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DOES HIGH ORGANIC MATTER CONTENT AFFECT POLYCHAETE ASSEMBLAGES IN A SHENZHEN BAY MUDFLAT, CHINA?

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Key words: macrofauna, polychaete, organic matter, intertidal mudflat, China, Shenzhen Bay.

ABSTRACT

Coastal areas are the first marine systems being impacted by anthropogenic pollution and eutrophication. Organic matter poses a particularly negative impact on the environment due to its oxygen depleting and eutrophying effects. Shenzhen Bay mudflat contains rich organic matter. Here, we compare changes of polychaete assemblage parameters on seasonal data obtained from a Shenzhen Bay mudflat in a three-year study. The results based on the seasonal and spatial variations of polychaete species number, density and biomass, Shannon-Wiener diversity index, evenness index and richness index confirmed that high organic matter content impacted their distribution. A significant negative correlation between the density and biomass of *Dendronereis pinnaticirris* and *Neanthes glandicincta* and organic matter content is explained by their limited tolerance to high organic matter exposition. A significant positive correlation between the density and biomass of *Namalycastis abiuma* and *Capitella capitata* and organic matter content is explained by their preference for organically enriched environments.

I. INTRODUCTION

The net carbon status and carbon dynamics of different coastal systems received increased attention recently [7, 8, 12-14, 25, 37]. The coastal mudflats ecosystem functioning is largely mediated by deposit-feeders that process material and energy connecting the main oceanic realms, as well as benthic and pelagic systems [27, 28, 31, 53]. Macrofauna are key components in the functioning of soft bottom coastal marine systems [38]. Macrofauna in marine sediments play an important role in ecosystem processes such as burial and dispersion off secondary production, nutrient cycling in general, and the metabolism of pollutants. They also change physical and chemical parameters of sediments, particularly those close to the sediment-water-column interface. They, in turn, show a close relationship to organic content, food availability in general, and grain size [20]. Deposit-feeders inhabiting the sediment are dependent on settled organic matter that may originate from primary producers but increasingly also from anthropogenic input [22, 32-35, 45]. Other important sediment parameters are grain size, organic content and food availability [23]. In turn provide deposit-feeding macrofauna an important trophic link back to the pelagic realm when predated, e.g. by fish and birds [12, 38]. Bioturbation by sedimentary fauna either leads to enhanced mineralization [9, 29, 51, 56] or burial of organic matter [16, 17, 57].

Among the macrofauna, polychaetes provide several sedentary deposit feeders [41, 48] and are generally suitable candidates for research into the impacts of anthropogenic disturbances of marine bottoms because they occupy a diverse array of ecological niches and thus reflect the diversity of habitat, feeding, and reproductive adaptations of other macrofauna [18, 23, 24, 50]. Polychaetes are used meanwhile in biomonitoring programs worldwide as organic pollution indicators to survey the health status of the coastal environment [19]. Of all the invertebrate groups studied in mangrove environments, polychaetes are suggested as key indicators of anthropogenic disturbances [20, 46].

Polychaetes were often connected in the past to the concept of opportunistic species being able to proliferate after an increase in organic matter. This made them suitable indicators for anthropogenic organic impact on soft-bottoms [19, 47]. Increasing experiences with this group, suggests that not only opportunistic species but also rather specialized species can provide suitable indicators [23]. The

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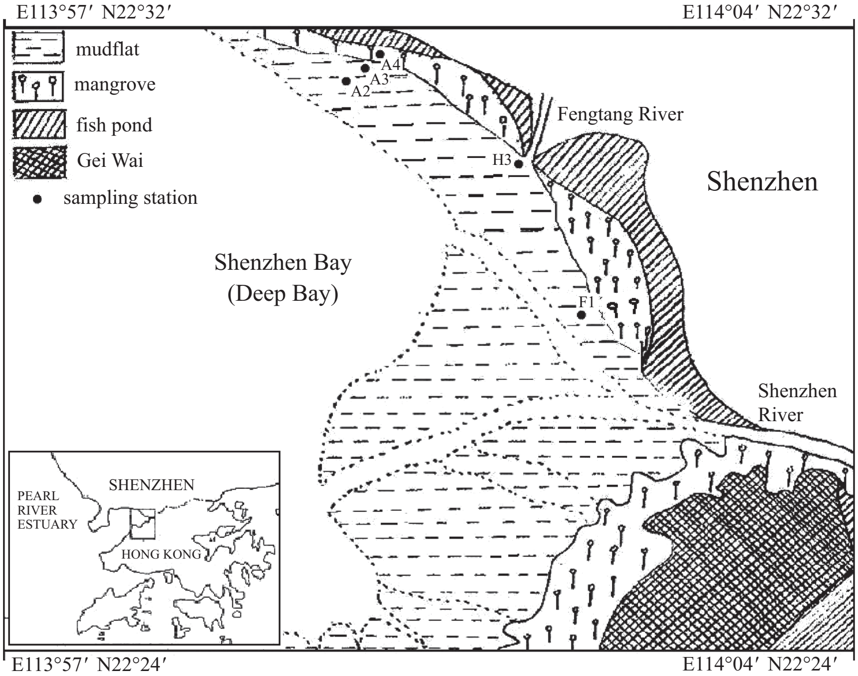

Fig. 1. Sampling stations of macrofauna in a Shenzhen Bay mudflat, China.

polychaetes *Dendronereis pinnaticirris* Grube 1878, *Neanthes glandicincta* Southern 1921 and *Namalycastis abiuma* Müller 1871 are important components of the endobenthos and constitute an important food resource for migrating waterfowl in the Futian intertidal mangrove and mudflat in Shenzhen Bay [1-5, 21, 26]. Some polychaetes are used primarily to ingest sediment deposits, but it is also capable of grazing some plant material and of facultative capture of small invertebrates [11].

The benthic biomass of the mudflat under study was dominated by nereid polychaetes of the genera *Dendronereis* and *Neanthes* and sabellid polychaetes of the genus *Potamilla* [1, 65]. These animals, therefore, are important structural and functional components of their respective environments, and provide food for shore birds. At the same time there is evidence that these populations may be under considerable stress due to man-made disturbances [4].

The Shenzhen Bay (Deep Bay) receives a rich supply of organic matter from the Pearl River and nearby streams [61]. Organically enriched sediments provide an abundant supply of food to the benthic infauna [42, 43, 62, 65]. Accumulation of high levels of organic matter in the sediments below fish farms has created environmental problems in coastal regions around the world, which not only results in the deterioration of habitats neighboring fish cultures, but also causes the ambient coastal zone to suffer from organic pollution [49, 59, 63]. Causal relationships have been shown between pollutants and benthic fauna, such as crabs [39, 40, 52].

Our research followed the assumption that populations and communities of benthic macrofauna and particularly of infaunal polychaetes would respond in their temporal succession as well as in developing a spatial gradient on mudflats that were differently enriched with organic material. The specific aim of this study was to test whether and how assemblage parameters of the four most dominant polychaete species responded to a high organic matter content based on a three-year continuous record of macrofaunal data.

II. MATERIAL AND METHODS

1. Study Area

Shenzhen Bay (Deep Bay) is located at 113°53′-114°05′E and 22°30′-22°39′N with an area of 75 km^2 [60]. It covers a shallow area of 115 km^2 of less than 6 m depth, with an average depth of 2.9 m, and a tidal range of 2.8 m. The intertidal mudflat of Shenzhen Bay covers an area of 27 km^2 at low tide. The upper margins of the mudflat are dominated by mangroves. The area is an important staging post for wintering waterfowl and migrant shorebirds. Since the 1980s, the industry of the Shenzhen Economic Zone was developing fast along the Shenzhen River and Deep Bay disturbing the area by pollution from various industries, aquaculture and municipal wastes [64].

A longitudinal transect including three sampling stations (A2, A3 and A4) and a horizontal transect including three sampling stations (A3, H3 and F1) was sampled seasonally from 2005 to 2007. Along the longitudinal transect taken near an Ecological Park, sampling station A2 was on an open mudflat, station A3 was between a mangrove and an open mudflat, and station A4 was inside the mangrove (Fig. 1). Sampling station H3 and F1 were near the Fengtang River outfall and the Shenzhen River estuary, respectively. Both of them were in the region between mangrove and mudflat.

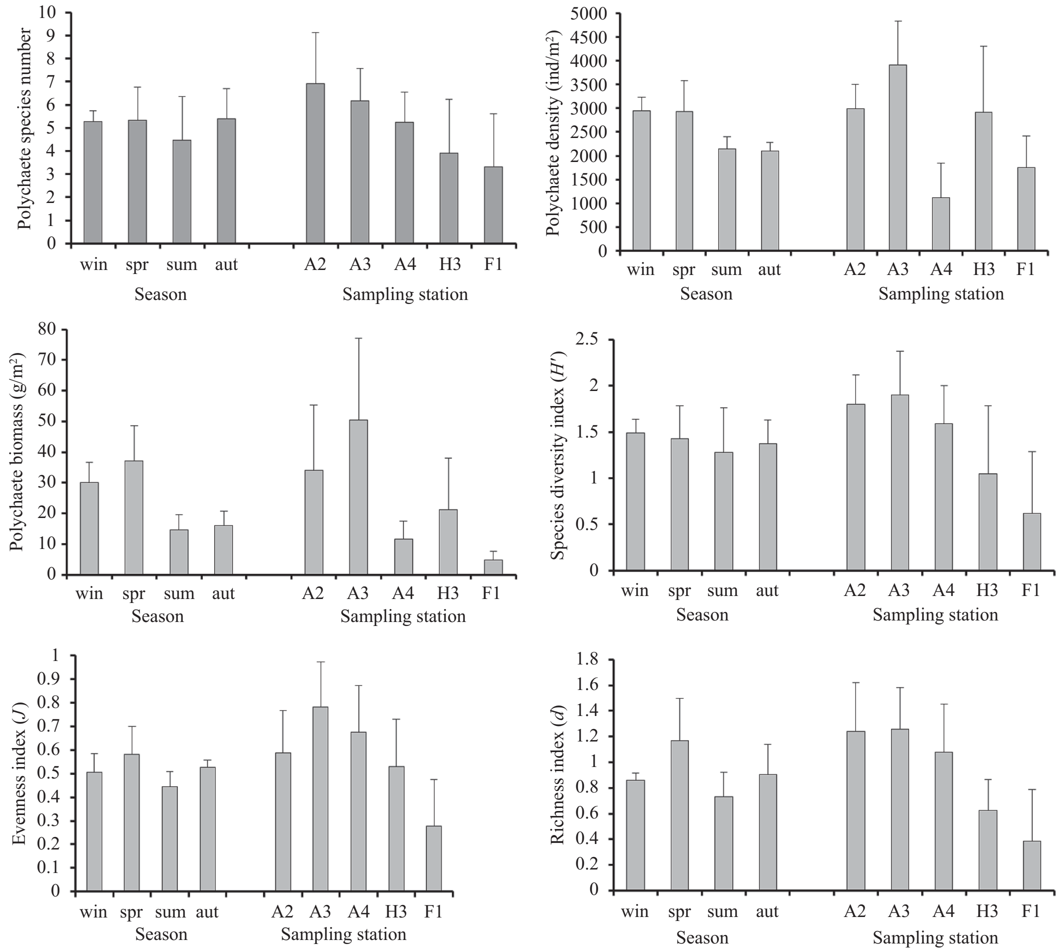

Fig. 2. Spatial and temporal fluctuations of polychaete parameters in a Shenzhen Bay mudflat.

2. Sampling and Data Analyses

Five replicate plastic core samples (diameter 10 cm, length 20 cm) were collected from each sampling station at low tide at each sampling time. The samples were processed through a 0.5 mm sieve. The organisms retained on the sieve were preserved with formalin, stained with Rose Bengal, and taken to the laboratory for sorting again, identification, counted under a dissecting microscope, and weighed with an electronic balance (0.1 mg). Polychaete individuals were counted according to the number of their heads.

Three replicate plastic core samples (10 cm in diameter) were taken from the top 5 cm sediment layer at each sampling station for sediment analysis simultaneously with the biological samples. Organic matter content of these samples was measured by ignition in an combustion oven over 16 h at 375°C, after drying at 90°C to a constant weight according to [54].

During the present research, 60 data sets from five sampling stations were selected during 4 seasons throughout three years, respectively (from 2005 to 2007). Each data set included organic matter content, polychaete density, biomass, species diversity index, richness index, densities and biomass of *D. pinnaticirris*, *N. glandicincta*, *N. abiuma* and *C. capitata*. Univariate two-way ANOVA was used to investigate differences between seasons (winter, spring, summer and autumn) and stations (A2, A3, A4, H3 and F1) for organic matter content, polychaete density, biomass, species diversity index, richness index, densities and biomass of the 4 polychaete species mentioned above with SPSS statistical software package. Nonparametric correlations (Spearman) were performed between polychaete density and organic matter with SPSS software.

III. RESULTS

1. Seasonal and Spatial Variations of Polychaete Assemblages in a Shenzhen Bay Mudflat

Twenty-five species of polychaetes in a Shenzhen Bay mudflat have been collected from 2005 to 2007. The common species were *D. pinnaticirris*, *N. glandicincta*, *Potamilla acuminata*, *N. abiuma*, *C. capitata*, *Chaetozone setosa*, *Nephtys oligobranchia*. The mean density percentage of *D. pinnaticirris*, *N. glandicincta*, *N. abiuma*, *C. capitata* during our three-year study were 2.18, 12.32, 2.41 and 16.50, respectively. The mean biomass percentages of *D. pinnaticirris*, *N. glandicincta*,

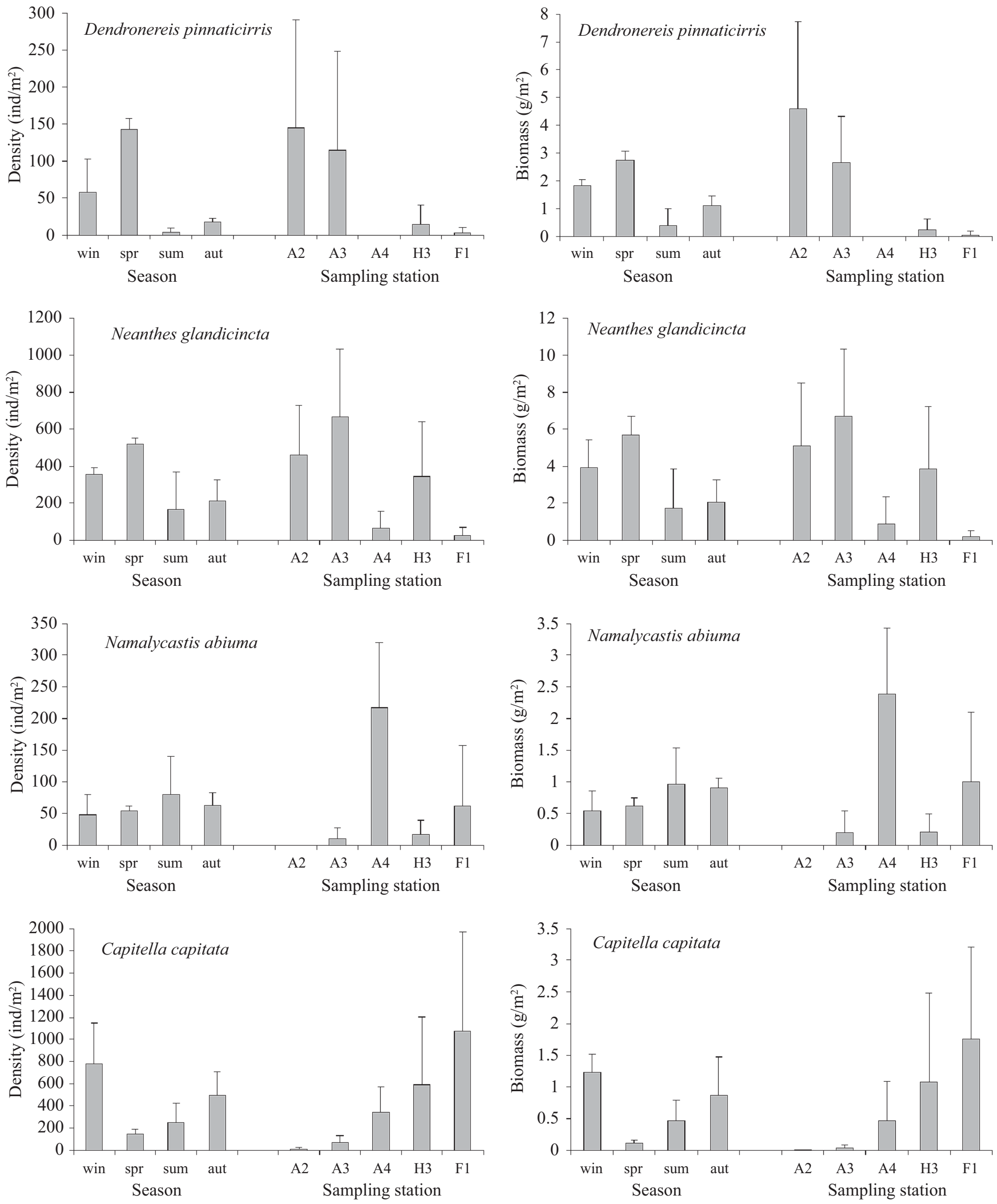

Fig. 3. Spatial and temporal fluctuations in four polychaete densities and biomass in a Shenzhen Bay mudflat.

N. abiuma, *C. capitata* in our three-year study were 6.16, 13.30, 3.09 and 2.72.

The seasonal variations of polychaete species number, biomass, species diversity index, evenness index and richness index were different, but all of them were low in summer (Fig. 2). At the longitudinal transect, the polychaete density, biomass, species diversity index, evenness index and richness index were all highest at sampling station A3, second highest at sampling station A2 and lowest at sampling station A4. At the horizontal transect, the polychaete density, biomass, species diversity index, evenness index and richness index were all highest at sampling station A3, second highest at sampling station H3 and lowest at sampling station F1 (Fig. 2).

Univariate tests on the distribution of polychaete density and biomass revealed that both of them were significantly influenced by season, station and season × station. Except for season and season × station, polychaete species number, species diversity index and evenness index were significantly affected by station. Except for season × station, the richness index was significantly affected by season and station (Table 1).

2. Seasonal and Spatial Variation of Four Polychaete Species in a Shenzhen Bay Mudflat

Both the densities of *D. pinnaticirris* and *N. glandicincta* were highest in spring, second highest in winter, third highest in autumn and lowest in summer. The density of *N. abiuma* was highest in summer but the density of *C. capitata* was highest in winter (Fig. 3).

Table 1. Univariate Two-way ANOVA tests of polychaete parameters and organic matter content.

Polychaete parameters and organic matter		df	F	Significance
Polychaete species number	Season	3	0.770	0.518
	Station	4	7.249	< 0.001[c]
	Season × Station	12	1.147	0.352
Polychaete density	Season	3	4.570	0.008[b]
	Station	4	20.137	< 0.001[c]
	Season × Station	12	2.898	0.006[b]
Polychaete biomass	Season	3	10.740	< 0.001[c]
	Station	4	23.869	< 0.001[c]
	Season × Station	12	2.104	0.039[a]
Species diversity index	Season	3	0.389	0.762
	Station	4	11.130	< 0.001[c]
	Season × Station	12	0.884	0.569
Evenness index	Season	3	0.345	0.793
	Station	4	6.743	< 0.001[c]
	Season × Station	12	0.928	0.529
Richness index	Season	3	3.816	0.017[a]
	Station	4	12.171	< 0.001[c]
	Season × Station	12	0.499	0.903
Density of *D. pinnaticirris*	Season	3	52.958	< 0.001[c]
	Station	4	51.902	< 0.001[c]
	Season × Station	12	16.218	< 0.001[c]
Density of *N. glandicincta*	Season	3	8.299	< 0.001[c]
	Station	4	21.576	< 0.001[c]
	Season × Station	12	1.660	0.114
Density of *N. abiuma*	Season	3	0.691	0.563
	Station	4	21.679	< 0.001[c]
	Season × Station	12	0.567	0.855
Density of *C. capitata*	Season	3	8.522	< 0.001[c]
	Station	4	14.479	< 0.001[c]
	Season × Station	12	2.589	0.012[a]
Biomass of *D. pinnaticirris*	Season	3	20.034	< 0.001[c]
	Station	4	68.376	< 0.001[c]
	Season × Station	12	7.590	< 0.001[c]
Biomass of *N. glandicincta*	Season	3	12.849	< 0.001[c]
	Station	4	23.666	< 0.001[c]
	Season × Station	12	2.240	0.018[a]
Biomass of *N. abiuma*	Season	3	1.378	0.263
	Station	4	24.105	< 0.001[c]
	Season × Station	12	1.030	0.442
Biomass of *C. capitata*	Season	3	6.123	0.002[b]
	Station	4	11.814	< 0.001[c]
	Season × Station	12	2.434	0.018[a]
TOM	Season	3	5.894	0.020[a]
	Station	4	311.109	< 0.001[c]
	Season × Station	12	0.691	0.750

[a]: significant at the 0.05 level; [b]: significant at the 0.01 level; [c]: significant at the 0.001 level.

Both the densities and biomass of *D. pinnaticirris* and *N. glandicincta* at our horizontal transect were highest at sampling station A3, second highest at station H3 and lowest at station F1, but both the densities and biomass of *N. abiuma* and *C. capitata* were reverse (Fig. 3).

Univariate tests on the density and biomass of *D. pinnaticirris* and *C. capitata* revealed that all of them were significantly influenced by season, station and season × station. Except for season × station, the density of *N. glandicincta* was significantly influenced by station and season. Except for season and season × station, the density and biomass of *N. abiuma* were significantly influenced by station (Table 1).

Table 2. Correlation coefficients between polychaete parameters and organic matter content (n = 60).

Polychaete parameters	Organic matter	Polychaete parameters	Organic matter
Polychaete species number	-0.339**	Density of *N. glandicincta*	-0.603**
Polychaete density	-0.611**	Density of *N. abiuma*	0.667**
Polychaete biomass	-0.585**	Density of *C. capitata*	0.307*
Diversity index (H')	-0.307*	Biomass of *D. pinnaticirris*	-0.711**
Evenness index (J)	-0.160	Biomass of *N. glandicincta*	-0.584**
Richness index (d)	-0.353**	Biomass of *N. abiuma*	0.701**
Density of *D. pinnaticirris*	-0.588**	Biomass of *C. capitata*	0.309*

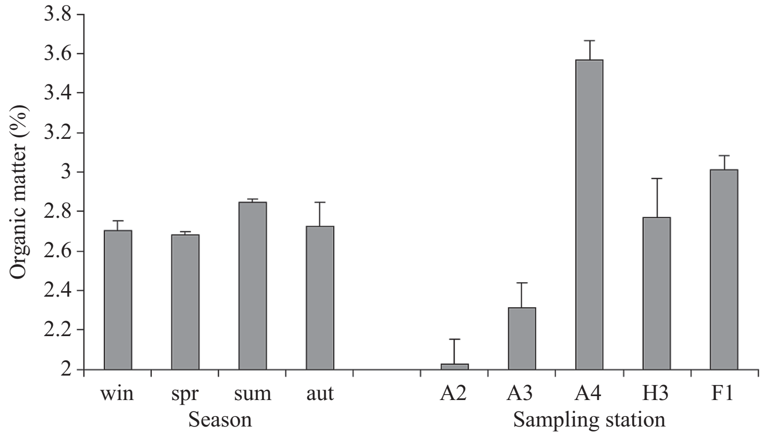

Fig. 4. Spatial and temporal fluctuation of organic matter content in a Shenzhen Bay mudflat.

3. Seasonal and Spatial Variation of Organic Matter in a Shenzhen Bay Mudflat

The organic matter content was highest in summer (2.846%), second highest in autumn (2.736%), third highest in winter (2.703%) and lowest in spring (2.679%). The mean organic matter content was highest at sampling station A4, second highest at station F1, third highest at station H3, fourth highest at station A3 and lowest at station A2 (Fig. 4).

Univariate tests on the spatial and seasonal distributions of organic matter content revealed that it was significantly influenced by season and station (Table 1).

4. Relationships between Sediment Organic Matter and Polychaetes

Correlation analysis showed a significant negative correlation between nine polychaete parameters and organic matter (Table 2). Nine polychaete parameters included polychaete species number, density, biomass, Shannon-Wiener diversity index, richness index, density and biomass of *D. pinnaticirris* and *N. glandicincta*. There was no significant correlation between evenness index and organic matter. Correlation analysis showed a significant positive correlation between the density and biomass of *N. abiuma* and *C. capitata* and organic matter content (Table 2).

There was a trend that polychaete species number, density, biomass, species diversity index, evenness index and richness index decreased with increasing organic matter content (Fig. 5). Higher density of *D. pinnaticirris* was found where the organic matter content was between 1.5% and 2.8% and a lower density was found where the organic matter content was between 2.8% and 3.8%. A higher density of *N. glandicincta* was found where the organic matter content was between 1.8% and 3.0% and a lower density was found where the organic matter content was between 3.0% and 3.8%. A higher density of *N. abiuma* was found where the organic matter content was between 3.0% and 3.8% and a lower density was found where the organic matter content was between 1.8% and 3.0%. Higher density of *C. capitata* was found where the organic matter content was between 2.5% and 3.8% (Fig. 6).

A higher biomass of four polychaete species was found at the same organic matter range as their densities (Fig. 7).

IV. DISCUSSION

Our correlation analysis showed a significant negative correlation between most polychaete parameters and organic matter on a Shenzhen Bay mudflat. The correlation could be confirmed by the seasonal and spatial variations of most polychaete parameters. The mean densities of *D. pinnaticirris* and *N. glandicincta* were both lowest in summer whereas the organic matter was highest in summer. Density and biomass of *D. pinnaticirris* were low in July [2, 3] and macrofaunal density in Shenzhen Bay intertidal zone was also low in

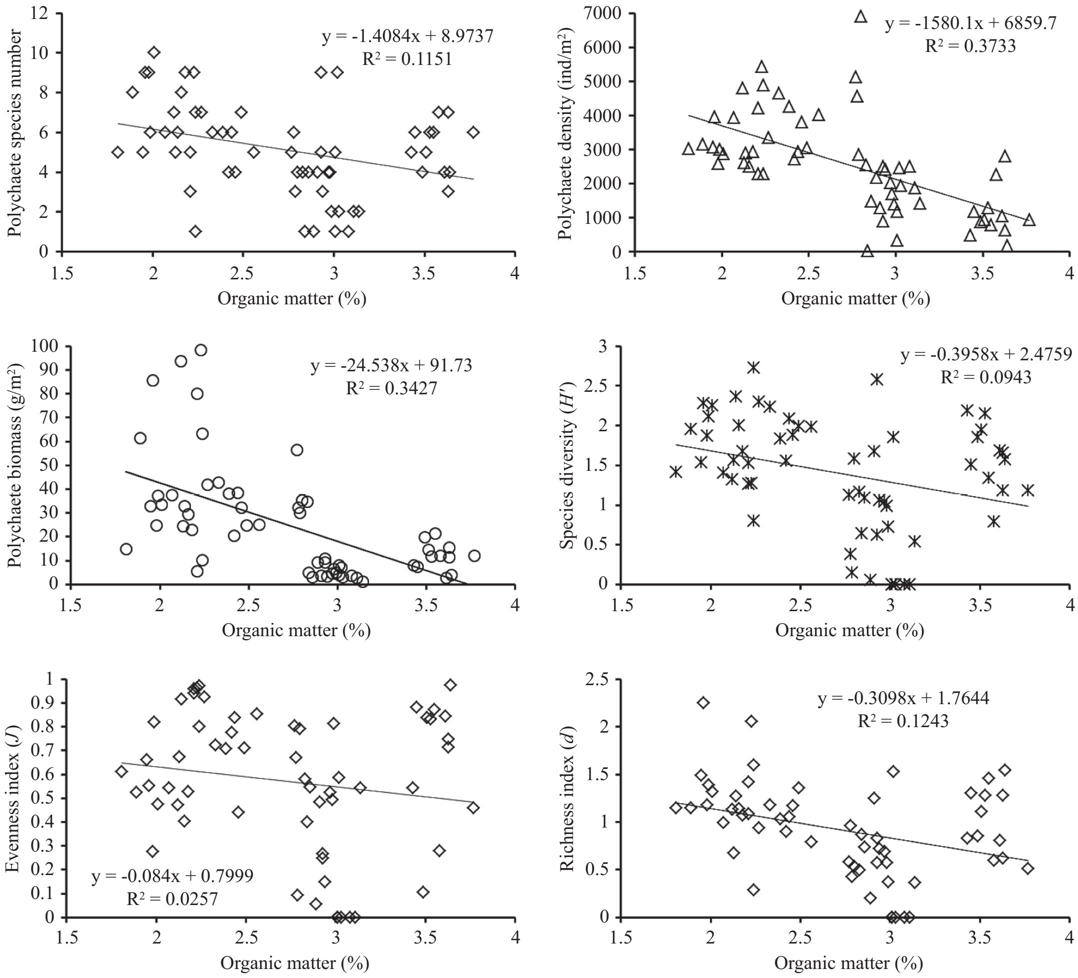

Fig. 5. The relationship between organic matter and polychaete parameters in a Shenzhen Bay mudflat.

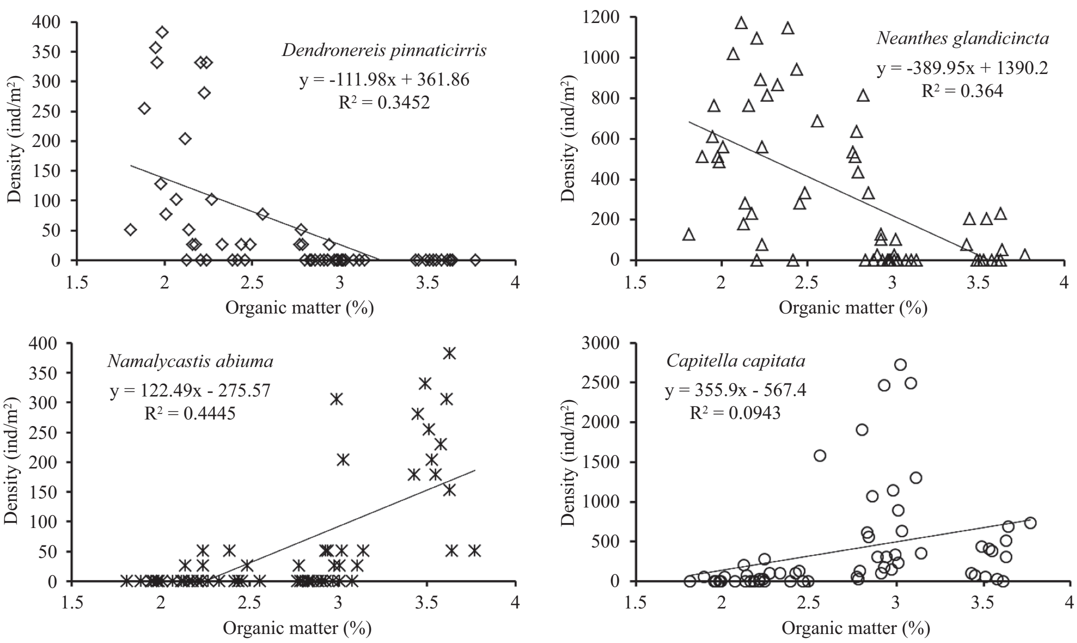

Fig. 6. The relationship between organic matter and the densities of four polychaete species in a Shenzhen Bay mudflat.

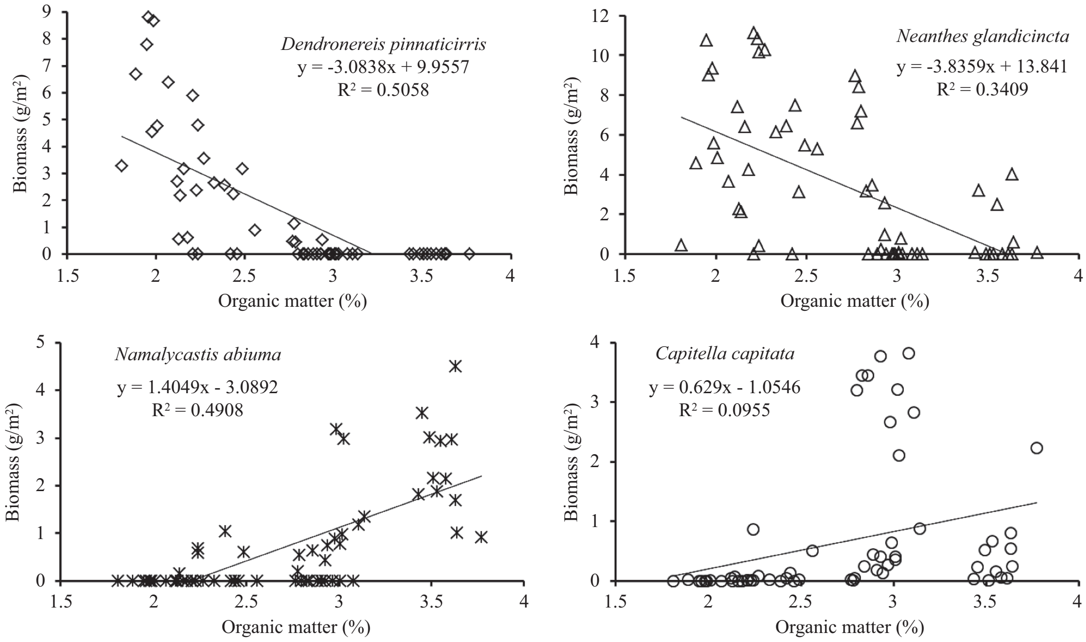

Fig. 7. The relationship between organic matter and the biomass of four polychaete species in a Shenzhen Bay mudflat.

summer and autumn [6]. Polychaete density, biomass, Shannon-Wiener diversity index, richness index, evenness index, density and biomass of *N. glandicincta* were all highest at sampling station A3, second highest at sampling station H3 and lowest at sampling station F1 with a converse trend of increasing organic matter content.

A significant positive correlation between the density and biomass of *N. abiuma* and *C. capitata* and organic matter were attributed to their spatial distribution patterns. Higher density and biomass of *N. abiuma* were found inside mangrove sediments and a lower density and biomass were found in the non-mangrove area in a Shenzhen Bay mudflat [21]. *N. abiuma* was one of seven species that appeared to be restricted to the mangroves of Darwin Harbor, in the Northern Territories of Australia, which was subsequently reported from other mangrove areas in northern Australia and from the Indo-West Pacific. It is also a characteristic member of the Indo-West Pacific mangrove fauna [46].

A significant positive correlation between the density and biomass of *C. capitata* and organic matter content may be attributed to its being an opportunistic species and tolerant to a high organic matter content. *C. capitata* was an opportunistic species tolerant to stressful conditions, and was often found in polluted waters where it out-competed less tolerant species [44]. The content of standing organic matter on a Shenzhen Bay mudflat was more than 1.75%. Larvae of the genus *Capitella* did not consistently choose the substrate with the highest organic content, and often metamorphosed sooner in response to substrates with insufficient organic material for optimal growth and reproductive success [10]. Types of sediment organic matter may play a more important role in the larval habitat selection process of the genus *Capitella* than the concentration of organic matter alone [55]. At the Besòs site, the constant and high enrichment of sediments produced high densities of *C. capitata* individuals that are characterized by smaller size ranges and a high biomass recorded here responded to the absolute values of the standing organic matter content [44].

The density of *N. glandicincta* in a Shenzhen Bay mudflat varied with season and sampling station. Similarly, recruitment by the nereid polychaete *Nereis diversicolor* was highly variable between years in a study by Volkenborn and Reise [58]. The impact of the same species *N. diversicolor* on the degradation of aged and fresh macroalgal detritus in coastal sediments was studied by Kristensen and Mikkelsen [36].

According to this study it occurred either irrespective of experimental treatments, or the responses were inconsistent. Our results along with Huang *et al*. [26] confirmed that a higher density of *N. glandicincta* was found in non-mangrove areas and a lower density was found inside mangrove sediments on a Shenzhen Bay mudflat. Imgraben and Dittmann [30] indicated that *N. vaalii* could not consume mangrove litter.

When tolerance levels to organic matter content were compared among the 4 polychaete species, higher density and biomass of *D. pinnaticirris* was found where the organic matter content was between 1.8% and 2.5%, for *N. glandicincta*, between 1.8% and 3.0%, for *N. abiuma* between 3.0% and 3.5%, and for *C. capitata* between 2.5% and 3.5%. If organic matter content was higher than 2.5%, we assume that the density of *D. pinnaticirris* would decrease or *D. pinnaticirris* would disappear. If the organic matter content was higher than 3.0%, the density of *N. glandicincta* would decrease or *N. glandicincta* would disappear. *C. capitata* could be found at an organic matter content of about 3.0% and, therefore, endures a higher organic matter content. *N. abiuma* was also found predominantly in mangrove wetlands and could endure an organic matter content as high as 3.5%.

V. CONCLUSION

Our findings suggest that in anthropogenically disturbed depository systems, the complex interactions between changing environmental conditions are likely associated with population and assemblage changes of polychaetes. Effects were strongly species-specific, demonstrating the importance of individual species preferences and tolerances. We also found that data should be seen in the context of the overall benthic environmental conditions under study. Our findings also suggest that in an anthropogenetically disturbed depository system, high organic matter content has an impact on polychaete assemblages in several respects. There was a trend that polychaete species number, density, biomass, species diversity index, evenness index and richness index decreased with increasing organic matter content on a Shenzhen Bay mudflat. We explain a significant negative correlation between the density and biomass of *D. pinnaticirris* and *N. glandicincta* and organic matter content by their limited tolerance to a high organic matter content. We explain a significant positive correlation between the density and biomass of *N. abiuma* and *C. capitata* and organic matter content by their preference for organic enrichment. Common diversity estimates such as species evenness and diversity are appropriate tools to examine either temporal successional changes or spatial transect transitions of macrobenthic polychaete assemblages in response to environmental gradients such as organic matter. This holds particularly for a longterm monitoring survey presented here rather than a short-term monitoring survey.

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