- PA - Particle Analysis
- ICES - International Council for the Exploration of the Sea
- SST - Sea Surface Temperature
- MSL - Mean Sea Level
- NHO - Naval Hydrographic Office
- RMS - Root Mean Square
- ENE - East North East
- WSE - West South East

## Appendix B

### List of manuscripts accepted/ under revision from the thesis

1. Grinson George, B. Meenakumari, M. Raman, S. Kumar, P. Vethamony, M. T. Babu, and X. Verlecar. Remotely sensed chlorophyll: A putative trophic link for explaining variability in Indian oil sardine stocks. *Journal of Coastal Research*, DOI:10.2112/JCOASTRES-D-10-00070, 2011. *In Press*
2. Grinson George, P. Vethamony, K. Sudheesh and M. T. Babu. Fish larval transport in a macro-tidal regime: Gulf of Kachchh, west coast of India. *Fisheries Rsearch*. *revised version under review*
3. Grinson George, D. V. Dattesh, Chetan A. Gaonkar, V. M. Aboobacker, P. Vethamony, and A. C. Anil. Barnacle larval transport in the Mandovi-Zuari estuarine system, central west coast of India: field measurements and numerical experiments. *Under review*.