1. Project Title : **Ecosystem Modeling of Cochin backwaters**

2. Principal Investigator : Dr. K.K. Balachandran.

3. Institution : National Institute of Oceanography,
Regional Centre, Kochi

4. Need of the Project :

The Integrated Coastal and Marine Area Management Project Directorate (ICMAM-PD), Chennai, has identified Cochin backwaters (Vembanad Lake) as one of the vulnerable wetlands along the Indian coast that is undergoing progressive deterioration due to increased developmental activities. It was therefore decided that restoration measures have to be taken to ensure development of this region without damaging its bio-resources. Due to the complex nature, a comprehensive study explaining the characteristics and functions of this estuary has not been done so far. In order to implement restoration measures for this region, ICMAM-PD suggested that National Institute of Oceanography, Kochi may take up an in-depth study of the region based on the concept of modeling. The study will explore and formulate an environmental management plan (EMP) so as to rejuvenate this ecosystem, keeping pace with ongoing developmental activities.

5. Objectives:

- Understand the varied estuarine processes in the Cochin backwaters.
- Solve the environmental coefficients used in the ecosystem model for the estuary.
- Characterize a test site in the estuary through the application of a model.
- Develop an ecosystem model for the test site predicting chlorophyll and zooplankton production.

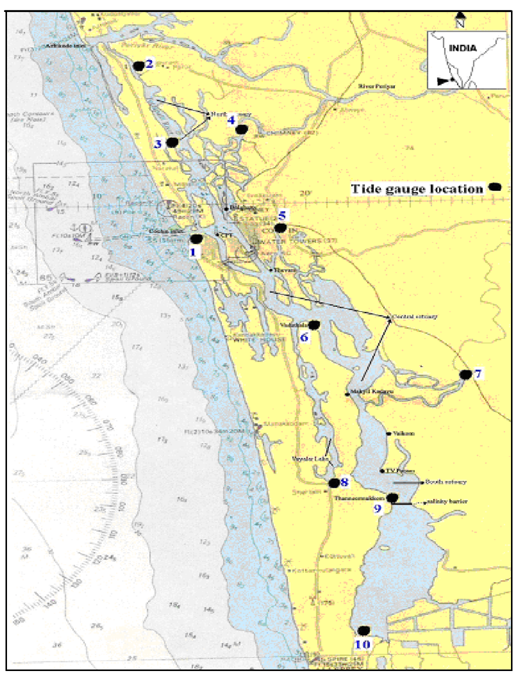
6. Tasks:

- Environmental data collection from the entire Cochin backwaters
- Shoreline and bathymetry data for the test domain
- Time-series data on physical, chemical and biological parameters
- Develop a coupled water quality-ecosystem model.

- Predict chlorophyll production in the estuary using the water quality model.
- Derive the coefficients used in the ecosystem model through experiments and field investigations such as nutrient uptake, regeneration, assimilation, production-growth-respiration-grazing of bacteria/phytoplankton/micro and meso zooplankton, species composition and succession of primary and secondary organisms.

7. Project Schedules:

Year	2003	2004	2005	2006	2007
Baseline data collection		↔	↔	↔	
Time-series data for odel	↔	↔			
Solving environmental coefficients			↔	↔	
Development & calibration of Water Quality model		↔	↔	↔	
Development & calibration of ecosystem model				↔	↔
Improve and validate ecosystem model				→	



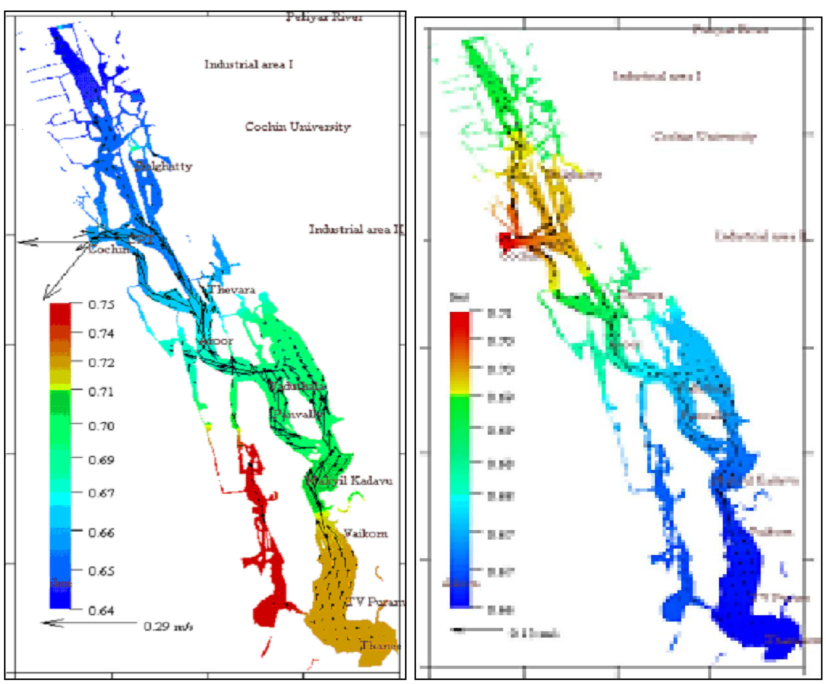
Monitoring locations for tides in the Vembanad Lake

8. Highlights of the study:

A. Hydrographic and environmental characteristics of the Cochin backwaters

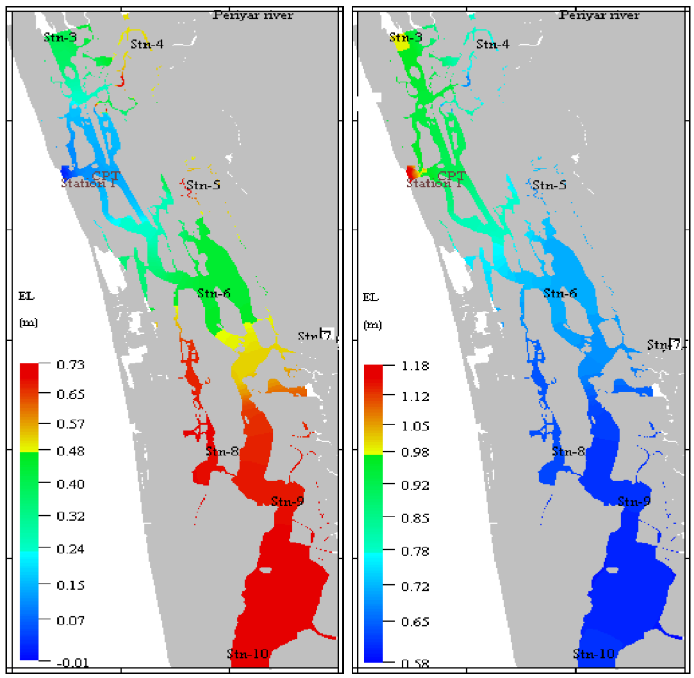
The development of a model for an estuary is based on their responses to physical, chemical and biological properties. The Cochin backwaters constitute one of the largest productive ecosystems in the country, encompassing an area of approximately 250 km^2, interspaced with numerous islands and network of canals and, receiving fresh water (20,000 $Mm^3.y^{-1}$) from 6 rivers. Reclamation over the years has reduced the estuarine volume by 40% and a proportional reduction in the flushing characteristics, ultimately transforming the system into a eutrophic one.

An ecosystem model can be achieved only through a total study of the system. In order to understand the physical features of the estuary as a whole, a hydrodynamic model (2D-Hydrodyn *FLOSOFT*) was developed to a domain of Vembanad Lake prepared by pooling all the available data and using the tide data at Cochin Port Trust. The results showed that there is an unusual amplification of tides in the south estuary when the Thanneermukkom bund is closed.



Predicted ebb and flood tide water levels during 2004 (bund closed)

Realizing the significance of tides in the Vembanad Lake, an intensive 10-point, 30-day simultaneous time-series measurements on tides were made during April-May 2006. As an outcome, the first comprehensive hydrodynamic model for the Vembanad Lake was developed with the help of M/s. Environ Software, Bangalore, which requires only validation for currents.



Predicted ebb and flood tide water levels during 2006 (bund open)

Both the models indicated that the Vembanad Lake hydrology has at least three different zones (North, Central and South) and that the flushing and circulation of this estuary is completely dependent on the exchange of waters between these zones. This is a very important finding, because it implies that biochemical activities in these zones should be considered separately for developing an ecosystem model. Another salient finding is that, contrary to the conventional understanding of a tidal estuary, Vembanad Lake is very sensitive to meteorological events such as wind and fresh water flow. This indicates that apart from the tide data, non-tidal forcing are also important factors to be considered in the model. The propagation of tides in the Vembanad Lake is mainly contributed by the mixed-predominantly semi-diurnal constituent (M_2). Furthermore, the southern part of the estuary indicating an amplification of the fortnightly tides (M_{sf}), is sluggish and could be vulnerable to pollution. The net movement of water has strong implication on dispersion of pollutants, which in turn, have a direct bearing on the ecology of the estuary.

In addition to the baseline information on the hydrodynamics of this estuary, a series of environmental data were collected during the period as follows:

- Daily monitoring at 3 locations in the estuary for one year (2003-04).
- Weekly collection of zooplankton from the above stations for one year (2003-04).
- Monthly survey in the estuary (10 locations) for one year (2003-04).
- Comprehensive survey in the estuary (56 locations) for three seasons (2005).
- Bi-weekly/monthly monitoring of the test site/coastal sea (2005-07).

All these sampling schemes have provided the much needed baseline information to characterize the dominant estuarine processes. Analysis of water quality data showed the existence of 3 zones (North, Central and South) in the estuary, in conformity with the model results mentioned above. This was corroborated by time-series observations indicating different physico-chemical and biological behavior of these zones. Further, a first study of the carbon biogeochemistry in the estuary also convincingly showed the differential response of the north and south estuaries. While the biogenic deposition is the characteristic of the north estuary, an excess carbon dioxide is the feature of south estuarine waters. The difference in the biochemical reactions in these zones could probably be informative on the system respiration and calcification, which is directly linked to benthic productivity. The zonal concept to the Vembanad Lake was a major achievement towards the ecosystem model development. Exclusive models developed for these zones are to be integrated to achieve a complete ecosystem model for Cochin backwaters.

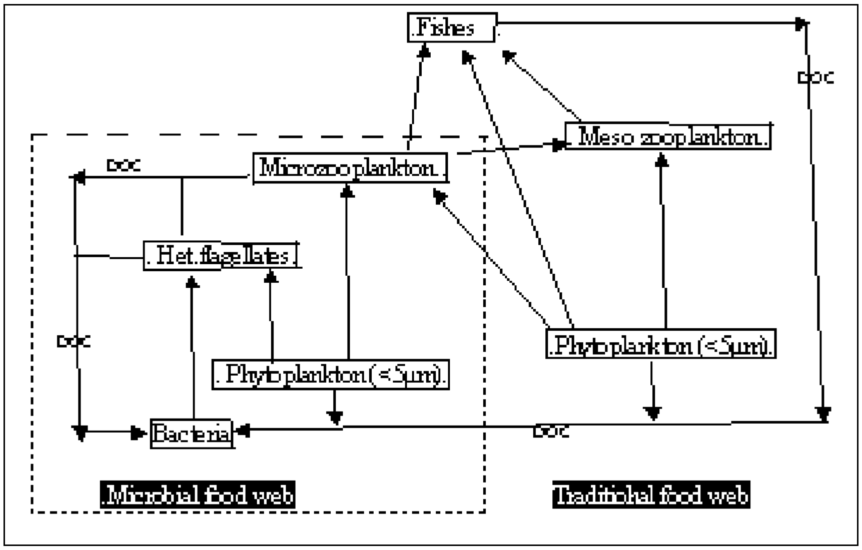
The studies in general, identified many specific characteristics and environmental issues that are quite alarming to the health of the system. It was found that anthropogenic interventions are the primary cause of mounting pollution and declining bio-resources in the estuary. The long-term trends indicating an increase in the N (ammonia), P and chlorophyll, but a considerable reduction in the zooplankton biomass is to be looked into. This is a major cause of concern and could be responsible for the disappearance or decline of some of the endemic species of fishes of economic importance. The grazing organisms (zooplankton and fishes) seem to be under severe stress due to the changes in the environment.

B. Phytoplankton species composition and importance of micro-zooplankton

The study showed that Cochin backwaters sustain surplus nutrients supporting chlorophyll production at consistently high level throughout the year. However, the relation between chlorophyll and primary production was found to be significant only at nano fraction level. This indicates an important trophic link amongst detritus, bacteria, nano plankton, micro-zooplankton and higher organisms. The zooplankton (mainly copepods) exhibited a strong dependence on salinity with maximum during pre monsoon and minimum during other seasons. Pre monsoon season is characterized by weakening of the estuarine flow, facilitating increased biological activities. This period also transform the estuary into marine condition, encouraging the proliferation of micro-zooplankton (MZP), which flourishes in systems where small phytoplankton dominates. It is probably this MZP that are grazed upon by the meso-zooplankton community to succeed during pre-monsoon period. The seasonal changes in micro-zooplankton composition could mainly be responsible for providing specific food for the herbivorous meso-zooplankton.

The fact that Cochin backwaters sustain independent cycles of phytoplankton and meso-zooplankton is quite invoking and could be indicative of the existence of alternate food chains that increases the efficiency of the planktonic food web. The proliferation of micro-zooplankton (MZP) could be one such pathway in transferring the energy from the nano plankton (including bacteria) to meso-zooplankton. Accordingly, the abundance and biomass of MZP were studied for the first time in the estuary. The study showed that the abundant MZP during pre monsoon, declined drastically during monsoon and post monsoon seasons.

Based on the present understanding on the microbial activities, the pelagic food web possible in Cochin backwaters is schematized below. It is clear that a reduction in planktonic grazers during monsoon, result in weak transfer of bacterial and primary carbon to higher trophic levels, leaving much of the basic food unconsumed. Considering the strong seasonality shown by MZP, a large surplus of basic food remains unconsumed in the estuary during monsoon and post monsoon season, which either settles down or get exported to the coastal sea.



Planktonic food web in the Cochin backwaters

C. Solving the environmental coefficients used in the model equations

The excessive nutrients from sewage and industries into the estuary have probably been responsible for consistently high levels of microbial and phytoplankton. Despite this, the zooplankton biomass showed a clear seasonal shift. Thus, the food chain operating in the estuary appears to be a complex one. Hence, it is essential to investigate the various processes controlling the productivity and also the dynamics of N-based nutrients regulating high chlorophyll, but a variable primary production. The relationship between bacteria, micro-zooplankton and meso-zooplankton are to be established to accomplish realistic predictive ecosystem model. Therefore, an intensive study was designed for the test site involving a series of observations/experiments. These involve very delicate experiments requiring specific laboratory facility. An attempt was also made to solve the coefficients used in the chlorophyll equation of the model. The importance of these measurements is that these studies are carried out for the first time in a tropical county like India, where the rates of biochemical reactions are still not known. Some of the experiments should be repeated several times to arrive at acceptable limits. The values obtained will be incorporated to the kinetic equations of the model. Considering the sparse information in this field, the outcome of these studies would be very crucial, and once derived, these coefficients can be applied to other tropical ecosystems as well.

a. Nitrogen (N^{15}) uptake
b. Bacteriological studies
c. Primary and secondary production
d. Fractionated primary production
e. Micro-zooplankton grazing
f. Oxidation of organic matter
g. Surface (I_s) and optimal light intensity (I_o)
h. Phytoplankton optimum growth rate (K_g)
i. Zooplankton grazing coefficient (K_z)

a. Nitrogen (N^{15}) uptake studies:

- NH_4 uptake (regenerated production) is 3 times higher than NO_3 uptake (new production).
- The *f* ratio [NO_3 uptake/ total N uptake] is an index of the influence of freshwater nitrogen sources on primary production.
- Non-interference of NH_4 with nitrate uptake is a new finding.

b. Bacteriological studies:

- Bacterial abundance is consistently high (0.7 to 12 x 10^{11} cells/L).
- Bacterial respiration > Bacterial production suggests their greater metabolic flexibility to environmental changes.
- BP and BR respond to variation in DOM.
- Physiological profile (BIOLOG) indicates that when DOC contains high molecular weight carbohydrates in regions of plankton bloom, bacteria shift to N-based uptake.
- BP: PP ratio kept low when phytoplankton production was maximum.
- During monsoon, the estuary shifts to net heterotrophy (BP: PP = 102%).

c. Primary and Secondary production:

- Chlorophyll *a* increased from post-monsoon to pre-monsoon.
- Annual average column production was 1343 $mgCm^{-2}d^{-1}$.

- Zooplankton biomass was low during monsoon & post-monsoon, but increased during pre-monsoon.

d. Fractionated primary production:

- Nano fraction contributed > 70% of total chlorophyll, indicating the significance of this fraction.
- Nano planktons are the dominant carbon source in the estuary.
- Transfer efficiency to higher trophic level changes with season.

e. Micro-zooplankton grazing:

Micro-zooplankton grazing experiment was conducted following the method Landry and Hasset (1982). The specific growth of phytoplankton (K) during the present experiment was 0.4 ± 0.02 and the grazing rate (g) was 0.6 ± 0.02. The experiment showed that 43% of phytoplankton was grazed by MZP per day.

f. Oxidation of organic matter:

One of the main variables that is used in the water quality model is the rate at which the system oxidizes the available organic matter. The rate of this reaction was measured in the Cochin backwaters and the reaction kinetics followed the Monod curve. The rate of oxidation estimated was 0.68 mg/l/day.

g. Phytoplankton culture:

Uni-algal was developed to understand the physiology and nutrient requirements of the individual phytoplankton species. In view of developing a biological model, a mixed diatom culture was developed. Later, monoculture of these species was developed using agar plate method and maintained in the laboratory. Experimental studies including application of ^{15}N isotopic uptake rates by phytoplankton are to be performed using these cultures.

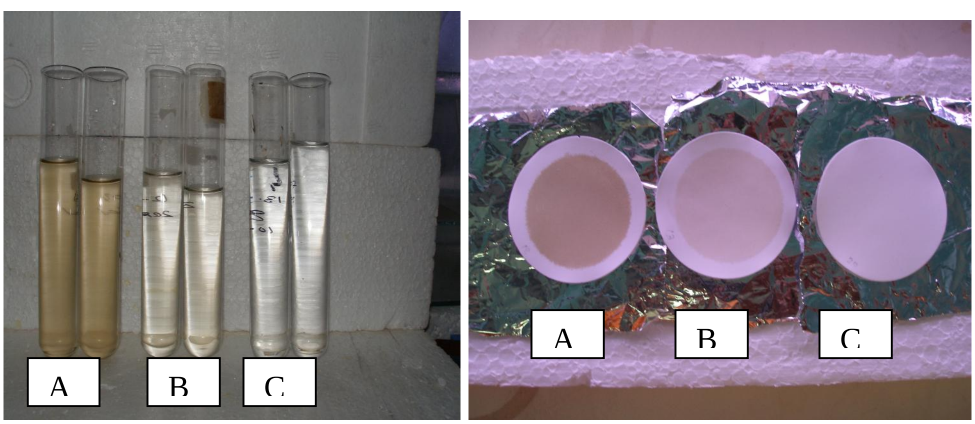
- Growth rate of diatoms in a mixed and uni algal culture showed that only a few species could proliferate in the enriched culture medium [f/*2*].
- Cell count, chlorophyll and dry weight estimation with pure culture showed that chlorophyll content in both diatoms are same.

- Chlorophyll content of pure culture at varying salinity showed that only *Nitzschia closterium* was euryhaline.
- Algal production and growth rate was estimated using ^{14}C method.

h. Zooplankton culture:

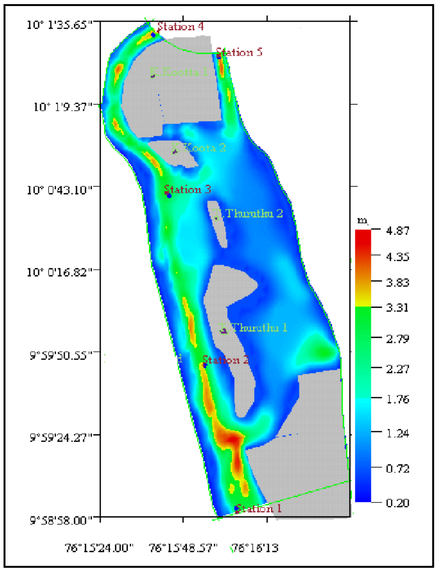
The meso-zooplankton in the Cochin backwaters are mainly contributed by copepod. Hence, copepod (*Labedocera* sp. *Acartia* sp. and *Pseudodiaptomus annandaleii*) was developed as a mono culture in the laboratory and observed on a daily basis for their life period.

Labedocera sp. survived for 21 days and *Acartia* sp. for 10 days. Presently the first generation of *Pseudodiaptomus annandaleii* is in progress. Grazing experiments were carried on these animal based the phytoplankton cell size. The copepods were starved for one day and fed with phytoplankton initial cell density (10^6 ml^{-1}) and chlorophyll was taken initially and after the termination of the experiment. The differences in these give the grazing rate. A control kept with algal cells alone was given as inoculums. All experiments were run in triplicates. Simultaneously productivity was also estimated.



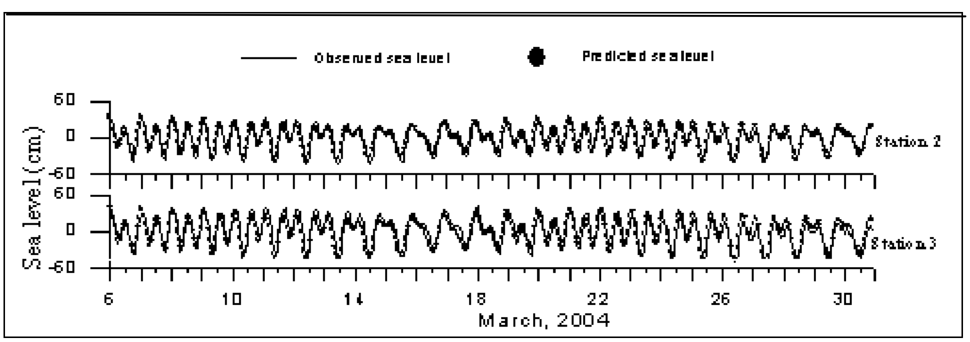
Grazing experiment A (inoculums), B (after 3hr) C (after 12hr)

D. Development of an ecosystem model for the selected test site

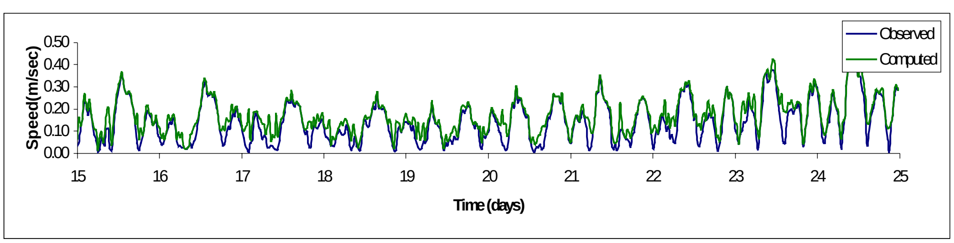


Test site in the north estuary for model development

Being a tropical monsoon estuary, the processes regulating the biological productivity in the Cochin backwaters are very complex. Development of an ecosystem model for such a water body requires a conceptual approach. Hence, it was decided that the initial model should be developed and calibrated with a small area (test site) before extending to the entire estuarine network. Accordingly, the hydrodynamic variables have been considered while developing the initial hydrodynamic model for the test site.



Comparison between predicted vs. observed tides



Comparison between predicted vs. observed currents

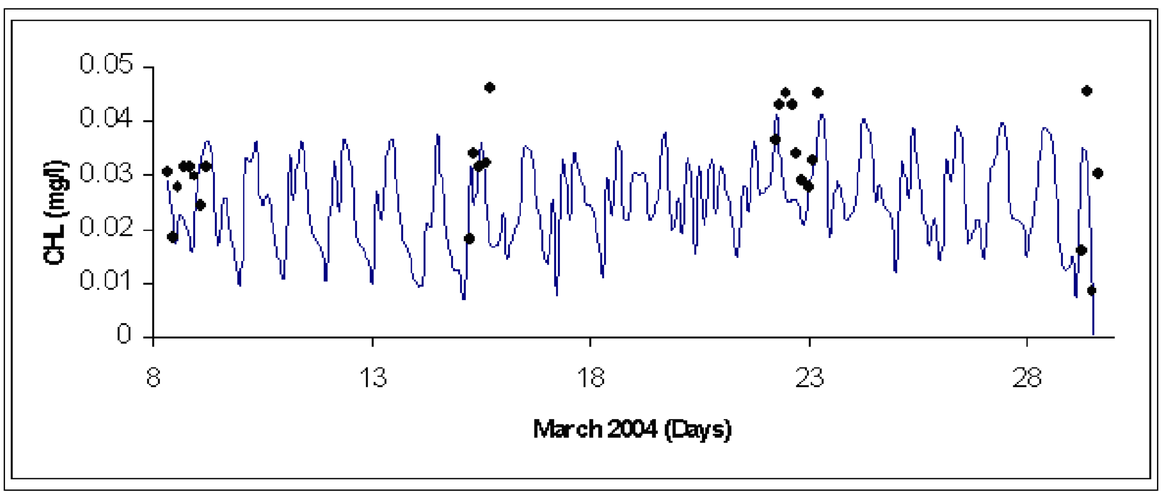
The coupled water quality model (WQM) used in this study was built based on a two-dimensional simulation program (2D-Hydrodyn *POLSOFT*). The initial model designed by M/s. Environ Software, Bangalore was modified with the association of ICMAM-PD. It comprises a complex of four interacting systems: dissolved oxygen, nitrogen cycle, phosphorus cycle, and phytoplankton dynamics. The water quality model involved 8 rate equations representing the following variables: dissolved oxygen (DO), chlorophyll a (Chl *a*), carbonaceous biochemical oxygen demand (C_{BOD}), ammonium nitrogen (NH_4), nitrate and nitrite nitrogen (NO_3), inorganic phosphorus (PO_4), organic nitrogen (ON), and organic phosphorus (OP). The model was achieved by coupling the physical transport process with water quality kinetic processes. Ecosystem model was finally developed from the WQM by including the kinetic equation for zooplankton biomass (herbivores). In all the compartments, the rate equations computed the mass balance of nutrients, their half saturation constants and preference to phytoplankton, rates of production-respiration-grazing-mortality of phytoplankton and zooplankton.

In general, the present model predicted various water quality parameters and chlorophyll in the test site for two different seasons. However, some deviations were observed for the chlorophyll values. The inconsistency in measuring the impact of nutrient-chlorophyll transformation is due to the variable chlorophyll content of different phytoplankton species and their photosynthetic efficiency. The coefficients used in this model have to be further modified with respect to their response in the Cochin backwaters. The variations could also be due to the unknown reactions involved in the microbial activities. The high variability observed also suggests that the coefficients derived in the present study may not be suitable for other regions or periods.

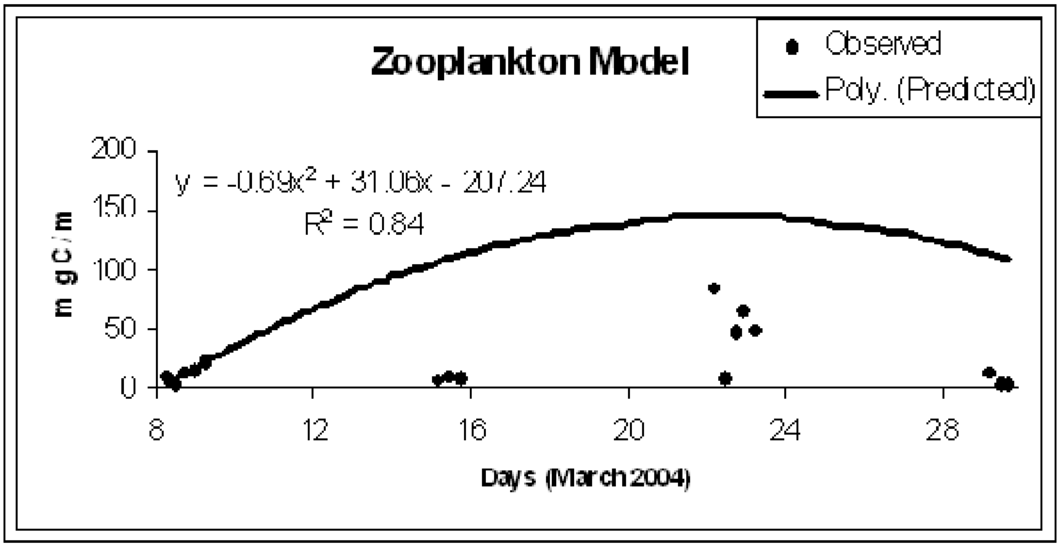
The zooplankton model was only partially successful in predicting their standing stock. This is probably because in Cochin backwaters, the secondary production is mainly represented by meso-zooplankton; especially copepods. These copepods fall in three distinct groups depending upon the feeding behavior (herbivore, omnivore and carnivore). The present model showed deviation since only the herbivores are considered. Therefore, the input of the model needs to be corrected for herbivorous copepod, instead of the total biomass. The model requires fine tuning for the coefficients and inclusion of more biochemical reactions (given below) before applying to an integrated ecosystem model.

Water Quality coefficients identified for Cochin backwaters

No.	Parameter	Value	
		In the model	Used for validation
1	K_7 BOD oxidation rate (d^{-1})	0.1	0.1
2	*f* Assimilation efficiency	0.1	0.5
3	P : Chl (mg/µg)	$1e^{-06}$	$1.1e^{-02}$
4	N : Chl (mg/µg)	$1e^{-05}$	$2.5e^{-04}$
5	C : Chl (mg/µg)	$1e^{-06}$	$2e^{-05}$
6	K_r Endogenous resp. (mg.d^{-1})	$4e^{-03}$	$4e^{-03}$
7	K_{mn} (mg/l)	$1.8e^{-02}$	$1.8e^{-02}$
8	K_{mp} (mg/l)	$6e^{-03}$	$6e^{-03}$
9	K_g Phyto opt growth rate (d^{-1})	0.121	1
10	K_e Light ext. coeff	1	1
11	I_0 Surface light intensity (W/m^2)	30	30
12	I_s Optimal light intensity (W/m^2)	20	20
13	K_z zooplankton grazing rate	$4e^{-03}$	0.5
14	K_2 hydrolysis coeff org.N	$2.5e^{-03}$	$2.5e^{-03}$
15	K_3 Nitrification rate	$1e^{-02}$	$1e^{-02}$
16	K_5 hydrolysis coeff. Org.P	$1e^{-03}$	0.22
17	K_{op} Photosynthetic coeff	1.4	1.4
18	K_{or} Respiration coeff	1	1
19	b Benthic oxygen demand	0.15	0.15
20	K_8 Re-aeration coeff	3.409^{e-004}	3.409^{e-004}



Comparison of predicted vs. measured chlorophyll a in the study region



Comparison of predicted vs. measured zooplankton biomass

The inconsistency with the present approach is probably non-inclusion of some of the major processes in this estuary contributed by (1) detritus (2) bacteria (3) micro-zooplankton and (4) benthic activity. During the next stage of model development, the reaction terms for these compartments should be incorporated appropriately.

Conclusions

The Cochin backwaters are highly impacted by human interventions, as evidenced by the declining bio-resources of the estuary. The eutrophication of the estuary and a reduction in the zooplankton biomass are the probable indication of the ecological degradation. The stress on the zooplankton community would be a critical step in the ecosystem model. The decline in the fish production reported from this estuary could also be linked with this observation of a decrease in the meso-zooplankton biomass over the years. Likewise, there are some important aspects to be considered for model development. The fact that the south and north estuary is weak in flushing is a very crucial finding of the present study, indicating that any study without addressing the propagation of tides in the estuary spread out between Azhikode and Alleppey, will be incomplete. The model should consider input from solar irradiance, winds and river flow because of the present finding that the Vembanad Lake is very sensitive to non-tidal forcing. The modification of the model should be done by incorporating the kinetic equations for compartments like detritus, bacteria, micro-zooplankton and meso-zooplankton.

Despite having several limitations and constrains in learning and execution in reaching the dream target, the concept of an ecosystem model for the conservation of deteriorating water bodies of India has been successfully launched and a similar concerted effort and pursuance would make significant contribution to the management of such vulnerable coastal areas.

<u>Publications under the project</u> (Total impact factor 7.853)

1. Jyothibabu et al., **2006**. **Estuarine, Coastal and Shelf Science.** Impact of freshwater influx on micro-zooplankton mediated food web in a tropical estuary (Cochin backwaters - India). 69, 3-4. 2006. 505-518.

2. Nair et al., **2006**. **Environmental Forensics**. Bioaccumulation of toxic metals by fish in a semi enclosed tropical ecosystem. 7, 3. 2006. 197.

3. Laluraj et al., **2006**. **Environmental Monitoring and Assessment**. Recovery of an estuary in the southwest coast of India from tsunami impacts. DOI 10.1007/s10661-006-9237-2.

4. Laluraj et al., **2007**. **Journal of Coastal Research**. Hydrodynamic and geomorphic controls on the morphology of an island ecosystem in the Vembanad Lake, west coast of India. 23, xxx-xxx.

5. Madhu et al., **2007**. **Estuarine, Coastal and Shelf Science**. Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters e India). xx 1-12.

6. Panampunnayil and Biju. **2007. Journal of Natural History**. A new genus and species of Heteromysini (Crustacea-Mysidacea) from the backwater of Kochi (Kerala, India). [Accepted].

7. Nisha et al., **2007. Estuarine, Coastal and Shelf Science**. Life history and population dynamics of an estuarine amphipod – *Eriopisa Chilkensis.*[Accepted]

Forthcoming articles under the project

1. Martin et al., 2007. Seasonality in P adsorption-desorption mechanism in sinking particles of a moderately polluted tropical estuary, southwest coast of India. **Environmental Forensics.**

2. Martin et al., 2007.Changes in benthic community structure associated with eutrophication of a tropical estuary (Cochin backwaters), India. **Estuarine, Coastal and Shelf Science.**

3. Martin et al., 2007. Fresh water influence on nutrient stiochiometry in a tropical estuary, south west coast of India. **Applied ecology and environmental research.**

4. Antony et al., 2007. Influence of episodic meteorological event on the physical characteristics of a tropical estuarine ecosystem (Vembanad Lake-southwest coast of India) and some features of tidal oscillation. **Water Research.**

5. Madhu et al., 2007. Short-term variability in the physico-chemical characteristics and its implication on primary production of a tropical estuary (Cochin backwaters), India. **Estuarine, Coastal and Shelf Science.**

6. Maheswari et al., 2007. Temporal and spatial variability of sedimentary organic matter in the mangrove environments of Cochin, southwest coast of India. **Wetlands.**

7. Nisha et al., 2007. Impact of organic enrichment on macrobenthic population in the Cochin estuary, southwest coast of India. **Estuarine, Coastal and Shelf Science.**

8. Haridevi et al., 2007. Ratio of chlorophyll a : production : cell count on major diatoms and nano plankters from Cochin backwaters. **Marine Biology.**

9. Haridevi et al., 2007. In vitro study on the grazing of herbivorous copepod (Pseudodiaptomus annandaleii) on a few cultures of micro algae. **Journal of Plankton Research.**

10. Balachandran et al., 2007. Numerical modelling of tides and tidal currents in the Vembanad Lake, southwest coast of India. **Estuarine, Coastal and Shelf Science.**

11. Antony et al., 2007. Vulnerability of Cochin backwaters to meteorological disturbances, with special reference to tidal propagation. **METOC 2007.**