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# Polychaete Assemblages in the Sungai Terengganu Estuary (East Coast of Peninsular Malaysia): Spatial Distribution Patterns

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**Abstract**
Urban developments in estuarine areas affect benthic organisms, notably the macrobenthos, by physically modifying the territory and generating waste. The polychaete assemblages and the environmental parameters in the estuarine area of Sungai Terengganu were examined based on nine stations along a salinity gradient from oligohaline to polyhaline. Samples were collected using a Smith McIntyre grab and yielded 1886 individuals, from 43 species grouped into 24 families. The fauna was mainly dominated by *Composetia* sp. (39.48%) and *Cossura* sp. (31.87%); the former in oligohaline areas and the latter in the polyhaline areas. The densities of both species had significant positive correlations with salinity, temperature, and silt, clay, and gravel contents. This study will benchmark the polychaete community distribution in this tropical estuary, which could be similar to environments along the east coast of Peninsular Malaysia (South China Sea).

**Keywords** Polychaete · Sungai Terengganu estuary · Salinity gradient · *Composetia* sp. · *Cossura* sp. · South China Sea

## Introduction

The highly dynamic and fragile estuarine environment plays a vital role as one of the most productive ecosystems in the world due to the combined influence of tides, and seawater and freshwater mixing (Scanes et al. 2017), with the physical, chemical, and biological fluctuations giving rise to highly functional and fertile systems. Estuaries are governed by complex interactions of wind, irradiance, rainfall, water level, and freshwater runoff. Thus, the associated biome may change significantly over time and space (Montagna et al. 2018). Changes may occur along gradients in salinity, sediment characteristics, water turbidity, nutrient composition, dissolved gases, and trace metals, affecting the organisms' abundance, diversity, and productivity (Wolanski et al. 2012). Estuaries are not only ecotones, but also provide habitats for a wide range of organisms, such as benthic invertebrates, mangroves, seagrass, and migratory and coastal birds (Barletta et al. 2017). Some inhabitants are permanent, while others are temporary (e.g., come in and out with the tides and during specific life stages). This gives rise to a highly diversified ecosystem, with complex and interconnected trophic relationships supporting many top predators, including humans (NOAA 2021).

Estuaries are frequent in temperate and tropical climates, and Malaysia is no exception (Scanes et al. 2020). Its tropical coasts harbor lagoon, mangrove, and river estuaries, which differ in the degree of closure and the amount of circulating freshwater and marine inflows (Scanes et al. 2017). Particularly, river estuaries in Malaysia are continuously evolving to cater to the local community's demands. Riverbanks are converted into residential settlements, while the estuaries receive modern harbors, fish farming, recreation and tourism activities, and waste disposal facilities (Boerema and Meire 2017).

The Sungai Terengganu estuary (sungai = river), located on the east coast of Peninsular Malaysia, is a center of development in Kuala Terengganu, the capital of Terengganu. With a surface area of approximately 46,000 $km^2$ and 65 km in length, its basin is made up of two main tributaries, the

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Sungai Terengganu and the Sungai Nerus (Lee et al. 2017), with the river mouth opening to the South China Sea. It is highly urbanized and has been extensively affected by urban development, marine fish landing, tourism, navigation channels, and other socio-economic activities (Suratman et al. 2018). Its socio-economic importance led the Terengganu state government to construct a semi-enclosed breakwater at the river mouth in 2008. With an opening of 200 m wide and a water depth of 8-10 m (Mohd-Salim et al. 2018), it shelters the Terengganu estuary from offshore waves, providing an environment quiet inner while deepening the area available for navigational purposes (Lee et al. 2017). These artificial barriers successfully reduced the wave energy impacting the coast, thus altering sedimentation rates, organic matter, and nutrient loadings, leading to drastic modifications of the associated benthic assemblages (Airoldi et al. 2005; Martin et al. 2005).

Nutrients carried by rivers contribute to high estuarine productivity (Fatin Adlina et al. 2019), which allows for maintaining a high abundance and diversity of organisms, including primary producers, such as salt marshes, grasses, algae, and phytoplankton. This attracts secondary consumers such as annelids, mollusks, arthropods, fishes, and birds to these areas (van Niekerk et al. 2020). Food is thus one of the main resources widely available in estuaries, with the smaller invertebrate species, including the soft-bodied polychaetes, being among the most appreciated prey for catadromous fish (Fontoura et al. 2019) and coastal birds (Rush et al. 2010).

Polychaetes are among the most abundant and diverse organisms in brackish and marine environments, particularly benthic communities (Martins and Barros 2022). These segmented, soft-bodied organisms are reported worldwide, with over 23,774 accepted extant species (Read and Fauchald 2022). Besides burrowing mainly in the mud and sand, they also inhabit under rocks, among coral crevices, rotten vegetation, algal holdfast, surf grassroots, and coconut husks (Díaz-Castañeda and Reish 2009; Glasby et al. 2021; Rouse et al. 2022). Polychaetes of body lengths from less than one millimeter and up to more than three meters (Al-Omari 2011; Górska et al. 2019) may act as bioturbators and ecosystem engineers while being an essential food web link between organisms with different feeding guilds (Campanyà-Llovet et al. 2017; Bergström et al. 2019; Kim et al. 2021). Moreover, they are typically considered as excellent bioindicators (Giangrande et al. 2005).

Most polychaete studies in Malaysia were conducted on the west coast of Peninsular Malaysia (Nakao et al. 1989a; Ahmad et al. 2011; Gholizadeh et al. 2012; Idris and Arshad 2013; Guan et al. 2014; Rosli et al. 2016), followed by the east coast (Nakao et al. 1989b; Ibrahim et al. 2017, 2019) with very few studies focusing on Sabah and Sarawak (Rosli et al. 2018). Considering the scarce information on polychaetes from the east coast of Peninsular Malaysia and their relationship with anthropogenic organic enrichment in estuarine environments, we are here describing the spatial distribution and diversity of their assemblages in relation to the parameters driving the environment in the Sungai Terengganu estuary.

## Materials and Methods

### Sampling

Sampling was carried out from June 2016 to July 2017 at nine stations (Fig. 1) from oligohaline (0.5–5.0 ppt) and polyhaline (18.0–30.0 ppt) zones (as defined by Montagna et al. 2013), along 7.14 km of the Sungai Terengganu estuary, at intervals of 0.30 to 1.70 km, and affected by different anthropogenic activities (Table 1).

Water temperature, pH, salinity, and dissolved oxygen (DO) were recorded *in situ* in triplicate readings using a Hydrolab Quanta Multiprobe. Three replicate sediment samples were collected at each station using a Smith McIntyre grab with a surface area of 0.05 $m^2$. Approximately 150 g of sediments from each replicate were separated and kept in plastic containers for further analyses of grain size and total organic matter (TOM) in the laboratory. The remaining sediments were wet-sieved through a 500 µ mesh sieve, and the retained polychaetes were extracted and preserved following Rouse et al. (2022) and brought back to the laboratory for identification.

### Laboratory Analyses

The identification of polychaetes to genus level was based on Glasby et al. (2000), Barrosa and Paiva (2007), Sendall and Salazar-Vallejo (2013), Zhadan (2015), and Jeong et al. (2017) and therefore has been used to avoid misidentifications during further monitoring (Masucci et al. 2021). All genera were checked for validity against the World Polychaeta Database (Read and Fauchald 2022). Specimens were stained using methylene blue solution to highlight the key identification character before observation using stereoscopic and compound light microscopes. The number of individuals per species was counted. The density was then expressed as individuals per square meter (ind/$m^2$) and used to estimate the Shannon diversity index, H’ (Shannon 1948), and the Pielou’s evenness index, J’ (Pielou 1975) of the assemblages.

The 150 g sediments from the plastic containers were dried in an oven at 60 °C for 72 h following Bachok et al. (2006). Then, TOM was determined using 5 g of the oven-dried sediments from each replicate by loss-on-ignition method (Sultan and Shazili 2010). Particle size distribution

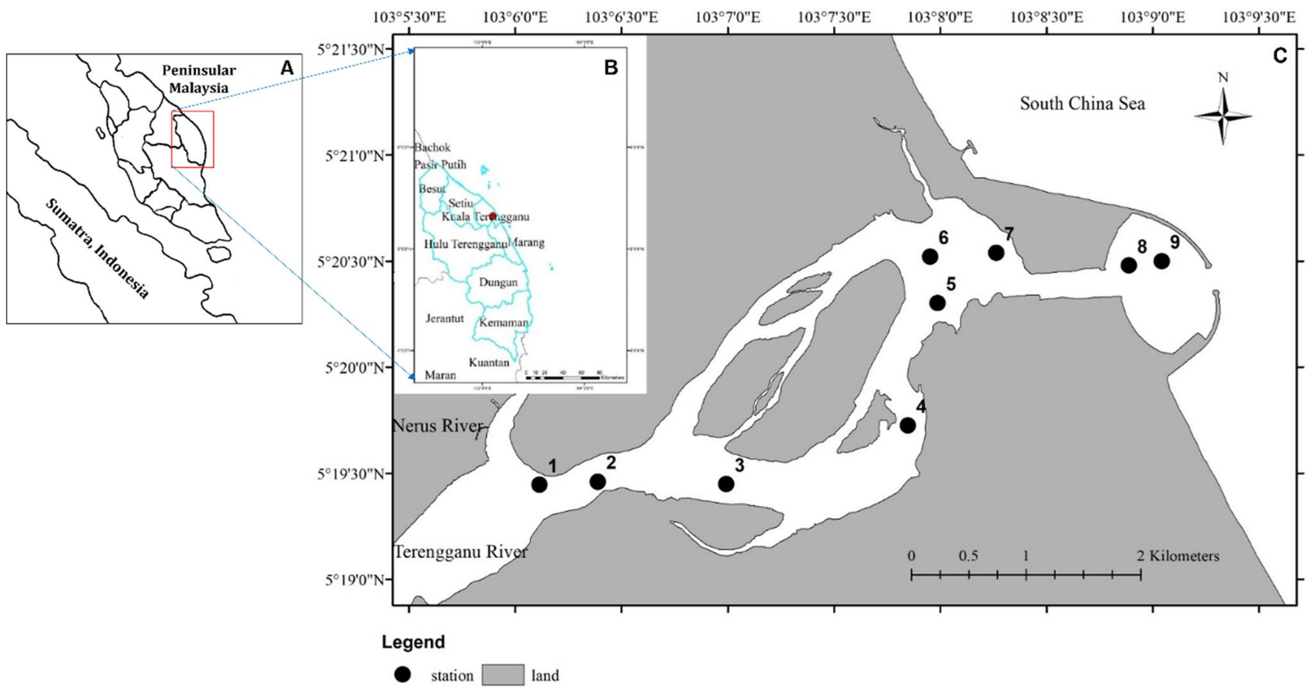



**Fig. 1** Sampling locations. **A** Peninsular Malaysia and Sumatra, Indonesia. **B** Terengganu state; red box showing the Sungai Terengganu estuary. **C** Location of the nine sampling stations in the estuary

**Table 1** Geographical location, description, and zonation of the nine sampling stations

| Station | Latitude (N) | Longitude (E) | Description | Salinity zonation |
|---|---|---|---|---|
| 1 | 5.32407° | 103.1019° | Surrounded by vegetation and housing area with the influence of sand mining activity | Oligohaline |
| 2 | 5.32432° | 103.1065° | Surrounded by vegetation and housing area with the influence of sand mining activity | Oligohaline |
| 3 | 5.32412° | 103.1165° | Located near edutainment park, jetty, and housing area | Oligohaline |
| 4 | 5.32874° | 103.1308° | Located near hotels, restaurants, and jetty with the influence of sand mining activity | Polyhaline |
| 5 | 5.33836° | 103.1331° | Influenced by domestic waste from fresh market and housing area | Polyhaline |
| 6 | 5.34200° | 103.1325° | Located near hotels, restaurants, jetty, housing areas, and aquaculture activity | Polyhaline |
| 7 | 5.34229° | 103.1377° | Located near housing areas and jetty with influence from drawbridge construction | Polyhaline |
| 8 | 5.34131° | 103.1481° | Situated within the semi-enclosed breakwater and influenced by drawbridge construction | Polyhaline |
| 9 | 5.34165° | 103.1507° | Situated within the semi-enclosed breakwater and influenced by drawbridge construction | Polyhaline |

was determined by both dry-sieve (particles ≥ 63 μm) and laser diffraction (particles < 63 μm) methods (Buller and McManus 1979; Bachok et al. 2006) and expressed as percentages of gravel, sand, silt, and clay, while the logarithmic method of moments was used to obtain the mean of sorting and skewness using GRADISTAT.

## Data and Statistical Analyses

Water quality, sediment characteristics, polychaete density, diversity, and evenness were $\log_{10}(x+1)$ transformed and analyzed by the Shapiro–Wilk test to check for normal distributions. Based on the non-normally distributed data (< 0.05), the mean comparisons of the abiotic parameters (water quality and sediment characteristics) and biotic parameters (polychaete' density, diversity, and evenness) among the nine sampling stations were analyzed by the non-parametric Kruskal–Wallis H Test.

The structure of the polychaete assemblages was assessed by hierarchical cluster analysis (CA) based on square root-transformed densities. The resemblance matrix was based on Bray–Curtis similarity, while the similarity profile routine (SIMPROF) was applied to identify the most significant similarity percentage between stations.

The principal component analysis (PCA) was used to assess the relationship between the water quality parameters (temperature, pH, salinity, and DO) and sediment characteristics (percentages of gravel, sand, silt, clay, and TOM) based on square-root transformed data and a Euclidean distance.

The relationships between abiotic and biotic parameters were assessed by the Spearman correlation coefficient based on a 95% confidence limit ($p = 0.05$).

Mean comparison and Spearman correlation analyses were performed using the IBM Statistical Package for Social Science (SPSS) version 20 (Arbuckle 2012), while CA and PCA were conducted using Plymouth Routine in Multivariate Ecological Research (PRIMER) Version 6 (Clarke and Warwick 2001).

## Results

### Abiotic Parameters

The temperature ranged from 27.69 ℃ ± 1.05 ℃ (station 2) to 29.62 ℃ ± 0.81 ℃ (station 9), the pH from 6.21 ± 0.90 (station 3) to 7.22 ± 0.65 (station 8), the salinity from 1.25 ppt ± 5.05 ppt (station 2) to 30.62 ppt ± 3.19 ppt (station 9), and the DO from 4.16 mg/L ± 1.73 mg/L (station 9) to 4.98 mg/L ± 0.99 mg/L (station 4). Temperature, pH, and salinity significantly increased ($p < 0.05$) from oligohaline to polyhaline stations, while DO did not significantly differ ($p > 0.05$) among the stations (Fig. 2; supplementary material).

The sediments in stations 1–5 were dominated by sand (50.02% ± 29.03% to 70.37% ± 19.45%) and gravel (7.92% ± 6.98% to 37.78% ± 14.68%), while in stations 6–9, the sediments consisted of silt (66.84% ± 33.30% to 83.00% ± 5.52%) and clay (8.90% ± 4.23% to 13.11% ± 3.83%) (Fig. 3). TOM ranged between 1.77% ± 1.19% (station 3) and 15.01% ± 7.26% (station 9), being significantly lower ($p < 0.05$) in the oligohaline than in the polyhaline stations (supplementary material).

The sediments in all stations were poorly sorted, which indicates high variability of grain size. In addition, skewness measurement showed all stations had fine skewed distribution except for station 5, which had very fine skewed distribution (Table 2).

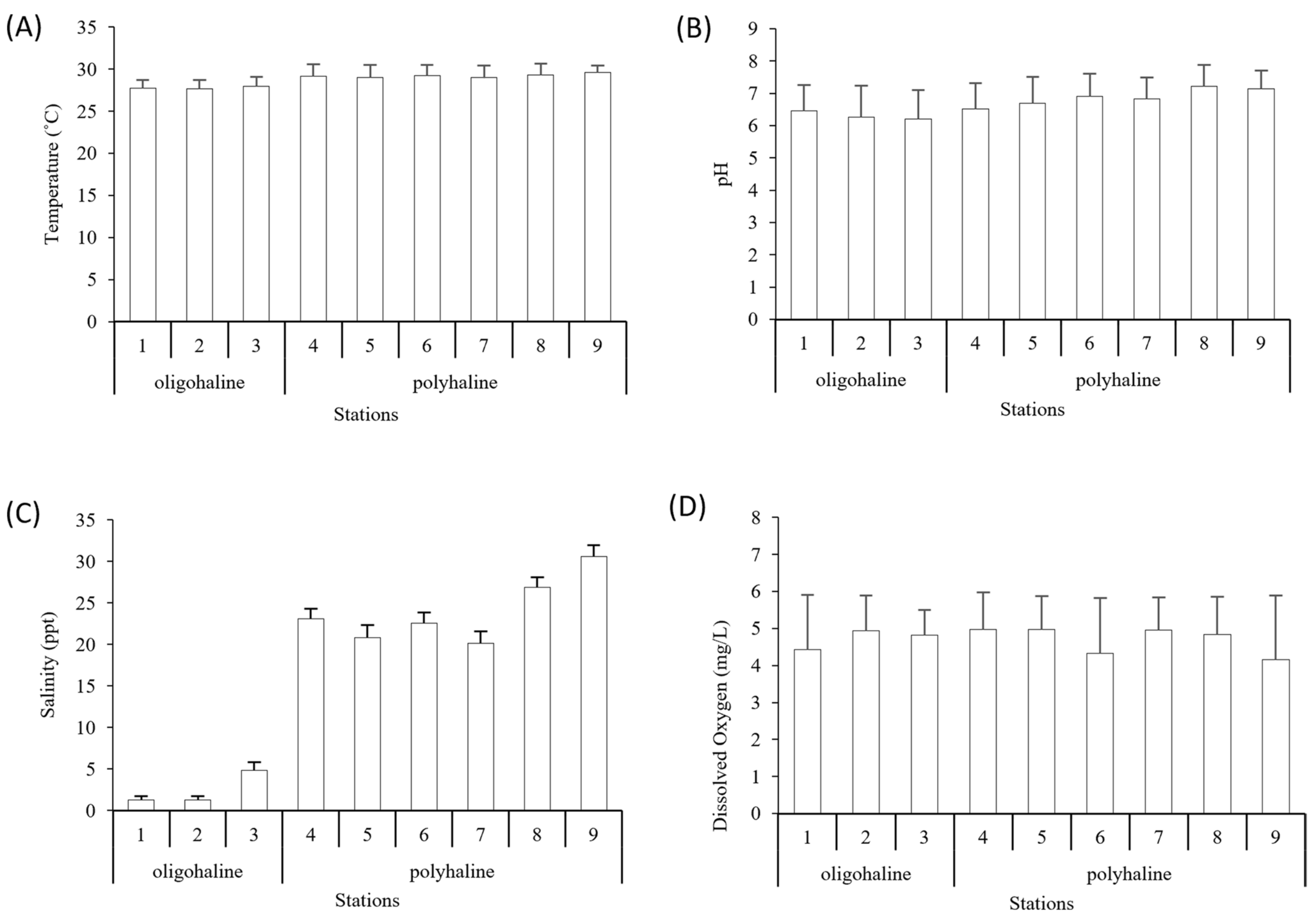



**Fig. 2** Water quality parameters (mean ± standard deviation) at the Sungai Terengganu estuary **A** temperature (°C), **B** pH, **C** salinity (ppt), **D** dissolved oxygen (mg/L)

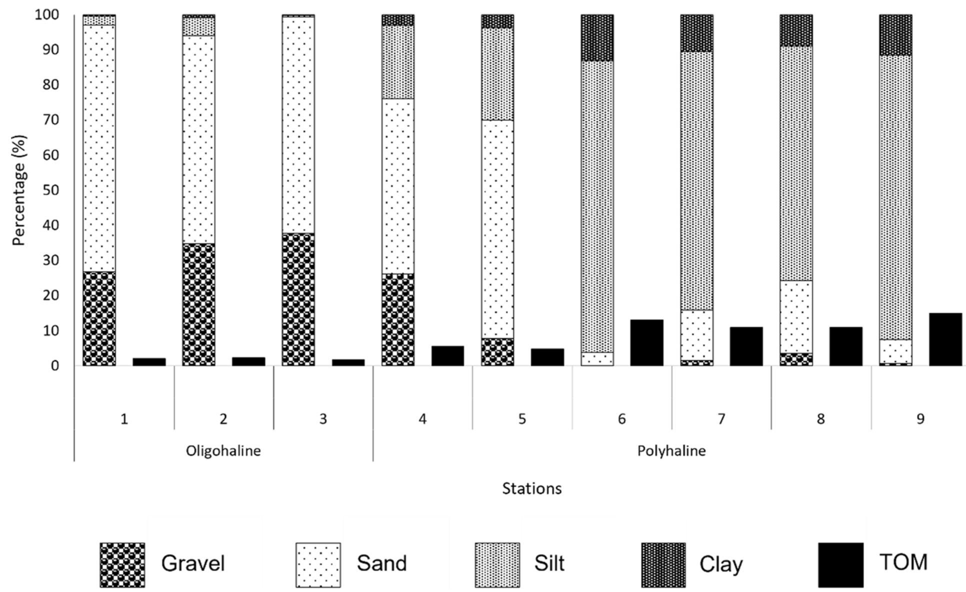



**Fig. 3** Percentages of grain particles (gravel, sand, silt, clay) and total organic matter (TOM) in sediments of the Sungai Terengganu estuary

**Table 2** The mean of sorting (phi) and skewness (phi) of sediments from the Sungai Terengganu estuary

| Station | Sorting (phi) | Description | Skewness (phi) | Description |
|---|---|---|---|---|
| 1 | 1.386 | Poorly sorted | 0.655 | Fine Skewed |
| 2 | 1.325 | Poorly sorted | 0.682 | Fine Skewed |
| 3 | 1.419 | Poorly sorted | 0.669 | Fine Skewed |
| 4 | 1.499 | Poorly sorted | 0.942 | Fine Skewed |
| 5 | 1.660 | Poorly sorted | 1.522 | Very Fine Skewed |
| 6 | 1.739 | Poorly sorted | 0.958 | Fine Skewed |
| 7 | 1.681 | Poorly sorted | 1.197 | Fine Skewed |
| 8 | 1.708 | Poorly sorted | 1.149 | Fine Skewed |
| 9 | 1.774 | Poorly sorted | 1.050 | Fine Skewed |

## Biotic Parameters

A total of 1886 individuals of polychaetes from 24 families and 43 species have been recorded in the Sungai Terengganu estuary (Table 3). The density ranged from 666.67 ind/m$^2$ ± 10.07 ind/m$^2$ (station 1) to 2186.67 ind/m$^2$ ± 12.74 ind/m$^2$ (station 8) and was significantly lower ($p < 0.05$) in the oligohaline than in polyhaline stations (supplementary material).

The most dominant species were *Composetia* sp. (752; 39.87%) in stations 1–5 and *Cossura* sp. (595; 31.55%) in stations 6–9 (Table 3; Fig. 4). The most dominant families were Nereididae (42.21%), Cossuridae (31.87%) and Capitellidae (12.68%) (Fig. 5), followed by Poecilochaetidae, Sternaspidae, Pilargidae, Spionidae, and Paraonidae (3.2% to 1.16%), while Maldanidae, Onuphidae, and Paralacydoniidae were represented by less than 1.0%.

H' ranged from 0.176 ± 0.034 (station 3; oligohaline) to 1.865 ± 0.190 (station 8; polyhaline) and J' from 0.335 ± 0.036 (station 4; polyhaline) to 0.652 ± 0.055 (station 2; oligohaline) (Fig. 6). H' was significantly higher and J' significantly lower in the estuarine river mouth (polyhaline) than in the landward (oligohaline) stations (supplementary material).

## Structure of the Assemblages

Two groups of stations were obtained at 33% of similarity in the CA (Fig. 7), including stations 1–4 (Group 1) and stations 5–9 (Group 2). Group 1 grouped stations homogeneously dominated by *Composetia* sp., whereas those at Cluster 2 were dominated by *Cossura* sp.

## Relationships Between Abiotic Parameters and Polychaete Assemblages

The first two axes of the PCA accounted for 93.4% of the cumulative variation in abiotic parameters, with PC1 explaining the highest percentage (i.e., 81.8%) resulting from an approximately equal-weighted combination of all parameters, except DO (mg/L). Conversely, DO and salinity were the most influencing for PC2 (Table 4). Stations 1–3 and 4–5, grouped along PC1, were associated with gravel and sand, respectively, meanwhile, stations 6–9 were correlated with silt, clay, TOM, temperature, pH, and salinity (Fig. 8).

Density and H' were positively correlated with temperature, pH, and TOM (Table 5), with the former being also positively correlated with salinity, and the latter being

**Table 3** Distribution and abundance of polychaete assemblages throughout the nine sampling stations of the Sungai Terengganu estuary

| Family | Species | Stations | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
| AMPHINOMIDAE | *Linopherus* sp. | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 1 | 6 |
| CAPITELLIDAE | *Capitella* sp. | 0 | 0 | 0 | 3 | 11 | 0 | 0 | 0 | 0 | 14 |
| | *Dasybranchus* sp. | 10 | 0 | 0 | 1 | 2 | 1 | 0 | 1 | 5 | 20 |
| | *Heteromastus* sp. | 0 | 1 | 0 | 2 | 25 | 30 | 52 | 8 | 1 | 119 |
| | *Leiochrides* sp. | 9 | 1 | 0 | 2 | 1 | 1 | 1 | 21 | 21 | 57 |
| | *Leiocapitella* sp. | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 4 |
| | *Mediomastus* sp. | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 1 | 3 | 8 |
| | *Notomastus* sp. | 4 | 0 | 0 | 0 | 3 | 2 | 0 | 4 | 1 | 14 |
| CIRRATULIDAE | *Cirratulus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| | *Tharyx* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| COSSURIDAE | *Cossura* sp. | 0 | 6 | 0 | 4 | 49 | 106 | 154 | 167 | 109 | 595 |
| DORVILLEIDAE | *Protodorvillea* sp. | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| EUNICIDAE | *Eunice* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 6 |
| | *Marphysa* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| FLABELLIGERIDAE | *Pherusa* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| GLYCERIDAE | *Glycera* sp. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 7 | 6 | 14 |
| GONIADIDAE | *Goniada* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | *Goniadella* sp. | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| LUMBRINERIDAE | *Abyssoninoe* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 5 |
| | *Augeneria* sp. | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 |
| MALDANIDAE | *Axiothella* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| NEREIDIDAE | *Composetia* sp. | 66 | 96 | 99 | 224 | 104 | 41 | 31 | 27 | 64 | 752 |
| | *Leonnates* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 3 |
| | *Namalycastis* sp. | 11 | 27 | 3 | 1 | 0 | 3 | 0 | 0 | 0 | 45 |
| | *Nereis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| | *Gymnonereis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| NEPHTYIDAE | *Aglaophamus* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 3 | 9 |
| OPHELIIDAE | *Ophelina* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| ONUPHIDAE | *Diopatra* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| ORBINIIDAE | *Leitoscoloplos* sp. | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 2 |
| PARALACYDONIIDAE | *Paralacydonia* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| PARAONIDAE | *Aricidea (Acmira)* sp. | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 14 | 4 | 21 |
| | *Aricidea (Aedicira)* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| PILARGIDAE | *Ancistrosyllis* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | *Cabira* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| | *Sigambra* sp. | 0 | 0 | 0 | 0 | 2 | 7 | 7 | 6 | 3 | 25 |

**Table 3** (continued)

| Family | Species | Stations 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| POECILOCHAETIDAE | *Poecilochaetus* sp. | 0 | 0 | 0 | 2 | 0 | 0 | 51 | 3 | 4 | 60 |
| SPIONIDAE | *Microspio* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | *Prionospio* sp. | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 8 | 6 | 18 |
| | *Pseudopolydora* sp. | 0 | 7 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 9 |
| STERNASPIDAE | *Sternaspis* sp. | 0 | 0 | 0 | 0 | 0 | 8 | 6 | 25 | 5 | 44 |
| SYLLIDAE | *Syllis* sp. | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 4 | 2 | 8 |
| TEREBELLIDAE | *Loimia* sp. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| Total no. of individuals | | 100 | 139 | 103 | 240 | 212 | 205 | 311 | 328 | 248 | 1886 |
| Total no. of species | | 5 | 7 | 3 | 9 | 17 | 13 | 14 | 29 | 24 | 43 |
| Total no. of family | | 2 | 3 | 2 | 5 | 11 | 8 | 10 | 19 | 16 | 24 |
| Density (ind/m$^2$) | | 666.67 ± 10.07 | 926.67 ±19.14 | 686.67 ±16.07 | 1600.00 ±50.76 | 1413.33 ± 37.45 | 1366.67 ± 10.26 | 2073.33 ± 11.24 | 2186.67 ± 12.74 | 1653.33 ±31.66 | |

positively correlated with silt and clay and negatively with gravel (Table 5). No significant correlations were found between J' and these abiotic parameters.

The high densities of *Cossura* sp. occurred in association with the highest temperature, salinity, and silt and clay contents, as well as with the lowest gravel contents (Fig. 9A), while *Composetia* sp. showed exactly an opposite trend (Fig. 9B).

## Discussion

The polychaete assemblages found in our study differs from the previous study in Sungai Terengganu by Nakao et al. (1989b) in the absence of Ampharetidae, Phyllodocidae, and Oweniidae, which are now replaced by representatives of 24 different families, of which Nereididae, Cossuridae, Capitellidae, Poecilochaetidae, Sternaspidae, Pilargidae, Spionidae, and Paraonidae showed > 1% in abundance. The increasing taxonomic complexity is probably related to the higher sampling frequency and covered area, and also differences in sampling methods (Rosli et al. 2018). Our study included nine stations along the whole estuary, versus the five downstream ones in Nakao et al. (1989b). Additionally, the reference materials were restricted and the involvement of polychaete taxonomists were limited in 1989 which, together with the absence of voucher specimens, raises some doubts on the validity of the identification.

In general, the oligohaline area is dominated by *Composetia* sp. (except in stations 4–5), while *Cossura* sp. dominates the polyhaline area (stations 6–9), which can be explained by these stations having particular specific characteristics in terms of salinity, sediment texture, and organic matter content (Rehitha et al. 2019). The capability of an organism to be adapted to altered physical environments and the resulting abiotic interactions are directly related to its capacity to survive, with the persistence of the environmental changes having direct and indirect impacts on biota endurance. *Composetia* sp., for example, has broad tolerance to environmental changes, which allows it to be dominant in most studied stations. Its co-occurrence with *Cossura* sp. appears to be possible thanks to their differences in feeding habits (Checon et al. 2017), as *Composetia* sp. is an omnivore, and *Cossura* sp. is a surface deposit feeder (Jumars et al. 2015). So, they are exploiting different compartments allowing them to avoid competing for the same food sources.

The polyhaline area was able to support higher polychaete densities than the oligohaline, as found in the Eastern Brazil Marine Ecoregion, Brazil (Bissoli and Bernardino 2018) and the Chesapeake Bay, Virginia USA (Seitz et al. 2011). In addition to salinity, sediment characteristics also influence the polychaete density and distribution (Rosli et al. 2018). The highest number of species and density were associated

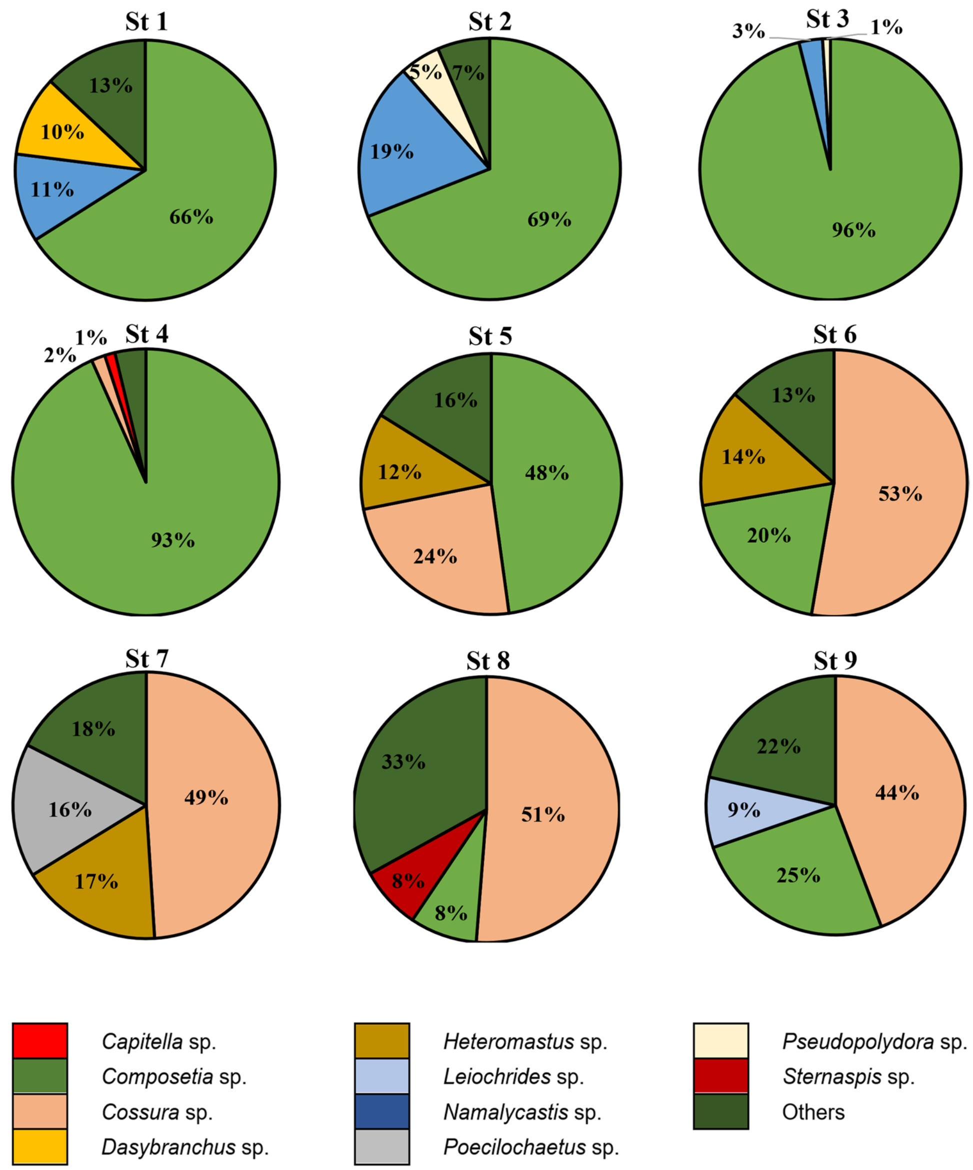



**Fig. 4** Relative abundances (as %) of the polychaete species in Sungai Terengganu estuary. St: Station

with the highest silty-clay and TOM contents at stations 6–9 (i.e., within the area semi-enclosed by the breakwater), which coincided with the finding of finer sediment, possibly caused by the lowering in water energy (Masucci et al. 2020). In contrast, the lowest number of taxa occurred in station 3, with the highest percentage of gravel and the lowest of sand, silt, and TOM. Moreover, the granulometry (and, thus, the associated assemblages) at this station was certainly affected by the infrastructure construction and sand mining nearby. Sediment organic content tends to decrease with the increasing grain size (Evans et al. 1990), with coarser sediments (i.e., sand and gravel) having a loose structure, difficulting an efficient organic matter retention (Soto et al. 2017). Conversely, silty-clayish sediments show a higher absorptive capacity and greater surface area, which explains their positive relationship with organic matter. This higher capacity of organic retention provides a vital food source for soft-bottom species (Soto et al. 2017), which favoured the presence of a high density of polychaetes (Rosli et al. 2018) in terms of biomass, and species (Dikaeva and Frolova 2020), and the Sungai Terengganu estuary is not an exception.

The spatial distribution of *Cossura* sp. was significantly influenced by the ratio of silt and clay *vs.* gravel, as reported for *Cossura coasta* Kitamori, 1960 (Varghese and Miranda 2014; Feebarani et al. 2016). The species of *Cossura* are deposit feeders being often abundant in silty areas (Musale et al. 2015), likely because fine sediments tend to have more available organic matter (Jayaraj et al. 2008). Therefore, we hypothesize that our species of *Cossura* could be better adapted to feed in muddy rather than in silty bottoms. *Cossura* sp. also dominates in stations 8–9. As some species

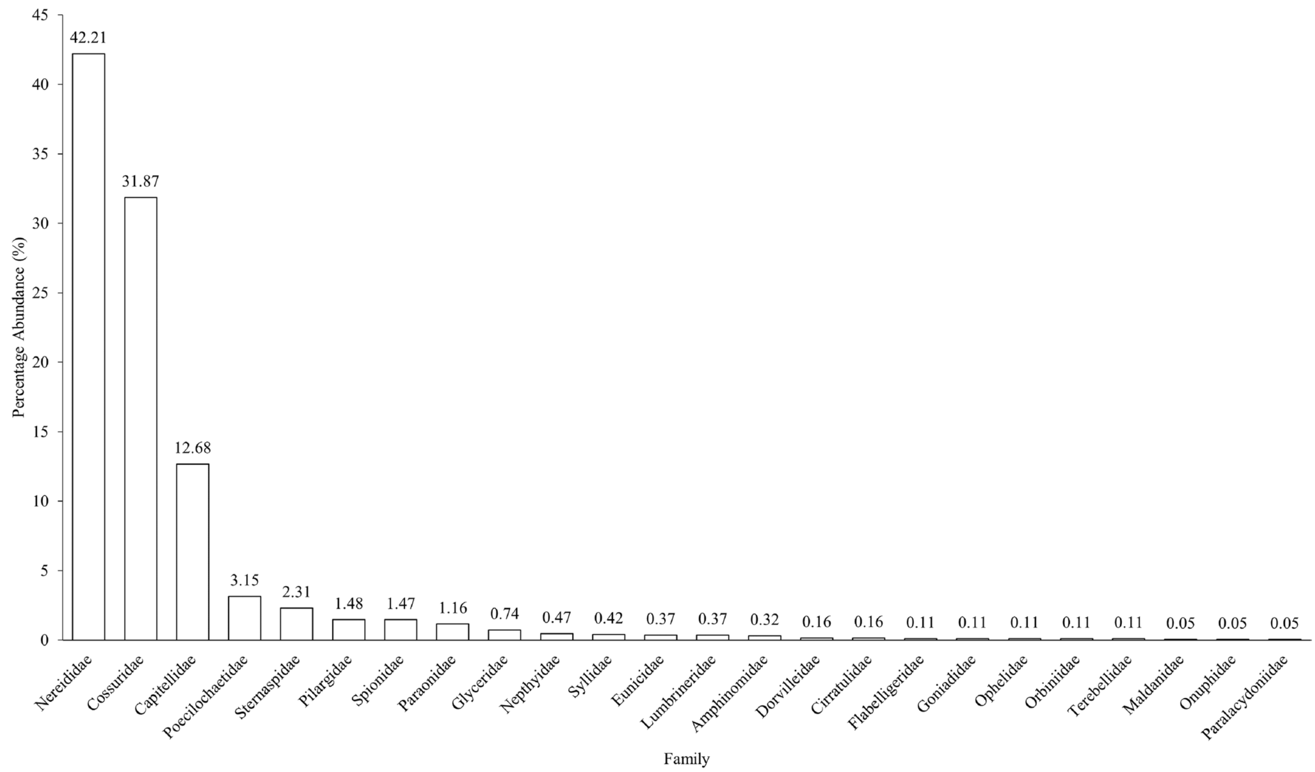
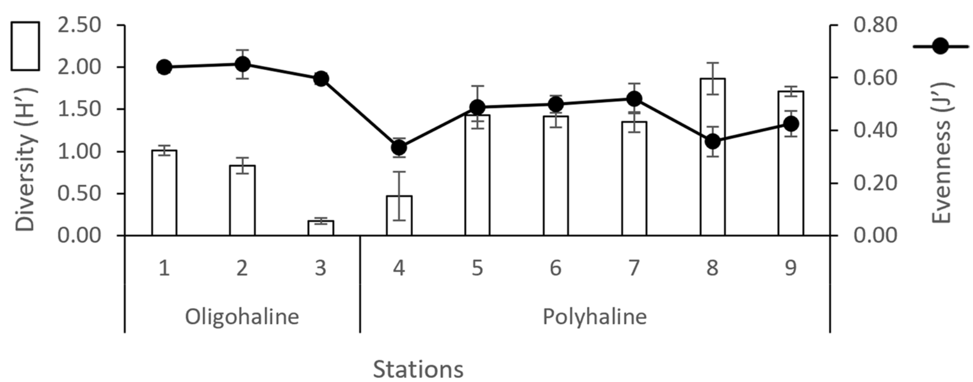



**Fig. 5** Relative abundances (as %) of the polychaete families found in the Sungai Terengganu estuary during the whole sampling period

**Fig. 6** H' and J' of the polychaetes assemblages (mean ± standard deviation) in the Sungai Terengganu estuary




of this genus have been reported as being an opportunistic and well adapted to survive in stressful environments, its presence suggests that the area might be organically polluted by urban runoff or sewage, as it occurs in the Wulan Delta estuary, Indonesia (Fadlillah et al. 2017). Polychaete diversity and abundance seem to be higher in modified than in non-modified estuaries, with organic enrichment contributing to an increased nutrient level and thus also polychaete diversity (Zan et al. 2015). *Composetia* sp. was dominant in the stations with high gravel content, although it also occurred (with much lower densities) in stations with high silt and clay contents. This suggests a wide trophic range, with a preference for macrophagic over filter or deposit feeding, allowing it to better survive in these conditions. The dominance of *Composetia* sp. also explains the lowest J' recorded at station 3, while at the nearby station 2, the equivalent representation of all species present gives rise to a much higher J'. Therefore, our data agree with the common trend of coarse sediments being dominated by carnivores and omnivores, and fine sediments being mainly dominated by deposit feeders (Abrogueña et al. 2021).

Besides silty-clay and TOM contents, higher polychaete density and H' were favored in the area with higher pH (polyhaline, downstream), as reported by van der Linden et al. (2017). Diversity was higher at the river mouth (polyhaline) than landward (oligohaline), as in the Uppanar and

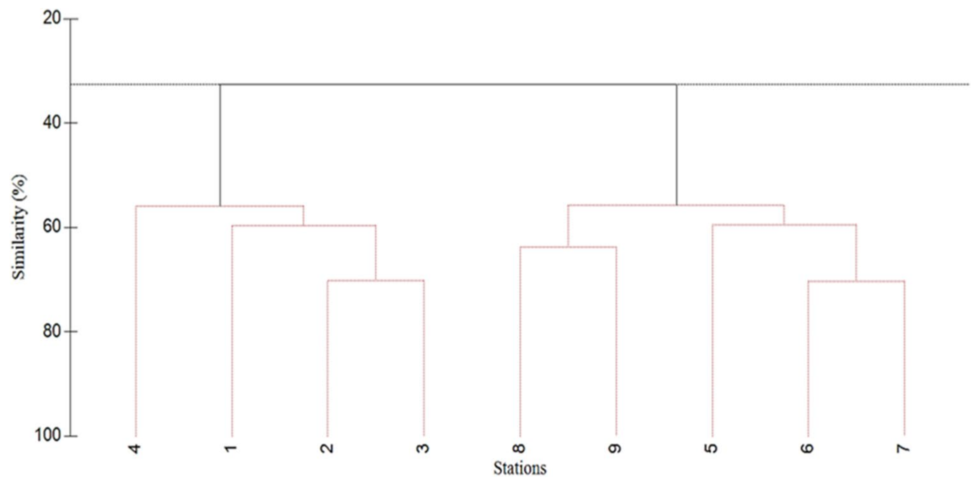



**Fig. 7** Dendrogram showing the cluster analysis result based on polychaete densities in the Sungai Terengganu estuary. Red vertical lines: $p > 0.05$, SIMPROF

Vellar estuaries, India (Ajmal-Khan et al. 2014). By affecting the tolerance to physiological stress (Carrier-Belleau et al. 2021), salinity often combines with depth, sediment grain size, and organic content to explain the spatial patterns of polychaete diversity in estuaries (Holzhauer et al. 2019). However, the overall H' in the Sungai Terengganu estuary was very low (i.e., <2.0), as it seems to be common in estuarine ecosystems, and being often in relation to high abundances of some macro-invertebrates taxa, as well as to the high levels of environmental variability (Xue et al. 2019). In India, a low polychaete diversity was related to anthropogenic pollutants in Thane creek (Quadros et al. 2009) and to disturbances by waterway dredging in the navigation channel of Mumbai Port (Sukumaran and Devi 2009). In the Sungai Terengganu estuary, we hypothesize that the low polychaete diversity could likely be attributed to urbanization and sand mining activities.

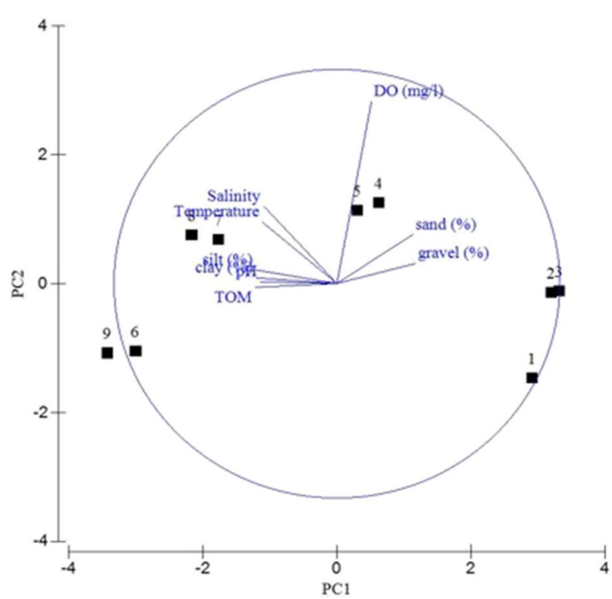



**Fig. 8** PCA biplot of abiotic parameters at nine sampling stations of the Sungai Terengganu estuary

**Table 4** The coefficient values of spatial water quality parameters and sediment characteristics

| Variables | PC1 | PC2 |
|---|---|---|
| Temperature (°C) | - 0.336 | 0.287 |
| pH | - 0.344 | 0.008 |
| Salinity (ppt) | - 0.327 | 0.359 |
| DO (mg/L) | 0.155 | 0.850 |
| TOM (%) | - 0.366 | - 0.018 |
| Gravel (%) | 0.352 | 0.094 |
| Sand (%) | 0.340 | 0.229 |
| Silt (%) | - 0.363 | 0.063 |
| Clay (%) | - 0.363 | 0.026 |

**Table 5** Spearman correlation coefficients between abiotic and biotic parameters in the Sungai Terengganu estuary

| Parameters | Density | Diversity |
|---|---|---|
| Temperature | 0.700* | 0.717* |
| pH | 0.800* | 0.950* |
| Salinity | 0.733* | |
| DO | | |
| TOM | 0.733* | 0.833* |
| Gravel | | −0.833* |
| Sand | | |
| Silt | | 0.817* |
| Clay | | 0.817* |

"*" indicates the significance level at $p < 0.05$

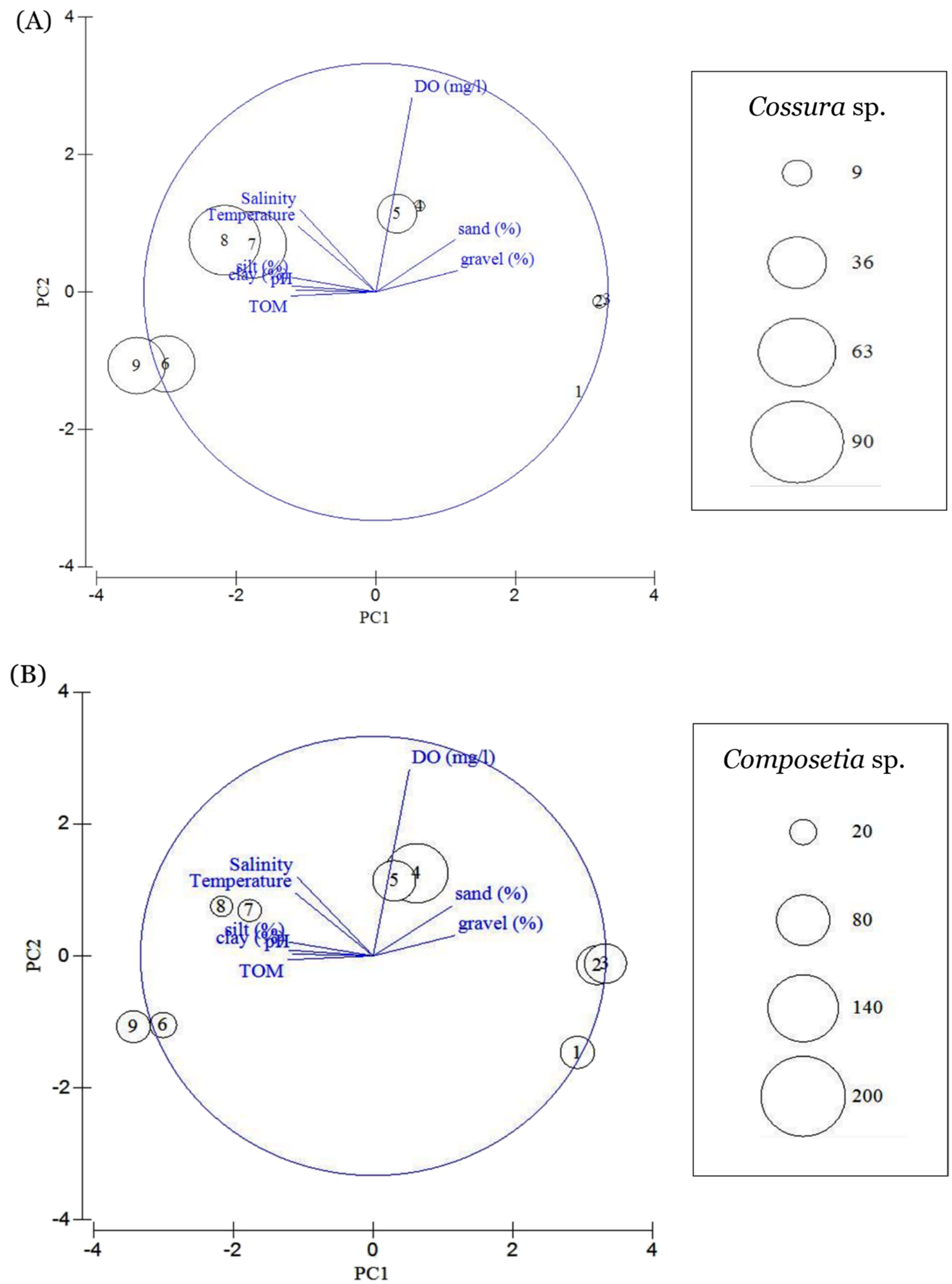



**Fig. 9** Densities of (**A**) *Cossura* sp. and (**B**) *Composetia* sp. plotted in the first two PCA ordination axis (PC1 and PC2). Bubble: ind/m$^2$

## Conclusion

The present study documented 43 polychaete taxa along the Sungai Terengganu estuary. Stations 1–5 (landward), dominated by *Composetia* sp., mainly had sand and gravels, while stations 6–9 (estuarine river mouth), dominated by *Cossura* sp., mainly had silt and clay sediments. The organic matter content was significantly lower in the oligohaline (1–3) than in the polyhaline (4–9) stations. Density and diversity were significantly lower in the oligohaline than in the polyhaline stations, and were positively correlated with temperature, pH, and total organic matter. We are thus concluding that, in the Sungai Terengganu estuary, the polychaete assemblages are influenced by complex interactions of water quality parameters and sediment characteristics, most likely including the influence of artificial constructions and urban waste pollution.

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**Authors Contributions** NSA designed the research, performed data collection and analysis, supervised by II and ZB. MAH and NFI prepared and revised the original drafts of the manuscript, performed data analysis, and edited by II. All authors read and approved the final manuscript.

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**Data Availability** The datasets used and analysed during the current study are available from the authors upon reasonable request.

**Code Availability** Not applicable.

## Declarations

**Ethics Approval** No ethics approvals were required for this research.

**Consent to Participate** Not applicable.

**Consent for Publication** Not applicable.

**Competing Interests Statement** The authors declare no conflicts of interest.

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