Mitig Adapt Strateg Glob Change (2012) 17:837–847
DOI 10.1007/s11027-011-9347-1

ORIGINAL ARTICLE

Assessment of trophic change and its probable impact on tropical estuarine environment (the Kodungallur-Azhikode estuary, India)

P. R. Jayachandran · S. Bijoy Nandan

Received: 21 November 2011 / Accepted: 30 November 2011 /
Published online: 14 December 2011

Abstract The cumulative effects of global change, including climate change, increased population density and domestic waste disposal, effluent discharges from industrial processes, agriculture and aquaculture will likely continue and increases the process of eutrophication in estuarine environments. Eutrophication is one of the leading causes of degraded water quality, water column hypoxia/anoxia, harmful algal bloom (HAB) and loss of habitat and species diversity in the estuarine environment. The present study attempts to characterize the trophic condition of coastal estuary using a simple tool; trophic index (TRIX) based on a linear combination of the log of four state variables with supplementary index Efficiency Coefficient (Eff. Coeff.) as a discriminating tool. Numerically, the index TRIX is scaled from 0 to10, covering a wide range of trophic conditions from oligotrophic to eutrophic. Study area Kodungallur-Azhikode Estuary (KAE) was comparatively shallow in nature with average depth of 3.6±0.2 m. Dissolve oxygen regime in the water column was ranged from 4.7±1.3 mgL^{-1} in Station I to 5.9±1.4 mgL^{-1} in Station IV. The average nitrate-nitrogen (NO_3-N) of KAE water was 470 mg m^{-3}; values ranged from Av. 364.4 mg m^{-3} at Station II to Av. 626.6 mg m^{-3}at Station VII. The mean ammonium-nitrogen (NH_4^+-N) varied from 54.1 mg m^{-3} at Station VII to 101 mg m^{-3} at Station III. The average Chl-*a* for the seven stations of KAE was 6.42±3.91 mg m^{-3}. Comparisons over different spatial and temporal scales in the KAE and study observed that, estuary experiencing high productivity by the influence of high degree of eutrophication; an annual average of 6.91 TRIX was noticed in the KAE and seasonal highest was observed during pre monsoon period (7.15) and lowest during post monsoon period (6.51). In the spatial scale station V showed high value 7.37 and comparatively low values in the station VI (6.93) and station VII (6.96) and which indicates eutrophication was predominant in land cover area with comparatively high water residence time. Eff. Coeff. values in the KAE ranges from −2.74 during monsoon period to the lowest of −1.98 in pre monsoon period. Present study revealed that trophic state of the estuary under severe stress and the restriction of autochthonous and allochthonous nutrient loading should be keystone in mitigate from eutrophication process.

P. R. Jayachandran (✉) · S. Bijoy Nandan
Department of Marine Biology, Microbiology & Biochemistry, School of Marine Sciences,
Cochin University of Science and Technology, Kochi 682016, Kerala State, India
e-mail: jayachandran2701@gmail.com

S. Bijoy Nandan
e-mail: bijoynandan@yahoo.co.in

Keywords TRIX · Efficiency coefficient · Eutrophication · Kodungallur-Azhikode Estuary · Estuarine monitoring · Global change

1 Introduction

The world's climate has changed and anthropogenic activities will continue to contribute to the acceleration of emission of greenhouse gases and rising temperatures. The effects of global climate change are already detectable in the decline in snow cover, glaciers and polar ice, which have led to a pole ward shift in plant and animal distributions, and caused changes in algal and fish communities, and food webs (Richard et al. 1999; IPCC 2007). The regional outcomes of the various global climate change scenarios will likely manifest in many different and synergistic effects on various components of ecosystems. This paper discusses trophic change and its potential impact on a tropical estuarine environment. Tropical estuarine systems experiencing heavy pressure, either as repositories for the effluent of industrial processes and domestic waste, or as prime sites for industry or urban development (McLusky and Elliott 2004). Eutrophication, defined as the increased rate of primary production and accumulation of organic matter, usually results from the excessive addition of nutrients, and results in undesirable changes in ecosystems (Nancy et al. 2009).

The effects of eutrophication on the coastal environment worldwide are well documented (Vollenweider et al. 1992; Philip and Alan 2010). Nitrogen and phosphorous loading from point and nonpoint sources can altered the global biogeochemistry and the most common effect on aquatic environment are perceived as increased in primary production (Smith et al. 1999). Runoff from the landscape to transitional waters increases linearly with the soil phosphorous content (Smith et al. 1995).The atmospheric deposition of nitrogen also can have strong effects on the structure and function of aquatic environment (Waring and Running 1998). In addition to the atmospheric and agriculture sources of nitrogen and phosphorous, human use flowing waters as convenient waste water disposal systems. The loading of nitrogen and phosphorous to the world's rivers, lakes, estuaries, and oceans is thus very strongly influenced by human population densities, the population densities of livestock, and land use (Jaworski et al. 1997; Smith et al. 1997). Utility functions for DIN and DIP were considered as the main criteria for trophic status classification (Vollenweider and Kerekes 1982; Vollenweider et al. 1998). Despite their relatively small volume, they contribute disproportionately to global primary production (Killops and Killops 1993). Since coastal eutrophication has become more common over recent years, words like oligotrophic, mesotrophic and eutrophic have also become more frequent in scientific literatures; oligotrophic means low productive and eutrophic means high productive aquatic environment. Several indicators and indices are available for assessing trophic status and quality of aquatic ecosystems and their evolution under different anthropogenic pressures and inherent threats (Jørgensen et al. 2005). However, misapplication of the limnological terminology to marine waters is even more likely to occur. This creates not only uncertainties between researchers, but also difficulties about the way the essence of findings are conveyed in a single manner to administrators and to the public at large.

In this perspective present study attempts to characterize trophic state of Kodungallur-Azhikode estuary by applying trophic index TRIX developed by Vollenweider et al. (1998); which integrates oxygen saturation, phytoplankton chlorophyll-*a*, nitrogen and phosphorus concentrations to assess the trophic state of coastal marine waters. These parameters are known to be key components in the overall productivity and biological integrity of estuaries. Assessment of these parameters will indicate state of estuarine environment and is vital in planning and management.

2 Materials and methods

2.1 Study area

The Kodungallur-Azhikode estuary (10°11′–10°12′ N and 76°10′–76°13′ E) is a tropical positive microtidal estuary having an area of 700 ha and about 20 km length (Fig. 1). The width of the estuary near barmouth is 750 m. Tides in the estuary are semidiurnal, with microtidal tidal range (McLusky and Elliott 2004); tidal effects extend to approximately 25 km landward of Azhikode (Revichandran and Abraham 1998) and average rainfall in the area was 310 cm. Two rivers flow into the Kodungallur-Azhikode estuary (KAE) that is the Karuvannur River and Chalakkudy River. Hydrographic observations were made monthly basis during July 2009 to June 2010 period from selected seven stations in the KAE (Fig. 1). Estuary receives considerable amount of nutrient rich fresh water from these two rivers mainly during south west monsoon. Fresh water input into the Azhikode estuary was varied between 21 m^3S^{-1} and 10 m^3S^{-1} during pre monsoon season and 123 m^3S^{-1} to 387 m^3S^{-1} during south west monsoon season (Revichandran and Abraham 1998). Human population density of the study area is approximately 1,806 km^2 (GOI 2011) and nearby Vypeen island known to be the island having highest density of human population in the world (2,158 km^2; GOI 2011). In the study area, historically practiced salt resistant pokkali paddy cum prawn farming method and eventually those infertile fields were reclaimed and used for single crop or semi intensive fish farming. Modern aquaculture, agriculture and other human activities in area produces huge amount of organic and inorganic wastes in to the KAE.

2.2 Sampling method

Sampling was carried out during morning hours using a motorized boat and water collected from the surface and bottom (3 m depth) using 2 L Niskin water sampler. The water transparency (Secchi disk transparency; SD) was measured by *Secchi disk* in the

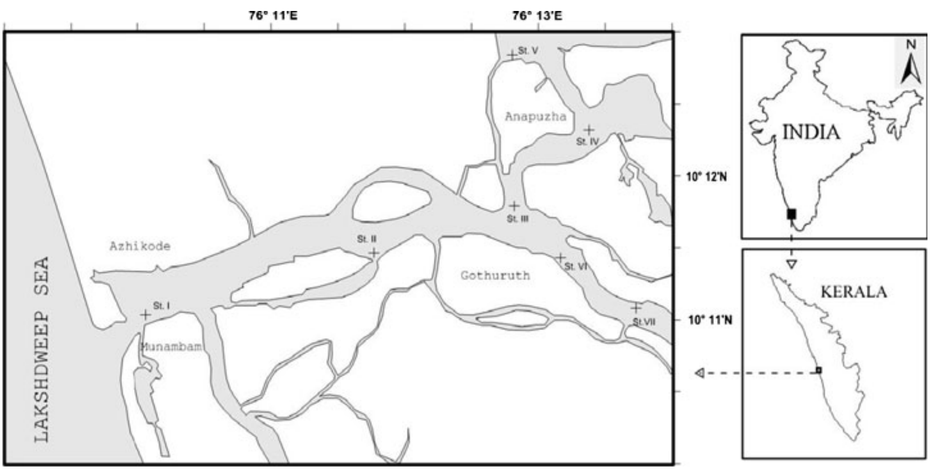


Fig. 1 Location of the sampling stations in the Kodungallur-Azhikode estuary (KAE)

field. Salinity by Systronics water analyser (Model No. 317; accuracy ± 0.01) calibrated with standard seawater (APHA 2005). Dissolved oxygen (DO) was estimated according to Winkler's method (Grasshoff et al. 1983). Samples for nutrients DIN (ammonium-nitrogen + nitrite-nitrogen + nitrate-nitrogen), DIP (dissolved inorganic phosphate) were analyzed following the standard methods (Grasshoff et al. 1983; Jia-Zhong and Charles 2005). For the estimation of Chlorophyll-*a* (Chl-*a*), 500 ml of water sample was filtered through 47 mm GF/F filters, extracted with 90% acetone for 24 h, and kept in −20°C. The extract was measured using a spectrophotometer (Systronics UV–VIS spectrophotometer, Model No. 117) before and after acidification (Strickland and Parsons 1972). Primary productivity was estimated by in situ incubation method using the light and dark bottle oxygen method (Strickland and Parsons 1972). Water samples were collected before the sunrise, immediately passed through a 200-μ sieve to remove large-sized zooplankton and transferred to 125 ml capacity DO bottles (two light bottles and two dark bottles). The light and dark bottles were incubated for 3 h and calculated hourly rate of primary production multiplied by the number of day light hours (~12).

2.3 Indices and indicator used in the present study

2.3.1 Trophic index TRIX formula is the following (Vollenweider et al. 1998)

$$\mathrm{TRIX} = (\mathrm{Log10}[\mathrm{Chl} - a \times \mathrm{aD\%O} \times \mathrm{DIN} \times \mathrm{DIP}] + \mathrm{k})/\mathrm{m}$$

Each of the four components represents a trophic state variable, to say:

- Factors that are direct expression of productivity:

  Chlorophyll-*a*: [Ch: mg m^{-3}]
  Oxygen as absolute (%) deviation from saturation: [abs$|$ 100–%0$|$ = aD%O]

- Nutritional factors:

  Dissolved inorganic nitrogen as N-(NO_3+ NO_2+ NH_4): [DIN = mN: mg m^{-3}]
  Dissolved inorganic phosphorus as P-PO_4: [DIP. PO_4: mg m^{-3}]

The parameters k =1.5 and m =12/10=1.2, are scale coefficients, introduced to fix the lower limit value of the Index and the extension of the related Trophic Scale, from 0 to 10 TRIX units. TRIX point values assign an immediate measurement to the trophic level of coastal waters. Values exceeding 6 TRIX units are typical of highly productive coastal waters. Values lower than 4 TRIX units are instead associated to scarcely productive coastal waters, while values lower than 3 are usually found in the open sea.

2.3.2 Efficiency coefficient (Eff. Coeff.; Vollenweider et al. 1998)

The Efficiency Coefficient is defined as:

$$\mathrm{Eff.\ Coeff.} = \mathrm{Log10}([\mathrm{ChA} \times \mathrm{aD\%O}]/[\mathrm{minN} \times \mathrm{DIP}])$$

To say as the log of the ratio between the two aggregated main components of TRIX. Numerically, values are usually negative, ranging from −4.48 to 0.45. Low values would indicate low, and vice versa, high values high nutrient utilisation.

3 Results

The estuary was comparatively shallow in nature with average of 3.6±0.2 m depth. water column remained relatively cool (Av. 28.9±2°C) throughout the study period; comparatively low water temperature was observed during south west monsoon (Av. 27.5±2.6°C) as compared to pre monsoon (30.4±0.8°C) and post monsoon (Av. 28.7±1.3°C) period. Tides in the estuary are semidiurnal, with amplitude of 1 m during spring tide and 0.6 m during neap tide and average rainfall in the area was 310 cm. Estuary receives considerable amount of nutrient rich fresh water from two rivers mainly during south west monsoon. Transparency values were generally low in the KAE especially during monsoon season (Av. 0.6±0.3 m). On a spatial scale, it was lowest in Station V (Av. 0.8±3 m) and highest in Station VI (1.1±0.5 m).

The average dissolved oxygen (DO) concentration of 5.1±1 mgL^{-1} was observed for the KAE; it ranged from 4.7±1.3 mgL^{-1} in Station I to 5.9±1.4 mgL^{-1} in Station IV. A discernible trend was observed in the DO regime, where the surface water (Av. 5.6±1.1 mgL^{-1}) was higher than the bottom waters (Av. 4.7±0.6 mgL^{-1}). Salinity of the KAE showed mixo-mesohaline in nature. A clear stratification was observed in the salinity values, whereas, the average bottom water salinity (Av. 16.9±8.9 psu) was highest compared to the average surface water salinity (12.4±7.4 psu). The salinity values showed a definite trend, where it decreased from estuarine mouth to head.

The average nitrate-nitrogen (NO_3-N) of KAE water was 470 mg m^{-3}; values ranged from Av. 364.4 mg m^{-3} at Station II to Av. 626.6 mg m^{-3}at Station VII. Comparatively high NO_3-N was observed during monsoon period (Av. 878.7 mg m^{-3}) due to high allochthonous nutrient input, relatively low NO_3-N content observed in post monsoon (Av. 340.4 mg m^{-3}) and pre monsoon (Av. 156.4 mg m^{-3}) seasons. The average nitrite-nitrogen (NO_2-N) content of KAE waters was 18.6 mg m^{-3} and highest value was recorded during pre monsoon period (24.8 mg m^{-3}). The mean ammonium-nitrogen (NH_4^+-N) varied from 54.1 mg m^{-3} at Station VII to 101 mg m^{-3} at Station III. Ammonium value shows monthly average of 81.1 mg m^{-3} in the KAE. Dissolved inorganic nitrogen content (DIN) in water column showed an average of 570.3 mg m^{-3} with highest peak observed during south west monsoon period (1283.6 mg m^{-3}). DIP values gave an average of 96.86 mg m^{-3} in the seven stations with highest during the pre monsoon season (Av.166 mg m^{-3}). Comparatively high content of PO4-P was observed in bottom waters (Av. 123.4 mg m^{-3}), when compared to surface waters (Av.75.9 mg m^{-3}).

The average Chl-*a* for the seven stations of KAE was 6.42±3.91 mg m^{-3} (Table 1), however it varied from 5.07±4.03 mg m^{-3} in Station II to 7.80±6.07 mg m^{-3} in station V. Peak value of Chl-*a* were observed during pre monsoon period (Av. 10.89±3.29 mg m^{-3}) then it decreased to an average of 5.16±2.10 mg m^{-3} during the monsoon season Slight variations was observed in vertical distribution of chl-*a* content in the KAE; high Chl-*a* content was noticed in the surface water (11.04±3.07 mg m^{-3}) as compared to bottom (9.04±3.03 mg m^{-3}) particularly during pre monsoon period. Peak value of Chl-*a* was noticed during the month of April (Av. 11.65±6.06 mg m^{-3}). Bray-Curtis similarity index of Chl-*a* value showed 90.6% similarity between Station I and III in the surface water. The month wise highest similarity (91.6%) of Chl-*a* content in the surface waters was observed between months of post monsoon season (November 2009 and January 2010); whereas, bottom water displayed highest of 90.8% similarity between pre monsoon months (March 2010 and April 2010). The GPP showed an average of 1,580±388 mg C m^{-3} day^{-1} in the estuary, whereas the NPP was 790±472 mg C m^{-3} day^{-1} during the study period. Highest GPP was observed during pre monsoon (Av. 1,785±434 mg C m^{-3} day^{-1}) followed by post monsoon (Av. 1,589±

Table 1 Statistical summary of monthly measurement of variables in the Kodungallur-Azhikode Estuary (KAE)

	AVG	STD	MAX	MIN	GeoM
pH	7.36	0.38	7.76	6.58	7.35
W. Temp. (°C)	28.88	2.07	31.36	23.92	28.81
Sal.(psu)	14.66	8.06	25.85	0.93	10.72
aD%O	33.39	9.99	51.11	18.42	32.02
Chl-*a* (mg m^{-3})	6.42	3.83	12.66	1.67	5.31
Trans. (m)	0.99	0.38	1.53	0.22	0.89
DIN (mg m^{-3})	728.91	788.59	3139.44	161.58	541.68
DIP (mg m^{-3})	96.84	116.01	449.43	24.99	67.91
N:P ratio	21.91	12.64	46.06	2.55	17.66
	Mon soon	post monsoon	pre monsoon		
TRIX unit	7.07	6.52	7.15		
Eff. Coeff.	−2.75	−2.27	−1.99		

377 mg C m^{-3} day^{-1}) and monsoon (Av. 1,517±381 mg C m^{-3} day^{-1}) respectively (Fig. 4a). A distinct variation in GPP was observed in the water column, that was high in the surface waters (Av. 1,702±406 mg C m–^{3} day^{-1}) when compared to bottom waters (Av. 1,500±357 mg C m^{-3} day^{-1}), whereas comparatively less variation was noticed during monsoon period due to well mixing of the water column. Generally, increased GPP was noticed in the stations nearby estuarine mouth (Station I; Av. 1,625±.824 mg C m^{-3} day^{-1}, Station II; Av. 1,750±0.989 mg C m^{-3} day^{-1} and Station III, Av. 1,750±737 mg C m^{-3} day^{-1}).

Trophic index evaluation in the estuary showed that, an annual average of 6.91 TRIX unit was noticed in the KAE and It ranges from 6.18 during the month January to 7.71 in July (Fig. 5). Seasonal highest was observed during pre monsoon period (7.15) and lowest during post monsoon period (6.51). In the spatial scale station V showed high value 7.37 (Fig. 2a) and comparatively low values in the station VI (6.93) and VII (6.96). Efficiency Coefficient values in the KAE ranges from −3.30 in month of July to −1.41 during March and it was ranging from −2.74 during monsoon period to −1.98 in pre monsoon period.

4 Discussions

Estuaries rank among the most heavily impacted aquatic ecosystem system on earth and rivers serve as rapid channel for anthropogenic pollutants to estuarine environments (Michael 2002). Various effects of nutrient enrichment in the water column cause eutorphication in estuarine system. According to Jesper et al. (2006) “eutrophication is the enrichment of water by nutrients, especially nitrogen and/or phosphorus and organic matter, causing an increased growth of algae and higher forms of plant life to produce an unacceptable deviation in structure, function and stability of organisms present in the water and to the quality of water concerned, compared to reference conditions”.

The possibility of applying a trophic index TRIX with supplementary index Efficiency Coefficient to understand the estuarine eutrophication has been considered in this study. Efficiency Coefficient values in the KAE indicate high rate of nutrient utilisation by phytoplankton. Similarly annual average N:P ratio in the water column of KAE showed nitrogen limited condition during pre monsoon period. However, phosphorous limitation observed during south west monsoon

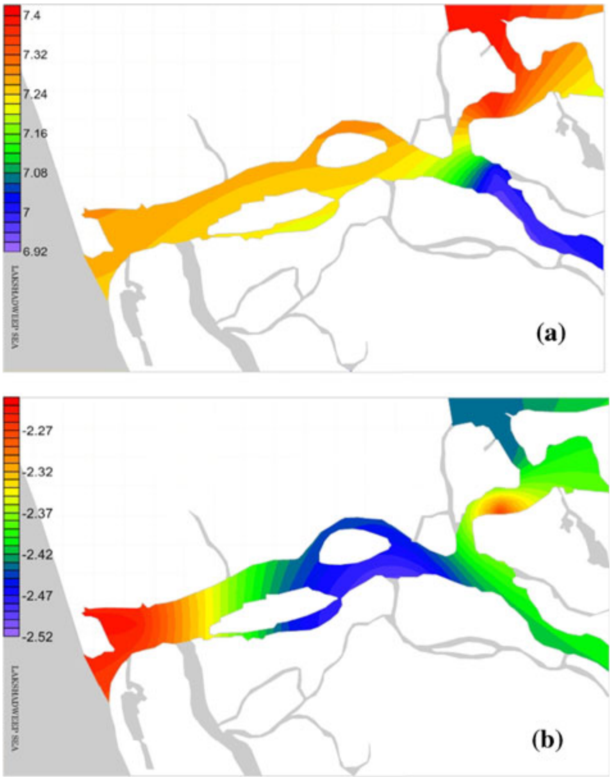


Fig. 2 Spatial variation of **a** trophic index TRIX and **b** Efficiency Coefficient in the Kodungallur-Azhikode Estuary (KAE)

period to onset of post monsoon. Trophic index (TRIX) showed supporting evidence to Efficiency Coefficient value. Annual mean TRIX showed that, KAE experiencing high productivity due anthropogenic eutrophication. TRIX units plotted against the corresponding state variables gives similar trend (Fig. 3) that was report by Vollenweider et al. (1998). When Efficiency Coefficient values plotted against TRIX unit, higher Efficiency Coefficient reduces the TRIX unit. Efficiency Coefficient and N: P ratio plot also showed that, higher Efficiency Coefficient reduces N:P ratio due to intense nutrient utilisation by phytoplankton (Figs. 4 and 5).

In the spatial scale, TRIX value in the KAE showed that highly eutrophicated conditions in the station V; were high rate of nutrient input from aquaculture (cages and extensive and semi intensive ponds) and agriculture, sand mining and construction activities. However, station VII showed comparatively low TRIX unit; that part of the estuary receive high fresh water input with low nutrient content and low water residence time. High rate of nutrient inputs stimulate phytoplankton growth and alter community composition. Primary consumers in the estuary recycle a part of theses carbon and nitrogen fixed in the phytoplankton cells. Bloom events triggered by nutrient loading may result in high rate of phytoplankton carbon deposition on sediment surface. Microbial degradation of these deposits may promote bottom water hypoxia or anoxia, which in turn smooth the progress of sediment nutrient leaching. Leaching of this sediment nutrient may promote algal blooms and eutrophication. The continued addition of these allothonous nutrients and less removal of nutrient by increased water residence time may intensify the eutrophication process in estuary (James et al. 2001).

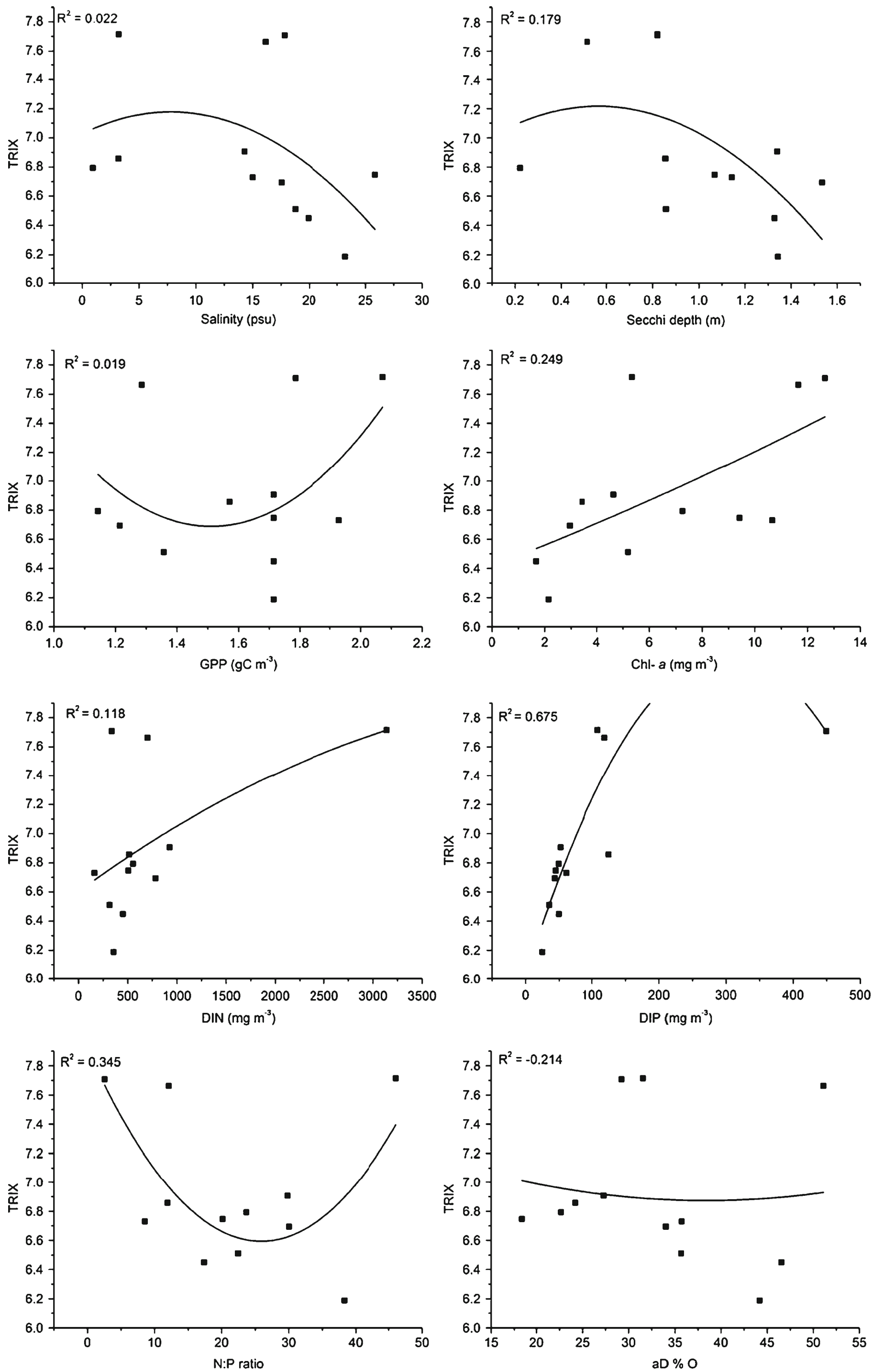


Fig. 3 Functionmnal relationships between TRIX means, its components and other related trophic state variables in the Kodungallur-Azhikode Estuary (KAE)

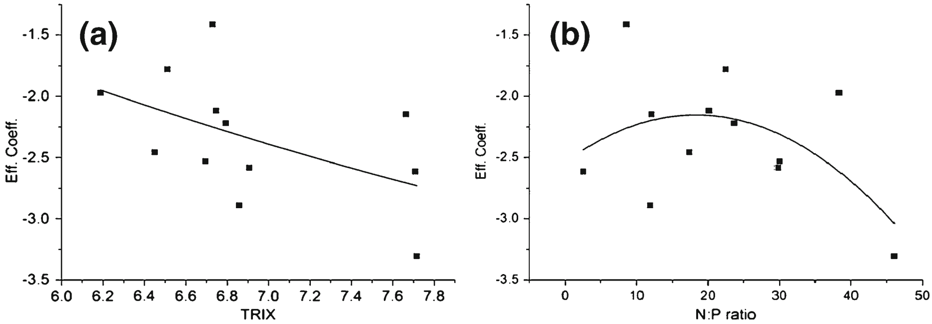
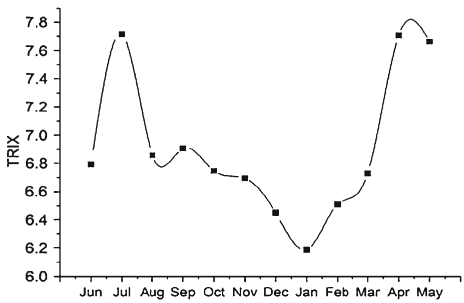


Fig. 4 **a** Nutrient utilisation: Efficiency Coefficient vs. TRIX means and **b** differece in utilisation efficiency as a function of N:P ratio in the Kodungallur-Azhikode Estuary (KAE)

Phytoplankton carbon loading can also have a direct impact on the oxygen dynamics of estuaries. Therefore, high rate nutrient and organic matter inputs can be play a role in determining the predominant species within phytoplankton communities. The alteration of nutrient concentrations and ratios may change the phytoplankton community composition significantly, with subsequent cascading impacts at higher trophic levels of the food web (McClelland and Valiela 1998). The anoxic conditions inhibit nitrification and release ammonium ions from the sediments cannot be nitrified to nitrate (Malone et al. 1996). This may result in high ammonium concentration in water column. Benthic release of phosphate is also enhanced under low dissolved oxygen concentrations (Malone et al. 1996). Therefore, continuous anoxia may result in elevated ammonium concentrations which are used by phytoplankton that capitalize on the readily available ammonium ions. If these conditions continue, phytoplankton blooms may occur and strengthen eutrophication process in the estuary.

Estuaries have long been supported a wide number of finfish and shell fish species, mainly because of their rich food supply. They act as nursery ground for many commercially important species (Bijoy Nandan 2008). However, unrestrained nutrient input in the estuary could also affect its natural resources especially fishery. Hypoxia or anoxia in the water column changes in the phytoplankton species composition that may result in reduction of food supply for consumers. The loss of the species diversity and abundance of food resources could result in the migration of nekton (zooplankton, fishes etc.) to more suitable habitats. Sessile organisms (mussels, clams etc.) may suffer from reduced reproductive fitness and significant mortalities due to starvation and reduced dissolved oxygen levels. Therefore, many important commercial and recreational fisheries are among groups that may be negatively impacted (NRC 1993).

Fig. 5 Monthly TRIX variation in the Kodungallur-Azhikode Estuary (KAE)



Limiting nutrients, such as N, P, and Si, promotes the growth of most phytoplankton species, and therefore high nutrient concentrations may produce algal blooms (NRC 1993). Some of these blooms may be composed of toxic species (ECOHAB 1995). The combined effect of increased water residence time and growing pollutant inputs has led to long exposure periods of opportunistic microorganisms to growth-promoting conditions. Several studies have shown that organic matter can stimulate the growth of marine dinoflagellates (Doig and Martin 1974). Bloom forming cyanobacteria are often superior competitors under these conditions and frequently thrive in nutrient-enriched waters (Vincent 1987). Present trend in the TRIX unit is indication for fishery in the KAE become more serious during the next years, obviously by larger number of depleted or collapsed fisheries stock and perhaps by other, more extreme reaching change in the structure of the impacted system.

5 Conclusions

Trpohic index (TRIX) evaluation combined with Efficiency Coefficient in the KAE revealed that trophic state of the estuary was under severe eutrophication and the restriction of external nutrient inputs should be keystone in restoration of estuary from its effect. The revitalization of estuaries is a multifaceted, long-term problem that requires the focused attention of government agencies and public. These entities must collaborate to ensure that the trophic state in estuaries is protected and maintained. Trophic index (TRIX) is a simple tool for assessing the trophic state of estuary and is easily understandable to both administrators and to the public at large.

Acknowledgement This work forms part of the research project entitled *"Ecology and fish production potential of the Kodungallur-Azhikode back water ecosystem"* funded by the Kerala State Council for Science, Technology and Environment (KSCSTE) and the authors are thankful for financial assistance. Authors are also thankful to Head and Ecology Division, Dept. of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology for providing necessary facilities.

References

APHA (2005) Standard methods for the examination of water and waste water. Am Publ Health Assoc 21:1 (1)–10(167)

Bijoy Nandan S (2008) Current status and biodiversity modification in the coastal wetland ecosystems of India with objectives for its sustainable management. Proceedings of conserve-vision conference, The University of Waikato, www.waikato.ac.n/wtass/conserve-vision

Doig MT, Martin DF (1974) The effect of naturally occurring organic substances on the growth of a red tide organism. Water Res 8:601–606

ECOHAB (1995) The ecology and oceanography of harmful algal blooms. A National Research Agenda. Woods Hole Oceanographic Institution, Woods Hole

GOI (2011) Census of India-2011, available from http://censusindia.gov.in/

Grasshoff K, Ehrhardt M, Kremling K (1983) Methods of sea water analysis. Verlag Chemie, Weinheim, pp 9–224

Intergovernmental Panel on Climate Change (IPCC) (2007) In: Parry MI, Canziani OF, Patulikof JP, PA Van derLinden, Hanson CE (eds) Climate change 2007-impacts, adaptation and vulnerability. Contribution of working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, p 976

James LP, Hans WP, Patricia T, Tammi LR (2001) The role of nutrient loading and eutrophication in estuarine ecology. Environ Health Perspect 109(5):699–706

Jaworski NA, Howarth RW, Hetling LJ (1997) Atmospheric deposition of nitrogen oxides onto the landscape contributes to coastal eutrophication in the northeast United States. Environ Sci Technol 31:1995–2004

Jesper HA, Louise S, Gunni A (2006) Coastal eutrophication: recent developments in definitions and implications for monitoring strategies. J Plankton Res 28(7):621–628
Jia-Zhong Z, Charles JF (2005) A simplified resorcinol method for direct spectrophotometric determination of nitrate in seawater. Mar Chem 99:220–226
Jørgensen SE, Constanza R, Xu FL (eds) (2005) Handbook of ecological indicators for assessment of ecosystem health. CRC, Boca Raton, p 439
Killops SD, Killops VJ (1993) An introduction to organic geochemistry. Longman Group, London
Malone T, Conley DA, Fisher T, Glibert P, Harding L, Sellner K (1996) Scales of nutrient limited phytoplankton productivity in Chesapeake Bay. Estuaries 19:371–385
McClelland JW, Valiela I (1998) Changes in food web structure under the influence of increased anthropogenic nitrogen inputs to estuaries. Mar Ecol Prog Ser 168:259–271
McLusky SD, Elliott M (2004) The estuarine: ecosystem ecology, threats, and management, Great Clarendon Street, Oxford OX26DP, pp214
Michael JK (2002) Environmental threats and environmental future of estuaries. Environ Conserv 29(1):78–107
Nancy NR, Eugene RT, Robert JD, Dubravko J (2009) Global change and eutrophication of coastal waters. International Council for the Exploration of the Sea. Oxf J. doi:10.1093/icesjms/fsp0471528-1537
National Research Council (NRC) (1993) Sustaining our water resources. National Academy, Washington
Philip GT, Alan RT (2010) Stoichiometric control of organic carbon nitrate relationships from soils to the sea. Nature 464:22
Revichandran C, Abraham P (1998) Mixing and flushing in the Azhikode estuary, south west coat of India. Indian J Mar Sci 27:163–166
Richard JTK, Robert JN, Nobuo M (1999) Coastal adaptation to climate change: can the IPCC technical guidelines be applied? Mitig Adapt Strat Glob Change 4:239–252
Smith RV, Lennox SD, Jordan C, Foy RH, McHale E (1995) Increase in soluble phosphorus transported in drain flow from a grassland catchment in response to soil phosphorus accumulation. Soil Use Manag 11:204–209
Smith RA, Schwarz GE, Alexander RB (1997) Regional interpretation of water quality monitoring data. Water Resour Res 33:2781–2798
Smith VH, Tilman GD, Nekola JC (1999) Eutrophication: impact of excess nutrients inputs on fresh water, marine, and terrestrial ecosystems. Environ Pollut 100:179–196
Strickland JDH, Parsons TR (1972) Bulletin of fisheries research board of Canada. 167–310
Vincent WF (1987) Dominance of bloom forming cyanobacteria (bluegreenalgae). N Z J Mar Freshw Res 21:361–542
Vollenweider RA, Kerekes JJ (1982) Eutrophication of waters, monitoring assessment and control. O.E.C.D, Paris, p 154
Vollenweider RA, Rinaldi A, Montanari G (1992) Eutrophication, structure and dynamics of a marine coastal system: results of a 10 years monitoring along the Emilia Romagna coast (Northwest Adriatic Sea). In: Vollenweider RA, Marchett R, Viviani R (eds) Marine coastal eutrophication. Elsevier, London, pp 63–106
Vollenweider RA, Giovanardi F, Montanari G, Rinaldi A (1998) Characterization of the trophic conditions of marine coastal waters, with special reference to the NWAdriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index. Environmetrics 9:329–357
Waring RH, Running SW (1998) Forest ecosystems: analysis at multiple scales, 2nd edn. Academic, San Diego