Journal of the Marine Biological Association of the United Kingdom, 2013, 93(1), 37–45.
doi:10.1017/S0025315411001858

Testing depth-related multivariate patterns of macrofauna on the Indian continental shelf using reduced taxonomic resolution and data transformation

T.V. JOYDAS[1] AND R. DAMODARAN

Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, Cochin–16, Kerala, India, [1]Present address: Center for Environment and Water, King Fahd University of Petroleum and Minerals, PB No. 1995, Dhahran, 31261, Kingdom of Saudi Arabia

Although taxonomic sufficiency (TS) was developed for rapid environmental assessments, it has recently been adopted to study the spatial patterns of macrobenthos in relation to natural environmental gradients. To accept TS as a routine approach in wider benthic studies, it needs to be valid for various taxa and geographically different water masses. This study examined the effects of taxonomic resolution on depth-related multivariate patterns of macrobenthic polychaetes on the western Indian continental shelf. An extensive data set based on samples collected from a wide geographical area (7°–22°N latitudes) covering a large depth gradient (30–200 m) has been analysed. Species level polychaete community data had shown a significant variation between shallow and deeper waters. Our results indicated that generic and family level data also can detect community shifts along a depth gradient in a similar way to species level data. The entire western continental margin (200 m depth) is lying in the oxygen minimum zone (dissolved oxygen <0.5 ml l^{-1}). This study indicated that family level results were sufficient to document the correlations of low oxygen on macrobenthic polychaetes. This study also tested the effects of transformations on depth-related patterns of polychaetes. In multivariate analyses, transformations play a role in defining the balance between contributions from common and rare species in the measure of similarity of two samples. Our results showed that the type of transformations did not make any prominent differences in the multivariate analyses.

Keywords: macrobenthos, polychaetes, taxonomic sufficiency, data transformation, oxygen minimum zone, Indian continental shelf

Submitted 15 September 2011; accepted 4 October 2011; first published online 6 December 2011

INTRODUCTION

For over two decades, considerable attention has been given to finding cost-effective methods for benthic studies owing to their inherent difficulties in sampling and laboratory processing efforts. Taxonomic sufficiency (TS) (Ellis, 1985), which is the identification of taxa to taxonomic levels higher than species, without considerable loss of information about community response, was found to be a convenient approach to reduce identification efforts. TS was initially used to identify effects of pollution on benthic communities (Heip *et al.*, 1988; Warwick, 1988a, b; Ferraro & Cole, 1990; Gray *et al.*, 1990; Warwick *et al.*, 1990; Somerfield & Clarke, 1995; Wright *et al.*, 1995; Mistri & Rossi, 2001; Gesteira *et al.*, 2003) and later was also found suitable to explain spatial patterns of benthic communities along natural environmental gradients (James *et al*, 1995; Chapman, 1998; De Biasi *et al.*, 2003; Lasiak, 2003; Dethier & Schoch, 2006; Sajan *et al.*, 2010). These studies analysed the costs and benefits when data from higher taxonomic levels are used. As identification moves progressively to species level, costs, in terms of the expertise and time needed also increase (Heip *et al.*, 1988). It is easier to train personnel to sort higher taxonomic levels than species, and the risk of potential taxonomic classification error is lower at a higher level of identification (Dauvin *et al.*, 2003). However, to accept TS as a routine approach in benthic studies, it needs to be proved valid for various taxa and in geographically different water masses. The present study investigates the validity of TS for macrobenthic polychaetes by analysing an extensive data set based on samples collected from a wide geographical area covering a large depth gradient. For this study, samples were collected from every degree square of the western Indian continental shelf (7°–22°N latitudes) with representative samples from 30, 50, 100 and 200 m depths. Polychaetes were the dominant macrobenthic group, contributing 57% of the population, with 165 species belonging to 32 families, showing shifts in community structure in relation to depth (Joydas & Damodaran, 2009; Joydas *et al.*, 2009).

Within marine benthic samples, there is usually a great range of abundances (Olsgard *et al.*, 1997). Some taxa are dominant, while others are occasional or rare. In multivariate analyses, data transformation plays a role in defining the balance between contributions from common and rare species in the measure of similarity of two samples (Clarke

Corresponding author:
T.V. Joydas
Email: joydastv@yahoo.com

& Warwick, 2001). In this study, we use various transformed forms of polychaete data of three taxonomic levels and test which analyses can document the species-level depth-related pattern in the western Indian continental shelf.

Our previous study on the environmental correlates of polychaete distributions revealed that depth-related patterns are a function of variation in bottom water dissolved oxygen (DO) and temperature (Joydas & Damodaran, 2009). Sharp decreases in DO and temperature with increase in depth were evident and the DO values observed in the 200 m depth zone (0.0005–0.24 ml l^{-1}) indicated that this area is lying within the oxygen minimum zone (OMZ: <0.5 ml l^{-1}; Levin, 2003).

The overall objectives of the study are: (i) to identify whether depth- and oxygen-related patterns of polychaetes at species level are conserved at reduced taxonomic levels in a natural environment; and (ii) to examine the effect of various data transformations on the community patterns of polychaetes.

MATERIALS AND METHODS

Sampling and laboratory analysis

Macrobenthic samples for the present study were collected on-board the Indian Fishery and Oceanographic Research Vessel (FORV) 'Sagar Sampada'. Data from two cruises (Cruise No. 162 conducted during February–March 2008 and Cruise No. 192A during February 2001) were used for this study. Seventy-five stations representing various depths, distributed along 17 transects (T) that were usually perpendicular to shore, were sampled; they extended from 07°10′22″ to 22°14′31″N and 67°57′41″ to 77°21′58″E (Figure 1). Sampling was conducted at depths of 30, 50, 100 and 200 m along each transect in order to study the change in fauna with depth.

Two grab samples were collected using a Kahlsico No. 214 WA 250 modified Smith–McIntyre grab (surface area: 0.1 m^2) from each station. The sediment samples were sieved through a 0.5 mm mesh and fixed in 5% neutral formalin mixed with rose Bengal stain. Macrobenthic organisms were initially sorted to higher taxa levels and members of the dominant taxon, polychaetes, were identified to species level (Fauvel, 1953; Day, 1967) followed by counting of individuals. The numerical abundance (as individuals) of polychaetes was expressed in individuals per m^2 and was the average of the two grab samples per station.

Data treatment

To study the effects of TS, we performed regression analyses to identify species versus genera and species versus family relationships for richness and species diversity of polychaetes using Microsoft Excel. Prior to this, univariate (Shannon–Wiener diversity, H′ $\log_2$) and multivariate analyses were carried out using PRIMER (Plymouth Routines in Multivariate Ecological Research, version 6.1.5: Clarke & Warwick, 2001) with the abundance matrices at the three levels of taxonomic resolution for 30, 50, 100 and 200 m depths. Resemblances (Bray–Curtis similarity index (Bray & Curtis, 1957)) among all the matrices were determined by the Spearman rank correlation coefficient (Clarke & Warwick, 2001). To reveal the effect of transformations in the multivariate analyses in explaining the depth variation of polychaete taxa, each of the matrices obtained previously were none, square root, fourth root, log(x + 1) and presence/absence transformed, which resulted in 60 matrices. The rank ordered correlations were treated like a similarity matrix and inputted to a second-stage non–metric multidimensional scaling ordination (second-stage MDS: Somerfield & Clarke, 1995). This method is appropriate to examine the degree of resemblance among similarity matrices obtained with different aggregations and depths. One-way analysis of similarity (ANOSIM) of PRIMER was used to test differences found in the communities (with various transformations of data of species, genus and family levels) between selected depth bands.

We also studied the patterns with environmental gradients on the species, genus and family levels of polychaete taxa. The variables selected were depth, DO, temperature and sediment organic matter % (OM). Analysis of variance (ANOVA) indicated that only temperature and DO showed significant depth variations ($P < 0.05$) on the western continental shelf of India. OM was included as it had shown higher levels in the central region of 30–100 m depths compared to north and south (Joydas & Damodaran, 2009). Stations were categorized as south (s: T1–T6), central (c: T7–T12) and north (n: T13 – T17).

Detrended normal q–q plotting was carried out to obtain the gradient length of all the data. Since the gradient lengths were ≤1.0 SD, a canonical correspondence analysis (CCA: ter Braak & Verdonschot, 1995) was performed to identify relationships between polychaetes of species, genus and family level taxa and environmental gradients. For CCA, we used density data for 20 dominant species, 15 dominant genera and 10 dominant families and environmental variables. CCA included a Monte Carlo permutation test (with 999 unrestricted permutations) to determine the significance of taxa–environment relationships. We used the Statistical Package for the Social Sciences (SPSS) version 16.0 for Windows for detrended normal q–q plotting and XLStat software (Version 2009.6.01, Addinsoft) for CCA and ANOVA.

RESULTS

TS in polychaetes of the western continental shelf of India

All polychaete families and their numbers of genera and species are presented in Table 1. Eunicidae (22 species), Spionidae (14 species) and Terebellidae (11 species) were the most speciose families. Many families were represented by only one species. Linear regression results showed strong ($R^2 > 0.87$) relationships between the three levels of taxonomic resolution for taxa richness (Figure 2A) and diversity (Figure 2B). Species and genus showed stronger positive correlations than species and family for both richness and diversity.

Testing depth-related patterns in polychaetes with TS and transformations

Community similarities for the three levels of taxonomic resolution at the selected depths were compared with a PRIMER

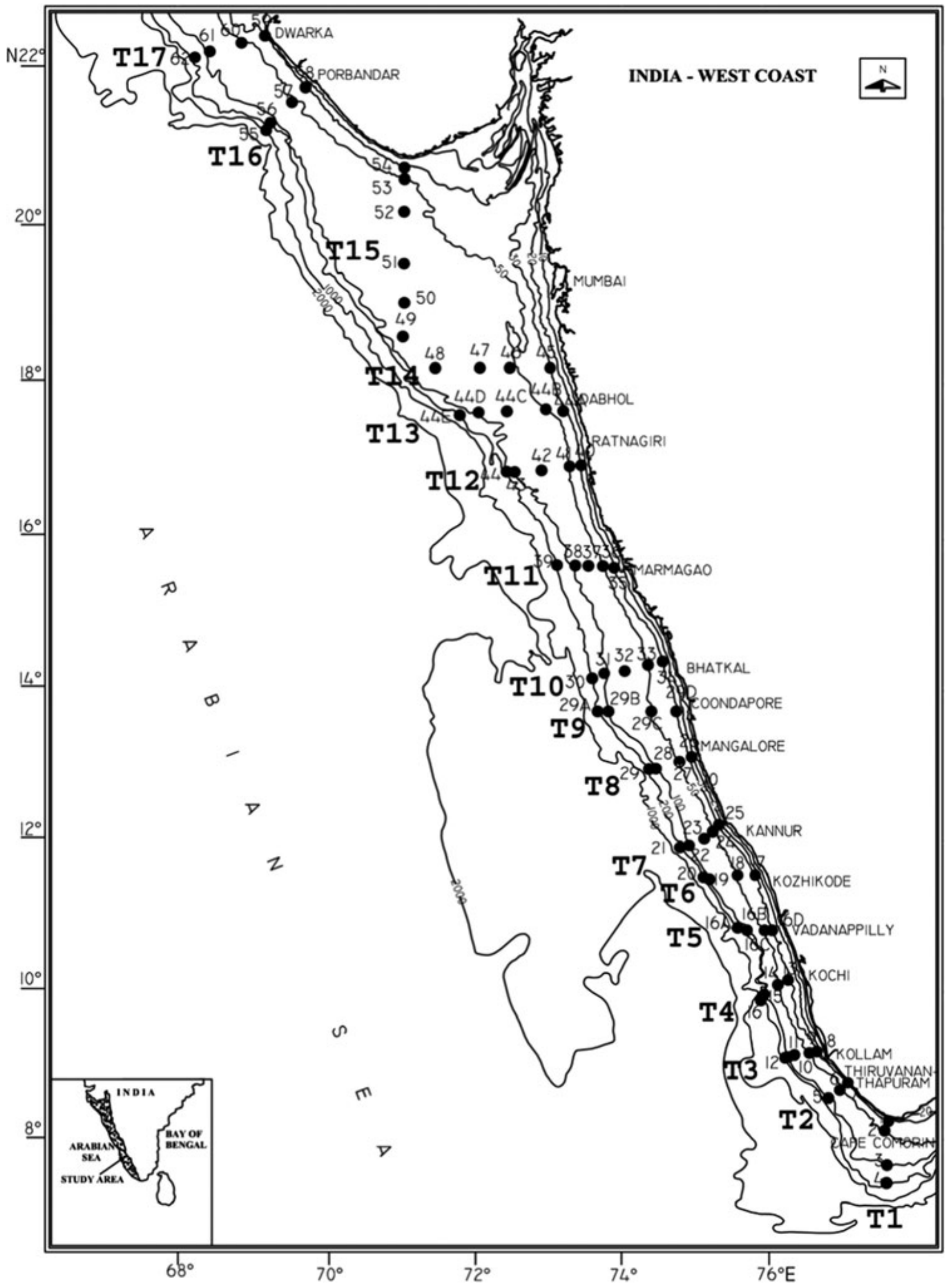

Fig. 1. Location of the sampling stations of the western Indian continental shelf.

second stage resemblance matrix. Each depth zone was distinctly plotted in the second stage MDS plot: within each depth zone, a vertical arrangement for different transformations was visible from none on the top to presence/absence on the bottom (Figure 3). The Spearman rank correlations obtained among the species similarity matrices and higher taxonomic levels of the five transformations were significant for all depths ($P < 0.001$) (Figure 4). Higher correlations were obtained for species–genus (R value range: 0.67–0.95) and genus–family (0.73–0.92) than species–family (0.42–0.82) similarity matrices. Considerably lower correlations ($R < 0.5$) were obtained for species–family matrices in the 50 m depth zone. In this depth zone, the highest number of taxa (122 species and 76 genera from 33 families) was observed and ten families had 6–15 species.

Polychaete community dissimilarity at various depths for each level of taxonomic resolution with various transformations was tested using one-way ANOSIM (Figure 5). Communities in the shallower waters (30 m and 50 m) showed significant differences ($P < 0.001$) from the deeper water (200 m) for all three taxonomic levels and five transformations. Evaluation of R values indicates that the community differences between shallow and deeper waters and between 100 m and 200 m depths were pronounced at family level. R values also revealed that the community differences between depths in species, genus and family levels were similarly expressed with square root, fourth root and log (x + 1) transformations. Generally, none and presence/absence transformations showed relatively lower R statistics.

Table 1. A summary of the families and the species and genus numbers in each family.

Family	Genus	Species	Family	Genus	Species
Aphroditidae	2	3	Chaetopteridae	1	1
Amphinomidae	5	7	Orbinidae	4	8
Pisionidae	1	1	Paraonidae	5	8
Phyllodocidae	2	3	Ophelidae	3	4
Alciopidae	1	1	Cossuridae	1	1
Pilargidae	1	3	Scalibregmidae	2	2
Hesionidae	5	5	Capitellidae	3	6
Syllidae	4	6	Maldanidae	1	1
Nereidae	3	4	Sternaspidae	1	1
Nephtyidae	1	6	Flabelligeridae	2	2
Lacydonidae	1	1	Pectinaridae	1	1
Glyceridae	2	8	Ampharetidae	5	5
Eunicidae	9	22	Terebellidae	4	11
Spionidae	9	14	Sabellidae	4	7
Magelonidae	1	1	Serpulidae	3	4
Cirratulidae	5	9	UI family	1	6
Trochochaetidae	1	1			

Links between faunal patterns and environmental variables

The CCAs demonstrated the relationship of DO and temperature to the depth-related patterns of polychaetes (Figure 6). The variables explained 69%, 77% and 81% of the variance of the first two CCA axes for species, genus and family levels respectively. Eigenvalues and the correlation coefficients of the variables for the three taxonomic resolutions are given in Table 2. The Monte Carlo permutation test (with forward selection) indicated that depth was positively correlated, whereas DO and temperature were negatively correlated with axis 1. OM exhibited a negative correlation with axis 2. Three clusters were distinct in these plots; the first cluster with stations belonging to 30 and 50 m, second cluster with stations from 100 m and third cluster with stations from 200 m depths. CCA plots indicated that in all three taxonomic levels, the first axis separated shallower stations (30 and 50 m) from deeper (100 and 200 m) stations. The second axis further divided 100 and 200 m depth zones in the family level plot. The DO and temperature were found to correlate strongly with depth variation in fauna, with DO having a primary role. The CCA plots revealed a latitudinal separation of stations which corresponded with the OM distribution. Generally, higher OM levels were recorded from the central (average 4.9%) than the southern (2.1%) and the northern (1.6%) latitude stations in 30 and 100 m depth zones. In the plots (Figure 6), the central latitude stations in these depth zones were positioned below the northern and southern stations. Such variation was not prominent in 50 and 200 m depth zones. The CCA also revealed relationships between dominant species (20), genera (15) and families (10) with the environmental variables. Species and genera belonging to the families Sternaspidae, Magelonidae, Cossuridae, Eunicidae, Pilargidae, Nephtydae and Glyceridae were typical of 30 and 50 m depths, while Maldanidae and Spionidae were typical of 100 m depths. Spionidae, Paraonidae and Cirratulidae were found to be typical of the OMZ.

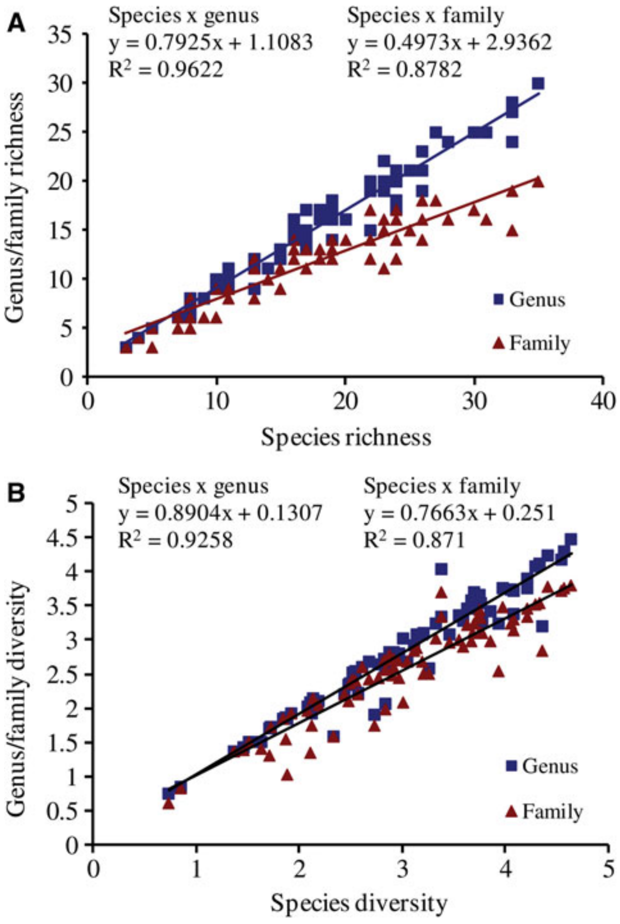

Fig. 2. Species versus genera versus family relationships for (A) richness and (B) diversity for the three levels of taxonomic resolution of polychaetes.

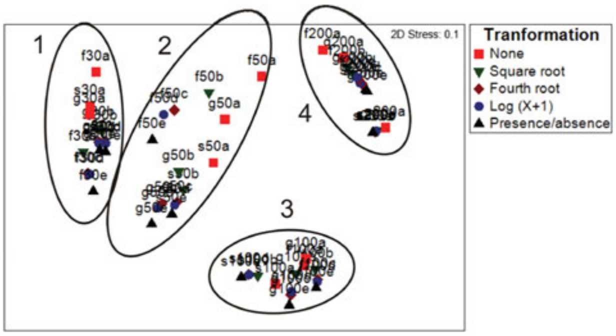

Fig. 3. Second stage non-metric multidimensional scaling of three taxonomic levels of polychaetes of the four depths with various transformations. Prefixes 's', 'g' and 'f' are species, genus and family respectively. Suffixes 'a', 'b', 'c', 'd' and 'e' are none, square root, fourth root, log (X + 1) and presence/absence transformations respectively. 1, 2, 3 and 4 represent clusters of 30 m, 50 m, 100 m and 200 m depth zones respectively.

DISCUSSION

Depth-related patterns in polychaetes and TS

The present study with a large data set showed that depth-related community patterns of polychaetes are conserved at lower taxonomic resolutions on the western Indian continental shelf. The Spearman rank correlations obtained among the species similarity matrices and higher taxa were

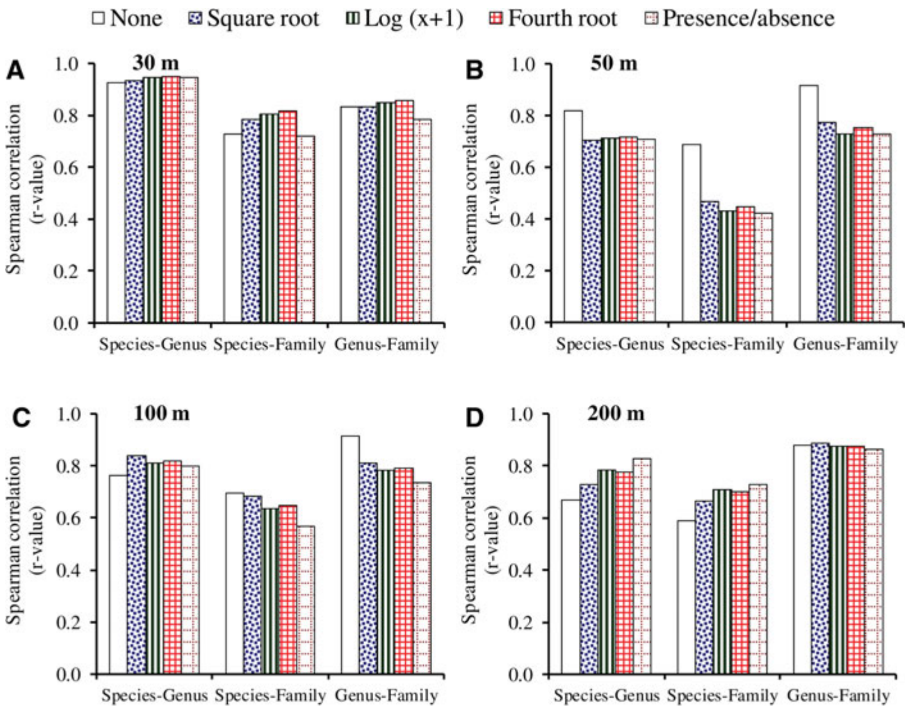

Fig. 4. Spearman rank correlations between data sets of species, genus and family and types of transformations in the four depth zones.

very high in most cases, although the R values decreased as it goes to family level. Our species level data exhibited a difference between shallow water and shelf edge communities and a similar variation was identified when generic and family levels data were tested. In this study, ANOSIM results revealed two types of community variations: (i) between stronger depth gradients (30 or 50 m and 200 m depth zones); and (ii) between weaker depth gradients (100 and 200 m depth zones). The former was visible at all three levels of taxonomic resolution, while, the latter was more evident in family level data. ANOSIM results indicate that community dissimilarity between 100 and 200 m depth zones increases from species level to family level (Figure 5).

Taxonomic sufficiency reduces the cost of identification up to 55% for family level identification versus species level (Ferraro & Cole, 1995), although, the potential for saving time depends on other factors such as the number of taxonomically difficult families and the expertise available (Olsgard *et al.*, 1997). Generally, identification errors that are common at the species level can be avoided by opting for family level identification. At the same time, species level identification is considered to be a fundamental tool to understand the functioning of ecosystems and there are problems with TS particularly in the exclusion of rare species and loss of valuable ecological information (Maurer, 2000). Although such issues remain, the TS approach is very convenient in fast-track community assessment studies, and our results recommend its use in the Indian continental shelf waters.

Depth-related patterns in polychaetes and transformations

Transformations can affect the analyses of multivariate patterns (Olsgard *et al.*, 1998; Legendre & Gallagher, 2001; Stark *et al.*, 2003) by shifting the emphasis from the most

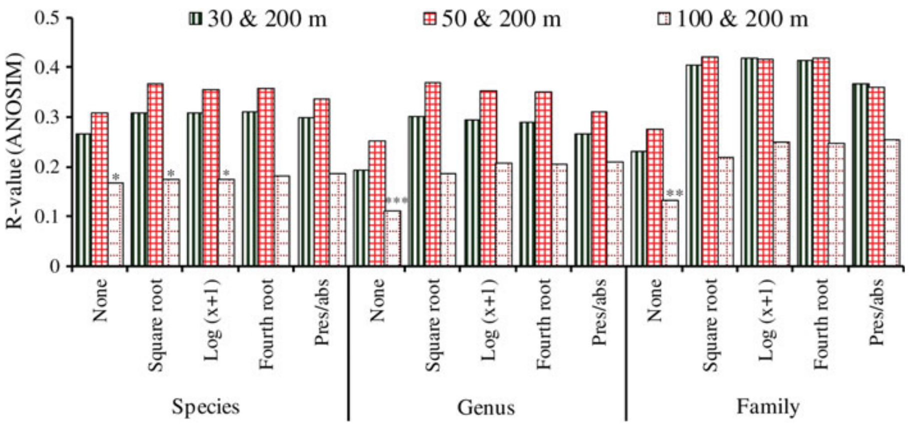

Fig. 5. Results of the analysis of similarity performed among depth zones using various taxonomic levels and types of transformations. *, $P < 0.002$; **, $P < 0.004$; ***, $P < 0.007$. Remaining community differences are at $P < 0.001$ significant level.

Table 2. Eigenvalues and correlation coefficients for the first two axes.

	Species		Genus		Family	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**	**Axis 1**	**Axis 2**
Eigenvalue	0.24	0.12	0.17	0.1	0.15	0.05
Correlation coefficient						
Depth	0.985	−0.057	0.964	0.135	0.832	0.512
DO	−0.939	0.266	−0.910	0.133	−0.892	−0.314
Temperature	−0.827	−0.117	−0.695	−0.308	−0.505	−0.830
OM	−0.103	−0.958	0.134	−0.887	0.416	−0.238

DO, dissolved oxygen; OM, organic matter.

abundant and dominant species or taxa (for untransformed data) to rare taxa (for presence/absence data) (Anderson *et al.*, 2005). In this study, the type of transformations did not make major differences in the R values when species data were correlated to higher taxa data and community patterns were tested along the depth gradients (Figures 3–5). The absence of a transformation effect is likely due to both low dominance and even lower number of rare species in the study area. Generally, the average dominance index was <0.22 at 30, 50 and 100 m depth zones and was slightly higher (0.32) at 200 m (Joydas & Damodaran, 2009). Our species level results also showed that about 72% of the species occurred in all the depth zones and that contributed to about 98% of the total individuals (Joydas & Damodaran, 2009). Thus, rare species did not make a sizeable contribution, resulting in presence/absence data not exhibiting notable differences compared to other transformations.

Faunal patterns versus environmental variables

The CCA showed that stations cluster according to depth, DO and temperature. The effect of DO was more pronounced in the 200 m depth zone, which lies within the OMZ. Previous studies have reported that OMZs support benthic fauna that differ fundamentally from those in well-oxygenated environments (Levin *et al.*, 2001; Levin, 2003; Hughes *et al.*, 2009; Ingole *et al.*, 2009). This is because there are oxygen thresholds below which most taxa are excluded through physiological intolerance to hypoxia, and above which selected taxa are able to take advantage of an abundant food supply (Levin *et al.*, 2009). The macrobenthos in OMZs typically shows reduced diversity and high dominance, in comparison with non-OMZ environments (Levin *et al.*, 2001). In the present study, *Prionospio pinnata* and *P. cirrifera* (family Spionidae), *Paraonis gracilis gracilis* and *Aricidea fauveli* (family Paraonidae), *Cirriformia* sp. 1 and *Cirratulus dasylophius* (family Cirratulidae) were found to dominate in the OMZ. Families such as Spionidae, Cirratulidae and Paraonidae were reported as the dominant species of OMZs in the Pakistan Margin (Hughes *et al.*, 2009), Oman Margin (Levin *et al.*, 2000) and central west coast of India (Ingole *et al.*, 2009). Macrobenthic composition data from other low oxygen systems, for example, Southern California borderland basins and Scandinavian fjords, suggest that polychaetes, particularly spionids are the predominant taxa when oxygen values fall between 0.1 and 0.5 ml l^{-1} (Arntz *et al.*, 1991; Levin *et al.*, 1991; Diaz & Rosenberg, 1995; Levin & Gage, 1998). Although latitudinal variation in fauna was not a prominent feature in this study, OM variation occurs at 30 and

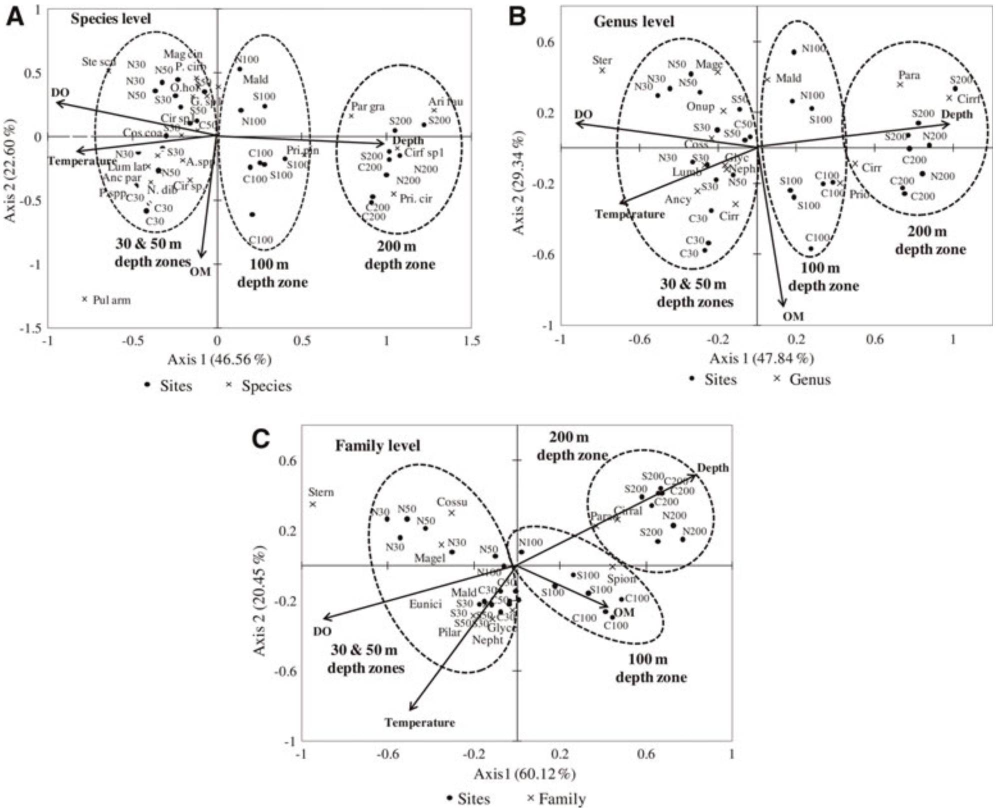

Fig. 6. Canonical correspondence analysis triplots showing scores of sites, the most abundant polychaete species/family and explanatory variables. DO, dissolved oxygen; OM, organic matter. Full taxa names are given in Table 3. A, species level; B, genus level; C, family level.

Table 3. Dominant polychaete species, genus and family in each depth zone with its percentage abundance. Abbreviation used in the canonical correspondence analysis plots (Figure 6) is given within parentheses.

Species	Genus	Family
30 m		
Magelona cincta (Mag cin)—33.4%	*Magelona* (Mage)—33.4%	Magelonidae (Magel)—33.4%
Sternaspis scutata (Ste scu)—10.6%	*Prionospio* (Prio)—15.7%	Spionidae (Spion)—16.3%
Prionospio pinnata (P.pin)—9.4%	*Sternaspis* (Ster)—10.6%	Sternaspidae (Stern)—10.6%
Ancystrosyllis parva (Anc par)—9.1%	*Ancystrosyllis* (Ancy)—9.8%	Pilargidae (Pilar)—9.8%
Prionospio spp. (P.spp.)—5.2%	*Lumbrineris* (Lumb)—5.5%	Eunicidae (Eunici)—7.7%
Lumbrineris latreilli (Lum lat)—4.3%	*Puliella* (Pulie)—3.2%	Cossuridae (Cossu)—3%
Puliella armata (Pul arm)—3.2%	*Cossura* (Coss)—3%	
Cossura coasta (Cos coa)—3%		
Cirrophorus sp. (Cir sp.)—2.1%		
50 m		
Magelona cincta (Mag cin)—43%	*Magelona* (Mage)—46.9%	Magelonidae (Magel)—46.9%
Cossura coasta (Cos coa)—13%	*Cossura* (Coss)—14.1%	Cossuridae (Cossu)—14.1%
Prionospio pinnata (P.pin)—6%	*Ancystrosyllis* (Ancy)—6.8%	Pilargidae (Pilar)—6.8%
Cirratulus sp.1 (Cir sp1)—4%	*Prionospio* (Prio)—4.9%	Cirratulidae (Cirral)—5.3%
Ancystrosyllis parva (Anc par)—4%	*Cirratulus* (Cirr)—4.6%	Spionidae (Spion)—5.3%
Lumbrineris latreilli (Lum lat)—2%	*Nephthys* (Neph)—2.9%	Eunicidae (Eunici)—4.3%
Prionospio spp. (P. spp.)—2%		
Nephtys dibranchis (N. dib)—2%		
A. spp. (A.spp.)—2%		
Maldanids (Mald) —2%		
100 m		
Prionospio pinnata (P.pin)—15%	*Prionospio* (Prio)—35.7%	Spionidae (Spion)—38.7%
Prionsopio spp. (P. spp.)—10%	*Glycera* (Glyc)—3.8%	Eunicidae (Eunici)—7.9%
Magelona cincta (Mag cin)—4%	*Lumbrineris* (Lumb)—3.7%	Paraonidae (Parao) —5.2%
Lumbrineris latreilli (Lum lat)—4%	*Magelona* (Mage)—3.4%	Glyceridae (Glyce)—5.2%
Cossura coasta (Cos coa)—3%	*Nephthys* (Neph)—2.8%	Cirratulidae (Cirral)—4.8%
Paraonis gracilis gracilis (Par gra)—2%	*Cirratulus* (Cirr)—2.6%	Magelonidae (Magel)—3.4%
Maldanids (Mald)—2%	*Ancystrosyllis* (Ancy)—2.4%	Nephtyidae (Nepht)—2.9%
Prionospio cirrobranchiata (P. cirb)—2%	*Paraonis* (Para)—2.1%	Pilargidae (Pilar)—2.5%
Prionospio cirrifera (P. cir) – 2%	*Cossura* (Coss)—2%	
Ancystrosyllis parva (Anc par)—2%		
Cirratulus sp.1 (Cir sp1)—2%		
Cirrophorus sp. (Cir sp.)—2%		
200 m		
Prionospio pinnata (P.pin)—41.8%	*Prionospio* (Prio)—49.4%	Spionidae (Spion)—48%
Paraonis gracilis gracilis (Par gra)—9.2%	*Paraonis* (Para)—9.2%	Paraonidae (Parao) —16.2%
Prionospio cirrifera (P. cir)—7.6%	*Cirriformia* (Cirrf)—5.7%	Cirratulidae (Cirral)—9.7%
Cirriformia sp.1 (Cirf sp1)—5.7%	*Cirratulus* (Cirr)—4.4%	Magelonidae (Magel)—3.3%
Aricidea fauveli (Ari fau) – 5.4%	*Magelona* (Mage)—3.5%	Eunicidae (Eunici)—1.7%
Magelona cincta (Mag cin) – 3.5%	*Cirrophorus* (Cirrp)—2%	Cossuridae (Cossu)—1.1%
Cirrophorus sp. (Cir sp.) – 2%	*Cossura* (Coss)—1.2%	
Cossura coasta (Cos coa)—1.2%		

100 m depths between latitudinal zones. The CCA plots revealed an OM effect on polychaetes in a similar way at the three taxonomic resolutions.

CONCLUSION

Depth-related multivariate community patterns in polychaetes in the western Indian continental shelf are conserved at family level taxonomic resolution. The family level data were also sufficient to illustrate the effect of OMZ on polychaete communities. Hence, we propose the use of TS in macrobenthic studies in the western shelf waters of India. The type of transformation did not affect the multivariate patterns of species, genus or family level data, which is attributed to the low dominance and lower number of rare species in the study area.

ACKNOWLEDGEMENTS

This work was supported by the Department of Ocean Development, New Delhi, India (grant number DOD/10-MLR 10/97/OD-II dt. 17.11.1997). We thank CMLRE, Cochin, India for providing enough ship time for successfully completing the sampling. We acknowledge and give our sincere thanks to Mr V. Raveendranath and Dr V.N. Sanjeevan, CMLRE, DOD, Cochin, India for all the help rendered to us. Thanks are also due to the Department of Marine Biology, Microbiology and Biochemistry, School of Marine Sciences, Cochin University of Science and Technology, India for the facilities offered to carry out the work. T.V.J. thanks the Research Institute, King Fahd University of Petroleum and Minerals, Saudi Arabia for the necessary support. We highly appreciate the anonymous referees for their comments and suggestions to improve the quality of the manuscript.

REFERENCES

Anderson M.J., Connell S.D., Gillanders B.M., Diebel C.E., Blom W.M., Saunders J.E. and Landers T.J. (2005) Relationships between taxonomic resolution and spatial scales of multivariate variation. *Journal of Animal Ecology* 74, 636–646.

Arntz W.E., Tarazona J., Gallardo V., Fores L. and Salzwedel H. (1991) Benthos communities in oxygen deficient shelf and upper slope areas of the Peruvian and Chilean Pacific coast, and changes caused by El Niño. In Tyson R.V. and Pearson T.H. (eds) *Modern and ancient continental shelf anoxia*. London: Geological Society Special Publication No. 58, pp. 131–154.

Bray J.R. and Curtis J.T. (1957) An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* 27, 325–349.

Chapman M.G. (1998) Relationships between spatial patterns of benthic assemblages in a mangrove forest using different levels of taxonomic resolutions. *Marine Ecology Progress Series* 162, 71–78.

Clarke K.R. and Warwick R.M. (2001) *Change in marine communities: an approach to statistical analysis and interpretation*. 2nd edition. Plymouth, UK: PRIMER-E.

Dauvin J.C., Gesteira G.J.L. and Fraga S.M. (2003) Taxonomic sufficiency: an overview of its use in the monitoring of sublittoral benthic communities after oil spills. *Marine Pollution Bulletin* 46, 552–555.

Day J.H. (1967) *A monograph on the Polychaeta of southern Africa, Part I (Errantia) & Part II (Sedentaria)*. London: Trustees of the British Museum, Natural History, London.

De Biasi A.M., Bianchi C.N. and Morri C. (2003) Analysis of macrobenthic communities at different taxonomic levels: an example from an estuarine environment in the Ligurian Sea (NW Mediterranean). *Estuarine, Coastal and Shelf Science* 58, 99–106.

Dethier M.N. and Schoch G.C. (2006) Taxonomic sufficiency in distinguishing natural spatial patterns on an estuarine shoreline. *Marine Ecology Progress Series* 306, 41–49.

Diaz R.J. and Rosenberg R. (1995) Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology: an Annual Review* 33, 245–303.

Ellis D. (1985) Taxonomic sufficiency in pollution assessment. *Marine Pollution Bulletin* 16, 459.

Fauvel P. (1953) Annelida Polychaeta. In Seymour-Sewell R.B. (ed.) *The fauna of India including Pakistan, Ceylon, Burma and Malaya*. Allahabad: The Indian Press.

Ferraro S.P. and Cole F.A. (1990) Taxonomic level and sample size sufficient for assessing pollution impacts on the Southern California Bight macrobenthos. *Marine Ecology Progress Series* 67, 251–262.

Ferraro S.P. and Cole F.A. (1995) Taxonomic level sufficient for assessing pollution impacts on the Southern California Bight macrobenthos—revisited. *Environmental Toxicology and Chemistry* 6, 1031–1040.

Gesteira G.J.L., Dauvin J.C. and Fraga S.M. (2003) Taxonomic level for assessing oil spill effects on soft-bottom sublittoral benthic communities. *Marine Pollution Bulletin* 46, 562–572.

Gray J.S., Clarke K.R., Warwick R.M. and Hobbs G. (1990) Detection of initial effects of marine pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. *Marine Ecology Progress Series* 66, 285–299.

Heip C., Warwick R.M., Carr M.R., Herman P.M.J., Huys R., Smol N. and Van Holsbeke K. (1988) Analysis of community attributes of the benthic meiofauna of Frierfjord/Langesundfjord. *Marine Ecology Progress Series* 46, 171–180.

Hughes D.J., Levin L.A., Lamont P.A., Packer M., Feeley K. and Gage J.D. (2009) Macrofaunal communities and sediment structure across the Pakistan margin oxygen minimum zone, North-East Arabian Sea. *Deep-Sea Research II* 56, 434–448.

Ingole B.S., Sautya S., Sivadas S., Singh R. and Nanajkar M. (2009) Macrofaunal community structure in the western Indian continental margin including the oxygen minimum zone. *Marine Ecology* 31, 148–166.

James R.J., Lincoln Smith M.P. and Fairweather P.G. (1995) Sieve mesh-size and taxonomic resolution needed to describe natural spatial variation of marine macrofauna. *Marine Ecology Progress Series* 118, 187–198.

Joydas T.V. and Damodaran R. (2009) Infaunal macrobenthos along the shelf waters of the west coast of India, Arabian Sea. *Indian Journal of Marine Sciences* 38, 191–204.

Joydas T.V., Jayalakshmi K.V. and Damodaran R. (2009) Polychaete community structure of Indian west coast shelf, Arabian Sea. *Current Sciences* 97, 634–636.

Lasiak T. (2003) Influence of taxonomic resolution, biological attributes and data transformations on multivariate comparisons of rocky macrofaunal assemblages. *Marine Ecology Progress Series* 250, 29–34.

Legendre P. and Gallagher E.D. (2001) Ecologically meaningful transformations for ordination of species data. *Oecologia* 129, 271–280.

Levin L.A. (2003) Oxygen minimum zone benthos: adaptation and community response to hypoxia. *Oceanography and Marine Biology: an Annual Review* 41, 1–45.

Levin L.A. and Gage J.D. (1998) Relationships between oxygen, organic matter and the diversity of bathyal macrofauna. *Deep-Sea Research II* 45, 129–163.

Levin L.A., Etter R.J., Rex M.A., Gooday A.J., Smith C.R., Pineda J., Stuart C.T., Hessler R.R. and Pawson D. (2001) Environmental influences on regional deep-sea species diversity. *Annual Review of Ecology and Systematics* 132, 51–93.

Levin L.A., Gage J.D., Martin C. and Lamont P.A. (2000) Macrobenthic community structure within and beneath the oxygen minimum zone, NW Arabian Sea. *Deep-Sea Research II* 47, 189–226.

Levin L.A., Huggett C.L. and Wishner K.F. (1991) Control of deep-sea benthic community structure by oxygen and organic-matter gradients in the eastern Pacific Ocean. *Journal of Marine Research* 49, 763–800.

Levin L.A., Whicraft C.R., Mendoza G.F., Gonzalez J.P. and Cowie G. (2009) Oxygen and organic matter thresholds for benthic activity on the Pakistan margin minimum zone (700–1100 m). *Deep-Sea Research II* 56, 449–471.

Maurer D. (2000) The dark side of the taxonomic sufficiency (TS). *Marine Pollution Bulletin* 40, 98–101.

Mistri M. and Rossi R. (2001) Levels of taxonomic resolution and choice of transformation sufficient to detect community gradients: an approach to hard-substrata benthic studies. *Italian Journal of Zoology* 67, 163–167.

Olsgard F., Somerfield P.J. and Carr M.R. (1997) Relationships between taxonomic resolution and data transformations in analyses of a macrobenthic community along an established pollution gradient. *Marine Ecology Progress Series* 149, 173–181.

Olsgard F., Somerfield P.J. and Carr M.R. (1998) Relationships between taxonomic resolution, macrobenthic community patterns and disturbance. *Marine Ecology Progress Series* 172, 25–36.

Sajan S., Joydas T.V. and Damodaran R. (2010) Depth-related patterns of meiofauna on the Indian continental shelf are conserved at reduced taxonomic resolution. *Hydrobiologia* 652, 39–47.

Somerfield P.J. and Clarke K.R. (1995) Taxonomic levels in marine community studies, revisited. *Marine Ecology Progress Series* 127, 113–119.

Stark J.S., Riddle M.J. and Simpson R.D. (2003) Human impacts in soft-sediment assemblages at Casey Station, East Antarctica: spatial variation, taxonomic resolution and data transformation. *Austral Ecology* 28, 287–304.

ter Braak C.J.F. and Verdonschot P.F.M. (1995) Canonical correspondence-analysis and related multivariate methods in aquatic ecology. *Aquatic Science* 57, 255–289.

Warwick R.M. (1988a) The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. *Marine Pollution Bulletin* 19, 259–268.

Warwick R.M. (1988b) Analysis of community attributes of the macrobenthos of Frierfjord/Langesundfjord at taxonomic levels higher than species. *Marine Pollution Bulletin* 46, 167–170.

Warwick R.M., Platt H.M., Clarke K.R., Agard J. and Gobin J. (1990) Analysis of macrobenthic and meiobenthic community structure in relation to pollution and disturbance in Hamilton Harbour, Bermuda. *Journal of Experimental Marine Biology and Ecology* 198, 119–142.

and

Wright I.A., Chessman B.C., Fairweather P.G. and Benson L.J. (1995) Measuring the impact of sewage effluent on the macro invertebrate community of an upland stream—the effect of different levels of taxonomic resolution and quantification. *Australian Journal of Ecology* 20, 142–149.

Correspondence should be addressed to:
T.V. Joydas
Center for Environment and Water
King Fahd University of Petroleum and Minerals
PB No. 1995, Dhahran, 31261, Kingdom of Saudi Arabia
email: joydastv@yahoo.com