Impact of environmental factors on macrobenthos distribution and abundance in mangrove ecosystems on the Northern Coast of Java

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Abstract. The coastal erosion in Bedono waters has resulted in severe degradation of the mangrove ecosystems, which also has impacted the life of macrobenthic organisms. This study aimed to analyse the environmental impacts on the macrobenthic community and determine the essential factors that control distribution and abundance of species. The grain size characteristics are analysed seasonally and spatially. The study was conducted at the end of the rainy season (March 2019) and dry season (October 2019) in the coastal area of Bedono waters. Samples were collected at six stations with three replicates in the two seasons, analysed in the laboratory and tested statistically using ANOVA and PCA. The results show that in March, two classes of macrobenthos were recorded: Bivalvia and Gastropoda, with a total of 9 genera. Bivalvia consists of *Anadara* sp., *Polymesoda* sp., *Solen* sp., *Placamen* sp., *Siliqua* sp.; Gastropoda consist of *Telescopium* sp., *Cerithidea* sp., *Nassarius* sp., *Littorina* sp. In October, three classes of macrobenthos were found with a total of 10 genera. Bivalvia consists of *Anadara* sp., *Tellina* sp., *Perna* sp., *Solen* sp.; Gastropoda consist of *Cerithidea* sp., *Nassarius* sp., *Littorina* sp., *Terebalia* sp.; Polychaeta consist of *Capitella* sp. and *Nereis* sp. It was revealed that in March the sediment texture was dominated by silt with an average value of 85.78 %, clay 8.90%, sand 5.35 %. Dissolved oxygen was 2.38 mg L^{-1}, sediment salinity was $19^0/_{00}$, and organic materials content was 14.95 %. In October, the grain size of sediment textures was dominated by sand with an average value of 40.13 %, silt 24.85 %, and clay 35.02 %. Dissolved oxygen was 4.38 mg L^{-1}, sediment salinity was $25^0/_{00}$, and organic materials content 14.65 %. Salinity was higher in October than in March. The abundance and diversity of macrobenthic organisms varied temporally and spatially due to organic matter content, sediment grain size characteristics and salinity.
Key Words: macrobenthos, sediment grain size, mangroves, Bedono.

Introduction. Coastal areas are regions where the sea meets land, and these areas are subject to changes regarding the geographical conditions, vegetation, and human population. The tidal processes influence the regions by time and space scales (Dyer 1986; Dahuri et al 2001; Ghoneim et al 2015), and the freshwater inflow influences the ecosystem function and structures (Palmer et al 2011). Studies also reveal that the gradual increase in population and physical development pressures can lead to coastal ecosystem changes (Djamali 2004; Wildsmith et al 2009). This trend is shown by erosion processes, seawater intrusion, degradation in aquatic products (van Wesenbeeck et al 2015). Some of the strategic locations of mangrove ecosystems have experienced overexploitation and have been converted to fish ponds (Asiyah et al 2015). The function of the coastal region as a supplier of natural resources has not been appropriately managed and therefore needs to be optimized. Mangroves leaves that fall go through the decomposition process and produce nutrients and organic materials which can be consumed by macrobenthic organisms (Arief 2003).

Mangroves have various kinds of benefits for humans and the environment (Nugroho et al 2013). Physically, mangroves have the function to protect the coastal area from winds, waves actions and erosion (Zhang et al 2012). The ecological role of mangroves for coastal fisheries includes the function (1) in life cycles of various fishes, shrimp and mollusks (Davies & Claridge 1993), and (2) as a supplier of organic materials for organisms living in the surrounding areas (Mann 1982). Mangrove ecosystems are one of the renewable resources which grow in abundance in the coastal area of Bedono. The ecosystems have experienced severe degradation due to anthropogenic activities, land subsidence, sea-level rise, erosion and shoreline changes (Marfai 2012; Damastuti & de Groot 2017; Muskananfola et al 2020). This has affected the mangrove forest area, which in turn will reduce the organic matter supply from mangrove leaves and affect the food supply for macrobenthos. Decreases in mangrove forest area also affects coastal erosion and shoreline changes (Lu et al 2008; Zhang et al 2012).

Macrobenthos functions as bio-indicators of the pollution level in the aquatic environment (Tweedley et al 2012). These macrofaunae cover various kinds: Gastropoda, Mollusca, Echinodermata, Bivalvia, and Annelida (Gray 1981; McLusky & Elliot 2004; Lu et al 2008). Macrobenthos, organisms living on the seabed, sessile, walking, or digging holes, play an important role in coastal ecosystem dynamics (Bartels-Hardege et al 1996; Platell et al 2006). The abundance and diversity are tremendously affected by the tolerance and sensitivity to environmental changes (Hong and Yoo 1996; Gray et al 2002; Kon et al 2012). These organisms have significant roles in coastal waters such as in decomposition processes and mineralization of organic material (Bengen 2000; Leung 2015). According to Parsons et al (1984), the life of benthic biotas, such as Gastropoda, Bivalvia and other macrobenthic organisms have an essential role in decomposing, mineralizing organic matter and have a prime position in the food chain.

Also, macrobenthos functions as food for various fishes, especially demersal fishes (Platell et al 2006; Nasi et al 2020). There have been a limited number of studies conducted in Java Sea, Indonesia on the vital role of macrobenthic organisms for benthic and environmental monitoring (Ruswahyuni 2008; Pamuji et al 2015; Sihombing et al 2017; Sahidin et al 2018). Therefore, studies on macrobenthos are essential as a tool for ecological and environmental monitoring in particularly for degraded coastal regions are of paramount importance.

The present study aims to investigate the seasonal and spatial impacts of environmental factors and sediment grain size characteristics on the macrobenthic community (i.e. individual abundance and diversity) in the mangrove ecosystems at degraded coastal waters of Bedono Demak. The study also analyses the essential factors controlling the distribution, abundance, and diversity of macrobenthos. The results are expected to serve as primary data and information contributing to future integrated management of Demak coastal regions and the surrounding areas.

Material and Method

Study site. The study was conducted at Bedono waters located in Demak Regency, the northern coast of mid-Java. This region has experienced massive devastation with an average erosion rate of -25 m yr^{-1}, and shoreline movement was -592 m (Muskananfola et al 2020). It is a low-lying region with an elevation of less than 2% and height of 0-5 m above sea level, dominated by silt and clay sediments (Muskananfola et al 2017). There are areas with scarce mangrove patches covering some portions of the shore and areas with dense mangrove ecosystems, which function as coastal protection.

Field sampling. Sediment samples were collected during the two transitional seasons (March 2019) and (October 2019) at six stations in the degraded coastal region of Bedono Demak (Figure 1). Stations 1, 2, and 3 were covered by mangroves trees of *Rhizophora* sp.; and stations 4, 5, 6 covered by mangrove trees of *Avicennia* sp. Samples for macrobenthic community analysis were collected with a 10 cm diameter pipe sampler for March field campaign, and a 0.01 m^2 van Veen grab sampler for October field campaign. For sediment grain size analysis and total organic matter (TOM) contents, only the surface sediments (0-1 cm layer) were used. Three replicate samples were collected at each station with a total of six stations. Samples were washed through a 1.0 mm sieve, and all retained organisms were collected and fixed in buffered formaldehyde

(10%). All organisms were sorted and identified using a stereomicroscope to the lowest possible taxonomic level, usually the genus/species, and were counted (Fauchald 1977; Carpenter & Niem 1998; Warwick 1988).

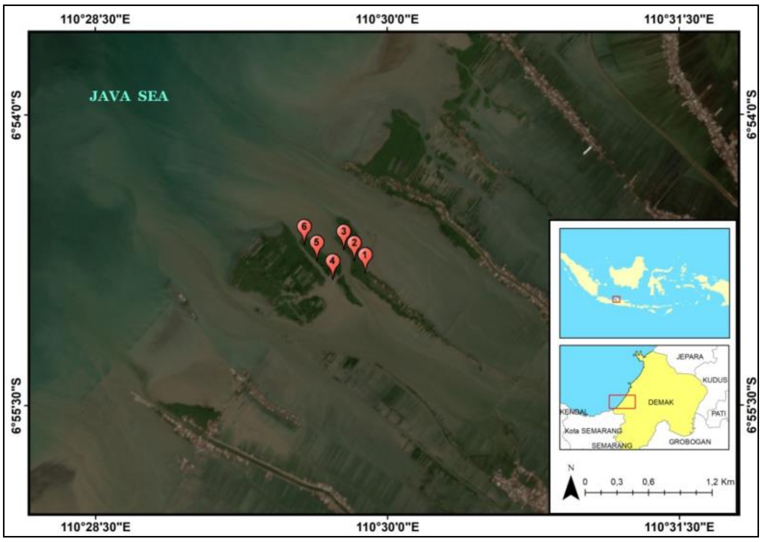

Figure 1. Research location at Bedono waters Demak Regency.

Measurements of environmental data were carried out in situ at the same time as the sediment samples were collected. Temperature, salinity, pH, and dissolved oxygen were measured using the Water Quality Checker U-53G Series at each sampling site. Water brightness was measured using the Secchi disk, and water depth was measured using a scaled wooden pole.

Data analysis. Composition of sediment grain size was quantified using the dry sieving method (Buchanan 1984). TOM in the sediment was analysed using the Loss of Ignition method (Heiri et al 2001) using the following formula:

$$BOT = \frac{(Wt-C)-(Wa-C)}{Wt-C}\ x\ 100 \qquad (1)$$

Wt = Total weight of crucible with samples before the furnace
C = Weight of empty crucible
Wa = Total weight of crucible with sample after the furnace
Organic matter conversion = % Organic matter x 1.724

Macrobenthos abundance was calculated based on the total of individuals per area (ind m^{-2}). Density and diversity data were calculated per square meter. The Shannon and Wiener diversity index H' data was calculated on the density data for each sample (Gray 1981) using the following formula:

$$H' = -\sum_{i=1}^{S} Pi \ln Pi \qquad (2)$$

Pi = Total number of individuals of i species (i = 1, 2, 3, …)
S = Total number of species
H' = Species diversity with the following criteria to describe Shannon-Wiener diversity (Wilhm 1975)
H' = < 1, represents low diversity
H' = 1–3, represents medium diversity
H' = > 3, represents high diversity

Analysis of Variance (ANOVA) was conducted to know the difference in macrobenthic communities between stations and seasons. Principal Component Analysis (PCA) tests were conducted to delineate the macrobenthic communities of the sampling sites into different groups and the effects of environmental variables on macrobenthos abundance and community patterns. Analysis of similarity linkage was carried out to estimate the contribution of each species to the similarity/dissimilarity of the whole groups. Biotic and environmental linking analyses were conducted to know the environmental variables that were highly correlated with the macrobenthic community (Clarke & Ainsworth 1993; Yu et al 2012). All the above calculations and analyses were performed using IBM SPSS Statistics 23 (Ghozali 2016).

Results

Environmental variables. Environmental values from March are presented in Table 1. The sediment textures were dominated by silt ranging from 72-96 %, with an average of 85.78 % in March 2019 (rainy-transition season I), clay 0.2-23.36 %, with an average of 8.90 %, sand 1.68-11.2 %, with an average of 5.35 %. Dissolved oxygen was 1.24-3.54 mg L^{-1}, with an average of 2.38 mg L^{-1}, sediment salinity was 17-21 $^0/_{00}$, with an average of 19 $^0/_{00}$, and organic materials content was 11.23-18.64 %, with an average of 14.95 %. The concentration of organic materials is high in station 1, 2, 3 towards landside and decreases towards the sea at station 4, 5, and 6. The values of other environmental variables: currents speed ranged from 0.008-0.021 m s^{-1}, with an average of 0.013 m s^{-1}; water depth ranged from 13-45 cm, with an average of 32.89 cm; water brightness ranged between 14-31 cm, with an average of 22 cm; sediment temperature ranged between 28-30 ^{0}C, with an average of 28.67^{o}C; and sediment pH ranged between 6-7, with an average of 7. The abbreviations used in the tables are the following: "Sta" for station, "Smpls" for samples, "DO" for dissolved oxygen, "Sed Temp" for sediment temperature, "Sed Sal" for sediment salinity, "OM" for organic matter, "Min" for minimum, "Max" for maximum, "Ave" for average, "Stdev" for standard deviation.

Table 1

Environmental values of the study area in March 2019

Sta	*Smpls*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*DO (mg L^{-1})*	*Current (m s^{-1})*	*Depth (cm)*	*Brightness (cm)*	*Sed Temp (^{0}C)*	*Sed pH*	*Sed Sal ($^0/_{00}$)*	*OM (%)*
1	1	3.84	86.00	10.16	2.25	0.009	43	16	29	7	18	18.64
	2	5.80	94.00	0.20	1.82	0.012	29	21	29	7	18	18.48
	3	8.72	82.00	9.28	2.93	0.017	30	24	30	6	17	15.85
2	4	4.88	94.00	1.12	1.98	0.009	45	31	28	7	18	15.62
	5	1.68	96.00	2.32	1.24	0.013	29	25	28	7	18	18.31
	6	5.96	90.00	4.04	2.15	0.016	29	25	30	6	18	17.19
3	7	2.20	94.00	3.80	2.64	0.008	42	22	29	7	17	15.91
	8	3.92	96.00	0.60	1.54	0.011	27	21	28	7	17	15.78
	9	2.92	90.00	7.08	2.62	0.014	34	20	30	6	18	17.53
4	10	2.16	88.00	9.84	2.33	0.008	42	24	28	7	21	13.53
	11	6.28	84.00	9.72	2.21	0.011	27	23	28	7	21	13.43
	12	6.60	76.00	17.40	2.28	0.014	34	18	28	6	18	13.13
5	13	10.68	82.00	7.32	1.76	0.012	40	14	28	7	21	13.34
	14	11.20	78.00	10.80	2.41	0.014	13	21	28	7	21	13.35
	15	9.84	74.00	16.16	3.54	0.017	27	19	29	7	18	11.23
6	16	4.64	72.00	23.36	3.36	0.013	41	25	29	7	20	13.45
	17	2.48	86.00	11.52	3.12	0.014	31	23	28	7	20	12.76

	18	2.56	82.00	15.44	2.68	0.021	29	19	29	6	18	11.58
Min		1.68	72.00	0.20	1.24	0.008	13	14	28	6	17	11.23
Max		11.20	96.00	23.36	3.54	0.021	45	31	30	7	21	18.64
Ave		5.35	85.78	8.90	2.38	0.013	32.89	22	28.67	7	19	14.95
Stdev		3.05	7.60	6.39	0.61	0.003	8.07	4	0.77	0	1	2.39

In October 2019 (dry-transition season II), the grain size of sediment textures is dominated by sand ranging between 3.20-85.24%, with an average of 40.13%, silt 2.46-60.92%, with an average of 24.85%, and clay 2.0-78.68%, with an average of 35.02% (Table 2). Dissolved oxygen was 4.10-4.70 mg L^{-1}, with an average of 4.38 mg L^{-1}, sediment salinity was 24-25$^0/_{00}$, with an average of 25$^0/_{00}$, and organic materials content was 11.8-21.3%, with an average of 14.65%. Salinity was higher in October than in March. There was no significant difference in the concentration of organic materials between the two periods. The values of other environmental variables were: current speed ranging between 0.15-5.54 m s^{-1}, with an average of 1.12 m s^{-1}, water depth ranging between 63-72 cm, with an average of 67.67 cm, brightness level between 41-60 cm, with an average of 51 cm, sediment temperature ranging between 28-31°C, with an average of 29.5°C, and sediment pH ranging between 7-8, with an average of 7.

Table 2

Environmental values of the study area in October 2019

Sta	*Smpls*	*Sand (%)*	*Silt (%)*	*Clay (%)*	*DO ($mg\ L^{-1}$)*	*Current ($m\ s^{-1}$)*	*Depth (cm)*	*Brightness (cm)*	*Sed temp (°C)*	*Sed pH*	*Sed sal ($^0/_{00}$)*	*OM (%)*
1	1	13.52	31.12	55.36	4.10	0.16	63	54	29	7	25	21.3
	2	15.16	21.48	63.36	4.10	0.16	63	54	29	7	25	13.14
	3	17.16	10.16	72.68	4.10	0.16	63	54	29	7	25	16.45
2	4	47.92	5.60	46.48	4.50	0.15	72	41	28	8	25	16.67
	5	55.04	4.72	40.24	4.50	0.15	72	41	28	8	25	13.12
	6	55.90	2.46	41.64	4.50	0.15	72	41	28	8	25	13.81
3	7	3.20	41.44	55.36	4.70	5.54	70	60	29	7	25	11.88
	8	6.12	60.92	32.96	4.70	5.54	70	60	29	7	25	16.17
	9	10.16	11.16	78.68	4.70	5.54	70	60	29	7	25	11.8
4	10	61.48	23.27	15.25	4.40	0.16	63	45	31	7	25	12.93
	11	60.24	24.61	15.15	4.40	0.16	63	45	31	7	25	17.46
	12	61.16	24.62	14.22	4.40	0.16	63	45	31	7	25	14.33
5	13	80.52	10.48	9.00	4.10	0.50	67	57	30	8	25	14.23
	14	85.24	12.76	2.00	4.10	0.50	67	57	30	8	25	14.86
	15	77.30	15.44	7.26	4.10	0.50	67	57	30	8	25	14.67
6	16	28.17	44.53	27.30	4.50	0.18	71	47	30	8	24	12.07
	17	23.51	51.43	25.06	4.50	0.18	71	47	30	8	24	15.69
	18	20.52	51.04	28.44	4.50	0.18	71	47	30	8	24	13.16
Min		3.20	2.46	2.00	4.10	0.15	63	41	28	7	24	11.8
Max		85.24	60.92	78.68	4.70	5.54	72	60	31	8	25	21.3
Ave		40.13	24.85	35.02	4.38	1.12	67.67	51	29.5	7	25	14.65
Stdev		27.61	18.04	23.16	0.23	2.04	3.74	7.00	0.99	0.38	0.39	2.38

Genus composition. The number of genera and its distribution in each station during March and October is presented in Figure 2. The overall trend shows that the total number of the genus was higher in October than in March. In March 2019, two classes of Bivalvia and Gastropoda with a total of 9 macrobenthic genera were recorded. Bivalvia consist of *Anadara* sp., *Polymesoda* sp., *Solen* sp., *Placamen* sp., and *Siliqua* sp.

Gastropoda consist of *Telescopium* sp., *Cerithidea* sp., *Nassarius* sp., and *Littorina* sp. In October 2019, a total of 10 macrobenthic genera were recorded with three classes: Bivalvia which consist of *Anadara* sp., *Tellina* sp., *Perna* sp., and *Solen* sp. Gastropoda, which consist of *Cerithidea* sp., *Nassarius* sp., *Littorina* sp., *Terebalia* sp. and Polychaeta which consist of *Capitella* sp., *Nereis* sp.

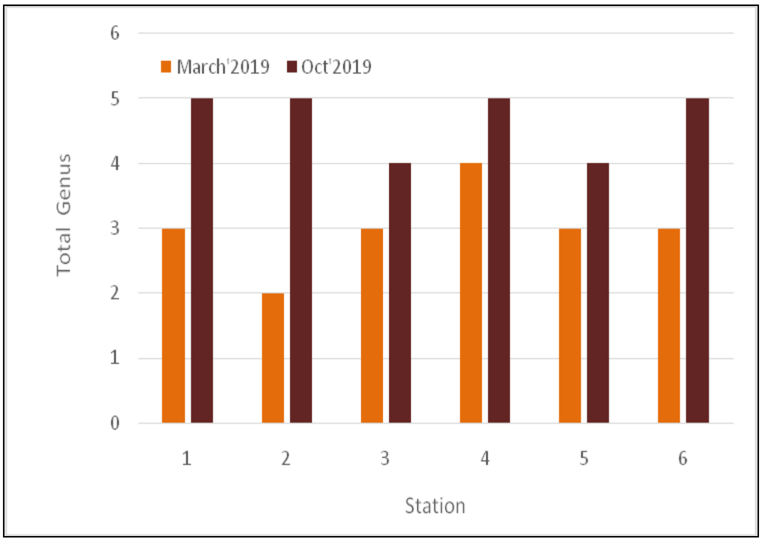

Figure 2. Number of genus of macrobenthos in March 2019 and October 2019.

Dominant genus. Based on Figure 3, some genera were found in both seasons and some genera were found only in a certain season.

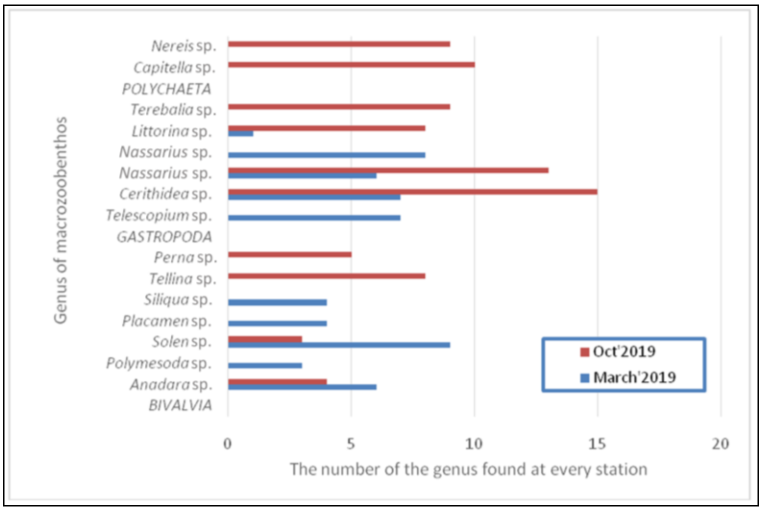

Figure 3. Frequency of macrobenthos found at the study site in Bedono waters Demak.

Figure 3. shows that *Cerithidea* sp. and *Nassarius* sp. (Gastropoda) were frequently found in almost all seasons. *Anadara* sp. and *Solen* sp. were the most frequently found from the Bivalvia group.

Macrobenthos abundance. The abundance of macrobenthos in the study area is presented in Figure 4. Individual density of macrobenthos in March ranged from 2038 ind m^{-2} (Site 2, 3) to 6752 ind m^{-2} (site 4) with an average of 4227 ind m^{-2}; while in October, the individual density ranged from 2216 ind m^{-2} (site 3) to 3389 ind m^{-2} (site 4, 5) with an average of 2954 ind m^{-2}. Generally, sites 4, 5 and 6 had higher individual densities than sites 1, 2 and 3. Macrobenthos data was statistically tested to know whether there are any differences between March and October (season), and between stations 1 to 6 spatially. The results of ANOVA showed a value of $p<0.05$, which means that there is a substantial difference in macrobenthos abundance between March and October where individual abundance in March is higher than October. The abundance in Stations 1, 2 and 3 are found to be different from the abundance in Stations 4, 5 and 6.

The analysis on the macrobenthos abundance shows a significant difference in March, while in October the macrobenthos abundance is relatively similar between stations. Variance analysis of stations shows a significant difference between stations ($p<0.05$). The abundance of macrobenthos at stations 1, 2, and 3 is similar, and its different than stations 4, 5, and 6.

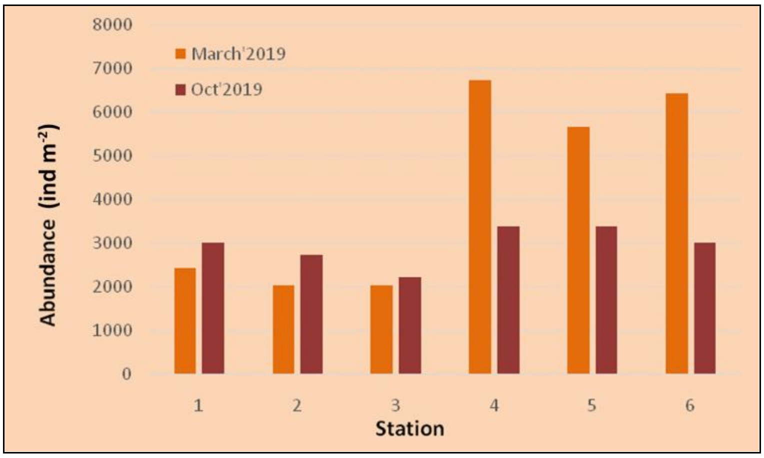

Figure 4. The abundance of macrobenthos at Bedono waters in March 2019 and October 2019.

Macrobenthos diversity. Diversity of macrobenthos in the study area in March and October is shown in Figure 5. The Figure shows that the diversity in October (dry season) is higher than in March (wet season). The value of H' for March ranged from 0.55 to 1.03 with an average of 0.86, and in October ranged from 1.05 to 1.45, with an average of 1.37. ANOVA test was conducted to reveal the significant difference in diversity between season and stations under study. Levene's Test of Equality of Error Variances with a level of significance of 0.429 shows a significant difference in macrobenthos diversity between season (March and October) and stations (1-6). The test revealed that the difference in biodiversity between seasons is more significant, while there are no different effects between stations, with R Squared=0.696. Further PCA test also shows that there are several factors affecting diversity such as sand, silt, dissolved oxygen, water depth, temperature, and salinity of sediment. Environmental factors that most affected diversity are temperature and salinity.

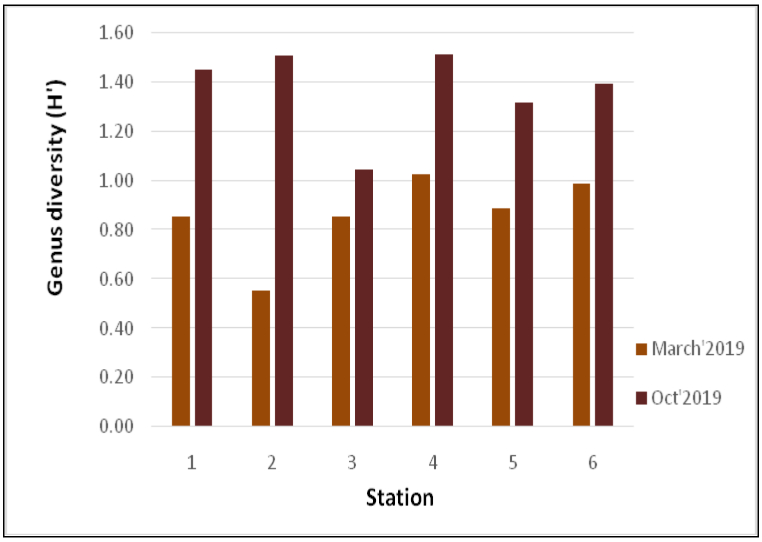

Figure 5. Diversity of macrobenthos in March 2019 and October 2019.

Factors controlling difference in abundance and diversity. Further analyses were performed to identify the main factors that control the difference in abundance and diversity of macrobenthos in Bedono waters. The Principal Component Analysis was adopted to extract the main factors that affect macrobenthos abundance spatially and seasonally in the study area. Fourteen variables were extracted using PCA and categorized into four data groups of significant variables. Group 1 represents 51.14 % of significant variables, group 2 represents 13.23 % (64.37-51.14 %), group 3 represents 10.6 % and group 4 represents 7.9 %, as shown in Table 3.

Table 3 shows that all the 14 variables are categorized into four matrices of significant components as follows: (a) First component consists of total species, diversity, sand, silt, dissolved oxygen, water depth, pH of sediment, and the salinity of sediment. (b) Second component consists of the clay, current and brightness. (c) Third component consists of sand and temperature of sediment. (d) Fourth component consists of abundance and organic matter.

Table 3

Rotated component matrix results

Rotated Component Matrix					
No	*Variables*	*Component*			
		1	*2*	*3*	*4*
1	Total Individuals	.039	-.399	-.518	-.532
2	Total Genus	.880	.012	-.046	.268
4	H'	.931	.008	-.016	.207
4	Sand	.706	-.167	.569	-.194
5	Silt	-.823	-.363	-.267	.124
6	Clay	.434	.777	-.276	.043
7	Dissolved Oxygen	.714	.517	.306	-.165
8	Current velocity	-.065	.874	.051	-.105
9	Water depth	.743	.491	.325	-.034
10	Water Brightness	.606	.619	.394	-.049
11	Sediment temperature	.210	-.008	.810	.127
12	pH sediment	.677	.014	.180	-.319
13	Salinity of sediment	.815	.428	.197	-.197
14	Organic matter	-.003	-.175	.069	.850

Analysis of the relationship of macrobenthos abundance with organic matter as the main determinant factor using the Chow test is presented in Figure 6. The test was to know a possible relationship between (i) organic matter with macrobenthos of March and (ii) organic matter with macrobenthos of October. The obtained results show F calculated=11.664 > F table (0.99; 2.32) = 9.61. This result indicates that the relationship of organic matter with macrobenthos for March and October have a significant difference and with a positive relationship in October and the negative relationship in March.

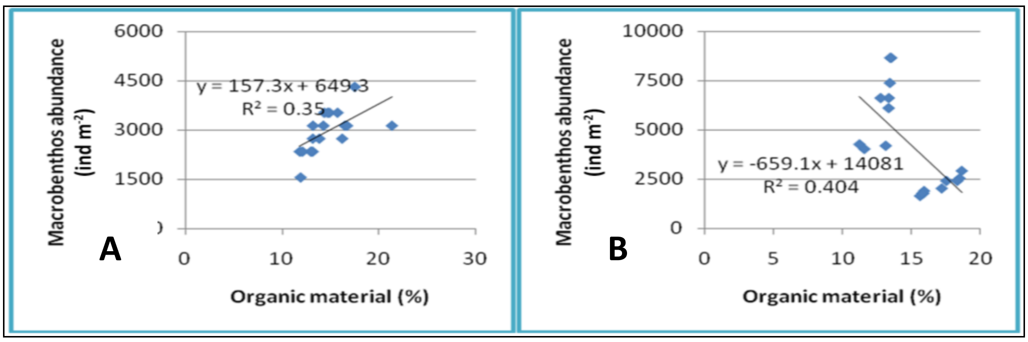

Figure 6. Relationship between organic matter content (%) with macrobenthos abundance (ind m^{-2}). (A=October 2019 with r value=0.592; and B=March 2019 with r value=0.636).

Discussion. The most important environmental variables that affect diversity and density patterns of the macrobenthic community in estuaries and coastal waters are salinity and the sediment grain size characteristics (McLusky & Elliot 2004; Leung 2015). Whereas Parsons et al (1984) and Hong & Yoo (1996) showed that the particle size and disturbance of the sediment might have been the most critical factor affecting the macrobenthic community patterns. In the present study, the grain size distribution was dominated by silt in March (Table 1), while in October, it is dominated by sand (Table 2). Salinity changed from 17-21$^0/_{00}$ in the rainy season (March) to 24-25$^0/_{00}$ in the dry season (October). It is assumed that freshwater inputs from rivers contribute to lower salinity in March affecting macrobenthos community patterns in Bedono waters. Diversity in March was lower than diversity in October; this is in agreement with Palmer et al (2011), that diversity was low in estuaries with salinity 1-17$^0/_{00}$ and increased in salinity up to 30$^0/_{00}$. Differences in the sediment textures in the two months (rainy-March and dry-October) could be related to the amount of freshwater flow and its characteristics from the upper regions (Yu et al 2012). Coarser sediment grain size could occur at low flow velocity during the dry season while smaller sediment grain size could be transported from upper regions and deposited at slack tide during the rainy season (Ghoneim et al 2015; Muskananfola et al 2020).

Moreover, the results of macrobenthos habitat and environmental analysis reveal several specific patterns: (a) sediment salinity was lower in March with an average of 19 $^o/_{oo}$ (stdev=1), while in October average salinity was 25$^o/_{oo}$ (stdev=0.39). (b) Silt content was high in March with an average of 85.78% (stdev=7.6), in October average content of silt was 24.85% (stdev=18.04). High values of salinity and silt content in March is due to the high volume of freshwater discharge during the rainy season, and low values in October is due to low volume of freshwater supply during the dry season (Palmer et al 2011; Yu et al 2012). Sand content in March averaged 5.35% (stdev=3.05) and in October average sand content was 40.13% (stdev=27.61). (c) Organic matter as important materials for macrobenthos tends to have high value in March, especially at station 1, 2, and 3, where each station has a content of 15.62-18.64%. While at the other three stations, the average content of organic materials was 14%. These findings of the high content of silt and high organic matter in March is scientifically acceptable. Since finer sediment grains have a wider surface area to hold more organic matter while coarse grain size has less surface area and less organic matter (Buchanan 1984; Dyer 1986; Zhang et al 2012).

Macrobenthos species composition is affected by the number of species and total individuals of species (Gray 1981; Warwick 1988; Gray et al 2002). The present study reveals that the number of genera, density, and diversity of the macrobenthos in Bedono waters varied between the two seasons (months) under study (Figure 5). Two classes of macrobenthos with a total of nine (9) genera were recorded in March, and three classes with a total of ten (10) genera were recorded in October. The newly recorded macrobenthic organisms in October is Polychaeta which consist of *Capitella* sp. and *Nereis* sp. The existence of this new class may be due to regular breeding season of Polychaeta in March where individuals are still in juvenile forms and are difficult to be sampled (Bartels-Hardege et al 1996; Yu et al 2012). Interestingly, Capitella sp. is a bioindicator species that usually grow in depressed marine environments. The existence of this Polychaete species proves that the area under study (Bedono waters) is a degraded region due to erosion and coastline change in the northern coast of mid-Java (Marfai 2012; van Wesenbeeck et al 2015; Muskananfola et al 2020).

The density of macrobenthos varies between March and October, where the number of individuals is higher in March than in October (Figure 4). The macrobenthos community structure in estuaries and coastal waters changes seasonally and regionally by the amount of freshwater discharge (Palmer et al 2011; Nasi et al 2020), and anthropogenic activities that caused detrimental effects in estuaries systems (Wildsmith et al 2009). Lu et al (2008) found that the macrobenthos community structures in an estuary are affected by salinity conditions and grain size of sediments. In the present study, it is assumed that the changes in macrobenthos community structures between March and October were affected by salinity and environmental variables such as sediment grain size and organic matter contents (Hong & Yoo 1996; McLusky & Elliot 2004).

This study reveals that several environmental variables influence the community structures of macrobenthos. Table 3 shows that based on the results of the Principal Component Analysis (PCA), there is a similar trend in the abundance of macrobenthos and organic substances. This trend suggests a functional relationship between the two variables as macrobenthos requires organic material for their food (Ruswahyuni 2008; Tweedley et al 2012; Pamuji et al 2015). Based on the seasonal difference, the relationship between organic materials and the abundance of macrobenthos is shown in Figures 6A and 6B. The graphs show contradictory trends, where Figure 6A indicates a moderate positive relationship between macrobenthos abundance and organic matter contents in October. Figure 6B shows a moderate negative relationship between macrobenthos abundance and organic matter contents in March. The positive relationship in October indicates that increase in macrobenthos abundance is proportional to the increase of organic matters. This relationship is in line with previous findings (Sihombing et al 2017; Sahidin et al 2018). On the other hand, the negative relationship that occurred in March is caused by a higher abundance of macrobenthos with a relatively stable organic matter content.

Conclusion. The distribution and abundance of macrobenthos in the degraded Bedono waters differ seasonally between March (end of the rainy season) and October (dry season), and spatially between stations 1 to 6. The main contributing factors to this difference are organic materials content, silt and clay content, and salinity of sediments. Seasonally, macrobenthos abundance varies between March and October where total individual abundance in March is higher than October. Spatially, the trend of individual abundance increases gradually from station one (landward region) to station six (towards coastal region) indicating that macrobenthos individual density increases from landside towards the seaside.

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