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Author(s): Nandan, S. Bijoy

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Current status and biodiversity modification in the coastal wetland ecosystems of India with objectives for its sustainable management

S. Bijoy Nandan

Dept. of Marine Biology, Microbiology & Biochemistry, School of Ocean Science & Technology, Cochin University of Science & Technology, Cochin 6820 16, India

email: < bijoynandan@yahoo.co.in>

Abstract

The South West (S.W.) coast of India is blessed with a series of wetland systems popularly referred to as backwaters covering a total area of 46128.94 ha. These backwaters are internationally renowned for their aesthetic and scientific values including being a repository for several species fish and shell fishes. This is more significant in that three wetlands (Vembanad, Sasthamcotta and Ashtamudi) have recently been designated as Ramsar sites of international importance. Thirty major backwaters forming the crux of the coastal wetlands form an abode for over 200 resident or migratory fish and shellfish species. The fishing activities in these water bodies provide the livelihood to about 200,000 fishers and also provide full-time employment to over 50,000 fishermen. This paper describes the changes on the environmental and biodiversity status of selected wetlands, during 1994-2005 period. The pH was generally near neutral to alkaline in range. The salinity values indicated mixohaline condition ranging from 5.20-32.38 ppt. in the 12 wetlands. The productivity values were generally low in most of the wetlands during the study, where the gross production varied from 0.22 $gC/m^3/day$ in Kadinamkulam to 1.10 $gC/m^3/day$ in the Kayamkulam. The diversity of plankton and benthos was more during the pre-monsoon compared to the monsoon and post-monsoon periods in most of the wetlands. The diversity of plankton and benthos was more during the pre-monsoon compared to the monsoon and post-monsoon periods in most of the wetlands. The average fish yield per ha. varied from 246 kg. in Valapattanam to 2747.3 kg. in Azhikode wetland. Retting of coconut husk in most of the wetlands led to acidic pH conditions with anoxia resulting in the production of high amounts of sulphide, coupled with high carbon dioxide values leading to drastic reduction in the incidence and abundance of plankton, benthic fauna and the fishery resources. The major fish species recorded from the investigation were *Etroplus suratensis, E. maculatus, Channa marulius, Labeo dussumieri, Puntius sp. Lutianus argentimaculatus, Mystus sp., Tachysurus sp.* and *Hemiramphus sp*. The majority of these backwaters are highly stressed, especially during the pre monsoon period when the retting activity is at its peak. The study has clearly reflected that a more restrained and cautious approach is needed to manage and preserve the unique backwater ecosystems of South-west India.

Key words: Coastal wetlands, Backwaters Biodiversity, Chemical and physical parameters, Plankton, Benthos, Fishery, Retting, sustainability, India

Introduction

Coastal wetlands are known to be an indispensable habitat to a variety of biologically and economically important resident and migratory aquatic fauna. Moreover, the interdependence of the adjoining marine and the estuarine zones in completion of the life cycle processes of innumerable aquatic species is amply described in fishery literature (Jhingran, 1988, Kurup and Samuel 1987). The biologic importance of the chain of backwaters/ estuaries/ wetlands (locally called as *kayals*) along with the canals are of special significance in this context. Plate 1 gives the Ramsar sites of Kerala and other important wetlands. Gopalan (1983) has presented a comprehensive account of the history of reclamation and the consequent shrinkage of the backwaters, especially the Vembanad backwaters. Similarly under the Indo-Dutch Collaborative Research Project on the Water Balance study of the Kuttanad Region, various aspects of the ecology and fisheries of Vembanad backwater were investigated and reported (Anon., 2001). Sarala Devi *et al* (1991) elaborated the coexistence of different benthic communities in the northern limb of Cochin backwaters. Murugan *et al* (1980) gave an account on the distribution and seasonal variation of the benthic fauna of the Veli Lake, Southwest coast of India. Devassy and Bhattathiri (1974), Kurian *et al* (1975), Desai *et al* (1983) and Gopalan *et al* (1987) undertook some of the investigations on the benthic fauna extending right from Cochin to Alappuzha. Sarala Devi *et al*. (1979) and Unnithan *et al* (1975) documented the effect of organic pollution due to industrial pollution on some water quality parameters in Cochin backwaters. There are few studies available on the general ecology of the backwaters, but studies on a comprehensive scale is greatly lacking. It was in this context that this contribution investigates the ecology and fishery potential of selected backwaters of Kerala for their wise use in the context of long term ecosystem management and conservation objectives.

Materials and Methods

Water samples were collected from selected backwaters as given in Table 1, below and analyzed for pH, dissolved oxygen, total sulphide, BOD_5, COD, free carbon dioxide, alkalinity, conductivity, total dissolved solids, nitrate, nitrite, phosphate and silicate (APHA, 1992). Sub surface water samples were collected using the Van Dorn sampler. Rate of primary production was estimated using the dark and light bottle method as described by the Strickland and Parsons (1972). Plankton was collected using bolting silk having 60μ meshes. The phytoplankton, zooplankton and benthic fauna were collected and analysed based on Davis (1955), Ward and Whipple (1959), APHA (1992). The diversity index (H' log_2), richness index (d), evenness index ('J) and dominance index (lambda') of plankton and benthos were also computed (Margalef, 1968). Fish fauna were identified based on Talwar and Jhingran (1991). Water and sediment samples were collected from 33 stations in these backwater systems for the physical and chemical analysis of samples on a seasonal basis. A Landing Centre Approach was adopted for collecting information on different fish species, fish yield and gears employed from the 38 fish landing centers around the eleven backwaters during the study (Cochran, 1977, Gupta *et al* 1997). The Catch per Unit Effort (CPUE) is expressed as kg/ catch per craft/hr was computed for the monthly and annual values and used as index of relative abundance. This contribution documented the environmental and fishery investigations in 11 backwaters in Kerala during 1996-98 periods on a seasonal basis (monsoon, pre monsoon and post monsoon) (Fig.1). The data on biota was subjected to multivariate analysis using the PRIMER Version 6, (Plymouth Routines in Multivariate Ecological Research) software.

Table 1: The eleven backwaters investigated during the study period

	Backwaters	Abbr. Used	District	Area (ha)
1	Kadinamkulam	KDK	Trivandrum	347
2	Achuthengu	ANG	-do-	552
3	Ashtamudi	AST	Kollam	6424
4	Kayamkulam	KYK	Kollam/Alp	1652
5	Azhikode	AZK	Trissur	696*
6	Chettuva	CTV	Trissur	714
7	Ponnani	PNI	Trissur	908**
8	Kadalundi -Beypore	KDL/BPR	Kozhikode	1192
9	Mahe	MHE	Kannur	88
10	Valapattanam	VPM	Kannur	3074
11	Neleswaram	NEL	Kasargod	825

* Kodungallur-Azhikode estuary ** Ponnani+ Puthuponnani

Results and Discussion

Water Quality

The water quality parameters were recorded from the eleven backwaters during the pre- monsoon, monsoon and post monsoon periods (Figs. 2, 3 & 4).

The pH was generally near neutral to alkaline in range. However, there was a reduction in its value particularly during the pre-monsoon period, owing to less mixing coupled with the impact of retting activity at certain stations. Anchuthengu, Kadinamkulam, Azhikode, Kadalundi and Chettuva recorded lower pH values. This was mainly due to the organic acids liberated during the retting. The mean pH values varied from 6.85 in Kadinamkulam to 8.12 in Chettuva backwater during pre-monsoon season. During monsoon, the variation was from 6.63 in Azhikode to 7.68 in Ashtamudi, whereas it varied from 6.74 in Ponnani to 8.20 in Neeleshwaram during the post-monsoon period.

Moderate to low transparency values were observed in the systems (0.29-1.54m). Retting areas had significantly lower values, particularly during the pre-monsoon period due to the accumulation of coir pith and ret liquor containing organic acids like pectin, pentosan, phenol, tannin, etc. in the water body. Turbidity from runoff substantially reduced the transparency in these shallow systems during monsoon while organic pollution resulted in low transparency during the pre-monsoon season. The salinity values indicated mixo-haline condition of these systems with a range of 5.20-32.38 ppt. during the pre-monsoon, 0.18 to 22.42 ppt. during the monsoon and 0.5 to 28.6 ppt. during the post-monsoon periods. Such high variation was also dependent on the tidal impact and sampling time.

The dissolved oxygen level did not exhibit wide variation during the monsoon while nil to low values were observed at certain stations during the post-monsoon and the pre-monsoon periods. The highly stressed environment was evident from the fact that on an average, 7 out of the 11 investigated water bodies recorded dissolved oxygen within a range of 1.73-4.57 ppm during the pre-monsoon survey. Marked depletion of dissolved oxygen leading to anoxic condition coupled with the presence of sulfide was the most conspicuous observation at certain stations. This was mainly due to the intense retting activity in these zones. The dissolved sulphides had an alarming concentration level in six of the systems during the pre-monsoon days. Sulfides exceeding 10mg/L coupled with nil-<2.0mg/L dissolved oxygen was prevalent in 12 of the 33 stations investigated during this season. Bottom layers of five sampling stations recorded no dissolved oxygen during the pre-monsoon months. This has been despite the exposure of the sampling stations to the tidal amplitudes twice a day.

The monsoon showers brought nutrients from allochthonous sources into the systems elevating the phosphate, nitrate and silicate concentrations in the water. Moderate to high COD values were observed during the post-monsoon when compared to the monsoon season. The high COD load could be due to the intense of retting activity and runoff from the surrounding areas.

The study indicated that retting of coconut husk in the backwaters has been the most contributing factor to the organic pollution leading to the depletion in the faunal resources in the backwaters as by the observations especially during the pre-monsoon survey. Nine of the eleven systems investigated were subjected to rampant retting activity.

The productivity values were generally low in most of the backwaters during the seasonal study. The gross production varied from a mean of 0.30gC/m ^{3}/day in Anchuthengu to 0.98 gC/m ^{3}/day in Azhikode kayal. Earlier investigations conducted on the primary productivity in the Kadinamkulam backwater reported zero values at retting zones during October to May and 0.02-1.49gC/m ^{3}/day at other stations and that in Ashtamudi the gross production rate was estimated at 143.88mgC/m^3/hr (Bijoy Nandan, 2004). The present results were in conformity with these studies. Anchuthengu kayal had consistently poor chlorophyll values indicating the severe stress originating from coconut husk retting and other anthropogenic influences.

The intense retting activity resulting in organic enrichment was also responsible for the higher organic content of the sediment in the southern backwaters as compared to the northern. Calcium carbonate was at its peak in Ashtamudi (Av.17.65%) during the pre-monsoon and the lowest in Anchuthengu backwater (Av. 0.29%) during the monsoon period. The mining activity of clams and oysters was more prevalent in the southern backwaters which could have resulted in higher values of calcium carbonate in the sediment. The available phosphorous content was high during the pre-monsoon with an average of 0.40% during the pre-monsoon followed by monsoon (Av.0.27%) and post-monsoon (Av. 0.28%) in the 11 backwaters.

Sand fraction dominated in all the backwaters investigated followed by clay and silt. The northern backwaters were higher in sand content as compared to the southern systems (Table 2).

The post-monsoon period was characterized by the peak sand fraction followed by pre-monsoon and the monsoon periods. Coarse sand also formed an important constituent of the sediment texture contributing a mean of 47.69 % (Av.) during the monsoon, 38.15% (Av.) during the post-monsoon and 36.34% (Av.) during the pre-monsoon. Silt distribution in the backwaters were very uneven without any steady pattern, where Ashtamudi had the highest average in the all the three seasons followed by Kadalundi during the pre-monsoon and Kayamkulam during the monsoon and post monsoon periods. The clay fraction was highest in the southern backwaters during all the three seasons with exceptionally high mean value in Anchuthengu (Av.39.15%). This could be due to the high organic enrichment due to retting activity as well as the stressed condition due to the dry pre-monsoon months prevalent in the backwater.

Impact of Retting Activity in the Wetlands

There are several anthropogenic interventions affecting the sustainability of floral and faunal resources (Bijoy Nandan 2004). These include effluent discharge from factories / industries, organic pollution from various sources. .The retting of coconut husk for the production of coir is the most extensive and damaging pollution affecting the entire backwater ecosystems of the region. Retting, is basically a "*soaking process*" where husks are arranged in bundles in huge coir nets known as ''*malis*" and allowed to float freely in the backwaters, until they get soaked, become heavy and gradually sink to the bottom. It involves bacteria, fungi and yeast.

Large chunks of pectin, phenol, cellulose, hemicellulose and tannin are released from the husk into the surrounding medium, during different stages of retting. In depth studies on the impact of retting activity on the backwater systems, was reported by Bijoy Nandan (2004).

Acidic pH condition coupled with anoxia and production of high concentrations of hydrogen sulphide were the outstanding feature, in the environmental quality of the retting zones. The higher concentration of free CO_2 in the retting zones could be attributed to the process of decomposition of organic matter like pectin, phenol, tannin etc. leading to a rise in temperature of the medium, along with the production of the gas. The retting zones showed rise in the concentration of sulphide accompanied with the production of CO_2, thereby establishing a positive direct relationship between CO_2 and sulphide values particularly in the retting zones. This corroborates with the studies conduced in the retting zones of Kadinamkulam estuary by Bijoy Nandan (2004) (Table 3).

The primary productivity mechanism was totally collapsed in the retting zones. It has thus shown that the productivity potency of the coastal ecosystems was adversely affected due to pollution from retting activity. The mean chlorophyll a (1.63mg/m^3) and algal biomass (1.09 g/m^3 wet wt.) values were very low in the retting zones as compared to the non-retting zones (chlorophyll a: 9.65 mg/m^3 ; algal biomass : 6.46 g/m^3 wet wt.). Studies by Bijoy Nandan (2004) have shown that the plankton, benthic fauna and fish biodiversity showed massive depletion in the retting zones as compared to the non retting zones. Mass mortality of fish and shell fish were reported from the retting zones, particularly during the pre monsoon period affecting the sustainable fish production in this region as well as the adjacent areas.

Biodiversity and Community Structure

The biomass values of plankton in the retting zones were greatly reduced. The lowest values were recorded in the retting zones of Kadinamkulam (0.4ml/L) and the highest in the non- retting zones of Valapattanam (12.8 ml/L). One retting zone each was selected in the eleven backwaters during the study. The incidence, abundance and diversity of fauna were greatly depleted in the retting zones as compared to the non-retting zones. This depletion was more prominent during the pre monsoon period when the retting process attained its peak, resulting in anoxic conditions coupled with the formation of high concentrations of sulphide in the medium. The diversity index (H' $\log_2$), richness index (d) and evenness index ('J) were generally low in the retting zones. The mean seasonal biomass values varied from 0.52 in Azhikode to 5.85 mL/m^3 in the Kadinamkulam backwater during the monsoon, whereas it varied from 0.28 in Mahe to 6.83 mL/m^3 in Ashtamudi estuary during the post-monsoon period. The high amount of detritus, sediment and other suspended materials collected along with the plankton samples during the monsoon showers resulted in higher settling volume in this period. This could be the reason for the higher biomass recorded during the monsoon period. Thus the highest value was obtained at Valapattanam (12.8 ml/m^3) and the lowest at Kadinamkulam (0.4 mL/m^3).

Phytoplankton and Zooplankton

The Kadinamkulam Estuary showed the maximum mean phytoplankton population during the monsoon period whereas the Chettuva estuary showed the maximum value in the post-monsoon period. The similarity profile indicated that it gave three groupings having the Kadinamkulam, Kayamkulam and Ashtamudi (southern systems) in one group the Kadalundi, Ponnani and Anguthngu in the second group and the third having the Mahe, Neeleshwaram, Azhikode, Chettuva and Valapattanam. The similarity in abundance of phytoplankton was highest in Kadalundi and Ponnani water bodies (93%) and the least in Kadinamkulam and Kayamkulam backwaters (74%) (Fig. 5).

Desmidaceae had a higher representation in the northern backwaters (Neeleswaram to Azhikode) during the monsoon season whereas this was replaced by either Bacillariophyceae or Chlorophyceae during the post monsoon season. The southern backwaters except Ashtamudi were dominated by Bacillariophyceae during monsoon, which got replaced by Myxophyceae during the post monsoon season. During the pre-monsoon period Chlorophyceae, Myxophyceae and Chrysophyceae showed higher percentage incidence in the southern backwaters whereas Bacillariophyceae showed higher incidence in the northern backwaters. *Campylodiscus* sp., *Staurastrum* sp., *Micrasterias* sp., and *Spondylosium* sp. contributed to the higher density of Bacillariophyceae. Chlorophyceae represented by *Microspora* sp., *Pediastrum* sp. and *Hormidium* sp., contributed to the high planktonic biomass in Chettuva and Ponnani estuaries.

Non-metric multidimensional Scaling (MDS) ordination of the abundance data showed that the phytoplankton was generally similar in 10 of the stations except Ashtamudi backwater with the overall similarity of the abundance as low at 20% whereas it was highly similar at about 80% between Chettuva - Valapattanam; Azhikode -Mahe - Neeleshwaram and Ponnani- Kadalundi backwaters. The stress factor overlying the MDS plot (0.08) was quite high indicating that the systems were stressed (Fig.6).

A total of 100 species of phytoplankton were recorded from the backwaters. The diversity index (H' $\log_2$) was highest in Kadalundi and lowest in Valapattanam backwater whereas richness of fauna (d) ranged from Ashtamudi (3.57) to Valapattanam (2.09), evenness index ('J) from Anjuthengu (0.96) to Chettuva and Ashtamudi (0.87) and the dominance index (lamba) ranged from Anjuthengu (0.09) to Mahe (0.15). (Fig.7) The monsoon period showed the presence of 14 groups of zooplankton whereas the post monsoon showed 20 groups in the backwaters. But during the pre-monsoon study conducted in the same water bodies during 1996 showed the presence of only 12 faunal groups. The southern backwaters (Kayamkulam to Kadinamkulam) showed higher incidence and diversity of the different planktonic groups when compared to the backwaters in the northern segment during monsoon as well as post-monsoon periods. During the pre-monsoon, the Kayamkulam backwater recorded the maximum numerical density (64273 Nos./ m^3) and the Mahe backwater recorded the minimum (3350 Nos./ m^3). *Centropyxis* sp., the protozoan showed its maximum incidence in the Mahe and Azhikode estuaries during the monsoon period. The retting zones in the ten ecosystems showed considerably lower planktonic abundance and diversity, coinciding with the poor water quality condition in the corresponding areas. Azhikode recorded the highest diversity index value ($H' \log_2$) during the monsoon period (2.74) and the lowest in Kayamkulam during the same season. Copepods and copepod nauplii formed an important component in all the ten systems in both the seasons (Fig.8). In the Neeleswaram backwater, 50% of the plankton was contributed by copepods during the post-monsoon period whereas the group formed 34.8% of the population during the monsoon period in the Kadinamkulam estuary. Altogether, 34 species of rotifers were recorded during the post-monsoon season alone in the ten backwaters. *Brachionus* species represented by B.*plicatilis*, *B. falcatus*, *B. calyciflorus* showed the maximum incidence among the rotifers in the present study.

Benthic fauna

Amphipoda, Polychaeta and Gastropoda formed the dominant groups in all the backwaters during both the seasons. The monsoon as well as post monsoon periods showed higher numerical density in the southern backwaters when compared to the northern segments. Nemertea (Ribbon worms), a rare group was recorded in the Neeleswaram (0.5%) and Ashtamudi backwaters (0.4%) during the post-monsoon period. The similarity profile indicated that it gave five groupings having as given in Fig. 9. The similarity was highest in Neeleshwaram and Valapattanam backwaters (85%) and lowest in Kayamkulam and Anjuthengu (68%) (Fig.10). The pre-monsoon was characterized by higher groups of benthic fauna like Oligochaeta, Polychaeta, Amphipoda, Insecta and Mollusca in the northern backwaters when compared to the backwaters in the southern side. The MDS analysis done with depth as a factor showed that abundance of fauna was similar in ten of the backwaters except Kadinamkulam backwater. The MDS also showed that the overall similarity in the abundance of benthos was low at 20% whereas it was similar at about 80% within each of the stations. (Fig.11).

The diversity index (H' $\log_2$) was highest in Valapattanam (4.14) and lowest in Kadinamkulam backwater (3.32) whereas richness of fauna (d) ranged from Chettuva (5.81) to Kadinamkulam (3.33), evenness index ('J) from Valapattanam (0.93) to Anjuthengu (0.83) and the dominance index (lambda') ranged from Kadinamkulam (0.124) to Valapattanam (0.064). (Fig. 12).

As observed above in zooplankton, the benthic fauna also showed considerable depletion in the retting zones of the present study. Thirteen groups formed the benthic population during the monsoon period whereas seventeen groups in the post-monsoon. Insect fauna showed higher incidence and diversity particularly in the backwaters in the northern side during the post-monsoon period. The retting zones in the backwaters showed higher dominance of *Chironomus* larvae and other insects.

The benthic forms were present at all seasons showing its maximum mean density (39 nos./m^2) during the monsoon. The high organic carbon content in combination with the higher percentage of sandy clay during the post-monsoon and pre-monsoon periods was a positive element in maintaining a high density of the benthic organisms. The proboscis worms or the nemertines belonging to the phylum Nimertinea was one of the rare groups of benthic fauna recorded during the present investigation. This is the first record of this worm from the inland waters of this geographic region.

Fish Production Potential

Ninety four species of fish and shellfish were identified in the fishery of the backwaters. Of the 94 species listed, 63 have been recorded from the marine waters by different workers, thereby establishing a close relationship of the backwater fishery with that of the marine system. Nineteen of them used to be predominantly recorded from the rivers and these take a sojourn to the backwater during the monsoon or immediately after the monsoon when the salinity remained very low in the upper reaches. Definite zone marking were observed in the distribution of these species in the backwater where *Puntius filamentosus, P. sarana, Labeo dussumieri, Mystus malabaricus, Anabas testudineus, Channa* spp., *Oreochromis mossambicus*, and *Mastacebelus armatus* could be cited as examples which inhabited the estuarine regions. Whereas the purely marine forms, *Rhinobatus halavi,* *Congressox talaboidenes, Lobotes surinamensis, Acanthurus strigosus, Eleotris fusca, Lepturocanthus savala, Platax orbicularis*, etc were recorded from the backwaters during the summer season in stray numbers.

Etroplus suratensis, *Penaeus indicus* and the *Metapenaeus monoceros* represented 2.0-13.9%, 2.5-29.6% and 1.0-8.2% in the total catches (Table 4). The total landings from different backwaters varied from 96.8t from Mahe to 2899t from the Ashtamudi. The average yield/ha varied from 410 kg at Anchuthengu to 2747.3 t from Azhikode estuary. The Catch per Unit Effort exhibited wide variation from gear to gear in the eleven backwaters. The high CPUE for the Stake Net (7.5 kg -18.1kg) was largely offset by the limited days of operation and the low market value fish forming the bulk of the catch. The Seine net also demonstrated a high CPUE (11.3 kg -74.7 kg), but the catch composition was composed largely of small fishes, young fishes and the low priced *M. dobsonii.*

From the 16, 472 ha backwaters covered under the investigation, the average yield per hectare was to the tune of 651kg/year. A total of 9, 667 tones was the annual yield from the 11 backwaters during the present study. Sugunan and Sinha (2001) had earlier reported an annual catch of 14, 000 -17, 000 t from a total area of 45,000 ha of backwaters in the State. Comparing this report with the present study, it could be inferred that the fish production in the backwaters investigated are quite encouraging. An estimation of the price share of fish also indicated that on an average, the fishermen received only 48-73% of the market price at the landing site through auction. The study clearly indicates the indisputable contribution of the backwaters to the inland fish production of the region both for internal consumption and for export. While the shellfish fishery largely support the export clientele (except *M. dobsonii*), the fishes serve the local populace.

Conclusions from the Study

1. The fishing effort should not be allowed to increase further and has to be restricted at least to the current level until further recommendations are made based on population dynamic investigations conducted on major fish/shellfish species of the backwater systems.
2. There is an urgent need to restrict the mesh size of the stake net, Chinese dip net and the drag net to ensure that sufficient fish reach the adult size classes. Though a minimum mesh size of 25 mm (stretched) is advisable, considering that *M. dobsonii* is also to be exploited, the minimum mesh size may be restricted to 18mm.

3. It has been observed that several units of purse seine are diverted to the backwaters during the closed season for marine fishing. This should be prohibited.
4. Several of the stake nets are being deployed during the tide incursion to the back- waters against the norms. The enforcement machinery should be strengthened to ensure that the stake nets are deployed only during the receding phase.
5. A considerable area of the backwaters has already been lost due to reclamation for agricultural, mining, urban area development and similar activities. Further encroachment/reclamation should be strictly regulated.
6. Several stretches of backwaters are subjected to extreme organic/industrial pollution. Hence pollution abatement measures should be given top priority. Technology for alternate coconut husk retting practice should be developed that do require the use of backwaters.
7. Reclaimed paddy lands such as at Kuttanad, Kattampally, etc should be utilized to raise an additional crop of fish during the fallow period.

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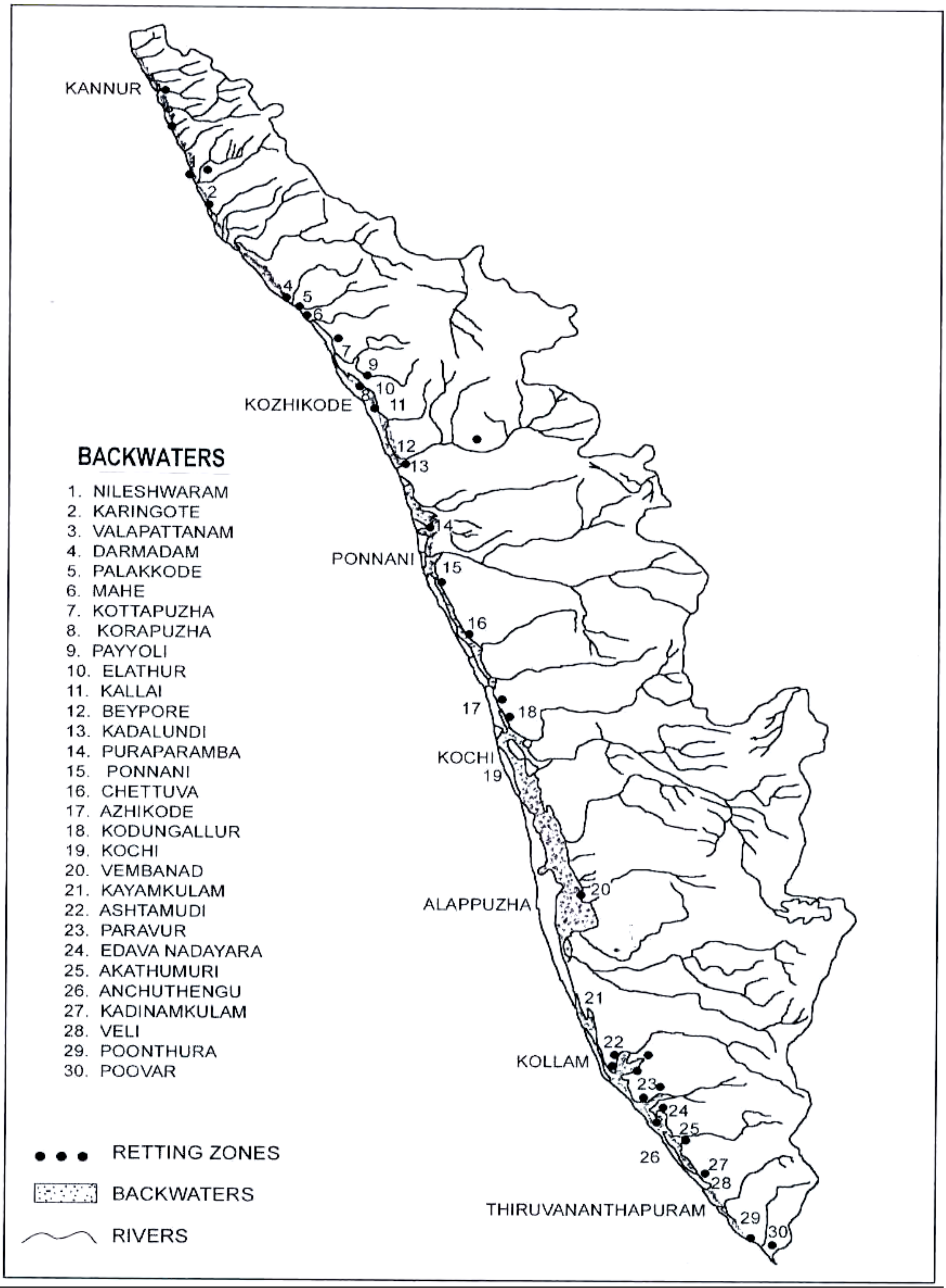
FIG. 1 MAP OF KERALA INDICATING THE MAJOR BACKWATERS, RIVERS & RETTING ZONES



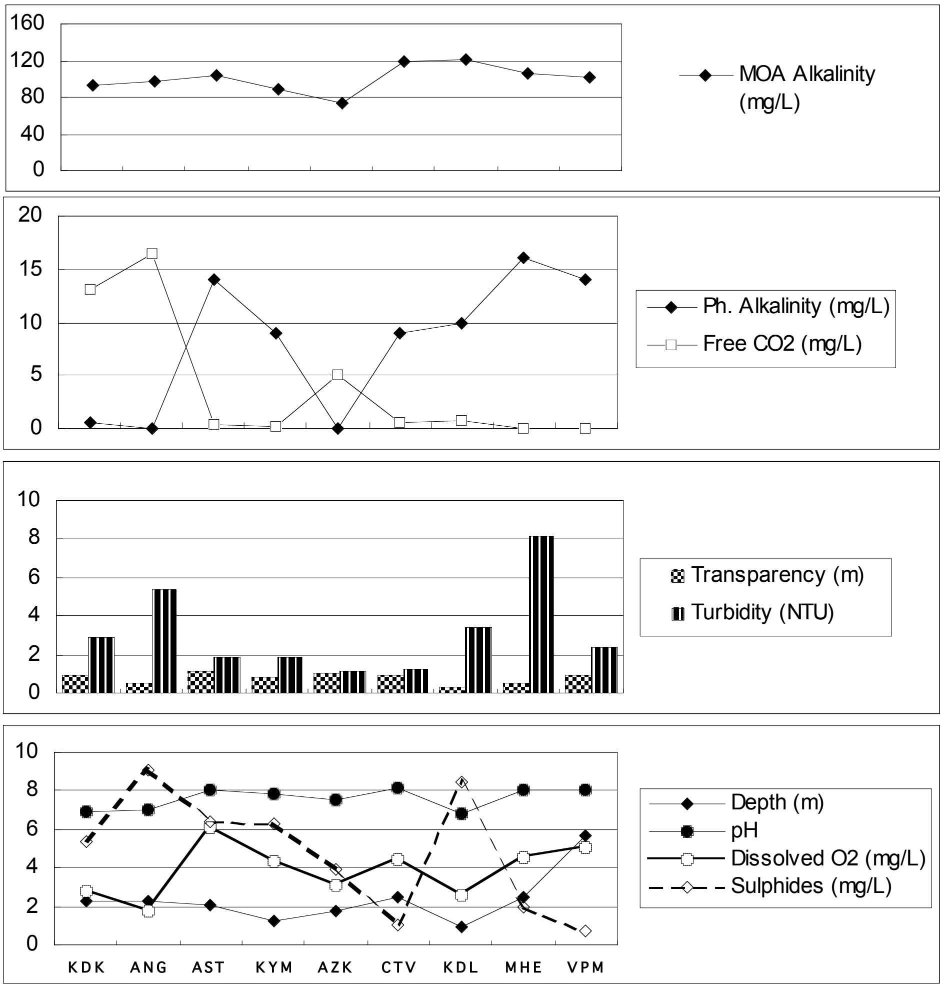


Fig 2: Mean water quality variations in selected backwaters during pre-monsoon period.

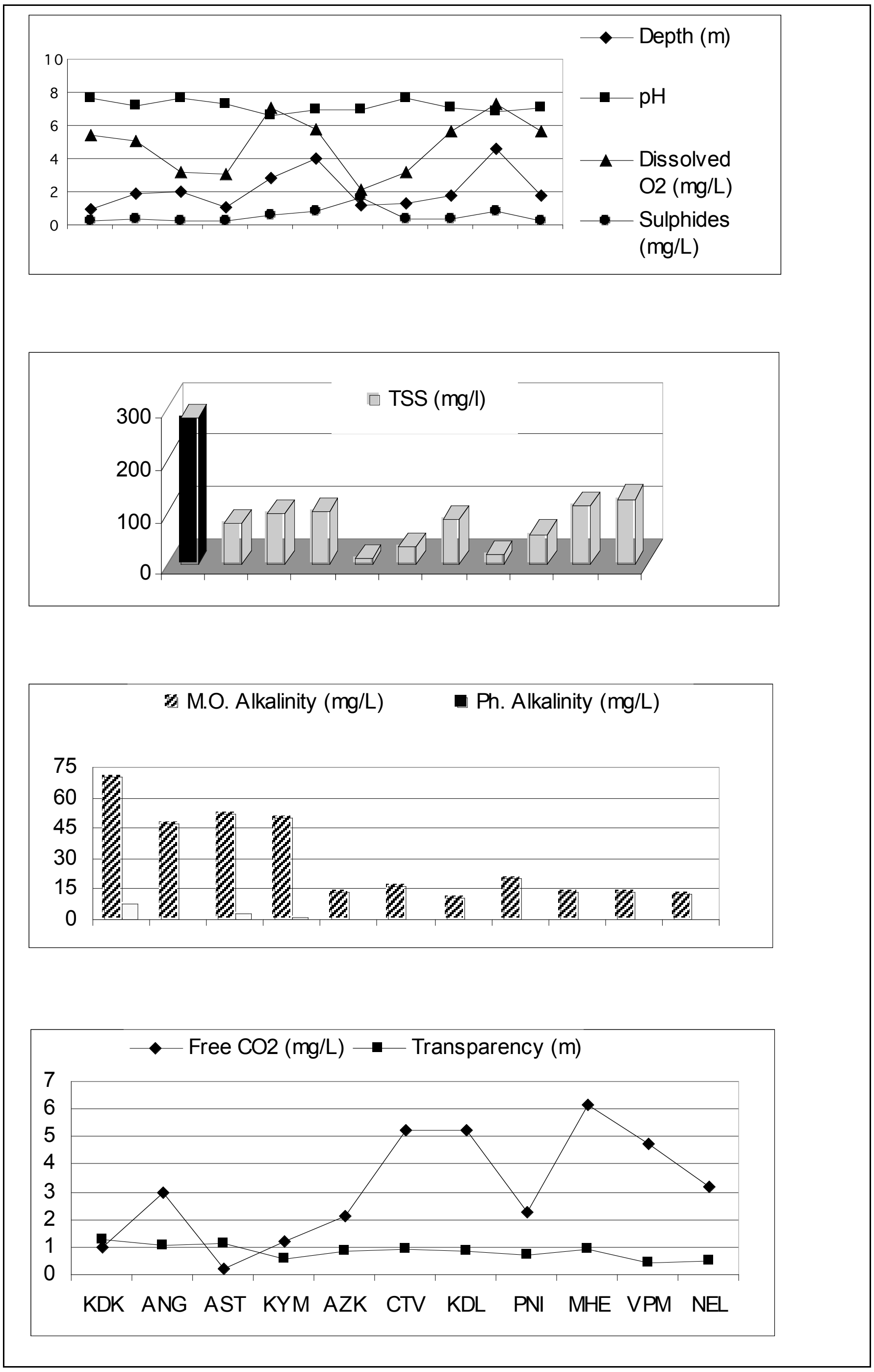


Fig. 3: Mean water quality variation in selected backwaters during the monsoon period

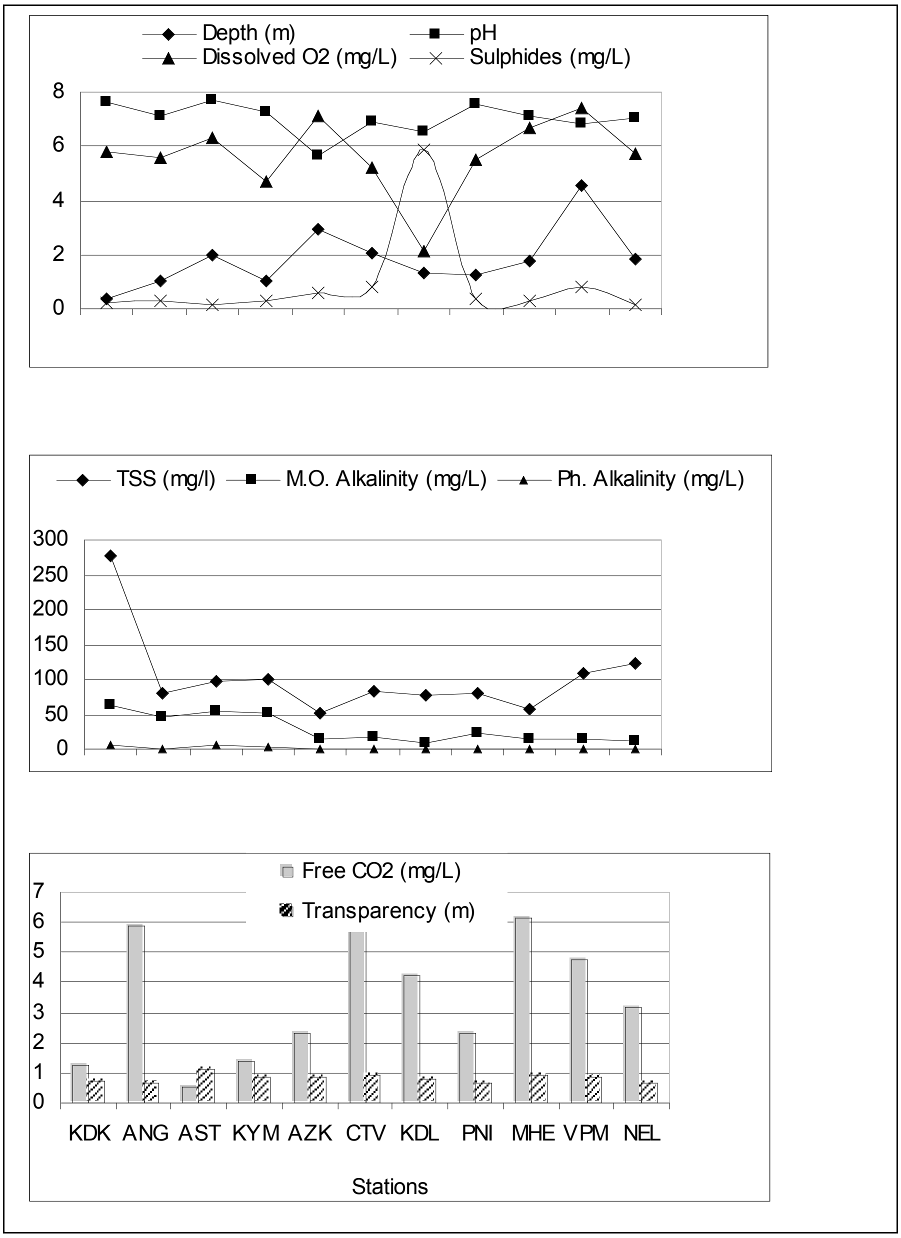


Fig. 4: Mean water quality variation in selected backwaters during the post monsoon period

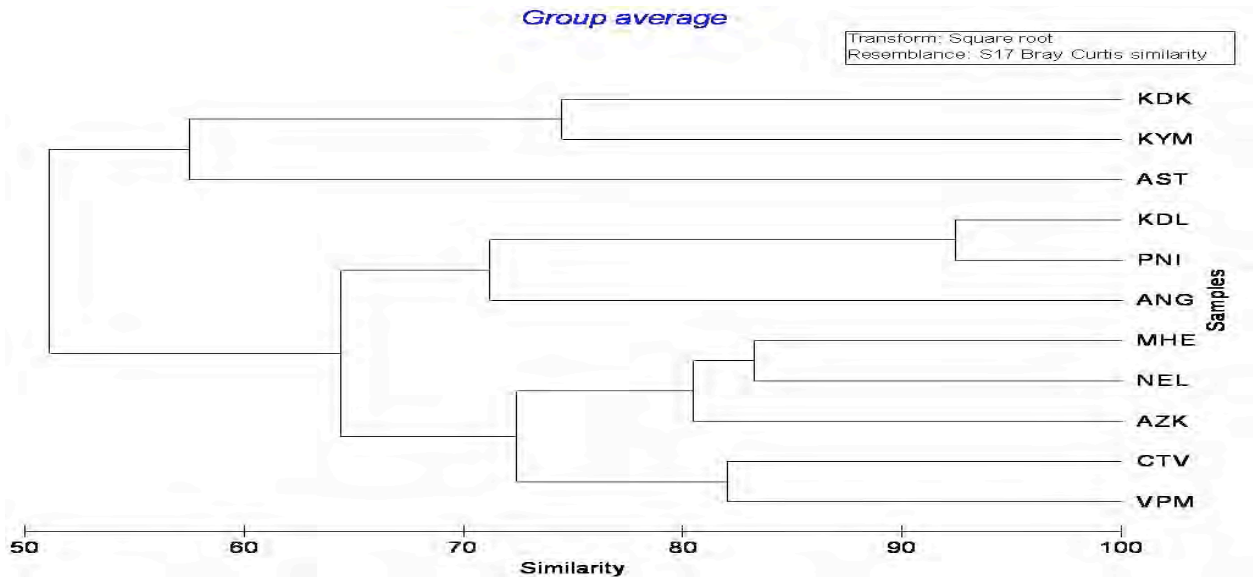


Fig. 5: Bray- Curtis similarity of phytoplankton abundance in the selected backwaters

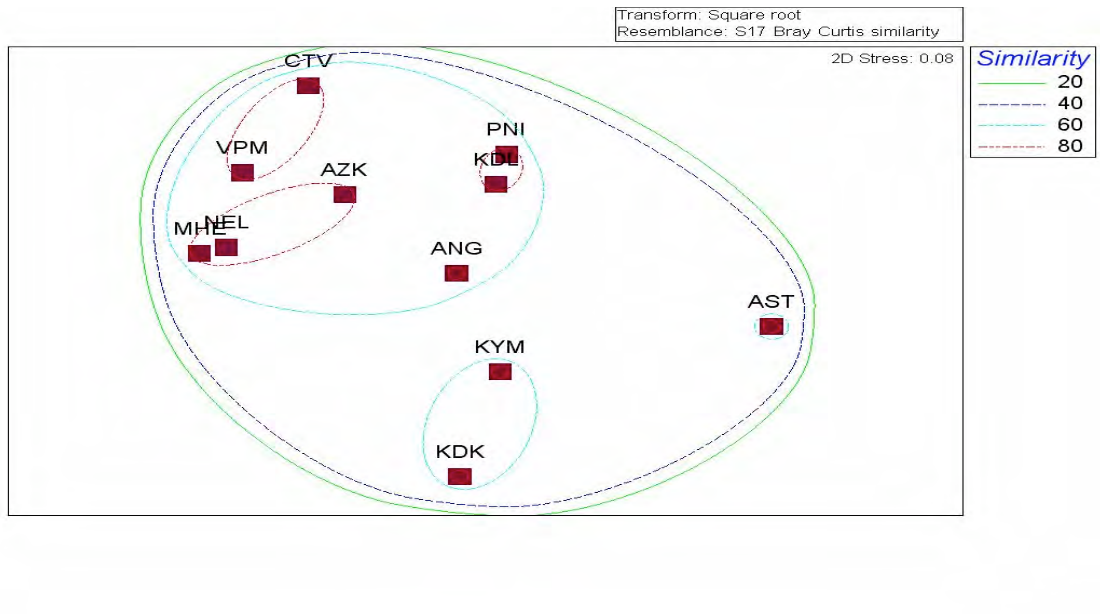


Fig.6: Multi dimensional plot (MDS) of Phytoplankton in the selected backwaters

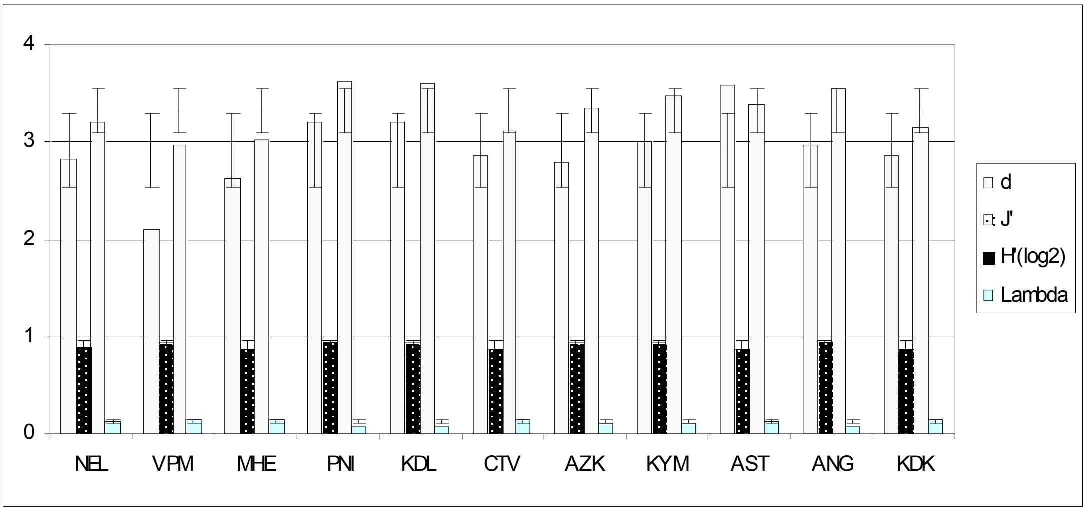


Fig. 7: Diversity indices of Phytoplankton in selected backwaters showing the error bars

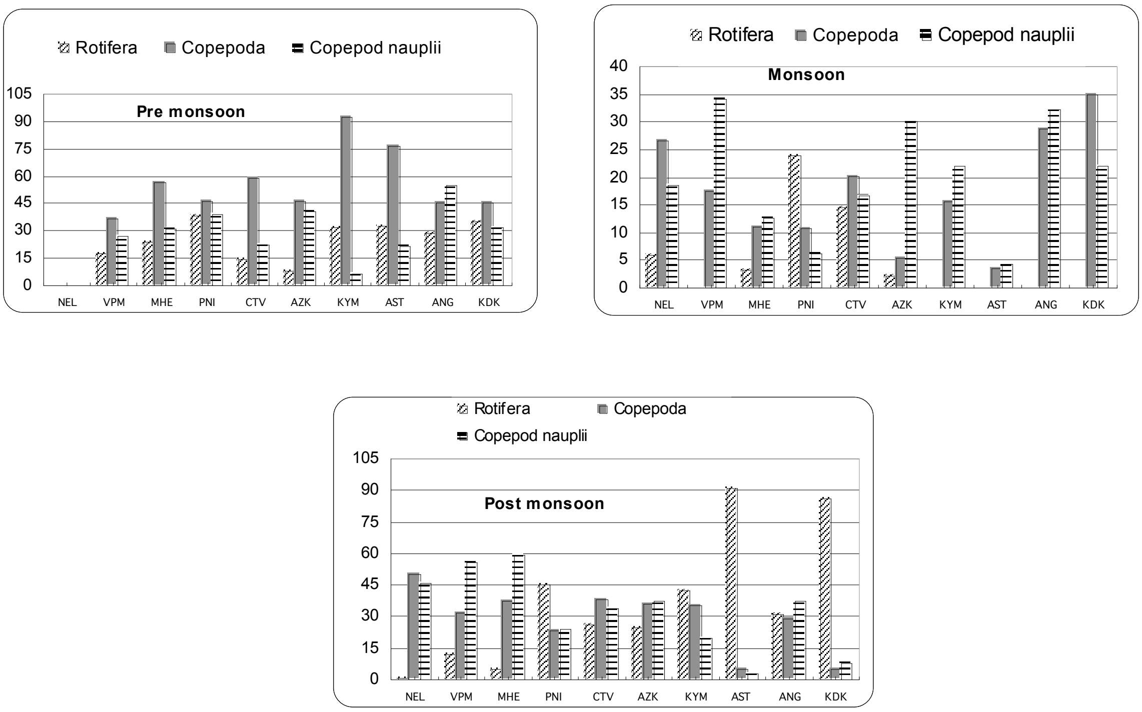


Fig. 8: Seasonal mean distribution (%) of selected zooplankton in the backwaters

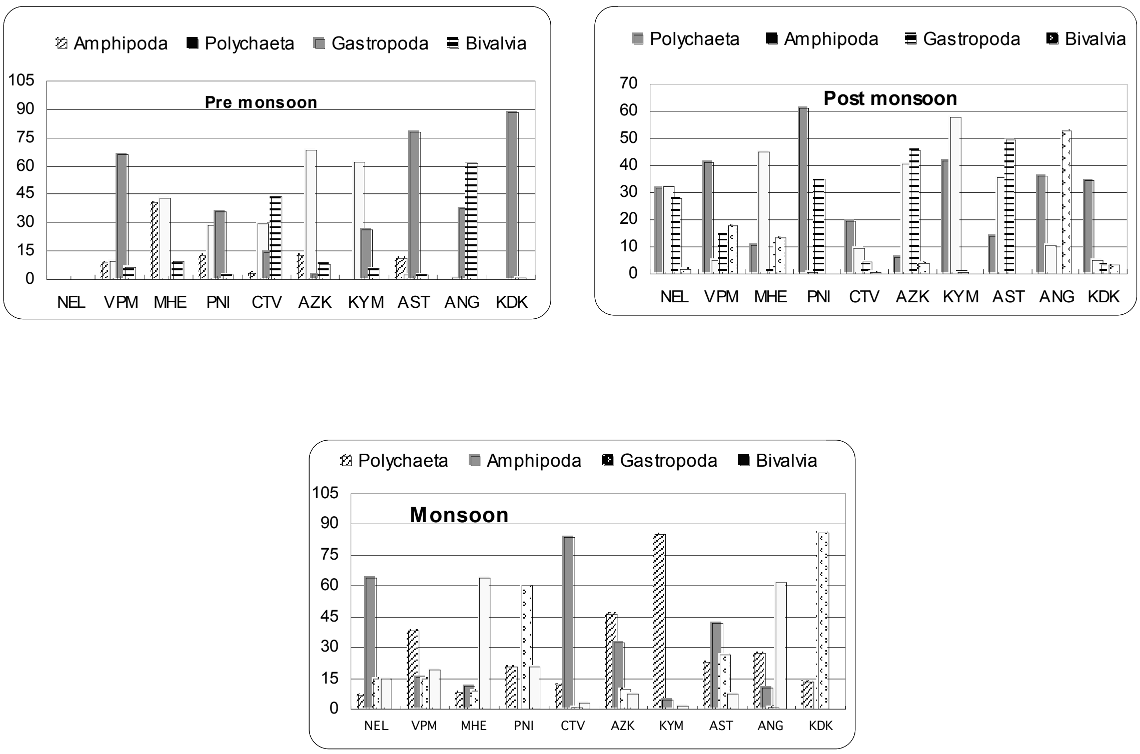


Fig. 9: Seasonal mean distribution (%) of selected benthic fauna in the backwaters

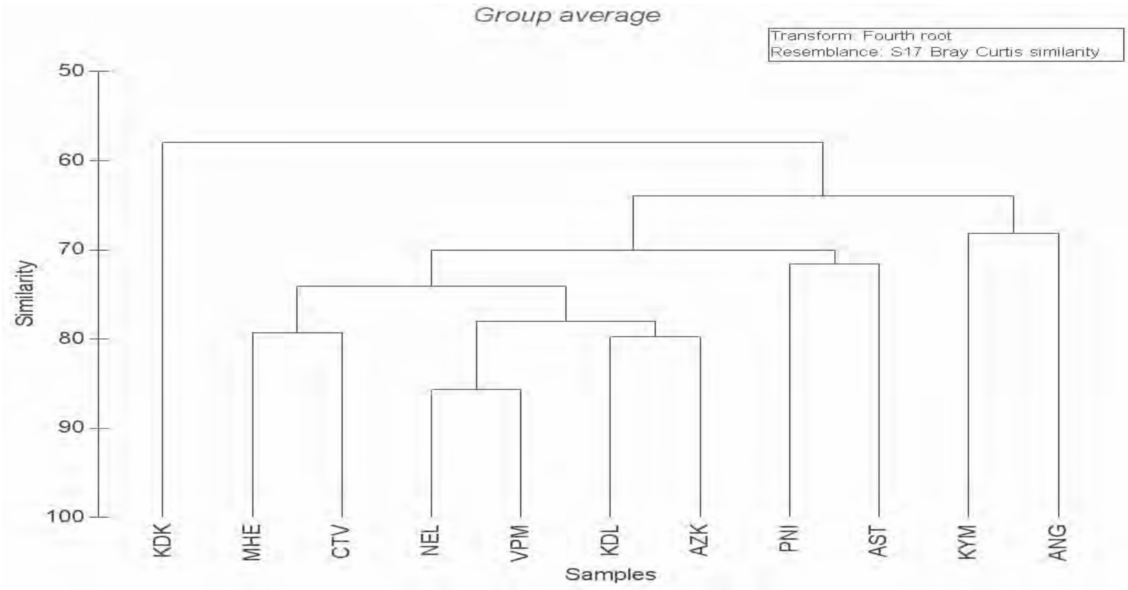


Fig. 10: Bray- Curtis similarity of benthic faunal abundance in the selected backwaters

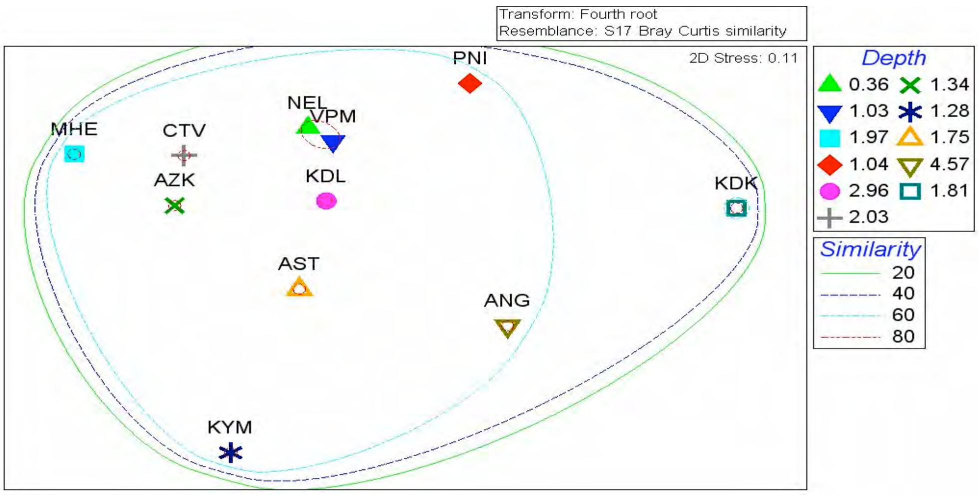


Fig. 11: MDS plot of total benthic fauna in the selected backwaters

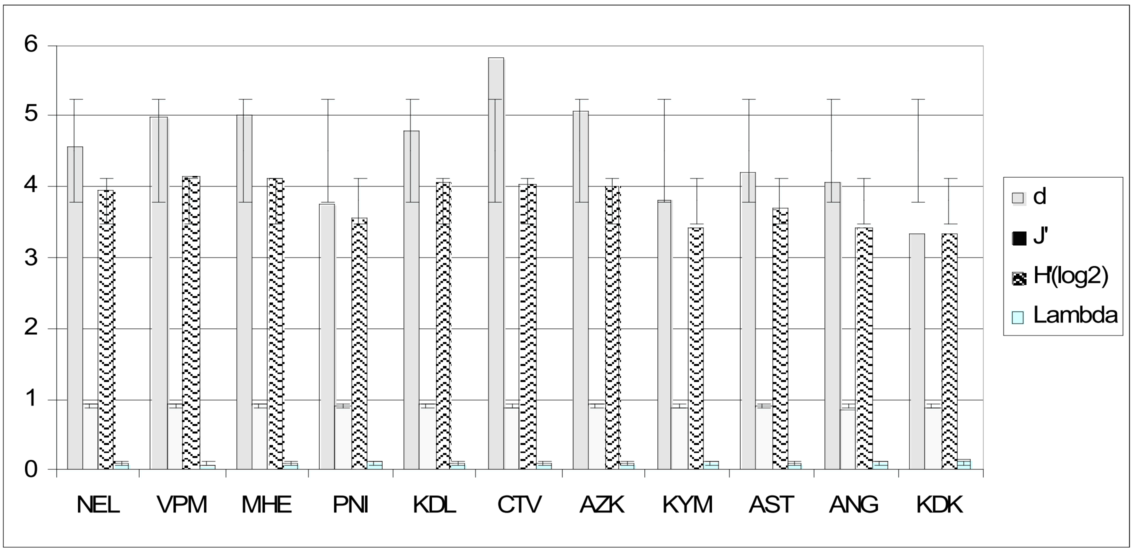


Fig. 12: Diversity indices of benthic fauna in the selected backwaters showing the error bars

Table 2: Mean percentage variation in sediment texture in selected backwaters

	PRE MONSOON											
	NEL	**VPM**	**MHE**	**PNI**	**KDL**	**CTV**	**AZK**	**KYM**	**AST**	**ANG**	**KDK**	**Mean**
Sand	40.64	33.94	34.2	34.74	37.12	31.22	37.26	53.42	30.47	28.49	38.26	36.34
Coarse sand	18.66	50.44	50.1	19.54	20.61	52.38	50.63	25.72	16.16	28.24	28.92	32.85
Silt	10.67	2.75	10.1	12.98	11.8	3.67	2.67	3	16.5	2.75	9.08	7.82
Clay	15.76	12.32	17.7	25.76	29.78	12.23	8.9	16.98	37.7	39.15	20.48	21.52
	MONSOON											
	NEL	**VPM**	**MHE**	**PNI**	**KDL**	**CTV**	**AZK**	**KYM**	**AST**	**ANG**	**KDK**	**Mean**
Sand	75.36	36.38	40.21	29.93	23.99	19.81	51.83	10.27	22.74	48.46	21.15	34.56
Coarse sand	19.39	54.27	52.25	67.5	16.56	55.35	37.47	59.53	45.71	45.98	70.59	47.69
Silt	2.18	3.55	2.08	1.25	10.54	5.4	1.45	4.75	16.83	2.77	3.5	4.94
Clay	2.57	4.9	5.07	1.21	17.98	11.96	8.45	21.34	13.86	2.3	10.59	9.11
	POST MONSOON											
	NEL	**VPM**	**MHE**	**PNI**	**KDL**	**CTV**	**AZK**	**KYM**	**AST**	**ANG**	**KDK**	**Mean**
Sand	53.62	45.4	46.41	50.76	21.43	25.45	47.57	45.48	7.45	48.6	27.52	38.15
Coarse sand	27.41	37.91	31.02	38.39	16.98	47.05	44.14	19.29	49.84	48.6	41.23	36.53
Silt	8.1	3.82	2.83	1.31	12.67	6.56	1.55	10.81	16.71	3.81	5.29	6.68
Clay	10.44	12.17	9.57	8.78	20.76	20.71	6.05	23.9	25.19	13	19.09	15.42

Table 3: Mean values of physico-chemical characteristics of retting and non-retting zones in the backwaters

	Retting zone	Non-retting zone
Depth (m)	1.88	2.88
Transparency (m)	0.60	0.69
pH	6.92	7.99
Dissolved oxygen (mg/L)	2.43	7.60
Total sulfides (mg/L)	8.80	3.01
Turbidity (NTU)	2.62	1.60
Free carbon dioxide (mg/L)	6.4	3.5
Alkalinity (MO) (Mg/L $CaCO_3$)	103	91
Alkalinity (Ph.) (Mg/L $CaCO_3$)	6.7	10
Inorganic phosphate (mg/L P)	40.6	36.5

Table 4: Percentage contribution by various species/groups to the total landings from selected backwaters

Species/ Groups	**Contribution (%) to total landings**	
	Range	**Mean% of Pooled data**
Acanthurus spp.	0.0-4.9	0.47
Gerres spp.	1.0-6.1	2.72
Platycephalus sp.	0.1-3.1	1.08
Leiognathus spp.	0.3-5.9	1.08
Etroplus spp.	2.0-13.9	5.68
Megalops sp.	0.0-5.8	0.60
Tachysurus spp.	1.9-10.4	3.20
Ambassis sp.	0.0-8.6	2.92
O. mossambicus	0.0-14.7	0.94
Stolephorus sp.	0.0-3.3	1.57
Sillago sihama	0.0-3.8	0.81
Caranx spp.	1.0-5.2	1.29
Lutjanus spp.	1.1-11.4	1.50
Mullets	1.5-16.5	5.07
Flat fishes	0.1-3.6	1.21
Half beaks	0.1-2.5	0.26
Others	6.4-20.0	10.66
Fishes total	26.9-75.0	**41.20**
Metapenaeus dobsonii	9.2-53.4	33.06
M. monoceros	1.0-8.2	6.53
Penaeus indicus	2.5-29.6	9.19
P. monodon	0.0-9.0	1.22
Other penaeids	0.0-2.9	0.64
Non-penaeids	0.0-1.3	0.46
Prawns total	**13.9-70.5**	**53.1**
Crabs	**2.6-11.1**	**5.75**
Total yield (kg/ha.)	246-2747	630.1