

BIOLOGICAL INDICATORS IN RELATION TO COASTAL POLLUTION ALONG KARNATAKA COAST, INDIA

XIVANAND N. VERLECAR, SOMSHEKHAR R. DESAI, ANUPAM SARKAR AND
S. G. DALAL

National Institute of Oceanography, Dona Paula-403 004, Goa, India.

Abstract:

Marine pollutants in relation to planktonic and benthic organisms were examined at two locations along Karnataka coast, one at Kulai (74⁰ 47.74" E and 12⁰ 55.16" N) receiving huge amount of industrial effluents from fertilizer, petroleum and chemical plants along with the sewage discharges. The other site Padubidri (74⁰ 45" E and 13⁰ 10" N) is located 20 kms away, which is a typically agricultural and fishing village having no stress of industrial discharges. Although the concentrations of dissolved oxygen (DO), nutrients and trace metals in water and sediment showed marginal differences at these two locations, the concentration of petroleum hydrocarbon (PHC) remained exceptionally high with a maximum of 1523 µg/l at Kulai which is 10 times higher than that at Padubidri (144 µg/l). Biomass and population of phytoplankton and zooplankton showed that the seasonal differences were more conspicuous rather than the regional changes. Macro and meiobenthic population remained high at both the locations during the two seasons. Phytoplankton species indicated that centric diatoms such as *Rhizosolenia*, *Leptocylindricus*, *Chaetoceros*, *Thalassiosira* and *Coscinodiscus* contributed to >90% of population in May and >70% in January at Kulai. While mixed population of centric, pennate, cyanophycean and dinoflagellates prevailed at Padubidri in January. Lower species diversity and richness accompanied with

dominance of fast growing centric diatoms over pennates observed at Kulai act as an index for detection of organic pollution and nutrient enrichment. Similarly proliferation of benthic bivalves >54% at Kulai relative to Padubidri suggests that these organisms could sustain organic and industrial pollutants. The results suggest that although Kulai receives large quantities of industrial and sewage effluents responsible for alteration of the ecosystem structure, the excellent wind driven mixing and tidal flushing keep the waters well aerated thus reducing the severe pollution stress by dispersing the organic and other pollutants. Direct relationship of PHC with Cd and Pb as contaminants, NO₃ and PO₄ as oxidants of excess PHC and species diversity as promoters of phytoplankton (centric diatoms) and benthic bivalves shown by multiple regression analysis further suggest that these biological parameters could serve as indicators for detecting moderately high environmental stress at Kulai, compared to Padubidri

Key words: Coastal pollution, Petroleum hydrocarbon, Trace metals, Nutrients, Bio-indicators, Plankton, Benthic organisms.

*Corresponding Author: E-mail: verlecar@nio.org Tel: 91-832-2450218

INTRODUCTION

Indian coast is continuously being threatened by effluent discharges from metropolis and industrial towns. This gives rise to immense environmental problems leading to deterioration of water quality. The extent of damage caused by indiscriminate discharges of wastes could be perceived from some of the published reports. Zingde and Govindan (2000) indicated that the coastal waters of Mumbai receives industrial discharges up to 230 million litres per day (MLD) and domestic wastes of around 2,200 MLD of which, 1800 MLD are untreated. This has affected the water and sediment quality, with consequent effect on aquatic communities. Similarly rapid industrial growth of the Gujarat State, has given rise to waste discharges in some major rivers such as Kolak, Damanganga, Amba and others, which is responsible to degrade the estuarine and coastal waters (Zingde and Desai, 1987). In the east coast, increased metal concentration in the coastal waters of Pondichery as reported by Govindasamy and Azariah (1999) was as a result of the effluent discharges of nearly 16 major and minor industries. Similarly Cheevaporn and Menasveta (2003) reported BOD loads of 659 to 34,376 tons/year from municipal and industrial waters in Gulf of the Thailand which was responsible to starve aquatic life and alter the ecosystem structure of the region. In the gulf of Trieste (Italy) Hg mining is responsible to discharge about 1.5 tons of Hg / year which has increased the levels in marine organisms exceeding 0.5 mg/kg (Sirca and Rajar, 1997).

In order to keep a check on coastal pollution Government. of India initiated surveillance programme "Coastal Ocean Monitoring and Prediction System

(COMAPS)” in which, 26 sites along Indian coast have been identified as hot spots which are either ecologically sensitive or severely affected by pollution. Kulai along the Karnataka coast near Mangalore harbour, is one such location, wherein recent years a number of industries have sprung up, which discharge industrial and domestic effluents in nearby coastal waters. In this study, distribution of the flora and fauna at the two sites Kulai and Padubidri, is examined in relation to concentration of contaminants in water and sediments in order to understand whether biological responses could be used as an indicator of pollution in environmental monitoring programmes.

MATERIALS AND METHODS

Study area:

Two locations selected for the study include industrial town of Kulai ($74^{\circ} 47' 7400$ E and $12^{\circ} 55' 1600$ N), close to northern part of the New Mangalore harbour, and another location which is an agricultural and fishery based village Padubidri ($74^{\circ} 45' 0300$ E and $13^{\circ} 10' 1200$ N), situated 20 km further north of Kulai along the *Karnataka* coast (Fig 1). Coastal waters of Kulai were subjected to discharge of effluents from various major and minor industries as well as contaminants arising from harbour operations. The daily discharges of effluents of some industries near Kulai, include KIOCL (Kuduremukh Iron Ore Corporation Ltd.) $40,000 \text{ m}^3$, MCF (Mangalore Chemical Fertilizers) $13,000 \text{ m}^3$, MRPL (Mangalore Refineries and petroleum Ltd.) $7,200 \text{ m}^3$ and BASF $3,600 \text{ m}^3$ in addition to Municipal waste water.

Padubidri, a typical agriculture and fishing village was selected as pollution free area which do not contain any industry.

Sample collection and analysis

Vertical profiles of salinity and temperature were obtained, using a portable CTD (Conductivity-Temperature-Depth) sensor (Seabird Electronics Inc USA). For current measurement, a self-recording current meter (RCM-7, Aanderaa Instruments Inc., Norway) was used. Water and sediment samples for chemical and biological studies were collected from 9 stations spread over 25 km² area at each of the two locations Kulai and Padubidri. Three stations each were located at 5, 10 and 15 m depth contour, to get the proper representative samples from coast to offshore. Water samples from surface and bottom were collected on fishing trawler using 5 L Niskin sampler. Samples were sealed in plastic bottles and frozen till analysis in shore laboratory. The sediment samples were collected using van-Veen grab with an area of 0.04 m². Those for chemical analysis were sealed in plastic bags and frozen. For biological analysis sediment was washed through 0.5 mm mesh sieve and retained samples were preserved in 10% seawater formalin containing Rose Bengal stain, for macrofauna studies. A core of 4 cm diameter from the grab was obtained for meofauna studies.

Primary productivity in the water column was estimated by C¹⁴ method using deck incubation. For Chla, water samples were filtered by GF/F filter papers, extracted in 90% acetone and analysed using Turner Designs Fluorometer. For phytoplankton cells, 500 ml water samples were fixed in Lugol iodine and formalin and cells enumerated and identified using Sedgwick rafter counting chamber, on

inverse microscope. Zooplankton was collected using modified Heron Tranter net, 330 μm and mouth of 0.25 m^2 , attached with calibrated flowmeter, to record the water filtered. Samples were preserved in 5% neutral formaldehyde.

Water quality parameters such as pH was analysed immediately after collection, dissolved oxygen (DO) and BOD was measured using Winkler method. Nutrients such as nitrate, nitrite, ammonia, total nitrogen, phosphate and total phosphorus were measured as per procedures described by Grasshoff et al. (1983). Petroleum hydrocarbons in seawater were extracted in double distilled hexane and quantified using Shimadzu RF-1501 spectrofluorometer, at excitation-emission wavelengths of 310 and 360nm. Cadmium (Cd) and lead (Pb) in water samples were analysed by filtering water samples with 0.45 μm millipore filter and pre-concentrating the water by chelating agent, ammonium pyrrolidine dithiocarbamate (APDC), followed by extraction of metal chelate into methyl isobutyl ketone and analyzing on Atomic Absorption spectrophotometer (AAS). For mercury analysis pre-concentration from sea water was done by complexing with dithizone at $\text{pH} < 2$. The complex was extracted in acid and back-titrated in 5 M HCl and brought to aqueous phase and measured by cold vapor AAS.

The frozen sediments were thawed in laboratory and dried in oven at 40°C , then finely powdered and digested in HF in pre-cleaned acid washed teflon beaker followed by treatment with HNO_3 and HClO_4 to remove organic matter. After evaporation of acid the residue was dissolved in dilute HCl and metal determined using furnace AAS.

Prior to statistical analysis, all variables were tested for homogeneity by comparing means and variances. After asserting the normality of data for all variables ANOVA was performed for these parameters.

RESULTS AND DISCUSSION

Physical features

Physical features indicated that the surface temperature in May varied from 30.32°C to 31.27°C at Padubidri and 29.28°C to 30.87 °C at Kulai, with warm waters near the coast. The bottom waters showed a reverse trend, with temperature increasing from coast to offshore in premonsoon (May). Temperature in postmonsoon (February) remained lower than May, the spatial variation was only 3°C and vertical temperature gradient was practically negligible at Padubidri with similar condition prevailing at Kulai. The salinity also showed high values near the coast propagating offshore in May at both locations. Salinity remained much lower in February with practically no vertical gradient.

Water quality:

Seasonal changes in mean and SD values of various chemical and biological parameters at the two locations are shown in Fig 2(a to h). It can be seen that mean values of pH in May'97 remained higher at Padubidri (8.01 ± 0.02) than at Kulai (7.83 ± 0.03), but in January '98 they were almost similar at both the locations (7.92 ± 0.02). The mean DO was more than 3 ml/l at both the locations indicating sufficient aeration of the study area. BOD, which generally remained below 2 mg/l, suggested low levels of organic load. Such low BOD values have also been reported for highly polluted waters of Mumbai coast by Zingde and Desai

(1987), where high BOD load flows from Thana, Mahim and Versova creeks. Constant renewal of waters by semidiurnal tides as reported by Swamy et al. (2000) for Mumbai coast, may also be applicable to Mangalore which maintains high DO and low BOD values in the study area. Although nutrients showed fluctuations in relation to stations and seasons, their mean values at Padubidri and Kulai remained low except for TN which were much higher at Kulai during 1998 observations. The highest concentration of NO_2 , NO_3 , NH_4 , TN and PO_4 , observed were 1.57, 0.86, 4, 143 and 1.73 $\mu\text{mol/l}$, respectively.

As observed with nutrients the trace metals dissolved in water and in sediments remained sufficiently low with variations during the seasons and between the two locations. Seasonal mean of Cd, Pb and Hg in water at each of the two locations did not exceed $0.59 \pm 0.48 \mu\text{g/l}$, $1.62 \pm 1.09 \mu\text{g/l}$ and $53 \pm 19 \text{ng/l}$, respectively. Similarly, the mean Cd and Pb in sediments did not exceed 0.019 ± 0.01 and $12.03 \pm 3.26 \mu\text{g/g}$, respectively. These values are much lower than those reported for some other coastal regions such as Pondichery and Mahabalipuram along the east coast with seasonal mean concentration of Cd, $25.6 \mu\text{g/l}$ and Hg, 60ng/l and Thane-Mumbai coast with mean concentration of Pb, $7 \mu\text{g/l}$ in water and $28 \mu\text{g/g}$ in sediments (Govindasamy and Azariah, 1999 and Krishnamurthy and Nair, 1999).

While nutrients and trace metals remained low dissolved/dispersed petroleum hydrocarbons showed abnormally high values at Kulai varying from 895 to $1493 \mu\text{g/l}$ in May and 765 to $1523 \mu\text{g/l}$ in January as compared to very low values ranging from 0.5 to $129 \mu\text{g/l}$ in May and 0.7 to $144 \mu\text{g/l}$ at Padubidri respectively

(Fig. 3). A thick film of petroleum was visibly evident covering the entire stretch of Kulai waters. Although, petroleum hydrocarbon was not estimated in bottom sediment, chunks of tar residues were collected in grab samples, which indicated continuous input of petroleum residues from the petrochemical industry located near, by the Kulai coast. Petroleum hydrocarbons at Kulai were much higher than those reported for Gujarat and Maharashtra coast ($<100\mu\text{g/l}$; Mehta et al., 1994) and during oil spill near Madras Harbour (11 to $139\mu\text{g/l}$; Selvaraj et al., 1999). Monitoring studies at Mangalore Harbour (near Kulai), under COMAPS, during 29 February to 1 March 1992, before the MRPL went into the production showed low PHC values ranging from 1.45 to $10.8\mu\text{g/l}$. An increase in PHC values was observed as soon as the factory was commissioned in March 1996, with values ranging from 12.2 to $158.54\mu\text{g/l}$ whereas a further increase up to $725.45\mu\text{g/l}$ was recorded in December, 1996 (NIO, 1998).

Community structure:

Although the regional changes in phytoplankton biomass and population in between Padubidri and Kulai was clearly evident, their seasonal difference appears to be equally conspicuous with Chl *a* and phytoplankton cell numbers remaining high in May '97 and low in Jan '98 (Fig 2e to h). However, the zooplankton showed a reverse trend with increased biomass and population in Jan'98 than in May '97. The population and biomass of macro and meiobenthos although varied independently, their values remained high at Kulai than at Padubidri. Thus the mean values of certain chemical as well as biological parameters showed sufficiently large seasonal as well as regional differences at

these two locations. In order to test whether the values differed significantly in relation to depth, stations, locations, seasons, etc, a two way nested ANOVA was carried out. The results given in fig 4 show that some of the parameters such as PHC, Pb, PO₄, NH₄, TN, Chla, phytoplankton and zooplankton differed significantly between the two locations, while others did not show major changes. This is the clear indication of the effects of industrial effluents at Kulai region. For waters receiving complex effluents, the role of strong physical forces becomes highly important, because of which adequate mixing is brought about by prevalent wind and tidal currents. This process is seen at Kulai where the effluents have shown tendency to mix and travel southwards. But the current reversal phenomenon prevailing occasionally in the region is also responsible to permit some of the effluents to travel in the northerly direction (NIO, 1995). This is responsible to maintain increased concentrations of parameters such as PHCs, NO₃, NH₄, PO₄, dissolved Cd and Pb at Padubidri during Jan'98 as compared to the other locations along the coast (NIO, 1996). One of the surprising features of these analysis is that although Kulai receives large quantities of PAH and other industrial inputs, most of the biological parameters remain high at this location compared to Padubidri. This perhaps could support the argument that effluents can favourably induce growth biological communities at Kulai. In order to understand this, detailed analysis of species composition of phytoplankton and group distribution of zooplankton and benthos was carried out.

Phytoplankton was represented by a maximum of 36 genera in May'97 and 32 in January'98 dominated by diatom species at both the locations. Station wise

Shanon Weaver's diversity index (H') and Margalef's species richness (d) showed that (H') ranged from 1.16 to 3.52 at Padubidri and 1.42 to 2.99 at Kulai and (d) from 4 to 11.6 at Padubidri and 3 to 9.4 at Kulai during the two observations. The lower diversity was clearly seen at Kulai in May '97. Species distribution chart shown in fig 5a&b indicates that *Rhizosolenia* dominated at both the locations in May contributing to >27% of the population followed by *Leptocylindrus* 15%, *Chaetoceros* 15%, *Thalassiosira* <13%, *Coscinodiscus* < 8%, *Nitzschia* <3% and dinoflagellates such as *Peridinium*, *Prorocentrum*, *Ceratium* and *Dyniphsis* together contributing to <6%. Going shape wise centric diatoms constituted > 90% of the population at both the locations in May, the balance being pinnate diatoms and dinoflagellates. However, the seasonal shift in population was clearly observed in January'98 with *Chaetoceros* 30% constituting a bulk at Kulai, followed by *Rhizosolenia* 9%, *Bacteriostratum* 8%, *Nitzschia* 8% and dinoflagellates *Peridinium*, *Prorocentrum*, and *Dyniphsis* <2.5%. A pattern of distribution grossly differed at Padubidri with *Nitzschia seriata* and *N. clostatum* together constituting about 22%, followed by *Asterionella* 14% *Navicula* 7%, *Rhizosolenia* 5%, *Chaetoceros* 5%, *Leptocylindrus* 5%, *Thalassiosira* 4%, blue green algae *Trichodesmium* 8.5%, and dinoflagellates *Peridinium* and *Prorocentrum* <4%. Common feature of January observation at Kulai was that as seen in May centric diatoms occurred in overwhelming numbers with >70% population, reducing the pinnates to 24%, dinoflagellates 3% and blue green *Trichodesmium* 2.5%. At the same the most distinguishing character in January was that pennates dominated at Padubidri with 54% occurrence while reducing the

centric to 32%, balance being blue green *Trichodesmium* 8.5% and dinoflagellates 5%. Thus dominance of centric diatoms over pinnates at Kulai suggests greater tolerance of centric diatoms to high PHC content.

In support of the above, Mumbai Harbour-Thana estuarine system, which receives sewage as well as industrial wastes was reported to principally sustain centric diatoms such as *Thalassiosira* and *Coscinodiscus* and partly pinnate *Nitzschia* from among 37 genera (Neelam Ramaiah et al., 1998). Similarly, in the sewage polluted Hooghly estuary of the 29 species, *Coscinodiscus* constituted the 34 to 71% as major phytoplankton followed by other centric diatoms such as *Trichodesmium*, *Rhizosolenia*, *Chaetoceros*, pinnates *Asterionella japonica*, *Skeletonema costatum* and still lesser dinoflagellates *Ceratium tripos* and *Silicoflagellate* species, during the annual cycle (De et al., 1994). The above observations suggest that lower species diversity accompanied by the dominance of fast growing centric diatom species (such as *Chaetoceros*, *Thalassiosira*, *Rhizosolenia*, etc) over pinnates as seen in Kulai can be identified as indices for detection of high organic loads and nutrient enrichment in a water body (Harrison et al., 1991 and Smyada, 1963). On the other hand high species diversity and the succession of species observed during the two seasons at Padubidri may represent less stressed environment for phytoplankton survival. Kimor 1992 reported shift of phytoplankton population from diatoms to dinoflagellates and down shift of in size towards a dominance of small size nonoplankton (i.e microflagellates and coccoids) as the effect of eutrophication. But such condition

was not observed in the study area indicating that impact of nutrient enrichment were not drastically high.

Spacio-temporal variation in benthic communities indicated that population and biomass at, Kulai is higher than Padubidri. Numerical abundance showed that polychaetes and bivalves dominated at Padubidri in May contributing to about 47 and 36% population respectively., the other minor groups being opheroidea, dentaleum, amphipoda and coelindrata (Fig 5c). Whereas, bivalves 60% formed a major bulk at Kulai and polychaetes reduced to 28% while other groups contributing to only 12%. A complete reverse pattern could be witnessed in January, 98 with polychaetes forming a majority of 78% at Padubidri and bivalves reducing to just 2.5% while opheroidea and amphipoda being minor groups. But at Kulai bivalves 53% continued to be an important group, polychetes 37%, being the next with other minor groups in balance. Meiofauna at both the locations was however represented by a single group of nematod population remaining higher at Kulai than Padubidri. Gopalakrishnan and Nair (1998) in their seasonal studies in 1998 at Kulai and south up to old Mangalore Port have also reported dominance of bivalves to >62% followed by gastropods <20%, scaphapoda <8.5% and polychaetes <7%, with minor fluctuation in population and biomass as compared to the present observations. An invasive bivalve species, *Mytilopsis sallei* (Recluz) has been reported to be successfully colonized in the Visakhapatnam Harbour in spite of high PHC content (Chandra Mohan and Raghu Prakash, 1998). These observations suggest that bivalves could be the most tolerant group to sustain organic and other industrial pollution at Kulai. But in Jan'98 some of the stress

tolerant species of polychaetes might also have colonized Kulai waters. In case of meiofauna, higher nematode population at Kulai suggest that are tolerant to the industrial stresses.

Zooplankton distribution showed no specific trend at the two locations, with copepods and cladocerans together contributing to > 80% of the population, while fish and other invertebrate eggs and larvae constituting the rest in May '97. During Jan '98, copepods was the only major group constituting > 97% population at both the locations (Fig 5c). Higher zooplankton biomass and density during January'98 dominated by single group may be the result of enrichment of organic matter in these waters. In the Mumbai harbour – Thane creek region also, copepods were reported to be the major group with lower species diversity indicating stress of sewage and other effluents on communities (Ramaiah Neelam, 1997). Observations during oil spill at Murud (Maharashtra coast) reported that although few of the phytoplankton such as *Nitzschia* were damaged by coating of black PHC layer, the zooplankton were not severely affected (Gajbiye et al., 1993).

It is clear from the results that petroleum hydrocarbon remains to be the major source of pollution in Kulai while the nutrients and trace metals showing indirect fluctuations at the two locations. To understand the statistical relation of petroleum hydrocarbon to biological and chemical constituents, a stepwise multiple regression analysis was carried out which is given in Table 1. The results indicate that except for mercury most of the parameters show significant relation to PHC either at Kulai or Padubidri for pre-monsoon and post-monsoon observations. Overall influence of all the parameters indicate significant relation during Jan 98

observation with $R^2 > 0.6$. From the positive relation it can be concluded that Cd and Pb could be mainly derived as contaminant from petroleum hydrocarbon discharges but the input of Hg could be from the other industrial effluents. Also the relation of nitrate and phosphate to PHC suggest the use of these nutrients as a source of oxygen for oxidation of excess hydrocarbons, under aerobic conditions, during bacterial degradation of oil (Zobell, 1962 cited by Selvaraj *et al.*, 1999). This ultimately keeps the nutrient values low in Kulai waters (Selvaraj *et al.*, 1999). Similarly, Chla along with phytoplankton diversity and species richness has positive relation to the petroleum hydrocarbon. In support of our earlier argument, that the effluents are favourable to selected biological communities, it is evident that very few species proliferate at Kulai while retaining high biomass, while mixed population prevails at Padubidri. This suggests that the contaminants at Kulai may be inhibitory to the other diverse species prevailing at Padubidri. This leads to a conclusion that only centric diatoms such as *Chaetoceros*, *Rhizosolenia*, *Thalassiosira* and *Leptocylindrus*, benthic bivalves and copepods among zooplankton are able to survive well at Kulai. Thus dominance of these organisms in a coastal water body receiving effluent discharges could serve as indicators of environmental stress. (De *et al.*, 1994 and Neelam Ramaiah *et al.*, 1998).

The phytoplankton diversity in the entire study area fluctuated between 1.16 to 3.52, which as per Hendy's classification relates to moderately or slightly polluted waters (Hendy, 1977). Phytoplankton growth studies at our laboratory have reported that the toxicity of oil increases with the elevated amounts of aromatic hydrocarbons which have tendency to get solubilised in water more than alkanes

(Phaterpeker and Ansari, 2000). It could be concluded therefore that the petroleum wastes discharges may contain less quantities of refined products, thereby producing limited stress to organisms, which are found proliferating in larger number at Kulai. Laboratory studies on *Chaetoceros tenuissimus* have shown that low Cd concentrations as prevailing at Kulai may not be stressful to phytoplankton species as their tolerance is much higher (Desai et al., 2006). Although Kulai receives large quantities of industrial and sewage effluents excellent mixing and flushing conditions due to tide and wind induced coastal currents keep these waters well aerated retaining sufficiently high oxygen and low BOD. These conditions are helpful in bringing dispersion of organics and other pollutants thereby reducing the severe pollution stress. However, as seen in multiple regression analysis petroleum hydrocarbons have direct relation with biological and chemical components. Hence lower species diversity and proliferation of certain species of centric diatoms and benthic organism could be used as a measure to detect moderately high environmental disturbances prevailing at Kulai (Smyada, 1963). Whereas higher diversity of diatoms and benthic organisms at Padubidri suggests stress free conditions which is favourable for healthy community growth.

CONCLUSION

- * Concentration of contaminants in water and sediments is examined at Kulai, a site receiving industrial pollutants and Padubidri, an undisturbed location along the Karnataka coast, to understand whether biological responses could be indicative of environmental pollution.

- * Loading of organic material is evidently seen at Kulai from high TN values in January '98, although other nutrients and BOD remained low with high DO. Similarly while the trace metals were low, more than 20 fold increase in dissolved petroleum hydrocarbons at Kulai, with a visible sheen of oil on water surface, suggests that petroleum inputs are derived from external source such as petrochemical industry.
- * Sharp differences in populations of phytoplankton, zooplankton and benthos observed at the two sites suggest the changes could be due to difference in organic loadings at the two locations.
- * Population studies indicate dominance in centric diatoms among phytoplankton and copepods among zooplankton, in water column and bivalves in benthic fauna at Kulai, while mixed population of phytoplankton with higher biodiversity prevails at Padubidri along with other pelagic and benthic organisms.
- * Current patterns have indicated their vital role at Kulai, in dissipation of contaminants, as intense mixing of waters by winds and southward flow of water mass have reduced the pollution stress for living communities.
- * A stepwise multiple regression tests for the data have confirmed that statistical relation exists between petroleum hydrocarbon and other biological and chemical constituents.
- * Accordingly it is seen that only centric diatoms such as *Chaetoceros*, *Rhizosolenia*, *Thalassiosira* and *Leptocylindrus*, benthic bivalves and copepods among zooplankton are able to survive well at Kulai. Thus dominance of these

organisms in a coastal water body receiving effluent discharges could serve as indicators of environmental stress.

Acknowledgements The authors are grateful to the Director NIO for encouragement. Thanks are also due to all the colleagues who assisted in collection and analysis of samples.

REFERENCES

- Chandramohan P. and Raghuprakash R. (1998) Concentration of petroleum hydrocarbons in bivalve *Mytilopsis sallei* and in the harbour waters of visakpatnam, east coast of India. Indian J. Mar. Sci. **27**, 496-498.
- Cheevaporn V. and Menasveta P. (2003) Water pollution and habitat degradation in the gulf of Thailand. Marine pollution Bulletin **47** (1-6), 43-51.
- De T. K., Choudhury A. and Jana T. K. (1994) Phytoplankton community organization and species diversity in the Hugli estuary, north east coast of India. Indian J. Mar. Sci. **23**, 152-156.
- Desai SR, Verlecar XN, Nagarajappa, Goswami U (2006) Genotoxicity of Cadmium in Marine Diatom *Chaetoceros tenuissimus* using the Alkaline Comet Assay. Ecotoxicology 15(4), 359-363.
- Gajbhiye S. N., Mustafa S., Mehta P. and Nair V.R. (1993) Assessment of biological characteristics on coastal environment of Murud (Maharashtra) during the oil spill. Indian J. Mar. Sci. **24** (4), 196-202.

- Gopal Krishnan T.C. and Chandrasekharan Nair K.K. (1998) Subtidal benthic macrofauna of the Mangalore coast, West coast of India. *Indian J. Mar. Sci.***27**, 351-355.
- Govindasamy C. and Azariah J. (1999) Seasonal variation of heavy metals in the coastal waters of Koromandal coast, Bay of Bengal India. *Indian J. Mar. Sci.* **28**, 249-256.
- Grasshoff K., Ehrhardt M. and Kremling K. (1983) eds. *Methods of seawater analysis*. Second revised and extended edition. Verlag Chemie, Weinheim, German. 419pp.
- Hendy N.I. (1977) In Proc. 4th Symposium. Recent and Fossil Marine Diatoms (University of Oslo, Nova Hedwig), 355, cited by Tiwari, L.R. and Nair, V.R. (1998) Ecology of phytoplankton from Dharmar creek, west coast of India. *Indian J. Mar. Sci.* **27**, 302-309.
- Harrison P.J., Clifford P. J., Cochlan W. P., Yin, K., St. John M.A., Thompson P.A., Sibbald, M.J. and Albright, L. J. (1991) Nutrient and plankton dynamics in the Fraser River plume, Strait of Georgia, British Columbia. *Mar. Ecol. Prog. Ser.* **70**(3), 291-304.
- Kimor B. (1992) Impact of eutrophication on phytoplankton composition. In: Vollnweider R. A, Marchetti R, Vicviani R. (Eds.), *Marine coastal Eutrophication*. Elsevier, Amsterdam:871-878.
- Krishnamurti A. J. and Nair V. R. (1999) Concentration of metals in shrimps and crabs from Thane-Bassein creek system, Maharashtra. *Indian J. Mar. Sci.* **28**, 92-95.

- Mehta P., Kadam A. N., Gajbhiye S. N. and Desai B. N. (1994) Petroleum hydrocarbon concentration in selected species of fish and prawn from northwest coast of India. *Indian J. Mar. Sci.* **23**(2), 123-125.
- NIO (1995) Oceanographic and environmental impact assessment studies for the disposal of effluent for BASF India Ltd., Mangalore. NIO technical report No. NIO/SP-17/1995, 1-58.
- NIO (1996) technical report. Coastal Ocean Monitoring And Prediction System (COMAPS). NIO technical report No. NIO/SP-24/1996, 1-147.
- NIO, (1998) technical report. Comparative environmental impact assessment for proposed facilities for Mangalore power plant at Padubidri, Karnataka. NIO technical report No. NIO/SP-17/1998, 1-141.
- Phatapekar P.V. and Ansari Z. A. (2000) Comparative toxicity of water soluble fractions of four oils on the growth of a microalga. *Botanica Marina* **43**, 367-375.
- Ramaiah Neelam. (1997) Distribution and abundance of copepods in the pollution gradient zones of Bombay Harbour-Thana creek-Bassein Creek, West Coast of India. *Indian J. Mar. Sci.* **26**(1), 20-25.
- Ramaiah Neelam., Ramaiah N. and Nair V.R. (1998) Phytoplankton characteristics in a polluted Bombay harbour-Thana-Bassein creek estuarine complex. *Indian J. Mar. Sci.* **27**, 281-285.
- Selvaraj K., Jonatham M. P., Rammohan V., Thangraj G. S., Pugalandhi M. and Jayaraman V. (1999) Observations on petroleum hydrocarbons and some water quality parameters during oil spills near Madras harbour. *Indian J. Mar. Sci.* **28**, 245-248.

- Sirca A. and Rajar R. (1997) Calibration of a 2D mercury transport and fate model of the Gulf of Trieste. In: Rajar R, Brebbia M. editors. Proceedings of the 4th International Conference on Water Pollution 97. Southampton: Computational Mechanics Publication, 503-512.
- Smayda T. J. (1963) Bull. Inter-Am. Trop. Tuna Comm., 7, 191 cited by Tiwari L. R., Nair, V. R. (1998) Ecology of phytoplankton from Dharmar creek, west coast of India. Indian J. Mar. Sci., **27**, 302-309.
- Swamy B. S., Suryawanshi, U. G. and Karande A. A. (2000) Water quality status of Mumbai harbour- an update, Indian J. Mar. Sci. **29**, 111-115.
- Zingde M. D. and Desai B. N. (1987) Pollution status of estuaries in Gujarat-An overview. Contribution in Marine Science-Dr. Qasim, S.Z. Ed. S. Vol. ed.: Rao, T. S. S., Natarajan R., Desai B. N., Narayanswamy G., Bhat S. R. NIO publ. 245-268.
- Zingde M. D. and Govindan K. (2000) Health status of Coastal waters of Mumbai and regions around. In : Environmental problems of coastal areas in India. ed. : Sharma V. K. Bookwell publ. New Delhi India, 119-132.
- Zobell C. E. (1962) Adv. Wat. Poll, **3**, 85, cited by Selvaraj K., Jonatham M. P., Rammohan V., Thangraj G.S., Pugalendhi M., Jayaraman V. (1999) Observations on petroleum hydrocarbons and some water quality parameters during oil spills near Madras harbour. Indian J. Mar. Sci. **28**, 245-248.

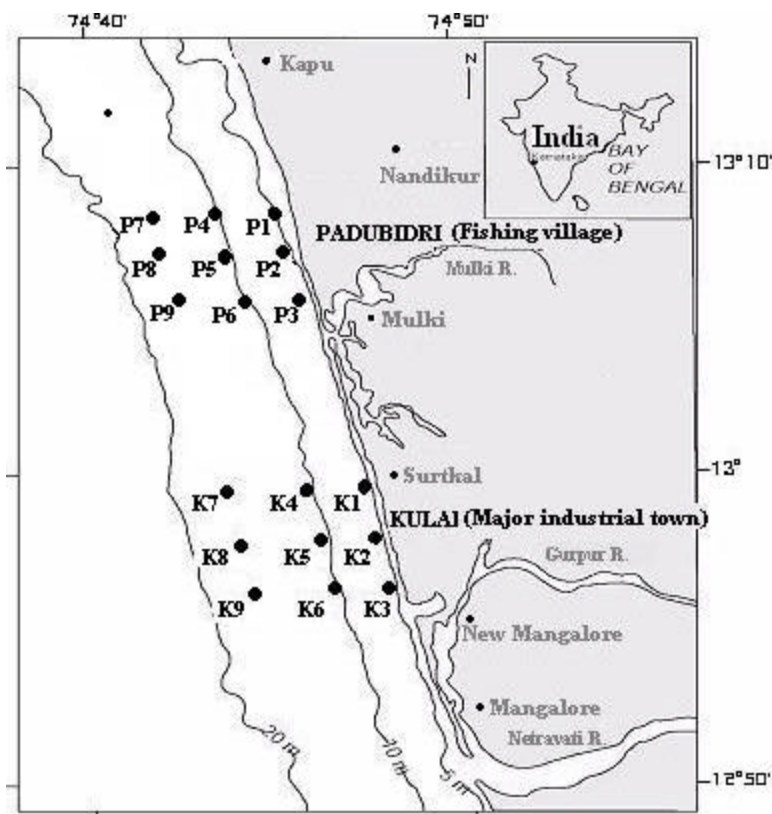


Fig.1: Study areas (Padubidri and Kulai) along the Karnataka coast

	P-97	P-98	K-97	K-98
Diversity	-0.04	0.42		-0.58
Species richness		-0.26		0.71
Chl	-0.42			0.5
Cd		-0.49		
Pb		0.84	0.25	0.53
Hg				
NO ₂ -N+NO ₃ -N+NH ₄ -N		-0.34		0.07
NO ₃	0.34			
NH ₄				0.29
PO ₄	0.5	-0.27	-0.52	0.19
Intercept	10.81	52.22	1343	35.43
R ²	0.326	0.62	0.26	0.68
Standard Error	5.33	42.47	155.68	32.32

Table 1: Stepwise multiple regression analysis of phytoplankton species diversity at the two locations of Padubidri (P) and Kulai (K) during May 1997 and January 1998. R²-Coefficient of determination

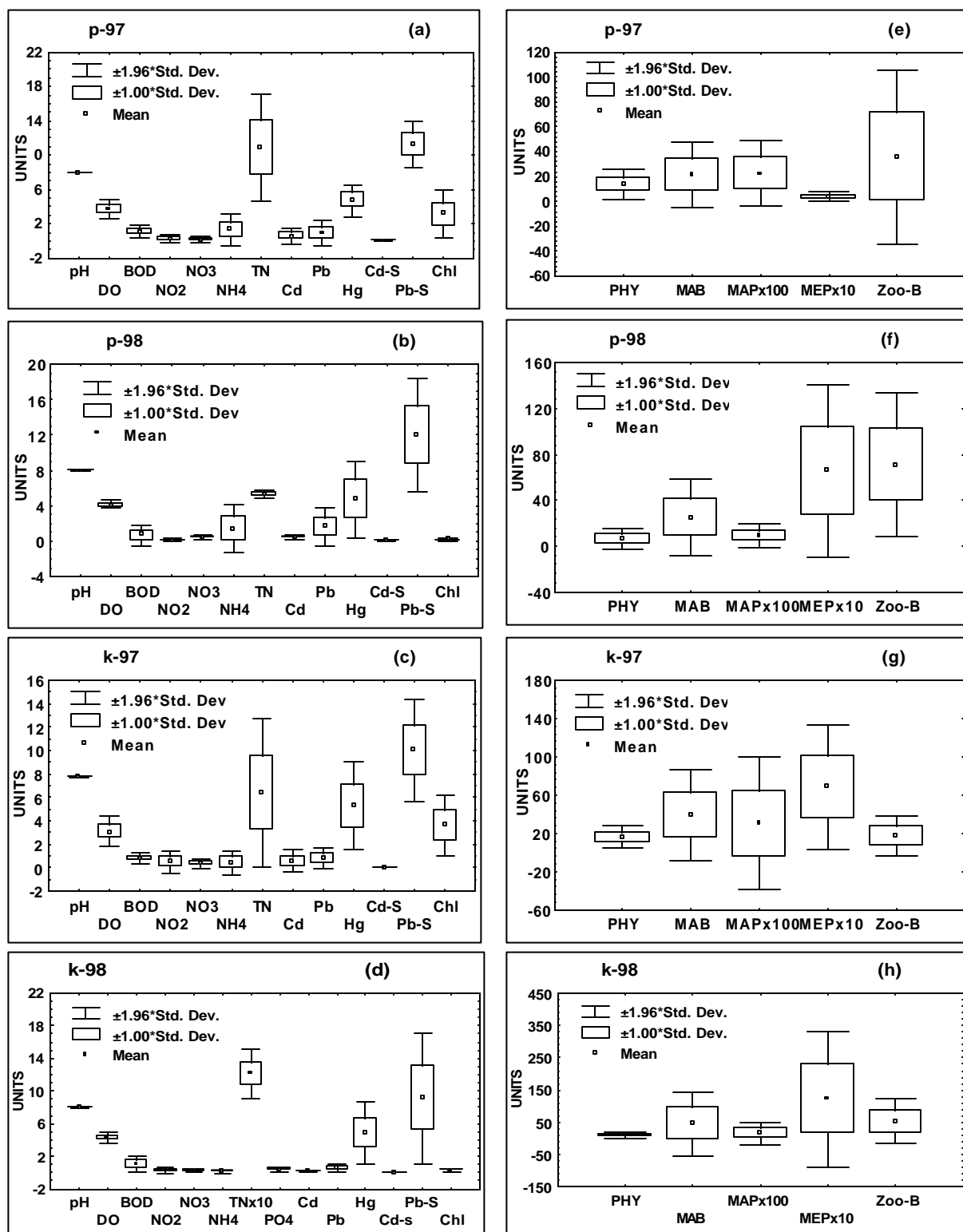


Fig. 2 a to h: Mean and SD values of different chemical and biological parameters in water column and sediments at Padubidri and Kulai during May 1997 and January 1998. Units on Y axis constitute, pH-units, DO ml/l, BOD mg/l, NO₂, NO₃, NH₄ & total nitrogen (TN) in $\mu\text{mol/l}$, Cd & Pb (in water) $\mu\text{g/l}$, Hg (in water) ng/l, Cd-s & Pb-s (in sediments) $\mu\text{g/g}$, Chl (chlorophyll) mg/m^3 , PHY-phytoplankton ($n \times 10^4/l$) & ZooB-Zooplankton biomass ml/100m³, MAB-Macrobenthos biomass, g/m². Some of the values are the multiples as given in x axis. [MAP-Macrobenthos population n/m², MEP - meiobenthic population n/10cm²].

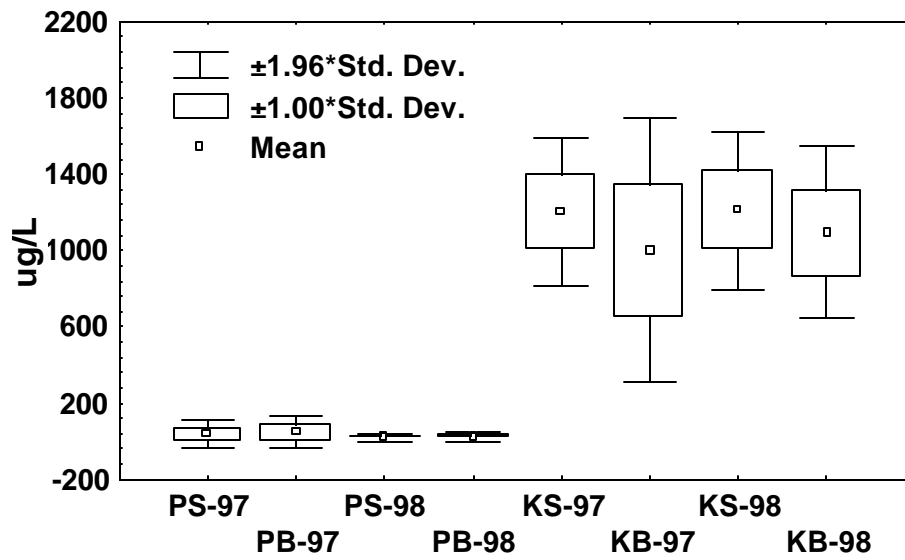


Fig. 3: Mean and SD of PHC ? g/l during May 1997 and January 1998 (PS & PB – Surface and Bottom waters at Padubidri, KS & KB –Surface and Bottom waters at Kulai).

		pH	PO ₄	NO ₃	NH ₄	TN	Chl	Phy	ZB	ZP	MAB	MAP	ME	Cd	Pb	Hg	PHC	Cd-S	Pb-S
Sites	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Time	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Depth	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Station	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Sites*Time	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Time*Depth	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Depth*Station	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Sites *Depth	S	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	B	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

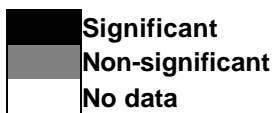


Fig 4: A two way ANOVA for various parameters in water and sediment in surface (S) and bottom (B) waters. (Phy-phytoplankton, ZB-zooplankton biomass, ZP-Zooplankton population, MAB-Macrobenothos biomass, MAP-Macrobenothos population, ME-Meiofenothos, Cd-s- Cadmium in sediment, Pb-s- Lead in sediment)

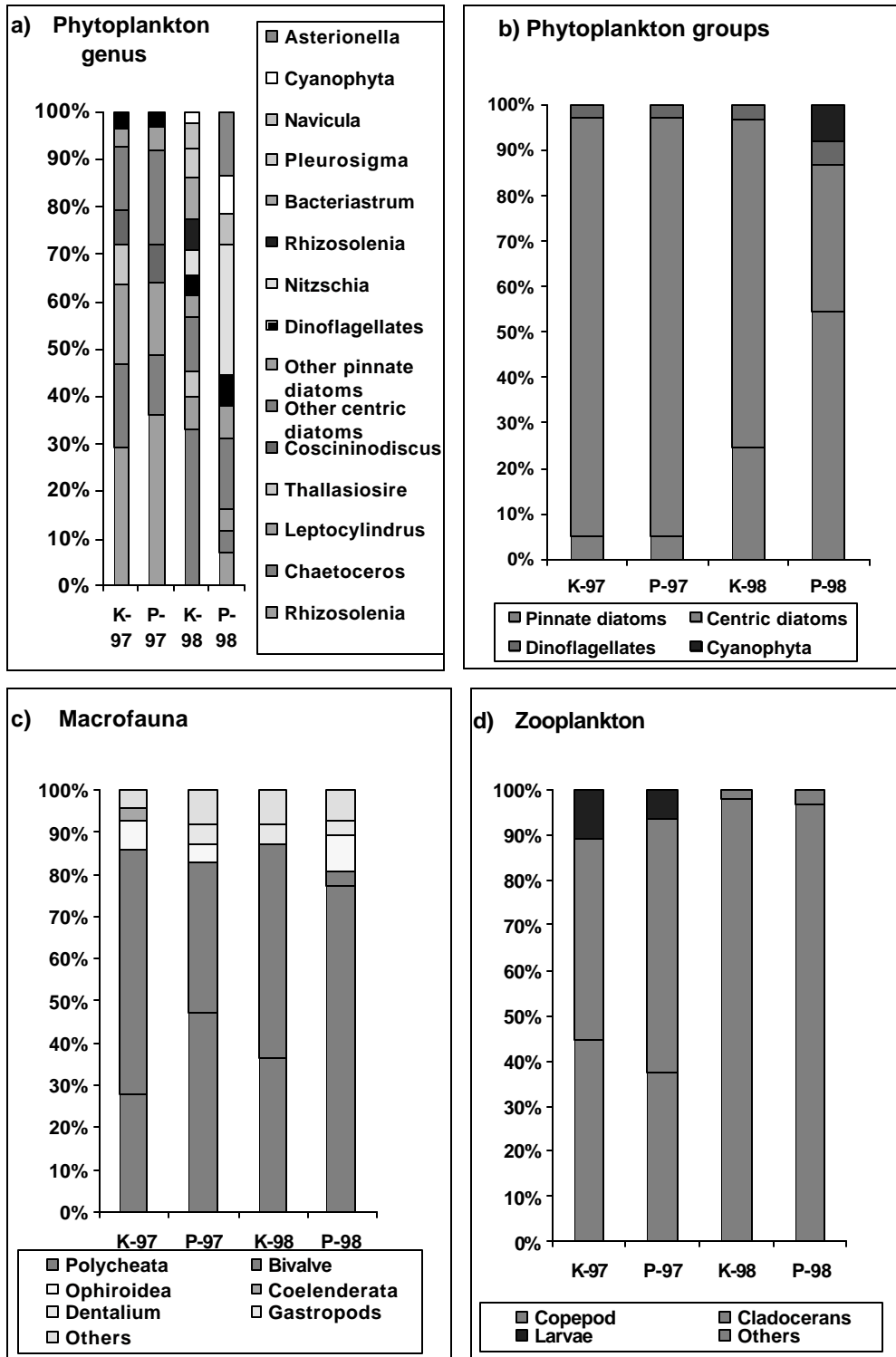


Fig. 5 a to d: Percent community distribution charts a) & b) phytoplankton genus and groups, c) benthos groups and d) zooplankton groups at Padubidri (P) and Kulai (K) during May 1997 and January 1998.