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SPATIAL DISTRIBUTION OF TROPICAL ESTUARINE NEMATODE COMMUNITIES IN SARAWAK, MALAYSIA (BORNEO)

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ABSTRACT. — Limited information is available on marine nematode assemblages from Malaysian waters. Field sampling was conducted at the river mouths of 10 estuaries along the coastline of Sarawak (Malaysia) in Borneo to determine the distribution pattern of marine nematode assemblages. Physico-chemical parameters were also recorded to determine if distribution of nematodes was correlated with salinity, temperature, dissolved oxygen, and pH. Overall, the sampled sites were characterised by low density and low diversity of nematodes. Multidimensional scaling (nMDS) and dendrogram showed high dissimilarity in species distribution. BioEnv recorded a low positive correlation between marine nematode species densities and environmental parameters (pH and particle fraction: silt). Functional feeding group (FFG) changed from the north to south suggesting adaption by marine nematodes to food availability. *Daptonema tenuispiculum*, *Sabatieria praedatrix* group and *Terschellingia longicaudata* were dominant in several study sites. In conclusion, a total number of 49 species of marine nematodes were recorded (excluding two freshwater species from the order Dorylaimida). Low densities and diversities together with the proportion of the functional feeding groups between the 10 study sites indicated a stressful environment for nematodes and nematode communities could potentially be used for future pollution assessment of estuarine habitats.

KEY WORDS. — Estuarine, functional feeding group, nematodes, physico-chemical, Malaysia

INTRODUCTION

Nematodes are categorised as one of the most diverse taxa amongst the meiobenthos fauna. They are numerous, widely distributed, and are well-known for their key ecological roles in aquatic ecosystem (Platt & Warwick, 1983). Free-living nematodes have been suggested to play important roles in the benthic ecosystem such as production of detrital organic matter and recycling of nutrients, thus enriching the coastal waters which support marine benthic production (Chinnadurai & Fernando, 2007).

Ecological studies of the marine nematodes (Heip et al., 1985; Yodnarasri et al., 2008; Adão et al., 2009; Hourtson et al., 2009) have shown the importance of the marine nematodes in the marine environment. In addition, the potential of using the marine nematode assemblages to determine the health of the coastal environment also attracted the attention of researchers globally. Changes of marine nematode community structure in term of species richness, species diversity, and species evenness can be indicative of changes in the environment quality. In the Ems estuary between Germany and Holland, the decreasing level of organic wastes caused a re-construction of nematode community structure from being dominated by enrichment opportunists towards a community of general opportunists (Essink & Keidal, 1998). Studies conducted by Mahmoudi et al. (2005) and Sánchez-Moreno & Navas (2007) showed that pollutants such as hydrocarbon and heavy metals affected the community composition of marine nematode assemblages. Several studies have also suggested that the dominance of marine nematode species such as *Daptonema* spp. (i.e., *D. tenuispiculum*), *Sabatieria* spp. (i.e., *Sabatieria pulchra* group and *Sabatieria praedatrix* group), *Terschellingia* spp. (i.e., *T. longicaudata*), and

Parodontophora spp. may indicate pollution and disturbance (Lampadariou et al., 1997; Pavlyuk et al., 2003; Liu et al., 2008; Moreno et al., 2008).

Most of the data available, not surprisingly, are based on the studies carried out in temperate regions of the world. Limited research had been done in tropical countries especially in Southeast Asia (SEA) (Shabdin & Othman, 1999, 2005, 2008; Gagarin & Nguyen, 2004; Gagarin et al., 2005; Nguyen et al., 2005). Studies of nematodes in Sarawak are still in their infancy. Very little information is available on nematode species composition and spatial distribution in Malaysian waters. The pioneering studies carried out by Shabdin & Othman (1999, 2008) was based on a single locality and can hardly be representative of the distribution pattern of marine nematodes in Malaysian waters. Several authors (Dye, 1983; Alongi, 1987; Ólafsson, 1995) mentioned that the density of nematodes varied considerably both on global and local scales.

The present study was therefore undertaken to study the spatial distribution of meiofauna with an emphasis on species composition and distribution of nematodes in relation to salinity, temperature, dissolved oxygen (DO), pH and sediment size of 10 estuaries along the coast of Sarawak, Malaysia.

MATERIAL AND METHODS

Field sampling. — Sampling was carried out during the dry season at subtidal regions in river mouths of 10 estuaries along the coast of Sarawak, Malaysia in 2008 (Fig. 1). Physico-chemical parameters (salinity, temperature, DO, and pH) were measured in situ using HORIBA U20-XD multimeter. A perspex corer with an inner diameter of 2.5 cm was used to sample the sediment during low tide. Two randomly located sediment samples were extracted from each site to a depth of 5 cm. Each sediment core was immediately fixed in 5% formalin diluted using water from the sampling site. The same corer was used to obtain an additional sediment sample from each study site for particle size analysis. The samples were labeled and brought back to the laboratory for further analysis.

Laboratory analysis. — Sediment analysis was conducted using standard methods described by Bale & Kenny (2005) and Buchanan (1984). After initial splitting of the silt-clay fraction, the retained sediment on a 63-µm sieve was transferred for dry sieving to determine the sand fraction. The suspension in the pan and basin were then transferred and subjected to the pipette method based on Stokes' Law (Buchanan, 1984).

Nematode extraction and preservation were done according to the methods described in Sommerfield et al. (2005). Nematodes were isolated from samples and put on a microscopic slide with anhydrous glycerol. Every nematode in each replicate was counted to obtain the density. The nematodes were identified under a high power compound microscope (Olympus BX 51). Nematode pictorial keys (Platt & Warwick, 1983, 1988; Warwick et al., 1998) for British waters together with the database shared by the Ghent University were used in identification. The nematodes were identified to the highest similarity level. The term "cf" is used to justify the identification for certain species.

In addition, each marine nematode species was assigned to one of four functional feeding groups (FFG) designated by Wieser (1953) on the basis of buccal cavity morphology as follows: 1A, selective deposit feeder (species without a buccal cavity, or with only a narrow tubular buccal cavity that can inject particles of bacterial size). 1B, non-selective deposit feeder (species with a large buccal cavity and not armed with any teeth). 2A, epigrowth or diatom feeder (species having a buccal cavity armed with small or moderately sized teeth). 2B, predator or omnivore (species with large teeth and jaws).

Data analysis. — Data were analysed in order to (a) compare the environmental factors between sites; and (b) characterise community distribution of nematodes in the estuaries along the Sarawak coastal waters in relation to environmental factors.

One-way analyses of variance (ANOVA) was performed to determine the significant level of the environmental variables (salinity [PSU], temperature [˚C], dissolved oxygen [DO; mg l^{-1}], and pH) between the 10 study sites. The H_0 for all the ANOVAs where the significant difference did not occur among the tested groups was rejected if the p-value <0.05.

Further analyses were conducted using the PRIMER v6 statistical package (Clarke & Gorley, 2006). Particle size fractions in each site were obtained and analysed using Principal Component Analysis (PCA) to determine visually the extent of any difference in particle fractions for each study site. The mean densities of the nematode species were used to determine species number, Shannon-Wiener species diversity index: H' = –SUM (Pi*Log (Pi)), Log base (e) and Pielou's evenness: J' = H' $(Log_2 (S))^{-1}$. Mean densities of the nematodes were square-root transformed prior to group-averaged hierarchical cluster analysis and non-metric multidimensional scaling (nMDS). BioEnv was

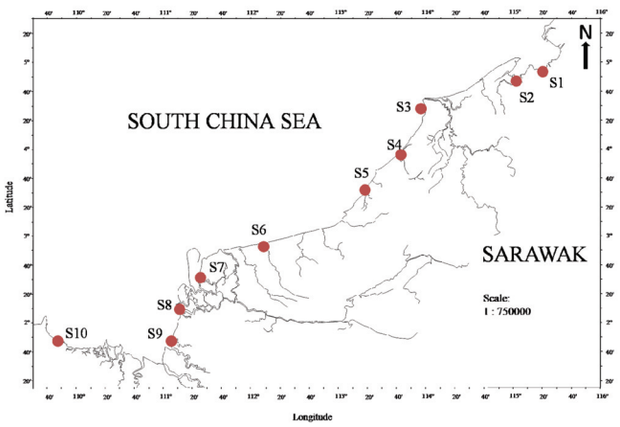

Fig. 1. The location of the sampling sites along Sarawak coastal waters.

Table 1. Mean of physico-chemical of the water variables ± standard deviation (SD) and the percentage of particle size fractions.

Site	Locality	pH	DO (mg l^{-1})	Temperature (°C)	Salinity (PSU)	Sand%	Silt%	Clay%
S1	Punang River	6.45 ± 0.03	1.84 ± 0.05	30.3 ± 0.15	23.0 ± 1.00	75.51	19.63	4.86
S2	Limbang River	6.56 ± 0.07	5.16 ± 0.04	30.8 ± 0.00	20.3 ± 2.08	3.28	78.38	18.34
S3	Lutong River	7.03 ± 0.01	6.87 ± 0.06	27.0 ± 0.21	26.0 ± 1.00	52.36	33.15	14.49
S4	Niah River	6.93 ± 0.00	5.04 ± 0.08	27.6 ± 0.06	19.0 ± 1.00	97.37	2.62	0.01
S5	Similajau River	6.91 ± 0.01	6.58 ± 0.08	30.5 ± 0.00	28.0 ± 0.00	27.35	54.20	18.44
S6	Mukah River	6.93 ± 0.00	3.33 ± 0.04	26.4 ± 0.06	20.3 ± 1.53	97.33	1.45	1.23
S7	Batang Lassa	6.81 ± 0.14	4.95 ± 0.18	26.6 ± 0.12	21.0 ± 1.00	16.31	64.86	18.83
S8	Jerijih River	7.31 ± 0.01	12.24 ± 0.07	29.9 ± 0.00	30.0 ± 0.00	98.60	1.07	0.33
S9	Kabong River	7.61 ± 0.01	4.09 ± 1.07	28.8 ± 0.15	28.5 ± 0.50	34.83	57.68	7.49
S10	Sematan River	7.68 ± 0.00	11.93 ± 0.51	27.3 ± 0.00	32.0 ± 0.00	70.58	24.71	4.70

*DO = dissolved oxygen

conducted using the environmental variables (salinity, DO, temperature, pH and particle fractions) and nematode species abundance to determine the best pairing or combination of the environmental variables that affected the nematode abundance (correlation) (Clarke & Gorley, 2006). Nematode species were divided into four FFG (excluding the freshwater nematodes). An MDS was conducted using the percentage of FFG.

RESULTS

Physico-chemical parameters. — One-way analysis of similarity (ANOSIM) showed that the physico-chemical parameters were significantly different between all the study sites (p-value <0.001; R statistic: 1.0). Most of the study sites located at the northern part of Sarawak except Lutong River (S3) were more acidic (pH <7.0), although the upper northern region (S1 and S2: Punang and Limbang Rivers) recorded lower pH values (6.4–6.6) compared to other sites. The southern region (S8 to S10: Jerijih River to Sematan River) was characterised by high pH (7.31–7.68).

High DO (dissolved oxygen) readings were recorded in all study sites. DO values ranged between 1.8 mg l^{-1} (S1) and 12.2 mg l^{-1} (S8). Water temperature ranged between 26.4°C (S6: Mukah River) and 30.8°C (S2: Limbang River). The highest salinity was recorded in S10 (32.0 ± 0.00 PSU) at 1.6 km away from the river mouth, while Niah River (S4) had the lowest salinity (19.0 ± 1.00 PSU) at 0.47 km from the river mouth.

Results of the PCA derived from the mean percentage of the particle size fractions are shown in Fig. 2. S1 was dominated by the particle fraction of 1 mm (coarse sand)

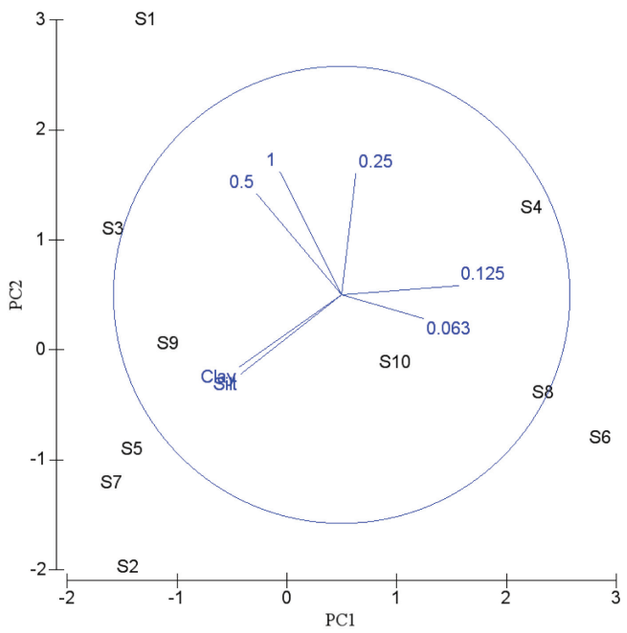

Fig. 2. Principal component analysis derived from the mean percentage of particle fractions in each study site. PC 1 and 2 accounted for 80.1 % of the total variation present.

Table 2. List of marine nematode species, functional feeding group (FFG) classification, and percentage composition at each of the 10 study sites in Sarawak.

Nematode species	FFG	Site									
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Anoplostoma cf. *viviparum*	1B	–	–	–	–	5.0	–	–	–	–	–
Chaetonema cf. *canellatum*	1B	9.0	–	–	–	–	–	–	–	–	–
Choniolaimus cf. *papilatus*	2B	–	–	–	–	–	–	25.0	–	–	–
Daptonema cf. *anticulatum*	1B	–	–	11.0	–	–	–	–	–	–	3.0
Daptonema sp 1	1B	–	–	7.0	–	–	–	–	–	–	–
Daptonema sp 2	1B	–	–	–	7.0	–	–	–	–	–	–
Daptonema cf. *setifer*	1B	–	–	–	9.0	–	–	–	–	–	–
Daptonema tenuispiculum	1B	35.0	5.0	–	–	–	–	25.0	–	–	–
Daptonema cf. *trabeculosus*	1B	–	–	15.0	–	–	–	–	–	–	–
Daptonema uncinatus	1B	–	–	–	–	–	–	–	–	25.0	–
Dorylaimid sp 1	FW	–	–	–	–	–	–	–	13.0	–	3.0
Dorylaimid sp 2	FW	–	–	–	–	–	–	–	19.0	–	–
Halalaimus sp.	1A	–	–	–		–	–	–	6.0	–	–
Halichoanolaimus cf. *consimilis*	2B	–	–	11.0	–	3.0	–	–	–	–	–
Hopperia australis	2A	–	–	–	–	–	–	–	–	–	5.0
Hopperia cf. *massiliensis*	2A	–	–	–	–	–	–	–	–	–	1.0
Metachromadora onyxoides	2B	–	–	–	23.0	–	–	–	–	–	–
Metachromadora sp 1	2B	–	–	–	–	–	–	–	–	–	7.0
Metachromadora sp 2	2B	–	–	4.0	1.0	–	–	–	–	–	–
Parodontophora cf. *danka*	2A	–	–	7.0	–	–	–	–	6.0	–	–
Parodontophora pacifica	2A	–	–	–	–	–	–	–	–	50.0	–
Pomponema sp 1	2B	–	–	–	1.0	–	–	–	–	–	1.0
Pomponema sp 2	2B	–	–	–	–	–	–	–	–	–	1.0
Pomponema polydonta	2B	–	–	11.0	–	–	–	–	–	–	–
Pomponema syltense	2B	–	–	11.0	–	–	–	–	–	–	–
Pomponema sp 3	2B	–	–	4.0	–	–	–	–	–	–	–
Pseudocella sp.	2B	17.0	–	–	–	–	–	–	–	–	–
Pseudocella cf. *tabarini*	2B	–	–	–	–	70.0	–	–	–	–	–
Pseudolella cf. *bengalensis*	1A	–	95.0	–	–	–	–	–	–	–	–
Sabatieria alata	1B	–	–	–	–	–	–	–	–	–	59.0
Sabatieria sp 1	1B	–	–	–	–	5.0	–	–	–	–	–
Sabatieria sp 2	1B	–	–	–	–	–	–	–	6.0	–	–
Sabatieria lawsi	1B	–	–	–	–	–	–	25.0	–	–	–
Sabatieria ornata	1B	–	–	–	–	–	–	–	38.0	–	–
Sabatieria cf. *vasicola*	1B	–	–	–	–	–	–	–	–	25.0	–
Sphaerolaimus lodosus	2B	–	–	–	–	3.0	–	–	–	–	4.0
Sphaerolaimus macrocirculus	2B	–	–	–	–	–	–	–	–	–	3.0
Sphaerolaimus megamphis	2B	–	–	–	–	–	–	13.0	–	–	–
Spilophorella cf. *papillata*	2A	–	–	–	–	14.0	–	–	–	–	–
Spirinia parasitifera	2A	–	–	–	–	–	–	12.0	–	–	–
Sprinia sp.	2A	–	–	–	–	–	–	–	6.0	–	–
Terschellingia cf. *brevicauda*	1A	–	–	4.0	–	–	–	–	–	–	–
Terschellingia longicaudata	1A	39.0	–	4.0	–	–	–	–	–	–	–
Theristus scanicus	1B	–	–	11.0	–	–	–	–	–	–	–
Trileptium sp.	2B	–	–	–	1.0	–	–	–	–	–	–
Trileptium otti	2B	–	–	–	38.0	–	–	–	–	–	–
Trileptium parisetum	2B	–	–	–	11.0	–	–	–	–	–	–
Viscosia antartica	2B	–	–	–	–	–	–	–	–	–	8.0
Viscosia sp 1	2B	–	–	–	2.0	–	–	–	–	–	–
Viscosia sp 2	2B	–	–	–	–	–	–	–	–	–	4.0
Viscosia stenolaima	2B	–	–	–	7.0	–	–	–	6.0	–	1.0

*1A = selective deposit feeders; 1B = non-selective deposit feeders; 2A = epigrowth or diatom feeders; 2B = predators or omnivores; FW = freshwater nematode.

while at S2, silt was predominant. S3 was characterised by the presence of both sand and silt. S4 (Niah River), S6, and S8 were distinguished as areas with fine sand (0.125 µm). S5 (Similajau River), S7 (Batang Lassa), and S9 (Kabong River) had a high percentage of silt. At Sematan River (S10), which is located at the southern part of Sarawak, fine sand and silt were present.

Nematode community structure. — A total of 51 species (20 genera and two freshwater species from the order Dorylaimida) was recorded (Table 2). Results of one-way ANOSIM showed that species densities were different in all the study sites (p-value <0.001; R statistic: 0.877). Overall, nematode densities were low in Sarawak estuaries. The highest density was recorded in the southern part of Sarawak at S10 (412.00 ± 5.66 indiv. per 10 cm^2), followed by S4 (328.00 ± 56.57 indiv. per 10 cm^2) and S5 (148.00 ± 50.91 indiv. per 10 cm^2). Nematodes were absent in the samples obtained from S6. Diversity was also highest in S10, followed by S3 (Fig. 4a). Low Shannon-Wiener species diversity indices were recorded in the present study (<2.0). Low evenness (J') (on a scale of 0–1) indicated that

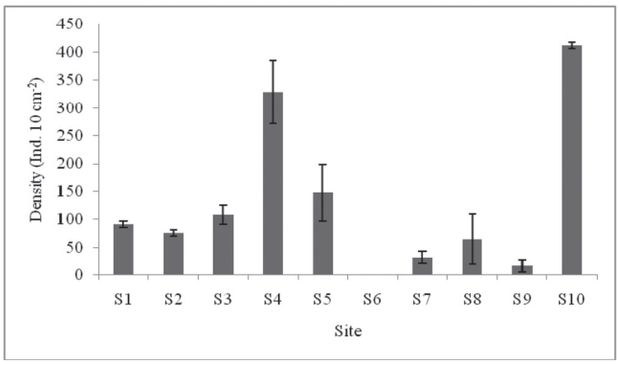

Fig. 3. Nematode density (Indiv. per 10 cm^2) of each study site.

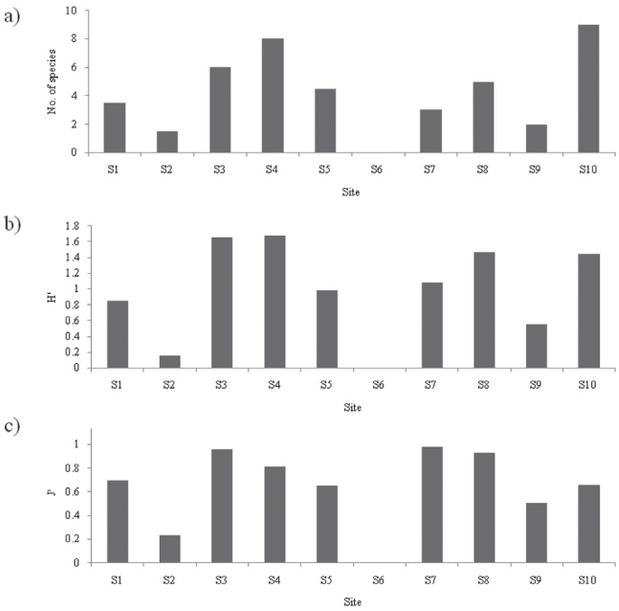

Fig. 4. a, Number of nematode species; b, Shannon-Wiener species diversity index (H'); c, Pielou's evenness (J').

Table 3. Results of the BioEnv subject to Spearman correlation (p-value = 0.04).

No. of variables	Correlation	Variables
2	0.339	pH, silt
4	0.327	pH, salinity, sand, silt
3	0.318	pH, sand, silt
3	0.315	pH, salinity, silt
5	0.294	pH, salinity, sand, silt, clay

nematode species were not evenly distributed along the Sarawak coastal waters (Fig. 4c). S7 possessed the highest evenness value (0.969).

A multi-dimensional scaling (nMDS) resemblance from Bray-Curtis similarity matrix showed that the sites were clustered into four distinct groups at 3% similarity level (Fig. 5). S1, S2, and S7 formed a distinct group. S9 and S6 were the other two separated groups. Low similarity percentage of nematode species densities was recorded between the study sites. The other five study sites were grouped together due to their similarity either in species density or diversity. At the similarity level of 20%, 10 site groups were formed (Fig. 5b). A BioEnv test was conducted to determine the interaction between nematode species densities and environmental variables. Certain environmental variables (DO and temperature) were not significantly correlated to the nematode abundance and were excluded. The match for BioEnv is even better with fewer variables (Clark & Gorley, 2006). Several pairings of environmental variables were calculated to correlate with nematode abundance. A combination of two environmental parameters (pH and silt) was positively correlated with the marine nematode species densities (correlation = +0.339; p-value = 0.04). The combination of environmental variables such as pH, salinity, sand and silt also affect nematode abundance in Sarawak estuaries (correlation = +0.327; p-value = 0.04). The results (Table 3) showed that such correlation decreased with the increase in number of environmental variables. When the

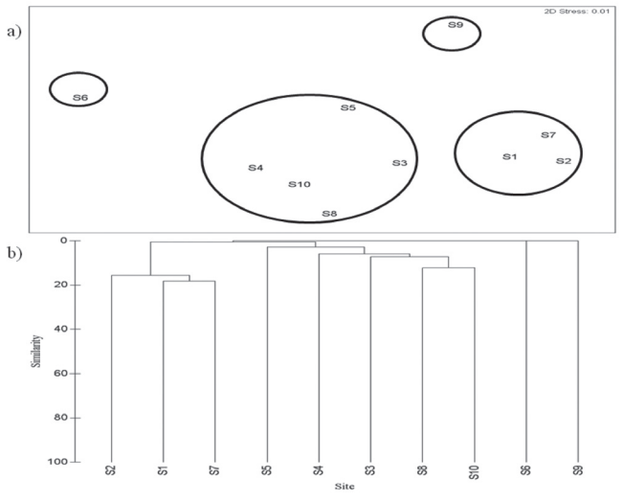

Fig. 5. a, Two-dimensional MDS ordination constructed from the mean density of each nematode species; b, dendrogram produced by cluster analysis showing the percentage of similarity between the 10 estuaries.

number of variables went up to five (an addition of clay), lower correlation was formed (correlation = +0.294; *p*-value = 0.04). The pH and silt were recorded in all the calculated pairings. A combination of pH and silt both contribute towards the community structure of marine nematode in the estuaries of Sarawak.

Functional feeding group. — The marine nematodes were categorised into the four functional feeding groups (FFG) excluding two freshwater species from the order Dorylaimida (Fig. 6). S1 was dominated by both selective (1A) and non-selective (1B) deposit feeders, while S2 was characterised by selective deposit feeders only. S3, S7, and S10 were dominated by a high proportion of non-selective deposit feeders followed by predators and omnivores species. Estuaries located in the southern part of Sarawak were dominated by non-selective deposit feeder, whereas both non-selective deposit feeders and epigrowth feeders were the dominant species in S9 while predators and omnivores were dominantly found in S4 and S5. Result of the MDS divided the study sites into six groups at 80% similarity level (represented by ellipses in Fig. 7). The results showed that the FFG were different geographically (northern and southern region). Overall, selective deposit feeders were highly found in the estuaries at the northern region of Sarawak (S1 and S2), whereas dominant species were non-selective deposit feeders in the southern region.

DISCUSSION

Twenty genera of free-living marine nematodes comprising 49 species were recorded in the estuaries of Sarawak (excluding one order consisting of two freshwater nematode species). The marine nematode density in the 10 estuaries examined was relatively low (0–400 indiv. per 10 cm^2) when compared to the results obtained by Chinnadurai & Fernando (2007) in India (200–800 indiv. per 10 cm^2). Low species diversity indices (<2.0) characterised most of the study sites. The Shannon-Wiener diversity index (Shannon & Weaver, 1949) is the most widely used measure of benthic community diversity (Clarke & Warwick, 1994) that may also be indicative of sediment conditions. Lewis (2005) mentioned that sediment quality is considered poor if the index value was 2.0 or less based on a frequency distribution of Ponar diversity values reported by Friedman & Hand (1989). It is generally accepted that sediment quality affects the community structure of marine nematodes. However, nematode diversity is also affected by other factors such as competition between species, predation pressure, structural heterogeneity of the habitat, and alterations in environmental predictability (Gray & Elliot, 2009).

Results of BioEnv showed that both pH and silt were included in all the combinations which were found to be correlated with the species density of marine nematode communities (Table 3). S1, which recorded with the lowest pH (6.46), was recorded with low species densities. High nematode species densities were recorded in S5, S9, and S10, which recorded high pH values (Tables 1, 2). High pH (towards natural seawater, pH ≈ 8.0) tends to increase the densities of nematode (Barnes et al., 2008). However, S3, S4, S7, and S8 which possessed high pH values were recorded with low nematode species densities (<40%). Besides that, the density of one nematode species, *Pseudolella* cf. *bengalensis*, was found to be extremely high (95% of total) in S2 even though it has a low pH (6.56). These results explain that pH is not the only factor influencing the community structure of the marine nematodes in Sarawak estuaries. It is also affected by the presence of silt in sediments, which was supported by the results of BioEnv (Table 3). The low pH site (S2) which was recorded with extreme high species density and low species diversity was probably due to the high silt content (78.38%). Overall, the nematode species densities in the present study showed a linear relationship with the proportion of silt in sediments. Fine and coarse sand areas (S4 and S8; S3 later) were recorded with low species densities but high number of species (Fig.2). For instance, Capstick (1959) and Adão et al. (2009) observed that muddy areas are often characterised by high abundance and few species, whilst sandy beaches have high nematode diversity. The increase of the size and grain shape also determines the sorting of the sediment. Angular, splintery articles are packed tighter than spherical ones. A higher angularity leads to more structural complexity, less water permeability, and usually higher abundance of meiobenthos (Conrad, 1976). The external surface area of sediment particles is an important determinant of meiobenthos diversity and abundance, as it directly defines the area available for the establishment of biofilms (mucus

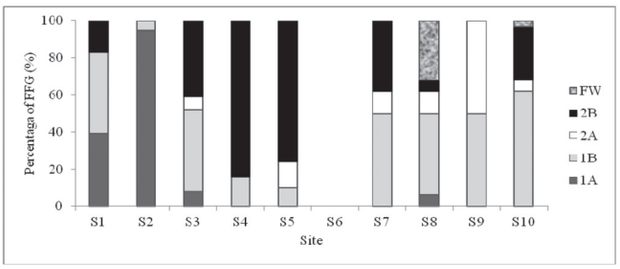

Fig. 6. Percentage of contribution of each functional feeding group in each of the sampled sites (1A, selective deposit feeder; 1B, non-selective deposit feeder; 2A, epigrowth or diatom feeders; 2B, predators or omnivores; and FW, freshwater nematode).

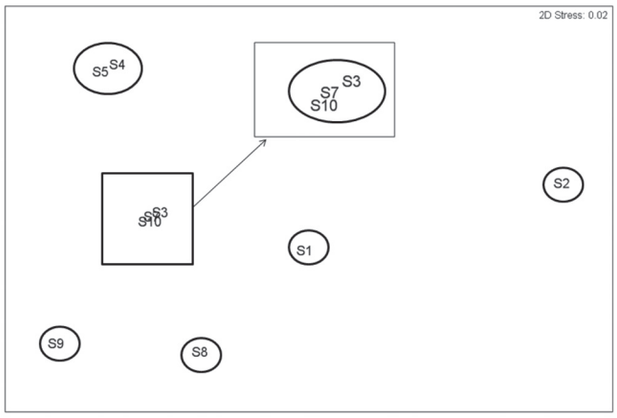

Fig. 7. Two-dimensional MDS ordination constructed from the percentage of nematodes' functional feeding group (FFG).

secretions of bacteria, fungi, diatoms, fauna) (Teal & Wiser, 1966; Giere, 2009). In addition, sediment heterogeneity and organic content also affect species diversity (Liu et al., 2008). Our results (Fig. 4) showed that the species diversity along the Sarawak coast was lower in muddy sites compared to sandy areas, concurring with the conclusions of Steyaert et al. (2003) and Adâo et al. (2009). All the sandy sites (except S6) in Sarawak estuaries examined in this study were more diverse than muddy sites. However, total species numbers and densities were still lower than expected in natural sandy and muddy areas. Platt & Warwick (1988) mentioned that species richness and diversity vary among habitats, being greatest in sandy beaches with typically over 100 species, while in muddy areas and in algal communities, the number of species is typically more in the range between 30 to 70 species.

Besides that, S7, which was dominated by silt content yet having low species densities, were suspected to be affected by other environmental variables such as salinity (Table 3). According to Heip et al. (1985), species composition is primarily influenced by grain-size characteristics and secondarily by salinity in an estuarine. In the study conducted by Coull & Wells (1981) in Wellington estuary (salinity range: 5–34), nematode densities were also been recorded to be low (22–444 indiv. per 10 cm^2). Adão et al. (2009) noted that the changes of the salinity can influence nematodes population and distribution patterns, and Barnes et al. (2008) showed that highest numbers of nematodes are associated with sites characterised by high salinity. Our results in general did show that nematode densities are correlated to salinity, except at S4. Nematode species from the genera *Daptonema*, *Metachromadora*, *Sabatieria*, *Sphaerolaimus*, and *Viscosia* which had been found in present study were determined to have a wide salinity tolerance. These findings agree with those of Capstick (1959) and Gal'tsova & Platonova (1985) who also showed that these nematode genera were present in a wide range of salinities. However, species from the genus *Trileptium* were only recorded in a study site with low salinity (19.00 PSU). Some species were affected by high salinity (Moens & Vincx, 2000). The unexpected observations at S4, where high nematode densities were found in low salinity (19.00 PSU) conditions, may be a result of other factors such as food availability and particle size playing a greater role in determining their abundance.

S4 was dominated by the predators and omnivorous species, probably indicating a wide variety of food source availability. The potential food items of the free-living marine nematodes include organic detritus, decomposing organisms, bacteria, diatoms, and other living organisms (Platt & Warwick, 1983; Heip et al., 1985). Free-living marine nematode species tend to be selective in the food selection and the presence of large amounts of particular food type at a locality would favour colonisation by species that belong to a particular trophic group or groups (Hourston et al., 2009). Most study sites in the northern region were dominated by FFG predators or omnivorous species (e.g., non-selective deposit feeders such as *Daptonema* spp. were found in S1 and S2; selective deposit feeders such as *Pseudolella* cf. *bengalensis* were mostly found in S2), whereas non-selective feeders, *Daptonema* spp., *Choniolaimus* spp., *Parodontophora* spp., and *Sabatieria* spp. were dominant in the southern region of Sarawak coast (Fig. 6; Table 2). The grouping of the nematodes according to feeding groups as implied from buccal cavity structure is an important criterion for understanding and explaining the food availability (Wieser, 1953; Chinnadurai & Fernando, 2007; Shabdin & Othman, 2008).

The community structure of nematodes in some of the study sites were found to be skewed away from the natural law of marine nematode distribution patterns (i.e., zero nematode was found in the sandy site (S6) and low total densities in most of the study sites). Previous studies conducted by the Natural Resources and Environment Board (NREB) of Sarawak indicated that several estuaries were polluted with excessive organic matter, total suspended solids, bacteria (faecal coliforms), hydrocarbon, and heavy metals (NREB, 2005, 2006, 2009; see Table 4). No nematode record in S6 is suspected to be due to the patchy distribution of nematodes. According to Warwick et al. (1990), patchiness of nematodes might be influenced by the minute habitat heterogeneities, temporal variations, and food web interaction. Besides that, Schratzberger et al. (2002) mentioned small oscillations reduce the intensity of competitive displacement and tend to enhance diversity, while severe disturbances negatively affect diversity which shows the reduction of the species diversities due to the disturbances of the habitats (pollution). In 2008, S6, which was recorded to be polluted by suspended solids, hydrocarbon, and heavy metal (Table 4), potentially contributed to the result of the present study (zero nematode) due to the migratory of nematode communities towards a cleaner environment. Besides that, the total nematode densities and the number of species were also recorded to be lower than expected. Pollution indicator species such as *Daptonema tenuispiculum*, *Terchellingia longicaudata*, *Sabatieria praedatrix* group, and *Parodontophora* spp. were also found in some of the study sites mentioned in Table 4. S1 was dominated by the marine nematodes *Daptonema tenuispiculum* and *Terschellingia longicaudata*. The presence of these two species could be indicative of the eutrophic conditions suggested in previous environmental studies of this river. Similarly, the heavily polluted S2 was recorded with a very low Shannon-Wiener diversity index and dominated by only two marine nematode species (*Pseudolella* cf. *bangalensis* and *D. tenuicpiculum*).

In conclusion, particle size fraction (sand and silt), salinity ,and pH appear to be key factors that influence species diversity and density of nematode assemblages in Sarawak estuaries, although other physico-chemical parameters also affect community structure. The relative proportions of nematode FFG changed from north to south along the Sarawak coast. The response of marine nematodes to both the food source availability and environment quality (presence of pollutants) are highly species-specific. Further studies are needed that takes into account the salinity gradient of each estuary to quantify the response of nematode communities to anthropogenic or natural stressors.

Table 4. Environment status (using the DOE National Water Quality Standards for Malaysia) of the study sites: 2004–2005 (NREB, 2005, 2006), 2007–2008 (NREB, 2009).

Site	Locality	Environment status*										
		2004				2005				2007	2008	
		OM	SS	B	HM	OM	SS	B	HM	Environment Quality	Environment Quality	
S1	Punang River	SP	P	HP	N/A	C	P	HP	N/A	N/A	N/A	
S2	Limbang River	SP	P	HP	N/A	C	P	HP	N/A	N/A	N/A	
S3	Lutong River	P	P	HP	N/A	P	C	HP	N/A	P (Class III)	Slightly polluted by hydrocarbon and suspended solids; polluted by bacteria, heavy metal	
S4	Niah River	SP	P	HP	N/A	C	C	HP	N/A	SP (Class IIB)	SP (Class IIB)	
S5	Similajau River	SP	P	P	N/A	C	C	P	N/A	C (Class II)	C (Class II)	
S6	Mukah River	SP	P	HP	N/A	C	P	P	N/A	N/A	Polluted by suspended solids, hydrocarbon, heavy metal	
S7	Batang Lassa Daro	SP	HP	HP	N/A	C	P	HP	N/A	N/A	N/A	
S8	Jerijih River	SP	HP	HP	N/A	SP	P	HP	N/A	N/A	Slightly polluted by hydrocarbon	
S9	Kabong River	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Slightly polluted by suspended solids	
S10	Sematan River	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Slightly polluted by domestic sewage and hydrocarbon	

*OM = organic matter pollution; SS = suspended solid pollution; B = bacteria pollution (total faecal oliforms); HM = heavy metal pollution; C = Clean; SP = slightly polluted; P = polluted; HP = heavily polluted; N/A = data not available.

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