Ecology of bivalves in the intertidal area of Ngemboh, Gresik, East Java, Indonesia

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Abstract. Bivalves are filter feeders that play important roles in providing food for local communities, as well as promoting ecosystem stability. A study of bivalve diversity, distribution and abundance, was conducted in the intertidal area of Ngemboh, Gresik, East Java, Indonesia, in March 2018, during rainy season. The aim was to investigate the ecological indices, like species richness and species abundance, as well as the environmental parameters that might influence these bivalve communities. Three replicates of 15 m transect lines with five 1x1 m quadrant plots in each line were set up seawards, perpendicular to the coastline. All bivalves in the quadrants were counted. There were 278 individual bivalves from 11 species, 8 genera, and 5 families in the research areas. On average, the species abundance was 3.08 ind/m^2. The values for Shannon's diversity index (H'), Pielou's evenness index (J'), and Simpson's dominance index (C) were 1.16, 0.82 and 0.34, respectively. The Pearson correlation showed that the dissolved oxygen (DO) had a very high correlation with both species richness and diversity index (r=0.93 and r=0.92 respectively, P<0.01). Furthermore, *Gafrarium pectinatum* dominated 30% of the total abundance from all stations, suggesting this species to strongly shape the ecologicall indices in most research stations.
Key Words: Bivalvia, *Gafrarium pectinatum*, Intertidal zone, species diversity.

Introduction. Bivalves can be found under phylum Mollusca, class Bivalvia, with about 10,000 living species throughout the world from freshwater lakes to the deepest abyss (Huber 2015; Rahman et al 2015; Turgeon et al 2009). They are soft-bodied invertebrates enclosed by two calcified valves joined by a two-hinged ligament (Yahya et al 2016). Bivalves include oysters, scallops, cockles, mussels, clams, and numerous other families that live in marine environment, as well as a number of families that live in freshwater environment. They are important organisms, acting as water quality and nutrient dynamics regulators by capturing particulate foods, such as phytoplankton, particulate organic matter and planktonic larvae (Asadi et al 2018; Newell et al 2002; Smaal et al 2019). Particles which cannot be used as food, like suspended particles and larger edible particles, are wrapped in mucus, expelled afterwards and transferred to the sediment (Gosling 2008; Silverman et al 2000). Therefore, bivalves stabilize the substrate, decrease erosion and promote habitat complexity (Asadi & Smaal 2015; Sueiro et al 2011).

Social and economic development of coastal areas around the world have inevitably impacted marine ecosystems, thus affecting many marine organisms, especially those that live at the intertidal zone such as bivalve mollusks. In the Jakarta Bay, mollusk diversity had decreased sharply from 171 to 58 species between 1938 and 2005, as a result of accelerated urbanization and pollution (van der Meij et al 2009). Heavy metals and polycyclic aromatic hydrocarbons (PAH) are pollutants from industrial and harbor activities that modulate the immune system of bivalves, causing mortalities in long-term exposures (Pipe & Coles 1995).

In East Java, Indonesia, rapid industrialization and urbanization has negatively affected many nearby coastal areas. Moreover, local communities harvest bivalves as a source of food (Asadi et al 2018). Therefore, the bivalves in the area could be severely affected by these anthropogenic threats. In this study, the diversity, distribution, abundance of bivalves at the intertidal zone of Ngemboh, East Java, Indonesia, as well as environmental parameters that influence their community structure were investigated. Species composition, abundance and distribution are very important in ecological studies because these basic elements which evaluate the biological community structures can change over time in response to disturbances (van der Meij et al 2009; Veras et al 2013).

Material and Method

Study area. The intertidal zone of Ngemboh is located in the district of Ujung Pangkah, Gresik Regency, East Java. Its coastal area spans 2 km in length with different hydro-geomorphic settings and sediment characteristics, thus promoting suitable microhabitat and niches for bivalves (Asadi et al 2018). The coordinates of the study areas are from 6.906171ºS to 6.902880ºS, and between 112.496090ºE and 112.505899ºE. This area is classified as a wet, tropical savanna (Aw) by Köppen and Geiger, with a temperature average of 27.5 ºC, and rainy season between November and May, with average rainfall of 1686 mm (Merkel 2012). The map and the coordinates of study areas are presented in Figure 1 and Table 1, respectively.

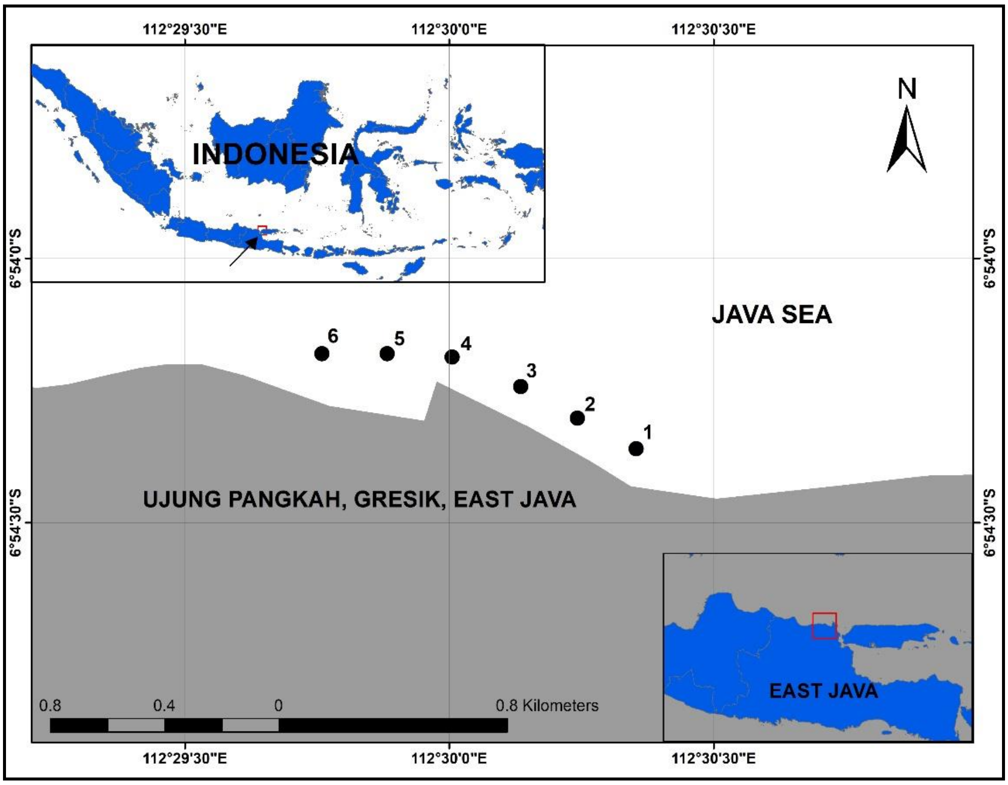

Figure 1. The six study areas located in the intertidal zone of Ngemboh, District of Ujung Pangkah, Gresik Regency, East Java, Indonesia.

Sampling procedure and laboratory analysis. Samplings were performed in March 2018, during the rainy season. At low tide, three transects, each with a length of 15 m, had been set up at each sampling station with an interval between transects of 25 m. In each transect, five 1 m^2 quadrants were laid perpendicular to the coastline, totaling 15 plots in each research station. Some bivalves samples were collected, while others were counted in situ, in each quadrant (1 m^2) at the depth of 20 cm (Asadi et al 2018; Urban & Campos 1994). The samples were preserved in 70% ethanol until further identification at the Marine Science Laboratory, from the University of Brawijaya. The samples were identified based on shell morphology by observing the shape as well as the size, thickness and design of the shells (Yahya et al 2016). The samples were also compared with bivalves illustrated in the references (Dharma et al 2005; Huber 2015, Lamprell & Healy 1998).

In order to determine particle size and grain size of the substrate, approximately one kilogram of the soil sample in each station was processed using a Sieve Analysis method according to ISO 3310 standards (ASTM 2016). The samples were dried using a drying oven at 75 ^{0}C for 3 days. The samples were then passed through a sieve shaker, weighted and analyzed using Microsoft Excel. Based on the percentage of grain size, substrates were grouped using the Shepard Classification Diagram (Asadi et al 2017; Hossain & Nuruddin 2016). Environmental parameters, such as temperature, salinity, turbidity and pH were measured *in situ* using the water quality profiler AAQ 1183. Meanwhile, dissolved oxygen (DO), biological oxygen demand (BOD) of the water and total organic matter (TOM) of water and substrate were determined in the chemistry laboratory of Brawijaya University.

Table 1
Coordinates and characteristics of research stations in the intertidal areas of Ngemboh, Gresik Regency, East Java, Indonesia

Station	*Coordinates*	*Characteristics*
1	6.906171 ^{o}S 112.505899 ^{o}E	Close to houses with substratum dominated by sand and considerably high amount of broken corals.
2	6.906079 ^{o}S 112.503905 ^{o}E	Fishing areas, close to estuary with substratum dominated by sand.
3	6.905178 ^{o}S 112.502193 ^{o}E	Close to houses with gravely sand substratum
4	6.904004 ^{o}S 112.499920 ^{o}E	Far away from houses with typical gravely sand substratum
5	6.903384 ^{o}S 112.498055 ^{o}E	Nearby aquaculture ponds (Locally known as Tambak) with sandy sediment substratum
6	6.902880 ^{o}S 112.496090 ^{o}E	Nearby aquaculture ponds with silty sand substratum

Data analysis. Abundance of bivalves was expressed as a total number of individuals per square meter (ind/m^2). Ecological indices, such as the diversity of the bivalve communities, was determined by using the Shannon-Wiener diversity index (H'), whereas the evenness of the bivalve communities was determined by using the Pielou's evenness index (J'). Meanwhile, the Simpson's dominance index (C) was used to describe the dominance of the communities. The Pearson correlation was also determined to reveal the relationship between environmental parameters and bivalve community structures, using GraphPad Prism 7 software.

Results and Discussion

Water quality parameters and sediment characteristics. Environmental parameters influence the distribution and diversity of bivalve composition in marine environments (Newell et al 2002; Satheeshkumar & Khan 2012; Veras et al 2013), in which anthropogenic threats have been linked to the deterioration of water quality and the decline of bivalves fauna (van der Meij et al 2009). The average pH in the research areas was 7.8, which was lower than the average ocean pH that is more basic, averaging 8.1 (Asadi & Khoiruddin 2017; Orr et al 2005). The DO concentrations were between 5.2 and 7.1 mg/L, which was fit for respiration of marine mollusks. Low levels of DO have significant impacts on marine bivalves, in which DO levels below 2 mg/L negatively affects most benthic organisms, as they have limited locomotion ability to avoid hypoxic waters (Long et al 2008).

The average BOD was 9.16 mg/L, the value being considered high for a marine environment (Simon et al 2011). The BOD is the oxygen demand for microbial metabolism of organic matter in waters, and therefore, it can be linked to the high amount of TOM in the research stations, averaging 115.82 mg/L (Gupta et al 2017).

The turbidity, temperature and salinity varied from 31.3 to 70.1 NTU, 27.5 to 34 ºC, and 26.7 to 32.9‰, respectively. Bivalves are able to tolerate a wide range of turbidity, temperature and salinity. Oysters, for instance, flourish from the high sea surface temperature of Qatari Waters, Arabian Gulf to relatively cold bays of Japan's waters (Gupta et al 2017; Smyth et al 2016). They are also widespread in estuaries, where turbid fresh water flows from rivers and streams, as well as in atolls or coral reefs, where the input of fresh water and suspended matter is limited (Andréfouët et al 2012; Rahman et al 2015).

Furthermore, the grain size analysis showed that the intertidal zone of Ngemboh was dominated by sand with the values from 66.7% at station 3, to 91.2% at station 5. Silt was the least common type of substrate, averaging only 8.9%. The variation of substrate types increases the available niche for suspension-feeder bivalves, and therefore, the more niche is expected to hold more bivalve species (Huber 2015; Oigman-Pszczol et al 2004). The environmental parameters of the research stations, as well as the substrate types are presented as mean and standard deviation in Table 2.

Table 2

Physico-chemical parameters as well as substrate characteristics of sampling stations presented as mean and standard deviation (SD)

	Station					
	1	2	3	4	5	6
Water parameters						
pH	8±0.0	7.9±0.1	7.8±0.2	7.5±0.1	7.8±0.2	7.8±0.1
DO (mg/L)	5.2±0.1	5.7±0.2	6.7±0.1	7.1±0.1	6.2±0.3	5.6±0.1
BOD (mg/L)	5±0.3	5±0.3	15±0.5	15±0.5	5±0.0	10±0.3
TOM of water (mg/L)	116.2±5	118.8±3	111.2±6	121.3±2	111.2±5	116.2±3
TOM of substrate (mg/L)	0.64±0.03	1.22±0.09	3.97±0.15	2.23±0.13	2.74±0.56	0.58±0.06
Temperature (ºC)	34±0.1	32±0.1	28±0.0	27.5±0.5	29±0.0	32±0.1
Salinity (‰)	32.9±0.2	31.6±0.1	28.5±0.3	26.7±0.1	29.6±0.5	30.3±0.4
Turbidity (NTU)	41.3±0.5	70.1±0.5	37.5±0.5	31.3±0.3	34.5±0.5	55.3±0.5
Substrate types						
Gravel (%)	15.6	11.4	21	18.8	8.3	10.5
Sand (%)	84.2	81	66.7	72.9	91.2	64.8
Silt (%)	0.2	7.6	12.3	8.3	0.5	24.7

DO – dissolved oxygen; BOD – biological oxygen demand; TOM – total organic matter.

Bivalve diversity, distribution and abundance. A total of 11 species, 8 genera, and 5 families of bivalves were recorded in the intertidal zone of Ngemboh, Gresik Regency, Indonesia. This record is higher compared to species found in the intertidal zones of Lamongan, where only 8 bivalves species were found (Asadi et al 2018). The latter area has populations concentrated in the coastal areas, and therefore the anthropogenic threats may have negatively affected the marine biodiversity in this area (Asadi et al 2017). Van der Meij et al (2009) documented the sharp decline of the number of species of marine mollusks in Jakarta Bay due to the effect of rapid urbanization, pollution and other anthropogenic threats.

The intertidal zones have a relatively lower bivalve diversity compared to shallow subtidal zones. For example, in the subtidal zones of the São Sebastião Channel, Brazil, and shallow subtidal zones of Bahía de Mazatlán, México, 52 and 76 bivalves species were reported, respectively (Esqueda-González et al 2014; Tallarico et al 2014). As filter feeder organisms, bivalves need to capture their food using their gills from the water column through pumping mechanisms, and therefore the shallow subtidal areas that are submerged constantly provide a better habitat for bivalves to sustain (Asadi & Smaal 2015; Tallarico et al 2014).

At the upper intertidal zones, mangrove habitats can only be encountered in periods of inundations during tidal flooding and high tide. Therefore, all bivalves are exposed to air during the ebbs period. Such a harsh, extreme environment makes it difficult for filter-feeder bivalves to adapt, resulting in only some species being able to occupy those environments (Dewiyanti & Sofyatuddin 2012; Tomascik et al 1998; Vannucci 2001).

Furthermore, the family Veneridae was the most diverse, with a total of 6 species found at all sampling stations. The venerids or venus clams are the largest family of marine bivalve mollusks with a size of minute to large, in which 765 venus clams species are estimated to exist (Huber 2015; Lamprell & Healy 1998). Its habitat is predominantly sandy sediments (Wilson 2013), and therefore venus clams flourish in the intertidal area of Ngemboh, as it has 76% sand in its substratum, on average (Table 2).

Gafrarium pectinatum, one of the members of the venus clams has the highest distribution and abundance observed in the sampling stations. It thrived in 5 out of 6 stations with the total abundance of 5.53 ind/m^2, forming 30% of all individual bivalves found in the whole research area (Table 2 and Figure 2). *G. pectinatum* is highly spread from the Mediterranean Sea to the Indo-Pacific Ocean and generally exists from upper intertidal areas to shallow subtidal zones, especially in waters with high concentrations of organic matter (Carpenter & Niem 1998). The TOM values of water, 116 mg/m^2 in the research areas were high (Table 2). This species also flourished in the intertidal zones of Lamongan, constituting 82% of all bivalves observed in the areas (Asadi et al 2018).

From Mytilidae family, *Perna viridis* was one of the species observed in the research area. The species is an economically important mussel with an average size of 100 millimeters in length (Soon & Ransangan 2016). In Ujung Pangkah waters, *P. viridis* is cultivated using bamboo structures for attachment in its subtidal zones and harvested for food (Fitra et al 2018). The presence of this species in the intertidal zone was probably because of the larvae dispersal from farms, as *P. viridis* can attach to many substrates such as floating rafts, bamboo structures and gravel. *P. viridis* is also able to survive in high suspended solids up to 1200 mg/L (Shin et al 2002).

Crassostrea iredalei was the only species of the Ostreidae family observed in the research areas (Table 3).

Table 3

Averages of Bivalve abundance in the intertidal zone of Ngemboh, Ujung Pangkah, Gresik Regency, Indonesia (ind/m^2)

	Station					
	1	2	3	4	5	6
Arcidae						
Anadara antiquata (Linnaeus, 1758)	0	0	0.26	0.06	0.2	0.13
Mytilidae						
Limnoperna supoti (Brandt, 1974)	2.66	0	1.13	1.4	0	0
Perna viridis (Linnaeus, 1758)	0	0	0	0	0.13	0
Psammobiidae						
Hiatula chinensis (Mörch, 1853)	0	1.86	0.46	0.46	0	0
Ostreidae						
Crassostrea iredalei (Faustino, 1932)	1.8	0	0	0.26	0.4	0
Veneridae						
Circe scripta (Linnaeus, 1758)	0	0	0	0.13	0	0
Gafrarium divaricatum (Gmelin, 1791)	0	0	0	0.2	0.2	0
Gafrarium pectinatum (Linnaeus, 1758)	0	1.2	0.6	1.73	1.6	0.4
Gafrarium tumidum (Röding, 1798)	0	0.13	0.2	0	0.13	0.4
Katelysia japonica (Gmelin, 1791)	0	0	0	0.06	0	0
Meretrix petechialis (Lamarck, 1818)	0	0	0.13	0	0.13	0
Total average abundance (ind/m^2)	4.46	3.19	2.78	4.30	2.79	0.93
Total species	2	3	6	8	7	3

Carpenter & Niem (1998) argue that this species distribution is restricted to the Philippine Archipelago. However, many studies show that *C. iredalei* thrives in some neighborhood countries of the Philippines. In Indonesia, for instance, *C. iredalei* was observed in the coast of Sulawesi and many coasts of the Java Sea (Asadi et al 2018; Sudradjat 2006). The possible mechanism of the oyster dispersion is through the ballast water discharged by ships. One of the species of Ostreidae that spread on many temperate coastal areas is *Crassostrea gigas.* It originates in the coastal areas of Japan, and through shipping discharges, it has spread out in almost all subtropical and temperate marine environments (Anglès d'Auriac et al 2017; Leppäkoski 1991).

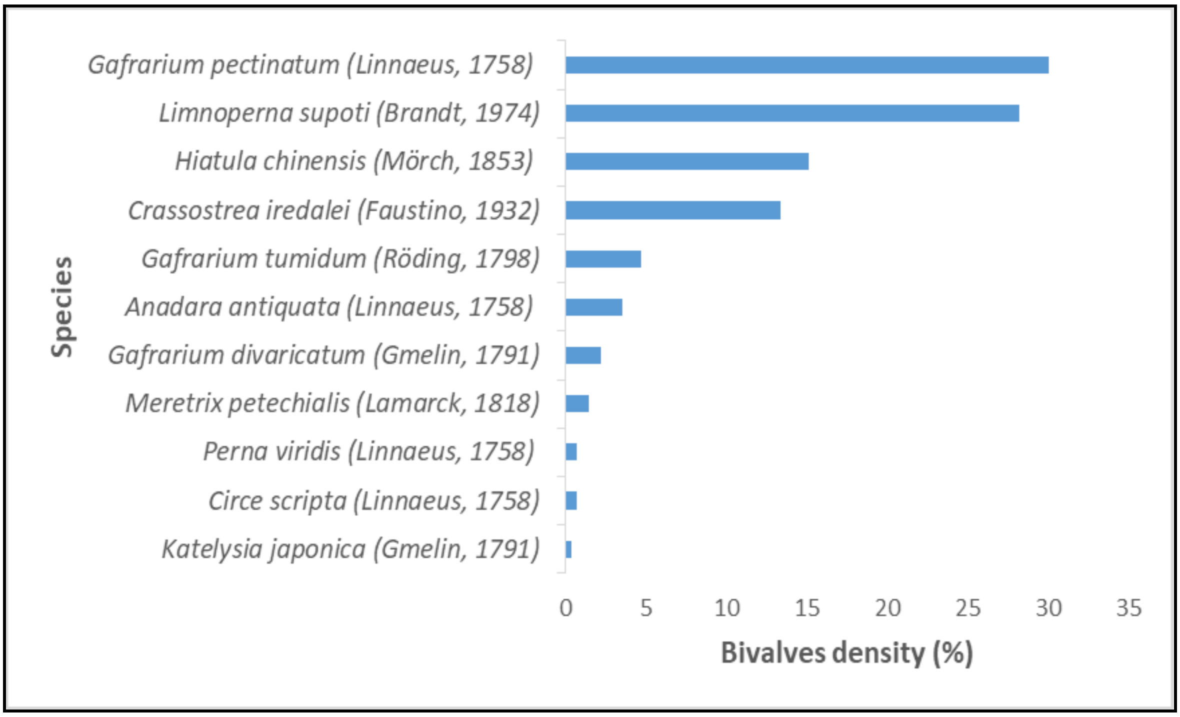

Figure 2. Percentage of bivalve density in the intertidal zone of Ngemboh, Ujung Pangkah, Gresik Regency, Indonesia.

Ecological indices. The bivalve fauna in the study area showed diversity index values between 0.67 and 1.55, with the average of 1.16. The higher species richness likely resulted in the higher diversity index (Karydis & Tsirtsis 1996). Although station 4 harbored a higher species richness (8 species) than station 3 (6 species), the latter station had a slightly higher diversity index with the value of 1.55 than that of the former station with the value of 1.52. This difference was because of the dominance of two bivalve species, *G. pectinatum* and *L. supoti* in station 4, in which both species had constituted 75% of the total bivalves found in the research station. Meanwhile, station 1 had the lowest diversity index with the value of 0.67, as there were only two bivalve species found in the station.

The evenness index ranged from 0.72 to 0.97, with the average of 0.82. The index measures how close in numbers is each species in a community or an environment. The value ranges between 0 and 1; the higher the J', the more evenness is in the community (Morris et al 2014). Station 1 had the highest evenness index as there were only two bivalve fauna that were evenly distributed. *L. supoti* and *C. iredalei* shared total abundances of 59% and 41% respectively. A healthy, balanced ecosystem remains maintains the size of population within a sustainable range (Morris et al 2014; Zhang et al 2012).

Meanwhile, the Simpson dominance index was between 0.24 and 0.52, with an average of 0.34, indicating low dominance in most research stations (Table 4). The dominance index of bivalve communities in the intertidal area of Ngemboh was lower compared to the intertidal areas of Lamongan. In the latter area, the dominance of *G. pectinatum*, 82% of all bivalves, induced a much higher dominance index. Meanwhile, in this study, *G. pectinatum* only contributed 30% of all individual bivalves.

Table 4

Diversity index (H'), the Evenness Index (J'), and Dominance index (D) at all sampling stations

	Station					
Ecological indices	1	2	3	4	5	6
Diversity index (H')	0.67	0.82	1.55	1.52	1.41	1.01
Evenness Index (J')	0.97	0.75	0.87	0.73	0.72	0.91
Dominance index (D)	0.52	0.24	0.25	0.28	0.36	0.38

The Pearson correlation among environmental parameters and ecological indices. The DO had a very high negative correlation with pH, temperature and salinity (r=-0.86, P<0.05, r=-0.97, P<0.01 and r=-0.96, P<0.01, respectively). The concentration of DO in intertidal areas is largely controlled by temperature and salinity. As the temperature and salinity increase, the solubility of oxygen decreases (Lange et al 1972). There might be no direct correlation between pH and the solubility of oxygen. However, fresh water flow in intertidal areas decreases the pH, as saline water has higher pH than freshwater. Water flow also increases the DO levels through the turbulent diffusion of atmospheric oxygen into the water column (Mackay & Fleming 1969; Mann & Lazier 2013).

There was a very strong negative correlation between temperature and species richness (r=-0.95, P<0.01) and a very high positive correlation between DO and species richness (r=0.92, P<0.01), meaning that lower temperature and higher DO resulted in higher species richness. This might be due to the fact that lower temperature environments induce a higher level of oxygen solubility, which are favorable for sedentary animals that have limited movement ability (Lange et al 1972; Long et al 2008). Environmental parameters and species richness data in station 4 showed that the species richness and DO were at the highest values while the temperature was at the lowest value among all research stations (Table 1 and 2). Furthermore, the correlation between evenness and species abundance was very weak (r=-0.13, P=0.8). Some stations with high species abundance (station 2 and 4) had uneven distribution in the number of individuals of each species, in which *Hiatula chinensis* shared 58% of all bivalve individuals in station 2 and *G. pectinatum* contributed 40% of the total abundance in station 4.

Table 5
The Pearson correlation of ecological indices and environmental parameters regarding bivalves in the intertidal area of Ngemboh, Gresik, East Java, Indonesia

	Ab.	*Ri.*	*Di.*	*Ev.*	*Do.*	*pH*	*DO*	*ToW*	*ToS*	*Te.*	*Sa.*	*Tu.*	*Gr.*	*Sa.*	*Si.*
Abundance	1.00														
Richness	0.17	1.00													
Diversity	-0.05	0.93	1.00												
Evenness	-0.13	-0.67	-0.50	1.00											
Dominance	0.14	-0.49	-0.55	0.65	1.00										
pH	-0.07	-0.82	-0.75	0.56	0.49	1.00									
DO	0.17	0.92	0.93	-0.58	-0.66	-0.86	1.00								
TOM (Water)	0.36	-0.11	-0.29	-0.17	-0.10	-0.36	0.03	1.00							
TOM (Sediment)	0.06	0.75	0.86	-0.38	-0.56	-0.37	0.77	-0.54	1.00						
Temperature	-0.04	-0.95	-0.98	0.62	0.66	0.79	-0.97	0.16	-0.85	1.00					
Salinity	0.01	-0.90	-0.92	0.53	0.59	0.93	-0.96	-0.06	-0.65	0.94	1.00				
Turbidity	-0.37	-0.70	-0.66	0.06	-0.18	0.47	-0.58	0.29	-0.55	0.59	0.56	1.00			
Gravel	0.46	0.28	0.38	0.22	-0.23	-0.32	0.54	0.11	0.46	-0.40	-0.44	-0.44	1.00		
Sand	0.45	0.00	-0.25	-0.33	0.33	0.35	-0.29	-0.14	-0.09	0.21	0.40	-0.08	-0.49	1.00	
Silt	-0.78	-0.16	0.08	0.26	-0.26	-0.22	0.03	0.10	-0.15	-0.02	-0.22	0.34	0.01	-0.87	1.00

Ab.= abundance, Ri.= richness, Di.= diversity, Ev.= evenness, Do.= dominance, ToW= TOM of Water, ToS= TOM of Sediment, Te.= temperature, Sa.= salinity, Tu.= Turbidity, Gr.= Gravel, Sa.= Sand, Si.= Silt.

Conclusions. Although the intertidal area of Ngemboh, Gresik Regency, East Java, Indonesia had high turbidity, the area was still favorable as a bivalve habitat, as the dissolved oxygen and other environmental parameters were still in the suitable range for marine mollusks. There were 11 species, 8 genera, and 5 families of bivalves, in which *Gafrarium pectinatum* constituted 30% of the total abundance found in all research stations. On average, the bivalve abundance was 3.07 ind/m^2, with the highest value in station 1, totaling 4.46 ind/m^2. Meanwhile, the averages of Shannon's diversity index (*H'*), the Pielou's evenness index (*J'*), and the Simpson's dominance index (C) were 1.16, 0.82 and 0.34, respectively. The low dominance value was due to the relatively high diversity index and species richness in stations with lower dominance index. Furthermore, higher dissolved oxygen strongly correlated with both diversity index and species richness (r=0.92 and r=0.93 respectively, P<0.01).

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