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Spatial distribution of recent ostracode assemblages and depositional environments in Jakarta Bay, Indonesia, with relation to environmental factors

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Abstract. Jakarta Bay is a semi-enclosed bay, located on the western side of the northern part of Java Island, Indonesia. This study reports the spatial distribution of recent ostracode assemblages from the top of 19 core samples collected in 1994 and the relationship between the assemblages and environmental factors. This study is the first of the ostracode species of Jakarta Bay, and succeeded in identifying 94 species living there. Ostracodes are common in the East Indian Province. The dominant species found were *Keijella carriei* Dewi, *Hemicytheridea reticulata* Kingma, *Loxoconcha wrighti* Dewi, and *Hemicytheridea ornata* Mostafawi. Species belonging to the genera *Cytherella*, *Cytherelloidea*, *Neomonoceratina*, and *Pistocythereis* were also abundant. According to Q-mode cluster analysis, three biofacies (I, II, and III) were recognized, clearly distributed from the inner to the outer parts of the bay. Biofacies I is distributed in the muddy bottoms of the inner to the middle parts of the bay and is composed mainly of *K. carriei*, *L. wrighti*, and *H. reticulata*. Biofacies II is distributed in the muddy bottoms of the outer part of the bay and is characterized by the abundance of *H. reticulata*, *H. ornata*, and *Cytherella* spp. Biofacies III is distributed in the sandy mud bottoms of the outer part of the bay, and is characterized by high-diversity assemblages composed of *Atjehella kingmai* Keij, *Foveoleberis cypraeoides* (Brady), *Neomonoceratina bataviana* (Brady), and *Pistocythereis cribriformis* (Brady). This study ~~correlated~~ relationships between dominant species and bottom environment factors such as total organic carbon (TOC), total sulfur (TS), total nitrogen (TN), total organic carbon/ total nitrogen ratio (C/N ratio), and total organic carbon/total sulfur ratio (C/S ratio). The results show that *K. carriei* and *L. wrighti* are common in areas with high TOC and TN contents, even when they are anoxic, while *H. ornata* and *H. reticulata* preferably thrive in deeper areas with low TOC and TN contents. Thus, because of these environmental factors, species diversity and density are low in near-shore sites where the TOC content of mud is relatively high and the bottom is anoxic or oxygen-poor even though the water is shallow.

Key words: Indonesia, Jakarta Bay, ostracodes, TN ,TOC, TS

Introduction

Jakarta Bay is a semienclosed bay located on the western side of the northern part of Java Island, Indonesia. It forms the southwestern shore of the Java Sea, which is a transoceanic gateway between the Indian Ocean to the west and the Pacific Ocean to the east, and a location that allows the investigation of the migratory pathway of Ostracoda (minute Crustacea) between these two distinct biogeographical regions. Titterton and Whatley (1988) introduced 13 ostracode zoogeographical provinces based on the geographical distribution of species and degree of endemism in the shallow waters of the Indo-Pacific Oceans. According to their study, ostracode assemblages from the present study area belong to the East Indian Province, which extends from West Papua to the Malacca Straits and the South China Sea. However, Tanaka *et al*. (2009) investigated the Recent ostracode assemblages from the northern coast of Vietnam and suggested that the assemblage belonged to the Khymerian

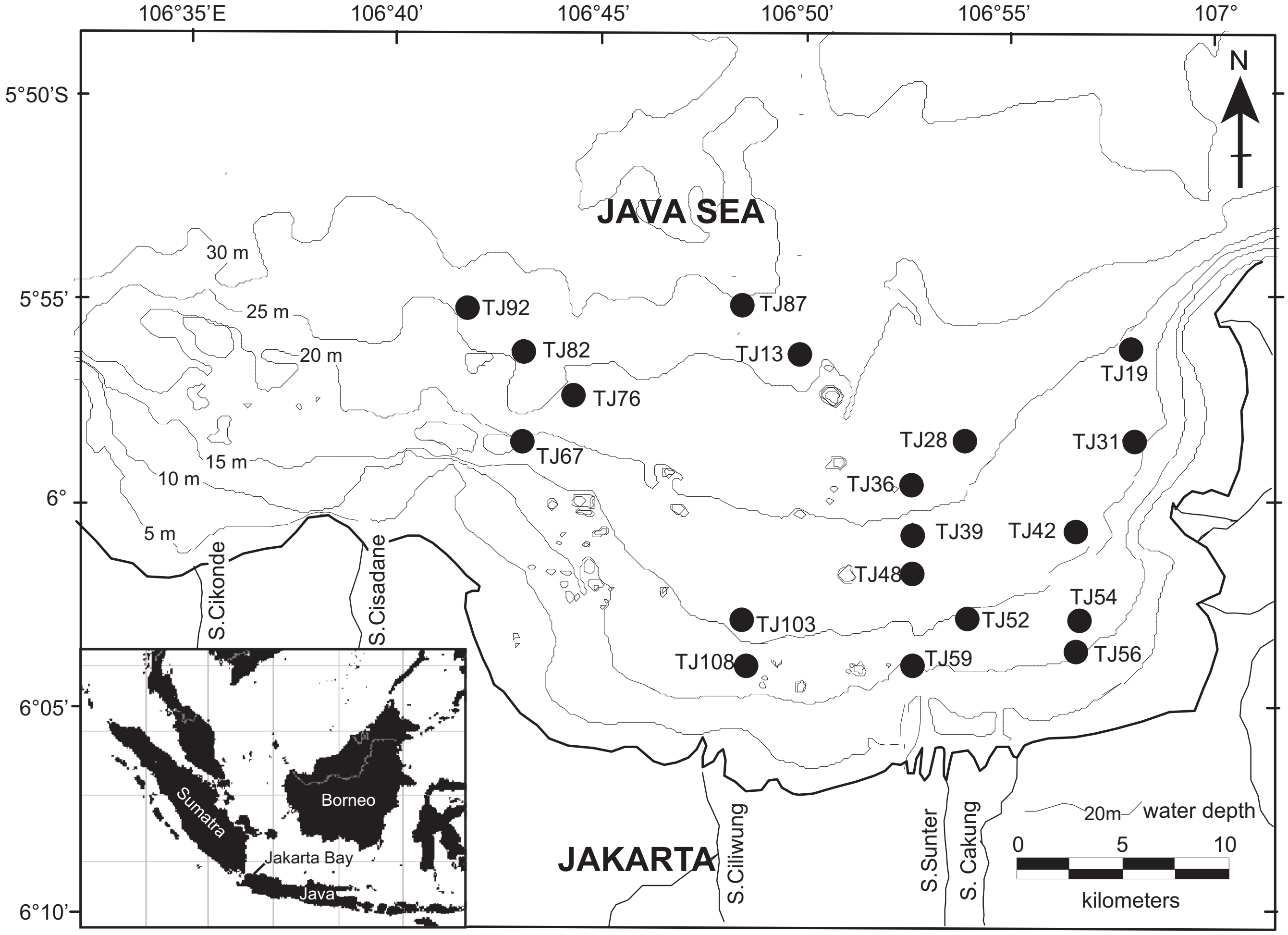


Figure 1. Location of Jakarta Bay and sample localities used in this study.

Province of Titterton and Whatley (1988). Thus, some problems are still left in the biogeography of ostracodes around southeastern Asia.

Ostracodes from Indonesian seas were first investigated by Brady (1880). Since then a number of studies have contributed to a better understanding of ostracodes found in Indonesian seas. However, research on ostracodes in the Java Sea is relatively restricted (Kingma, 1948, Java Sea; Whatley and Watson, 1988, Thousand Island; Dewi, 1997, Bawean Island; Mostafawi *et al.*, 2005, Bali Strait), and there have been no studies of ostracodes from Jakarta Bay, which faces the capital city of Indonesia, Jakarta.

This study aims to elucidate the recent ostracode fauna in Jakarta Bay and discusses the relationship between its distribution and environmental factors.

The bay is close to a large capital city (population greater than 9 million) and receives discharges from 13 rivers around Jakarta, owing to which serious anthropogenic impacts in this area have been recently observed (Fachrul *et al.*, 2005; van der Meij *et al.*, 2009). Among the various environmental factors, bottom sediment quality and oxic/anoxic conditions are of particular importance to reconstruct paleoenvironments in the southeastern Asian areas, since they strongly affect the density and faunal composition of ostracode associations (Irizuki *et al.*, 2009a, 2010, 2011).

Study area

Jakarta Bay is a very fertile area as a result of an abundant supply of nutrients from rivers that cross the city. It covers an area of approximately 514 km^2 (Figure 1) with an average depth of approximately 15 m. Aside from being a major port, Jakarta Bay supports fisheries and tourism, and has been the main recipient of wastewater from domestic and industrial activities in the surrounding

Table 1. ~~List ofSample data~~

sample no.	Latitude	Longitude	Depth (m)	Md ϕ	Mud (%)	TN (wt%)	TOC (wt%)	TS (wt%)	C/N	C/S
TJ13	106° 49' 44.4"E	5° 56' 20.4"S	27.2	8.0	98.9	0.135	0.883	0.312	6.564	2.831
TJ19	106° 58' 0.4"E	5° 56' 18.4"S	17.8	8.1	99.4	0.125	0.918	0.207	7.358	4.427
TJ28	106° 53' 54.4"E	5° 58' 31.7"S	21.0	7.9	99.7	0.136	0.901	0.459	6.605	1.962
TJ31	106° 58' 1.4"E	5° 58' 28.6"S	16.5	8.5	99.4	0.133	0.895	0.533	6.744	1.679
TJ36	106° 52' 33.6"E	5° 59' 34.8"S	21.0	8.4	97.8	0.128	0.806	0.593	6.288	1.359
TJ39	106° 52' 37.0"E	6° 0' 44.5"S	19.5	8.3	96.8	0.134	0.777	0.748	5.777	1.039
TJ42	106° 56' 38.2"E	6° 0' 43.1"S	17.0	8.3	99.4	0.134	0.831	0.414	6.187	2.009
TJ48	106° 52' 34.3"E	6° 1' 46.3"S	17.8	8.2	98.1	0.077	0.561	0.835	7.287	0.672
TJ52	106°53' 52.8"E	6° 2' 49.2"S	15.2	7.6	77.8	0.144	1.294	0.950	8.958	1.363
TJ54	106° 56' 40.5"E	6° 2' 52.4"S	13.1	8.7	97.0	0.165	1.406	1.056	8.500	1.332
TJ56	106° 56' 38.9"E	6° 3' 39.7"S	11.0	8.4	78.5	0.128	0.941	1.192	7.330	0.790
TJ59	106° 52' 37.0"E	6° 4' 1.1"S	10.4	7.5	91.1	0.166	1.949	1.291	11.769	1.510
TJ67	106° 42' 57.6"E	5°58' 26.4"S	19.6	7.9	76.3	0.088	0.608	0.417	6.939	1.458
TJ76	106° 44' 16.8"E	5° 57' 21.6"S	22.7	8.6	76.9	0.108	0.728	0.233	6.766	3.128
TJ82	106° 43' 1.2"E	5° 56' 13.2"S	29.1	7.8	48.3	0.046	0.532	0.703	11.505	0.756
TJ87	106° 48' 27.6"E	5° 55' 10.6"S	29.7	8.2	94.8	0.121	0.819	0.326	6.747	2.511
TJ92	106° 41' 34.8"E	5° 55' 8.4"S	24.8	8.5	93.1	0.051	0.334	0.107	6.598	3.116
TJ103	106° 48' 25.7"E	6° 2' 50.6"S	16.0	7.7	97.6	0.164	1.109	0.498	6.773	2.229
TJ108	106° 48' 26.8"E	6° 3' 58.5"S	13.7	8.2	99.8	0.148	1.328	0.974	8.990	1.363

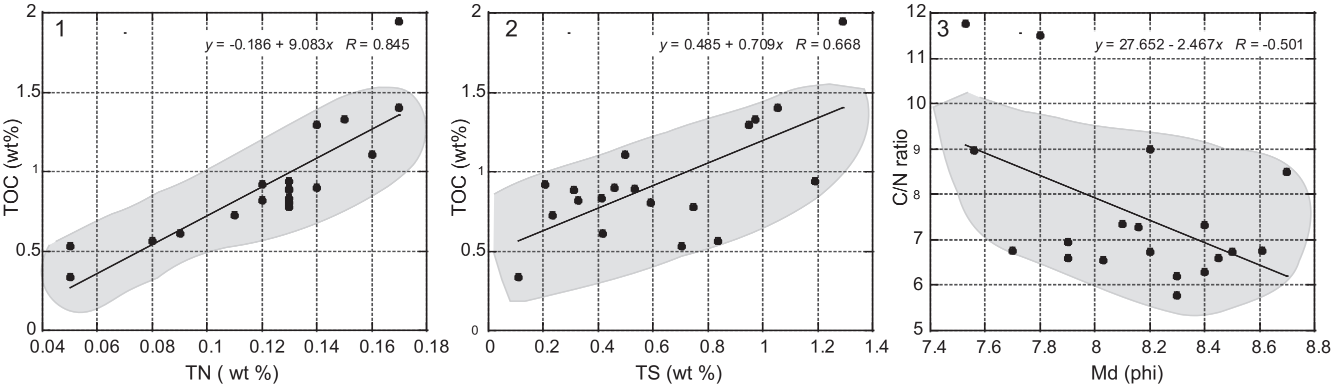


Figure 2. Relationships between environmental factors in the surface sediments in Jakarta Bay. **1**, Cross-plots of TOC and TN; **2**, Cross-plots of TOC and TS; **3**, Cross-plots of C/N ratio and median grain size (Md).

area. Thus, there are a number of pressures on the marine environment throughout the year, leading to the deterioration of the bay.

Ilahude and Liasaputra (1978) and Ilahude (1995) measured water temperature, salinity, and dissolved oxygen in the bay as follows.

Water temperature.—Surface and bottom water temperatures ranged from 28.8 to 31.0°C and ~~28.4~~ to 29.0 °C, respectively. Surface temperature was higher than bottom temperature. Differences between the surface and bottom temperatures were insignificant. Water temperature is almost the same in all locations, except in areas close to Tanjung Priok harbor, where the temperature is higher (Ilahude and Liasaputra, 1978).

Salinity.—The salinity of the surface and bottom waters ranged from 30.2 to 32.0 ~~psu~~ and ~~31.7~~ to 32.2 ~~psu~~, respectively. Salinity increased toward the outer part of the bay. Salinity distribution in this area is affected by water circulation, evaporation, rainfall, and river flow (Nontji, 1987).

Dissolved oxygen.—Dissolved oxygen in the bay ranged from 4.28 to 5.16 mL/L. During the fall transition season (September–November), dissolved oxygen is higher in the east and decreases toward the west coast (Ilahude, 1995). Oxygen saturation levels of intermediate to surface water are high, indicating that the process of organic decay is limited in intermediate to surface water from estuaries or from land; offshore, water circulation

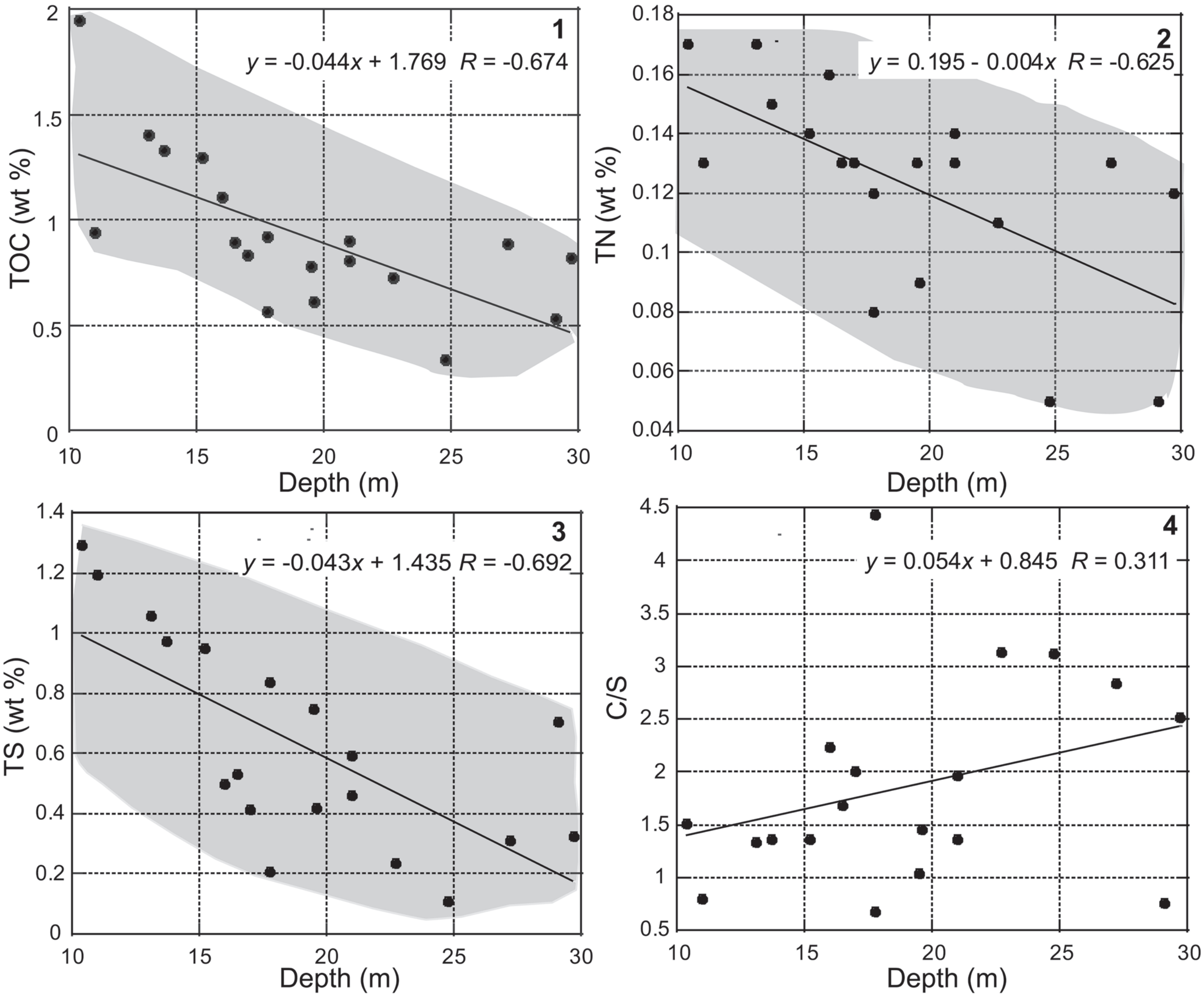


Figure 3. Cross-plots of water depth (m) and environmental factors. **1**, TOC; **2**, TN; **3**, TS ; **4**, C/S ratio. Shaded areas show the range of values. The solid line is the regression line.

provides oxygen saturation. However, dissolved oxygen in the water is seasonally changeable and has not been revealed in the bottom water.

Materials and methods

Sediment samples used in this study were collected in 1994 by the Indonesian Marine Institute. Nineteen sediment cores were collected using a gravity corer (Figure 1, Table 1). The top 1–2 cm of these cores were used for ostracode faunal studies, sedimentology, and analyses of total organic carbon (TOC), total nitrogen (TN), and total sulfur (TS) contents.

Samples were weighed and washed through a ~~63-μm~~ sieve, then dried in an oven, and finally the residues were sieved into ~~125-μm~~ fractions. The dried sediments were weighed and mud content was calculated based on water content and weight of residue from the washed samples.

The samples of ~~>125-μm~~ fractions containing abundant ostracode specimens were divided into parts containing approximately 200 specimens each, using a sample splitter. The number of specimens refers to the sum of left and right valves. One carapace was counted as two valves.

Grain size analysis was conducted using a laser diffraction particle size analyzer (SALD-3000S, Shimadzu

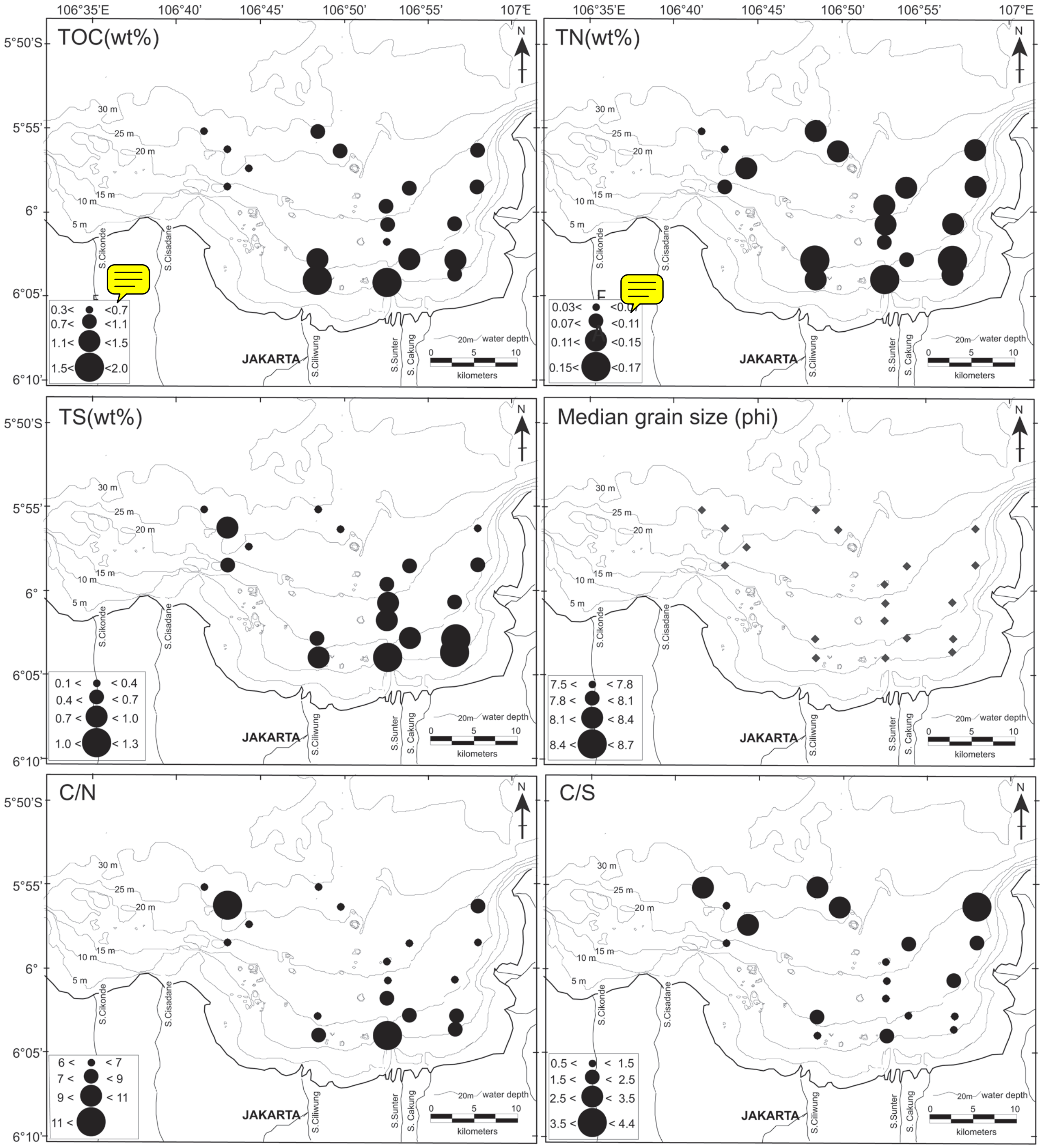


Figure 4. Distribution of environmental factors (TOC, TN, TS, Median grain size, C/N ratio, C/S ratio).

Table 2. Faunal list of recent ostracodes from Jakarta Bay

	TJ13	TJ19	TJ28	TJ31	TJ 36	TJ39	TJ42	TJ48	TJ52	TJ54	TJ56	TJ59	TJ67	TJ76	TJ82	TJ87	TJ92	TJ103	TJ108	sum
Acutinocythereis scutigera (Brady)	1				1		2	4	3				5	5	8	8	3		1	41
Aglaiocypris sp.		1		1		1	2				1							6		12
Alocopocythere kendengensis (Kingma)								1	1				2							4
Alocopocythere sp.							3													3
Argilloecia cf. *lunata* Frydl														1		1	1			3
Argilloecia sp. 1								1												1
Argilloecia sp. 2	1												5	10	1	3				20
Argilloecia sp. 3																2				2
Atjehella kingmai Keij	2	1				1		2	3			1	8	8	12		22	2		62
Bythoceratina bicornis Mostafawi																	1			1
Bythoceratina hastata Mostafawi													1							1
Bythoceratina nelae Mostafawi															1		1			2
Bythoceratina sp.																	2			2
Callistocythere sp.																	1			1
Caudites jasonensis Zhao and Whatley									4			1			1		1			7
Copytus posterosulcus Wang		1	12	8		8	8	2	2	8		5		2		5	2	7	1	71
Coquimba poga Hu														1						1
Corallicythere sp.																	2			2
Cytherella incohota Zhao and Whatley	5				1	3	3	7	1			4	12	12		11		3		62
Cytherella javaseaense Dewi	4		4	1	3	6	7	2	12	6			3			7		4	4	63
Cytherella semitalis Brady						4	4		11			5	16	26	3			2		71
Cytherelloidea cingulata (Brady)	5												1	8	8	5	10	1		38
Cytherelloidea excavata Mostafawi						4			8	12		16				1				41
Cytherelloidea leroyi Keij			2			5		3	5			5	18	2	4			4		48
Cytheropteron sp. 1															1					1
Cytheropteron sp. 2													1							1
Foveoleberis cypraeoides (Brady)															10		14			24
Hemicytheridea ornata Mostafawi	23		25	1		25	25	39	4	1	2	12	13	10	4	32		13	11	240
Hemicytheridea reticulata Kingma	4		23		39	34	26	65	29	2		14	23	23	17	5	9	14	7	304
Hemicytherura cuneata Hanai																	1			1
Hemikrithe foveata Guan								1												1
Hemikrithe orientalis van den Bold	3				1		3	1		9		1	1	4	1	2	1	1		28
Hemikrithe peterseni Jain							1						2			3				6
Javanella sp.														1						1
Keijella carriei Dewi	20	3	52	50	26	48	33	2	28	52	38	15	5					55	8	435
Keijella gonia Zhao and Whatley			2	1				1	5			4	3					2		18
Keijella multisulcus Whatley and Zhao									1			1		1	7		2			12
Keijella? sp.														1	2					3
Keijia borneoensis Mostafawi								1							2		1			4
Keijia labyrinthica Whatley and Zhao	6		1	1			1		1			1	3		13	8	21			56
Keijia tjokrosapoetroi Dewi						3		1				1		4	4	2	1	2		18
Loxoconcha lilljeborgii Brady									7				1							8
Loxoconcha paiki Whatley and Zhao								1	2				1		1					5
Loxoconcha wrighti Dewi	8		18	13	14	23	26	12	13	23	18	29	7	7	5	4		22	2	244
Loxoconcha sp. 1												1								1
Loxoconcha sp. 2										1		1					2			4
Macrocypris decora (Brady)																	3			3
Malaycythereis trachodes Zhao and Whatley	2								2				2	3	2					11
Miocyprideis cf. *spinulosa* (Brady)									3					1						4
Neocytheretta murilineata Zhao and Whatley						1		2	3			1	5				1	3		16
Neocytheretta novella Mostafawi									2					1	6		6			15
Neocytheretta spongiosa (Brady)													1	3	2		2			8
Neomonoceratina bataviana (Brady)												1	5	10	12	6	15	1		50
Neomonoceratina columbiformis Kingma	1		4		2		1	1	4			4	1	2	8	1	3	4	2	38
Neomonoceratina delicata Ishizaki and Kato							2	3				5	2		1	17				30
Neomonoceratina cf. *entomon* (Brady)			4	2			4		1			1								12
Neomonoceratina iniqua (Brady)	31		3		6	2	14	7					6			2			7	78
Neomonoceratina macropora Kingma									3											3
Neomonoceratina rhomboidea (Brady)			5	10		11			5	11	6	4					2	21		75
Neosinocythere sp.												1								1
Paijenborchella iocosa Kingma	1																			1
Paracypris nuda Mostafawi			1																	1
Paracytheridea sp. 1												1					1			2
Paracytheridea sp. 2															1		1			2
Paracytherois sp.			1								1	2								4
Paracytheroma ventrosinuosa Zhao and Whatley															7		5			12
Parakrithe placida Mostafawi	1			1			4							2		5	1			14
Parakrithella sp.			1									2		6	19	5	18		2	53
Paranesidea sp. 1									2											2
Paranesidea sp. 2									2											2
Phlyctenophora orientalis (Brady)								3	8		11	8	3	6	3	1	4	2	1	50
Phlyctocythere sp.														1						1
Pistocythereis cf. *bradyformis* (Ishizaki)	6		16	8	5	14	10	4	2	8	1		3	2		4	1	10	9	103
Pistocythereis cribriformis (Brady)						5			12			6	6	6	11	2	10			58
Pistocythereis euprectella (Brady)	1													1	1	1				4
Propontocypris sp. 1	2	9	6	10	7	3	10	1	3	13	4	4			1	2	1	18		94

Table 2. Continued.

	TJ13	TJ19	TJ28	TJ31	TJ 36	TJ39	TJ42	TJ48	TJ52	TJ54	TJ56	TJ59	TJ67	TJ76	TJ82	TJ87	TJ92	TJ103	TJ108	sum
Propontocypris sp. 2			1			3	4										1			9
Pseudopsammocythere sp.	7				6		3	3	1				1	5	2	10	2			40
Robustaurilla australiensis (Hartman)									1								1			2
Semicytherura borneoensis Mostafawi															1		1			2
Semicytherura contraria Zhao and Whatley															1		3			4
Semicytherura indonesiana Whatley and Zhao														1			9			10
Spinoceratina spinosa (Zhao and Whatley)															2		2			4
Stigmatocythere indica (Jain)	11		2		4	10	4	12		1		3	4	1		12		6		70
Stigmatocythere kingmai Whatley and Zhao														4			2			6
Stigmatocythere roesmani (Kingma)			1			1			3	1		1	3			1		1		12
Stigmatocythere rugosa (Kingma)													1	5		3				9
Tanella gracilis Kingma				2	1				1	3		6	1	1	1		1	1		18
Typhlocythere sp.									1			1		1						3
Venericythere papuensis (Brady)	3	2	4	3	8	6	5	11	11			6	19	4	2	10		5	1	100
Xestoleberis cf. *hanaii* Ishizaki	1											3			4		6			14
Xestoleberis malaysiana Zhao and Whatley	13								2				1	5	3	24				48
Xestoleberis sp.									1											1
Gen. et sp. indet.			5	2			1		2			2	1						2	15
Number of specimens	162	17	193	114	126	221	206	193	215	151	82	179	196	197	195	205	200	210	58	3209
Number of species	25	6	23	16	15	23	26	28	42	15	9	38	39	40	41	33	46	26	14	94
Diversity	2.67	1.40	2.44	1.97	2.12	2.57	2.75	2.33	3.16	2.13	1.55	3.07	3.15	3.19	3.24	3.03	3.07	2.63	2.32	
Equitability	0.60	0.67	0.52	0.45	0.56	0.57	0.60	0.39	0.62	0.56	0.52	0.62	0.63	0.66	0.69	0.65	0.60	0.53	0.72	
Sample weight	4.629	5.24	6.025	6.375	2.04	5.788	3.692	9.382	7.692	6.301	1.616	4.749	12.13	6.009	7.736	6.053	14.89	5.055	4.36	
Split	2	1	1	1	2	4	1	4	4	2	2	2	32	16	32	4	32	2	1	
Split sample weight (g)	2.315	5.24	6.025	6.375	1.02	1.447	3.692	2.345	1.923	3.15	0.808	2.374	0.379	0.376	0.242	1.513	0.465	2.527	4.36	
No. of individuals / 1g weight	69.99	3.245	32.03	17.88	123.5	152.7	55.79	82.29	111.8	47.93	101.5	75.39	516.9	524.5	806.7	135.5	429.8	83.09	13.3	

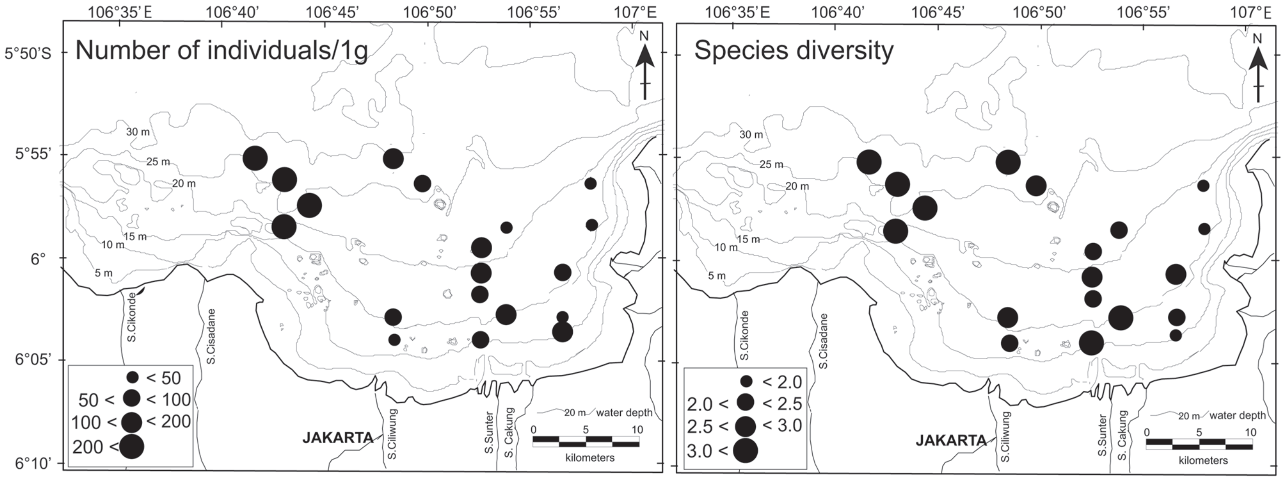


Figure 5. Distribution of total number of individuals/1g sediment sample and species diversity (Shannon index) in Jakarta Bay.

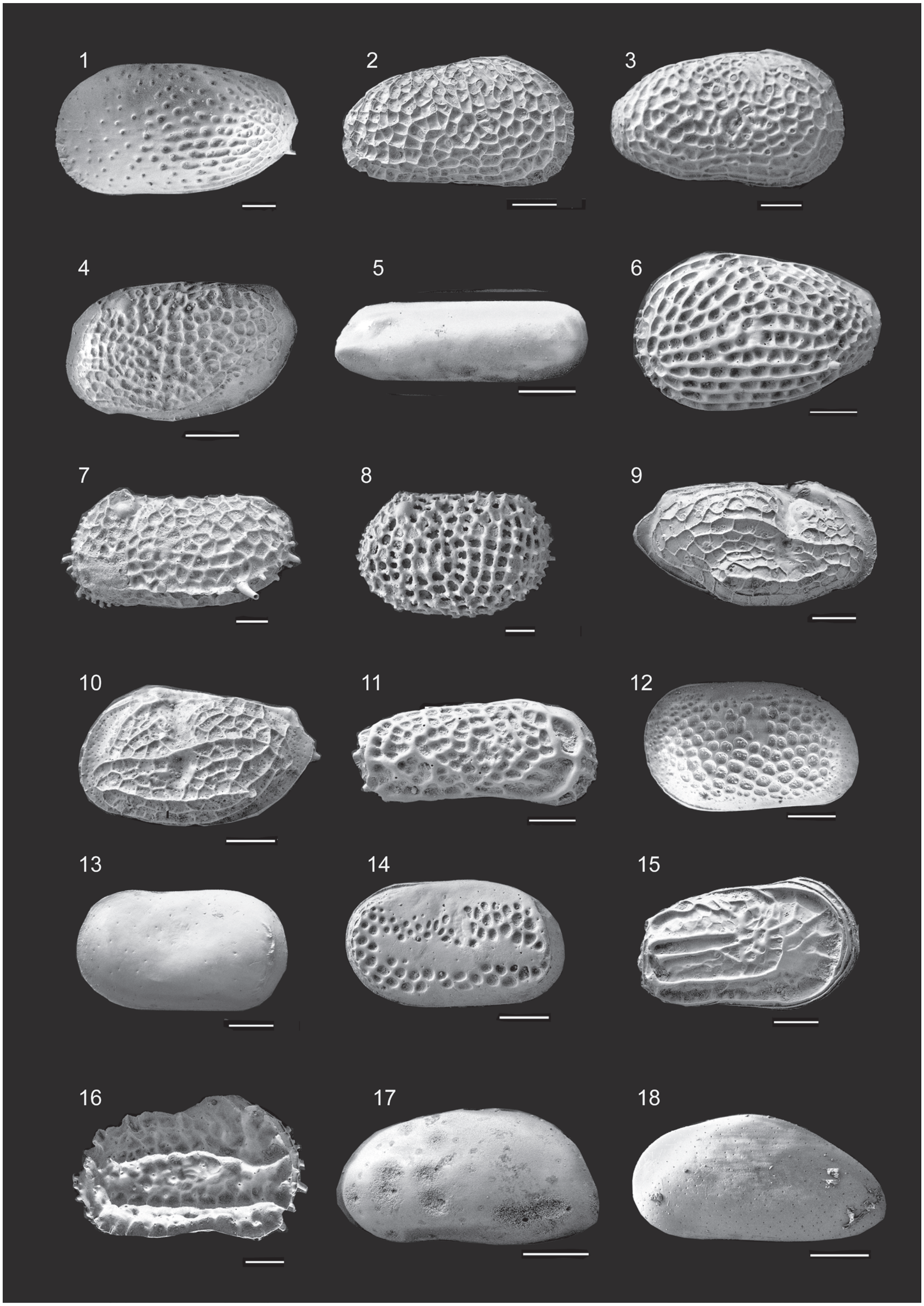
Co., Ltd., Japan) after decomposition of organic matter and pyrite with H_2O_2 for several days.

TOC, TN, and TS concentrations were measured by the combustion method at 1000°C in a FISONS elemental analyzer EA 1108, after treatment to remove the carbonate fraction. This treatment was performed by adding 1M HCl to the weighed sediment in Ag cups.

Results and discussion

Grain size and CNS (TOC, TN, and TS) elemental analysis

The median grain size of the bottom sediment in the study area ~~is~~ approximately 7.5–8.7 ϕ (Table 1). The mud content of all samples was greater than 76%, except in site TJ82 (Table 1).


1
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TOC and TN contents in the study area were 0.3–2.0 wt% and 0.04–0.17 wt%, respectively (Figure 2.1). TOC ranged from 0.9 to 2.0 wt% in the inner part of the bay at water depths of 10–16 m, and decreased to 0.3–0.9 wt% in the middle to ~~the~~ outer parts of the bay at water depths of 16–30 m (Figures 3.1, 4, Table 1). TN showed the same trend as TOC; the values were 0.13–0.17 wt% in the inner part of the bay and decreased to 0.05–0.14 wt% in the middle to ~~the~~ outer parts of the bay (Figures 3.2, 4, Table 1). TS values were low, ranging from 0.95 to 1.29 wt% in the inner part of the bay and decreasing to 0.11–0.84 wt% in the middle to ~~the~~ outer parts of the bay (Figures 3.3, 4, Table 1). Thus, TOC, TN, and TS distributions generally showed the same profiles, decreasing toward the outer part of the bay (Figure 4) and negatively correlated to water depth (Figure 3).

The weight ratio of TOC to TN (C/N ratio) ranged from 5.8 to 11.8 (Figure 2.3, Table 1). The C/N ratio has been used as a simple proxy to reconstruct the marine and land paleoenvironment. The C/N ratio in aquatic systems is formed by the mixing of autochthonous and terrestrial organic matter. Freshly deposited organic matter derived mainly from planktonic organisms has ~~a C/N ratio~~ of 6–9, while terrestrial vascular plants and their derivatives in sediments have C/N ratios of 15 or higher (Bordowskiy, 1965a, 1965b; Prahl *et al*., 1980; Biggs *et al*., 1983; Ertel and Hedges, 1984; Post *et al*., 1985; Ertel *et al*., 1986; Hedges *et al*., 1986; Orem *et al*., 1991; Sampei and Matsumoto, 2001). Sediment fractions with different grain sizes have different C/N ratios. The C/N ratios of organic matter in fine-grained sediment fractions are lower than those in coarse-grained sediment fractions (Figure 2.3), because coarse-grained sediment fractions contain a larger proportion of intact land-plant debris than ~~do~~ fine-grained sediment fractions (Meyers, 1997). As TOC increases with TN, the nitrogen is mainly supplied by planktonic organic matter (Figure 2.1)

The weight ratio of TOC to TS (C/S ratio) ranged from 0.7 to 4.4 (Figure 3.4, Table 1). Plotting TS against TOC showed positive correlations (Figure 2.2). This suggests that TS content in this bay is indeed controlled by organic matter concentration, which could decrease dissolved oxygen in the bottom water. Cross-plots of TOC and TS for depositional environment observed in Figure 2 (Berner and Raiswell, 1984) show that 80% of areas with TS and TOC <1 wt% have TOC/TS ratios ranging from 1 to 3, which overlap the ranges of TOC/TS ratios for a semi-closed brackish coastal lake and a normal marine area (Sampei *et al*., 1997).

Ostracode assemblages, biofacies, and their distribution

All specimens sampled in this study were carapaces or valves of dead ostracodes. A ~~1- to 2-~~ cm thick layer of core-top sediment was used in our ostracode analysis. Most ostracode specimens were collected from very fine silt or clayey samples, suggesting that there were few transported valves. Thus, ostracode assemblages in the present study may be comparable to the within-habitat time-averaged assemblages of Kidwell (1991). Total ostracode density (total ostracode number per 1 g dry sediment) ranged between 3 and 807 (Table 2), with a minimum in sample TJ19 and a maximum in sample TJ82. The total ostracode density and species diversity (*H*(*S*): Shannon index) tended to increase toward the outer part of the bay, with increasing water depth, though there are some exceptions in shallow areas (Figure 5).

At least 94 ostracode species were identified from 19 samples (Table 2). Most of them have been reported from southeastern Asia (Brady, 1880; Kingma, 1948; Keij, 1954, 1964; Whatley and Zhao, 1987, 1988; Whatley and Watson, 1988; Zhao and Whatley, 1989; Mostafawi, 1992; Dewi, 1997; Mostafawi *et al*., 2005; Montenegro *et al*., 2004; Tanaka *et al*., 2009, 2011). Especially they are most closely related to those from the west of Bawean Island, Java Sea, which belongs to the East Indian Province of Titterton and Whatley (1988) (Dewi, 1997). Ostracode preservation was moderate to good. Micrographs of 18 dominant species are shown in Figure 6. Among the 94 species, four species individually exceed 5% of the total number of specimens, and 23 species have 1–3% frequencies. The remaining species are each less than 1%. Figure 7 shows the spatial distribution of the frequency of the four dominant species.

The most abundant species was *Keijella carriei* Dewi, which comprised 13.6% of the total ostracodes sampled

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⬅ **Figure 6.** Scanning electron micrographs of the dominant species. (ALV: adult left valve, ARV: adult right valve, JRV: juvenile right valve). **1**, *Keijella carriei* Dewi, ALV, sample TJ31; **2**, *Hemicytheridea reticulata* Kingma, ARV, sample TJ48; **3**, *Hemicytheridea ornata* Mostafawi, ARV, sample TJ48; **4**, *Loxoconcha wrighti* Dewi, ALV, sample TJ42; **5**, *Copytus posterosulcus* Wang, ARV, sample J103; **6**, *Venericythere papuensis* (Brady), JLV, sample TJ67; **7**, *Pistocythereis* cf. *bradyformis* (Ishizaki), ALV, sample J103; **8**, *Pistocythereis cribriformis* (Brady), ALV, sample TJ52; **9**, *Neomonoceratina rhomboidea* (Brady), ARV, sample TJ 103; **10**, *Neomonoceratina iniqua* (Brady), ALV, sample TJ67; **11**, *Keijia labyrinthica* Whatley and Zhao, ARV, sample TJ92; **12**, *Cytherella javaseaense* Dewi, JLV, sample TJ52; **13**, *Cytherella incohota* Zhao and Whatley, ALV, sample TJ67; **14**, *Cytherella semitalis* Brady, ALV, sample TJ76; **15**, *Atjehella kingmai* Keij, ARV, sample TJ92; **16**, *Stigmatocythere indica* (Jain), ARV, sample TJ4; **17**, *Parakrithella* sp. ALV, sample TJ76; **18,** *Propontocypris* sp. 1, ALV, sample TJ56. Scale bars = 0.1 mm

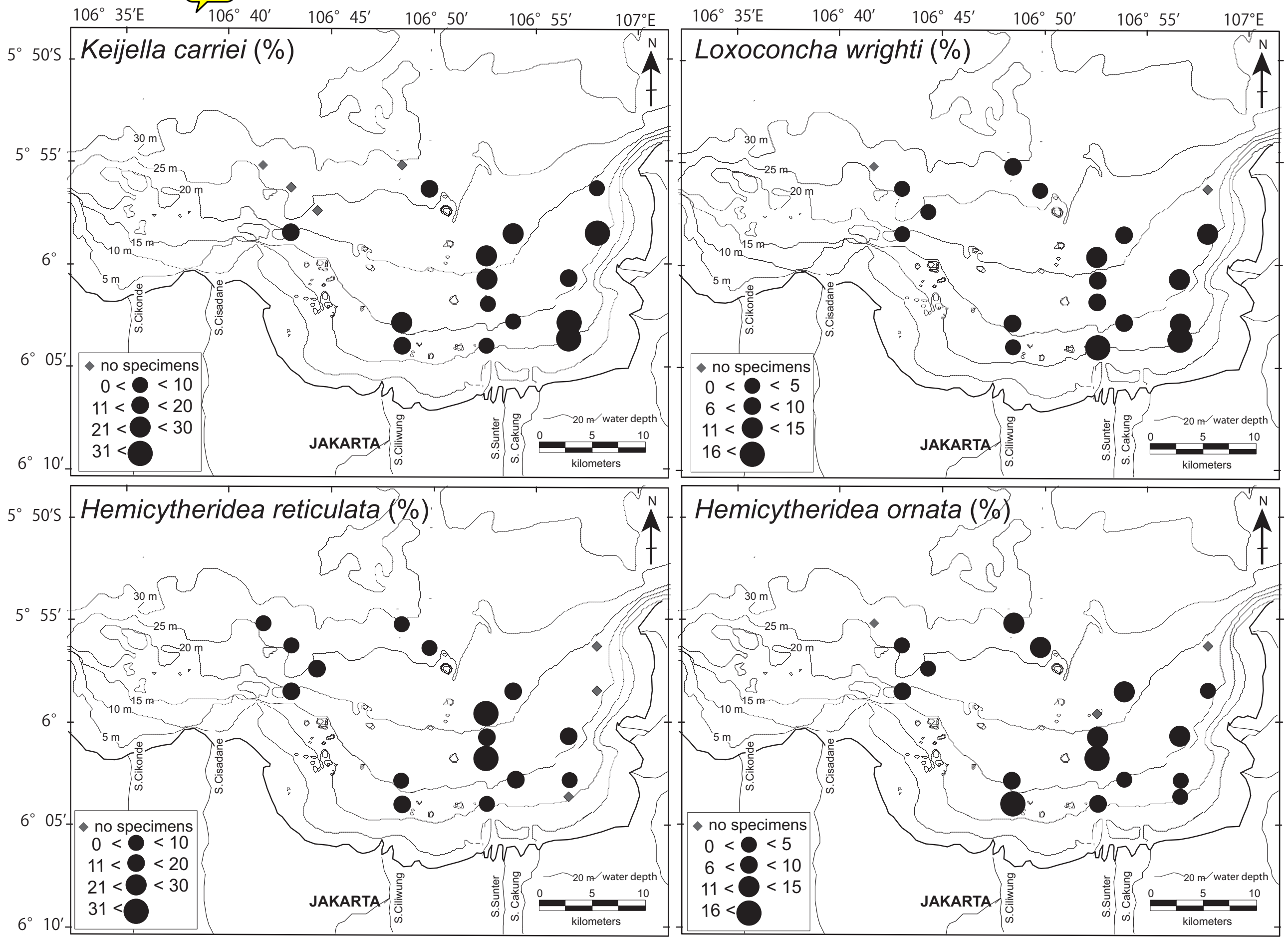

Figure 7. Distribution of frequency (%) of dominant species in Jakarta Bay: *Keijella carriei* Dewi, *Loxoconcha wrighti* Dewi, *Hemicytheridea reticulata* Kingma, and *Hemicytheridea ornata* Mostafawi.

and was found in 15 out of 19 samples. Its density ranged from 0 to 47 individuals/g. Maximum density was found in sample TJ56, collected from the innermost part of the bay. This species is widespread at a water depth of less than 22 m, being abundant in the inner shallowest part and decreasing toward the outer part of the bay. It has been reported only from the Java Sea, west of Bawean Island, Indonesia (Dewi, 1997).

The second most abundant species was *Hemicytheridea reticulata* Kingma, which comprised 9.5% of the total ostracodes and was found in 16 out of 19 samples. Its density ranged from 0 to 70 individuals/g. Maximum density was found in sample TJ82, collected from the outer bay. This species is common in the Malay Peninsula (Zhao and Whatley, 1989).

The third most abundant species was *Loxoconcha wrighti* Dewi, which comprised 7.6% of the total ostracodes and was found in 17 out of 19 samples. Its density ranged from 0 to 22 individuals/g. Maximum density was found in sample TJ56, collected from the innermost part of the bay. It has so far only been found in the Java Sea (Dewi, 1997).

The fourth most abundant species was *Hemicytheridea ornata* Mostafawi, which comprised 7.5% of the total ostracodes and was found in 16 out of 19 samples. Its density ranged from 0 to 34 individuals/g. Maximum density was found in sample TJ67, collected from the outer part of the bay. This species is distributed in the Singapore Platform and the Java Sea (Dewi, 1997) and the Sunda Shelf (Mostafawi, 1992).

The remaining species individually fell below 4% of the total ostracodes. Species belonging to the genera *Cytherella*, *Cytherelloidea*, *Neomonoceratina*, and *Pistocythereis* were also commonly observed. ~~*Neomonoceratina*~~ *delicata* Ishizaki and Kato, commonly found in eastern Asian enclosed bays (Zhao and Wang, 1988; Iri-

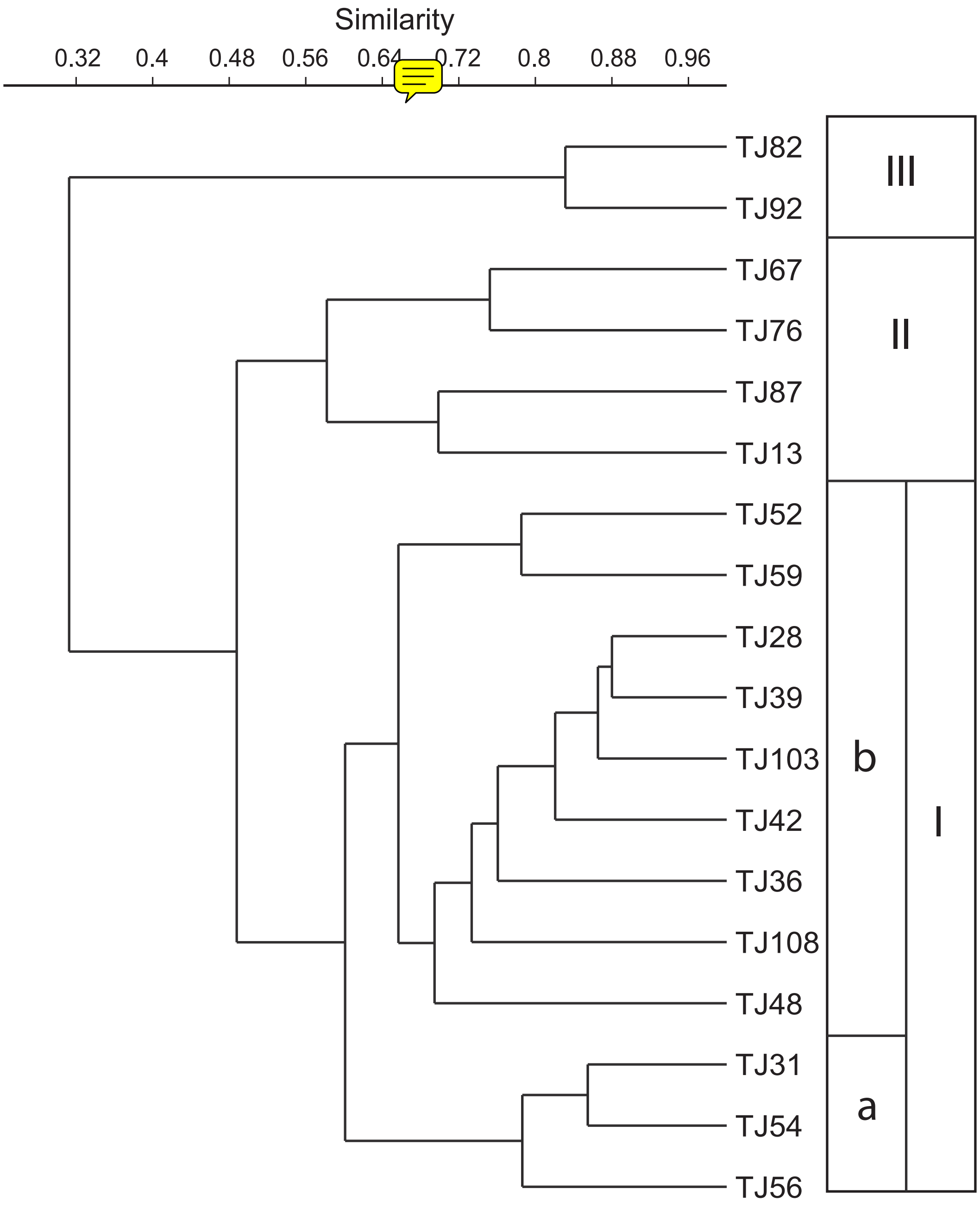

Figure 8. Dendrogram of Q-mode cluster analysis. I, II, and III refer to biofacies. a and b denote sub-biofacies of biofacies I.

zuki *et al*., 2009b, Tanaka *et al*., 2009), was also identified.

To clarify the spatial distribution patterns of ostracode assemblages, Q-mode cluster analysis was conducted. Fifty-eight species represented by more than three specimens in any of the samples were used in this analysis. Horn's overlap index (Horn, 1966) was used as a similarity index and clustering was made by the unweighted pair group method with arithmetic mean. The computer program used for the analysis was PAST (Paleontological Statistics), which is designed for paleontological data (Hammer *et al*., 2001).

The results demonstrate that three biofacies (I, II, and III) can be identified (Figure 8), and that they are clearly

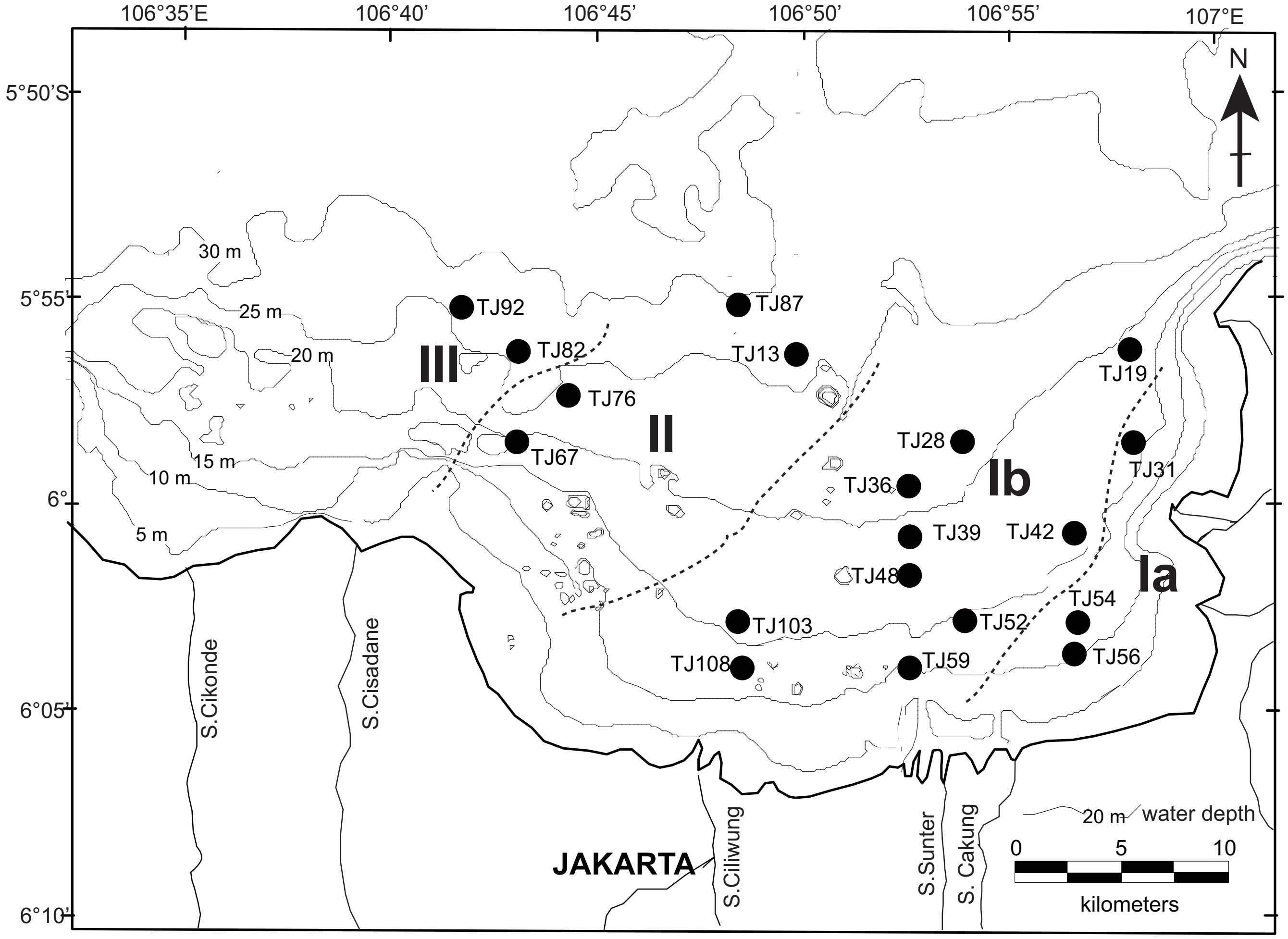

Figure 9. Distribution of biofacies (II, III) and sub-biofacies (Ia, Ib) in Jakarta Bay based on Q-mode cluster analysis.

distributed from the inner to the outer parts of the bay (Figure 9) as follows.

Biofacies I is divided into two subbiofacies (Ia and Ib). Subbiofacies Ia comprises three samples and is distributed in the inner part of the bay at water depths of 11.0–16.5 m. The median grain size of the bottom sediment ranges from 8.5 to 8.7 ϕ. The dominant species are *K. carriei* and *L. wrighti*. *Neomonoceratina rhomboidea* (Brady), *Pistocythereis* cf. *bradyformis* (Ishizaki), and *Propontocypris* sp. 1 are common in this biofacies. Species diversity is the lowest among the biofacies ($H(S)$ = 1.6–2.1). Subbiofacies Ib comprises nine samples and is distributed in the middle part of the bay at water depths of 10.4–21.0 m. The median grain size of bottom sediments ranges from 7.5 to 8.6 ϕ. The dominant species are *K. carriei*, *H. reticulata*, *L. wrighti*, and *H. ornata*. *P.* cf. *bradyformis*, *Propontocypris* sp. 1, *Copytus posterosulcus* Wang, *N. rhomboidea*, and *Venericythere papuensis* (Brady) are common. Species diversity is low to high ($H(S)$ = 2.1–3.2).

Biofacies II comprises four samples in the outer part of the bay. The grain size of bottom sediment ranges from 8.3 to 8.5 ϕ. The dominant species are *K. carriei*, *H. reticulata*, *L. wrighti*, and *H. ornata*. *P.* cf. *bradyformis* is common. Species diversity is moderate to high ($H(S)$ = 2.69–3.24).

Biofacies III comprises two samples that are distributed in the outermost part of Jakarta Bay. The grain size of bottom sediment ranges from 7.8 to 8.1 ϕ. It is characterized by high-diversity assemblages comprising *Parakrithella* sp., *Keijia labyrinthica* Whatley and Zhao, *Atjehella kingmai* Keij, and *Neomonoceratina bataviana* (Brady). *Foveoleberis cypraeoides* (Brady), *Pistocythereis cribriformis* (Brady), and *Cytherelloidea cingu-*

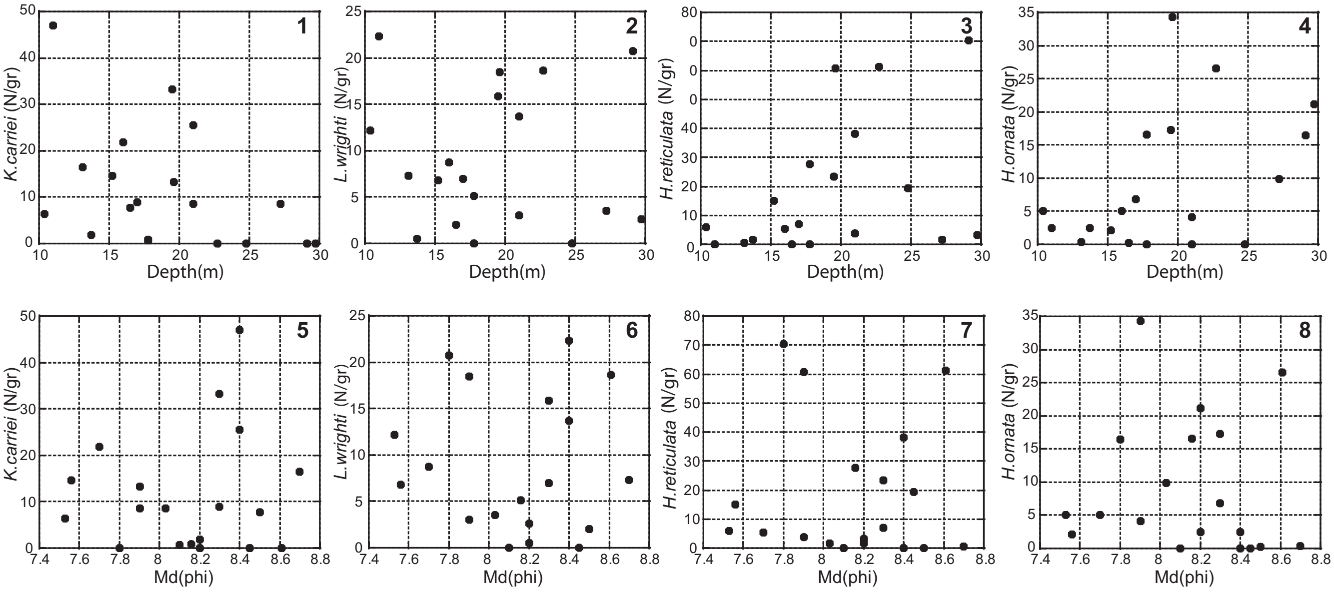

Figure 10. Cross-plots of density of dominant species against water depth (**1**–**4**) and median grain size (**5**–**8**).

lata (Brady) are common. Species diversity is highest among three biofacies ($H(S)$ = approximately 3.3).

~~Biofacies I, II, and III range in water depth from~~ 10.4–21.0 m, 19.6–29.7 m, and 24.8–29.1 m, respectively. Thus, biofacies I is characterized by near-shore shallow areas at ~~a water depth~~ of less than approximately 20 m, while biofacies II and III are characterized by off-shore deeper areas under the influence of open waters at ~~a water depth~~ of more than approximately 20 m.

Relationship between dominant species, biofacies, and environmental factors

The dominant species in this bay are *K. carriei*, *H. reticulata*, *L. wrighti*, and *H. ornata*, in decreasing order. Figures 10 and 11 show the relationship between the dominant species and environmental factors, such as depth, median grain size, TOC, TN, TS, and C/S ratio.

~~The depth–density of dominant species plots~~ show different trends for each of the species (Figures 10.1–10.4). The density of *K. carriei* tends to be low in shallower water depths, but to range widely in deeper water depths (Figure 10.1), while *H. reticulata* and *H. ornata* are not abundant at water depths less than approximately 15 m (Figures 10.3, 10.4).

The median grain size–density of dominant species plots did not show significant relationships because the median grain sizes are essentially the same for all sites (Figures 10.5–10.8).

The plots for TOC–density of dominant species (Figures 11.1–11.4) and TN–density of dominant species (Figures 11.5–11.8) are similar. *K. carriei* can live even in high TOC and TN contents, although it may be inferred that optimal TOC and TN for *K. carriei* are approximately 1.0 and 0.13 wt%, respectively (Figures 11.1, 11.5). *L. wrighti* is also common even in highest TOC and TN contents (Figures 11.2, 11.6), while concentrations of *H. reticulata* and *H. ornata* decrease abruptly at more than 0.8 and 0.14 wt% in TOC and TN, respectively (Figures 11.3, 11.4, 11.7, 11.8). Thus, the latter two species prefer to live in lower TOC and TN contents.

TOC and TN contents in this area are parallel with the ostracode biofacies. In biofacies I, both values are moderate, while in biofacies II and III, they are low (Figures 4 and 9).

Measurements of the C/N ratio reveal two sources of organic matter in the study area: planktonic organisms with terrestrial organic matter in the inner part of the bay and mainly planktonic organisms in the outer part of the bay excluding the river mouth (Figure 4). This indicates that ostracodes thrive on nutrients derived from ~~plankton~~.

Usually, the C/S ratio in sediment has been used to distinguish between marine and freshwater environments and also between deposition from normal marine conditions (those underlying oxygenated bottom waters where sulfate reduction begins a few centimeters below the sediment/seawater interface) and from an anoxic brackish water column (Berner and Raiswell, 1984). A reductive environment (anoxia) has ~~a C/S ratio~~ <1 (Berner and Raiswell, 1984), while a dysoxic (oxygen-poor) environment has C/S ratios between 1 and 3 (Sampei *et al.*,

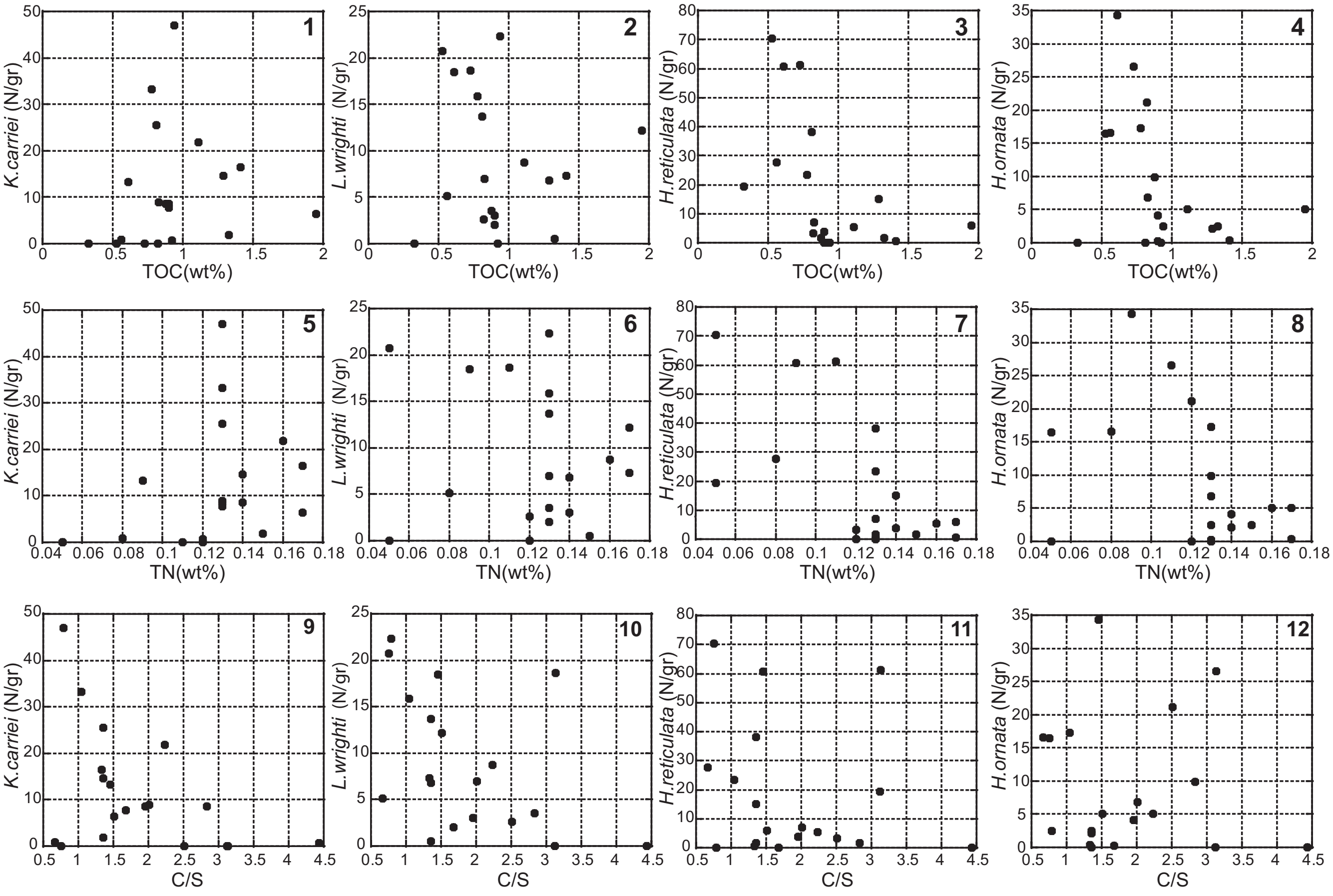

Figure 11. Cross-plots of density of dominant species against TOC (**1–4**), TN (**5–8**), and C/S ratio (**9–12**).

1997), and an oxidative environment has C/S ratios > 3 (Berner and Raiswell, 1984). Based on the C/S ratio, the study area is an oxygen-poor or anoxic bottom environment, except for sites TJ19, TJ76, and TJ92, which are oxidative environments. ~~The C/S ratio-density of dominant species profiles~~ did not show good correlations, but peak density is present in the range ~~of 0.5 to 1.5~~ C/S for all species (Figures 11.9–11.12), suggesting that the dominant species in this area develop better in anoxic to oxygen-poor environments. C/S ~~ratio~~ tends to increase toward deeper water (Figure 3.4), indicating that the deep bottom is more oxic than the shallow bottom in the bay.

The value of TOC and TN contents, C/S ratio, and density of *K. carriei* and *L. wrighti* in this area suggests that the substrate may have been impacted by river water carrying household and industrial effluents. We conclude that *K. carriei* and *L. wrighti* can be used as indicator species for organic-rich environments. On the basis of Q-mode cluster analysis, TOC content, and the C/S ratio, the distribution pattern of ostracodes in this area have been demonstrated to be affected by organic matter concentration/type, anoxic bottom conditions, water depth, and terrestrial influx.

Conclusions

1. A total of 94 ostracode species were identified from 19 bottom surface samples from Jakarta Bay. The dominant species were *Keijella carriei* Dewi, *Hemicytherideа reticulata* Kingma, *Loxoconcha wrighti* Dewi, and *Hemicytheridea ornata* Mostafawi.
2. Q-mode cluster analysis revealed three biofacies (I, II, and III).
3. *K. carriei* and *L. wrighti* are abundant in the eastern part of the bay, The density of *K. carriei* and *L. wrighti* increases around ~~the value~~ 0.5–1.5 wt% of TOC and 1.0 of C/S ratio, showing that these two species are common in bottom environments with high organic matter concentrations and low oxygen levels and are indicator species for organic-rich and anoxic-oxygen poor environments.

4. Density and diversity of the total ostracode species increases toward the outer bay with increasing water depth. However, the dominant species, *K. carriei*, decreases in density with increasing water depth.

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