Description of bivalve community structure during dry season in the intertidal area of Lamongan, East Java, Indonesia

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Abstract. Bivalves play an important role in regulating bodies of water as well as in providing a wide range of ecosystem services including habitat complexity provision. A study of bivalve community structures in intertidal areas of Lamongan regency was conducted in June 2017 during the beginning of the dry season. It aimed to assess the species richness and ecological indices, as well as to analyze physicochemical parameters that might influence the community structures. Three 50-m long transect lines in each station were laid perpendicular to the coastline with five 1 x 1 m quadrant transects in each line. Results showed that there were 4 families, 8 genera and 8 species of bivalves of which *Gafrarium pectinatum* had the highest density, representing 82% of all bivalve individuals. On average, the Shannon's diversity index (H') and the Pielou's evenness index (J') were 0.4 and 0.35 respectively, while the Simpson dominance index (D) was 0.75. Ostreidae was evenly distributed and probably played an important role to govern the higher diversity and evenness indices, while *G. pectinatum* was responsible for the low value of diversity and evenness indices as well as the high value of the dominance index.
Key Words: density, bivalves, *Gafrarium pectinatum*, intertidal, Ostreidae.

Introduction. Bivalves are soft-bodied mollusks enclosed by two valves joined by an elastic ligament. The mollusks are very common in aquatic environments, including freshwater, brackish water, and saltwater (Gosling 2008; Thorp & Rogers 2016). In marine environments, the mollusks habitats are from the intertidal areas to the deepest abyss. Bivalves bury themselves in sand or mud, attach to mangrove leaves, crawl on seagrass blades, attach to shells and rocks, and even bury in driftwood and coral rocks (Keast 2000; Turgeon et al 2009; van der Meij et al 2009). Overall, there are 8,500 valid species of all marine and brackish water specimens currently recognized (Huber 2015). The South China Sea, encompassing an area from the Karimata and Malacca Straits to the Strait of Taiwan, has the highest bivalves biodiversity in the world with about 802 species (Liu 2013).

As suspension feeders, bivalves filter particulate food such as phytoplankton, organic matter, planktonic larvae, and even inorganic particles from the water column. As a result of extracting processes of the water through the gills, bivalves eject feces and pseudofeces (unsuitable or too large to digest particles) which transfer organic and nutrient-rich matters to the bottom of adjacent environments (Asadi & Smaal 2015; Newell et al 2002; Silverman et al 2000). Therefore, bivalves clarify the water column and stabilize substrates as well as promote habitat complexity (Newell et al 2002; Sueiro et al 2011).

The patterns of the biological community structure of bivalves such as the species composition, density, and species distribution may change over time in response to environmental pressures and disturbances (Dewiyanti & Sofyatuddin 2012; van der Meij et al 2009; Veras et al 2013). The severe deterioration of Jakarta Bay, for example, affects the biological community of mollusks, in which the records of mollusks in the bay drop dramatically, from 171 species in 1937 to only 58 species in 2005 (van der Meij et al 2009).

Social and economic development of coastal areas in developing countries inevitably accelerate environmental pressures, particularly on marine ecosystems (Lopez y Royo et al 2009). The majority of the Java Island population lives in coastal areas and therefore the resources in the areas are under considerable human pressures (Rudiarto et al 2018). Those pressures along with overexploitation of resources accelerate loss of habitats and biodiversity of intertidal areas, where microclimate and microhabitats support a large number of marine bivalve species (Oigman-Pszczol et al 2004; Torreblanca-Ramírez et al 2012). In Lamongan Regency of East Java, Indonesia, the pressure of coastal areas also affect its natural resources by reducing the biodiversity of its intertidal areas (Asadi et al 2017). Thus, this study was aimed to identify the bivalve species and to assess the biological community structure of the bivalves of intertidal zone of this region and to analyze the physical and chemical parameters that might influence their community structure.

Material and Method

Description of the study sites. The study was conducted at Lamongan Regency with the sampling coordinates between 6°52'38.75"S and 6°52'9.05"S, and from 112°15'33.84"E to 112°21'7.56"E. Lamongan Regency is located at the northern west of the province of East Java and known as part of the Surabaya Metropolitan Area. With approximately 47 km of coastal line, more than 170,000 people live in an area of 120 km^2 of coastal areas, leading to an increase of environmental pressures in its intertidal areas (Asadi et al 2017; BPS 2018). According to Köppen-Geiger climate classification, the coastal areas of Lamongan Regency have a tropical savannah climate, humid with a temperature average at 27.4°C and precipitation averages at 1465 mm (Asadi et al 2017; Merkel 2012). The research station coordinates and their characteristics and the map of the research areas are presented in Figure 1 and Table 1 respectively.

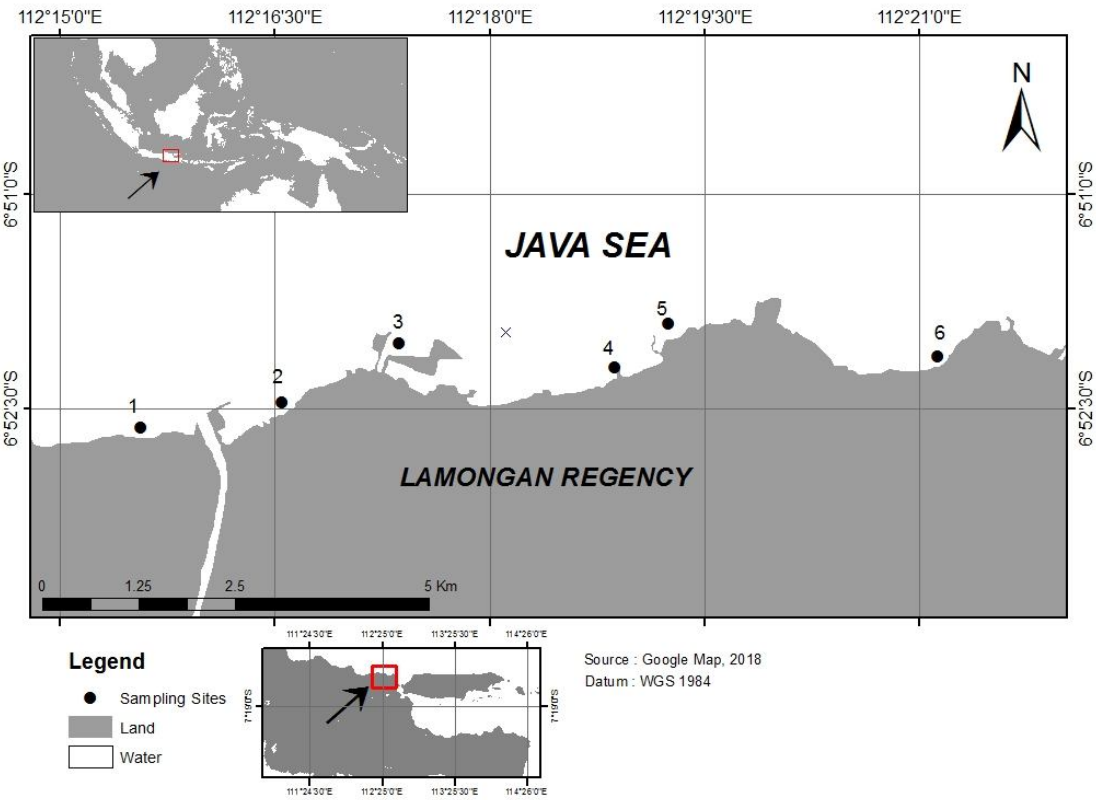

Figure 1. The map of bivalve's sampling sites in the intertidal areas of Lamongan, East Java, Indonesia.

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

Station	*Coordinates*	*Characteristics*
1	6°52'38.75"S; 112°15'33.84"E	Close to aquaculture ponds, the water was relatively clear.
2	6°52'28.63"S; 112°16'33.60"E	Landfill area, close to houses, and reclamation area.
3	6°52'4.48"S; 112°17'22.20"E	Inside the area of PPN Brondong, a fisheries port.
4	6°52'13.91"S; 112°18'52.92"E	Close to a fish processing factory, the water was relatively clear.
5	6°51'56.12"S; 112°19'14.88"E	Mangrove areas with considerable high amount of clay substrate and relatively high turbidity.
6	6°52'9.05"S 112°21'7.56"E	Relatively preserved recreation area.

Sampling procedure. All research was conducted in intertidal areas of Lamongan Regency in June 2017 at the beginning of the dry season. During low tide, three transects in each station were laid seawards perpendicular to the coastal line. In each 50 m long transect, five 1 x 1 m square plots were applied with plot and transect intervals at 10 and 30 meters respectively, thus a total of 15 plots per station and 75 plots in the entire research area. Bivalve samples in the plots were collected by wading and through dredging the substrate at depth of 15 cm below the surface of the sediment. The dredging was performed as some species prefer to move into deeper substrate as they grow, with short siphons living just underneath the substrate surfaces (Asadi et al 2018; Sassa et al 2011). Only living bivalves were identified according to Carpenter & Niem (1998), Dharma et al (2005), Huber (2015), and Lamprell & Healy (1998).

In order to support field data, some oceanographic parameters such as salinity, pH, dissolved oxygen (DO), temperature and turbidity were measured in situ using the water quality profiler (AAQ 1183). The analysis of total organic matter (TOM) and biological oxygen demand (BOD) of water were performed ex situ at Unit Pelaksana Teknis Pengembangan Budidaya Air Payau (UPT PBAP) Bangil, East Java. Meanwhile, the TOM of sediment was determined at Unit Pelaksana Teknis Pengembangan Agribisnis Tanaman Pangan dan Hortikultura (UPT PATPH) Lawang, East Java. Furthermore, the analysis of sediment grain size was performed at the laboratory of Soil Science Department, Brawijaya University. In brief, sediment samples of each station were dried using an oven at $60^{o}C$ for ±3 days followed by sieving using dry method with Vibratory Sieve Shaker AS 200 control. The material retained in each sieve was weighted, and these weights were divided by the total dry weight of the sample. Shepard Sediment Classification Diagram was then used for grouping the sediment (Asadi et al 2017).

Data and statistical analysis. The density of bivalves was expressed as the average density per species per square meter (ind m^{-2}). The diversity and evenness were determined using the Shannon's diversity index (H') and the Pielou's evenness index (J') respectively. Meanwhile, the Simpson's dominance index (D) was used to determine the species dominance. The relationship among physicochemical parameters as well as the grain types and the ecological indices of bivalves was statically computed using Pearson Correlation processed with GraphPad Prism 7 software. The same software was also used to draw the graphs (Morris et al 2014; Hamsiah et al 2016; Asadi et al 2018). One-Way ANOVA, Two-Way ANOVA, Repeated Measures one-way ANOVA were used to compare an environmental parameter among stations, some environmental parameters among stations, and the bivalve density and percentage among stations respectively that were also performed using GraphPad Prism 7 software.

Results and Discussion

Environmental parameters and sediment characteristics. The environmental parameters of intertidal zones in the research areas are presented in Table 2. Community structure of bivalves in the intertidal zones is highly influenced by the surrounding physicochemical characteristics of both water column and sediment as well as by the anthropogenic threat in the ecosystems (van der Meij et al 2009; Satheeshkumar & Khan 2012; Asadi & Smaal 2015; Asadi et al 2018). The DO concentrations were between 5.54±0.51 and 8.07±0.58 mg L^{-1}. Those levels were exceeding the minimum requirement for macrozoobenthos communities to sustain, which in general, a saturation level of at least 5 mg L^{-1} is required (Lakani et al 2013). The hypoxic condition (DO < 2 mg L^{-1}) during low tide is a significant stressor in bivalve communities as those organisms are unable to move in order to avoid this extremely low oxygen condition (Long et al 2008).

The surface temperatures of water column in all sampling stations were between 26.9±0.8 and 29.7±0.5^{o}C. The sampling in each station was not performed on the same day; therefore, the surface temperature differences were significantly different ($p < 0.01$). However, the temperature fluctuations were still in the optimal temperature for tropical benthic communities to sustain, which could stabilize the bivalve communities in those intertidal areas (Ahmedou-Salem et al 2014). The drastic change in sea surface temperature during the warm phase of the El Niño Southern Oscillation could kill bivalves, in which some bivalve species could not tolerate the temperature change higher than 13^{o}C (Urban 1994).

The turbidity varied from 0±0.0 NTU in station 4 to 67±6 NTU in station 2. The former station was dominated by sand sediment and had high water clarity, while the later station was the area impacted by land reclamation activities, leading to an increase in the turbidity in the area. Bivalves regulate water column by reducing the excessive turbidity and phytoplankton concentrations (Satheeshkumar & Khan 2012). However, the extremely high turbidity with low organic matter content could negatively impact the scope for growth of the bivalve species (Asadi & Smaal 2015).

Furthermore, the average pH of the intertidal area of Lamongan was 7.95±0.3, which was slightly lower than the average pH of ocean (8.1). Typically, intertidal zones may have variability in the pH values depending on their hydrography and sediment characteristics (Orr et al 2005; Ceballos-Osuna et al 2013). However, this pH level would not affect the bivalve communities as it was still in the range of optimum pH level for the sustainability of bivalves (Hamsiah et al 2016).

The TOM of waters was significantly higher than TOM of sediments ($p < 0.01$), in which the TOM of waters had at least 38±5 mg L^{-1} while the TOM of sediments could be as low as 0±0 mg L^{-1}. The high level of disturbance due to the effect of tide in intertidal zones could drive organic matter in the sediment to the water column, which in turn increases the level of TOM in waters (Fenchel et al 2012). Moreover, as suspension feeders, bivalves feed by filtering organic matter, bacteria and phytoplankton from the water column and therefore the level of TOM in the water column should be high enough to support the sustainability of the bivalves (Smaal & Prins 1993). The absence of organic matter in the sediment of station 1 is due to the fact that the station was dominated by coarse sand and gravel with no clay or mud presented. Organic matter in soil tends to increase as finer sediment increases due to its higher porosity to trap organic material (Asadi et al 2017).

Based on grain size, on average, the sediment of intertidal areas of Lamongan was dominated by sand (< 90%). However, in station 4, the considerably high amount of mud was prevalent in its substrate. High levels of nutrients, phytoplankton and bacteria reflected in high level of TOM as well as sand sediment were favorable to bivalves in coastal ecosystems (Huber 2015).

Table 2
Physicochemical parameters of the intertidal areas Lamongan, East Java, Indonesia at the beginning of the dry season (June 2017)

	Station					
	1	*2*	*3*	*4*	*5*	*6*
Water qualities ($\bar{x}$±SD)						
pH	8±0.1	7.9±0.3	8.1±0.3	7.9±0.7	7.9±0.4	8±0.4
DO (mg L^{-1})	8.07±0.58	6.85±0.15	7.50±0.52	8.01±0.16	5.54±0.51	7.90±0.36
TOM of waters (mg L^{-1})	61±8	56±4	62±9	63±6	38±5	63±4
TOM of substrate (mg L^{-1})	0±0	0.56±0.12	0±0	2.1±0.15	2.8±0.3	0.74±0.11
Temperature (^oC)	29.5±0.5	27.3±1.1	29.7±0.5	28.4±0.6	27±0.8	26.9±0.8
Salinity (‰)	30±1.1	29±0.5	33±0.5	33±2.9	32±1.3	30±0.7
Turbidity (NTU)	21±2	67±6	20±4	0±0.0	33±3	7±1
Substrates						
Gravel (%)	5.77	0.84	9.39	0	0	0
Sand (%)	94.23	91.53	90.46	93.97	84.2	92.46
Mud (%)	0	7.63	0.15	6.03	15.8	7.54

The richness and density of the bivalves. There were 8 species, 8 genera, and 4 families of bivalves recorded in the intertidal areas of Lamongan. The species diversity was slightly lower than that found on the intertidal areas of Gili Ketapang Island, in which 9 bivalve species were recorded in the areas (Asadi et al 2018). This could be understood as the anthropogenic threat on the island was relatively low as the area is not directly connected to heavily populated areas of the coastal areas of Java which highly influenced the intertidal areas of Lamongan (Asadi et al 2017).

The species richness in the intertidal areas of Lamongan was much lower compared to the intertidal and subtidal areas of the São Sebastião Channel that record 52 bivalve species (Tallarico et al 2014). However, the intertidal areas commonly have lower diversity of bivalves than the subtidal areas. The study of bivalve diversity of Bahía de Mazatlán, México revealed the species increase from 44 species in the upper intertidal to 76 species in the shallow subtidal (Esqueda-González et al 2014). The shallow subtidal and the upper intertidal have more variety and stability of sediment as well as lower tidal fluctuations, which in turn promoted more diverse niches to support higher bivalve diversity (Levine & HilleRisLambers 2009).

In this study, the species diversity was higher than that recorded in mangrove areas of the district of Aceh Besar and Banda Aceh, Indonesia, in which in both areas there were only 5 bivalve species recorded (Dewiyanti & Sofyatuddin 2012). The trees commonly grow in the upper intertidal areas that might limit the feeding activity of bivalves, as most mangrove areas are inundated only during high tide. Therefore, only bivalve species adapted to a harsh environment might able to occupy the areas (Vannucci 2001). Anoxic condition and high temperature of mangrove soil during low tide reduce bivalve ability to adapt, thus leading only some species of bivalves occupied in those areas (Tomascik et al 1998). In this research, there were only 2 species of bivalves observed in the mangrove area (station 5) with the total density only 1 ind m^{-2}. Meanwhile, the seagrass ecosystem of Pangkep, South Celebes, Indonesia, had 14 bivalve species during rainy season observation. Typically, seagrass ecosystem is submerged constantly, thus providing a more stable and better habitat to marine bivalves than that of intertidal zones, in which the areas are constantly exposed during low tide (Tallarico et al 2014; Hamsiah et al 2016).

The Veneridae and Ostreidae family were the most diverse species found in the intertidal areas of Lamongan, representing each 3 genera and 3 species. The Veneridae, common name the venus clams, are a very large family of marine bivalve with about 765 species recognized so far (Dharma et al 2005; Huber 2015). The sand sediment that dominated the intertidal areas of Lamongan were found suitable for the bivalve family as the verenids is an infauna groups of marine bivalve molluscs that prefers sandy bottom sediments for their habitats (Wilson 2013). *Gafrarium pectinatum* was the most abundant Veneridae in the research areas with a total individual of 67 observed at 5 out 6 research stations which encompassed 82% of all bivalves observed. This species is highly distributed from Indo-Pacific to Mediterranean Sea and commonly found in upper intertidal areas to shallow subtidal depths, specifically in the areas with high concentration of organic matters (Carpenter & Niem 1998). It is supported by the TOM of waters in the research areas that were very high from 38±5 to 63±6 mg L^{-1} (Table 2). However, there were no *G. pectinatum* recorded in the station 1. This may be due to the fact that coarse sand and gravel dominated the sediment in the station with no clay measured. This type of habitat may not be suitable for the species settlement as it prefers soft sandy sediment with an adequate amount of mud or clay (Gab-Alla et al 2007).

The Ostreidae family in the research areas was represented by *Alectryonella plicatula, Dendostrea folium*, and *Crassostrea iredalei*. Species in this family are characterized by their irregularly and inequivalve shaped solid shell, in which the lower (left) valve is commonly larger and deeper cemented in the substrate (Carpenter & Niem 1998). Oysters are filter feeder bivalves living mainly in intertidal and shallow subtidal areas which often form oyster reefs that promote habitat complexity in marine environments (Carpenter & Niem 1998; Asadi & Smaal 2015). *A. plicatula* and *D. folium* are widespread in the Western Indo-Pacific, in which *D. folium* distributions also encompass the Melanesian region to the South of Queensland. Although *C. iredalei* distributions were considered only restricted to the Philippine Archipelago (Carpenter & Niem 1998), the existence of this species is also reported in some areas of Indonesia, from the coast of Sulawesi to Banten (Sudradjat 2006). Therefore, this species has been an invasive species in Indonesian archipelago waters for at least the last two decades, which may spread through larvae in ballast water. The Pacific oyster, *Crassostrea gigas,* which originated from Japan, is also widespread in the temperate and subtropical intertidal and subtidal zones around the world through larvae release from the ballast water (Leppäkoski 1991).

Meanwhile, Arcidae and Donacidae family were represented by *A. antiquata* and *D. faba* respectively. The former species is characterized by 35 to 44 radial ribs at each valve with a narrow median groove on the top. The color of its periostracum is dark brown. Its inner side is white, and in the umbonal cavity is sometimes light yellow. The habitat is on muddy bottoms of intertidal and subtidal zones to a maximum depth of 25 m (Carpenter & Niem 1998). This is supported by this study in which this species was prevalent in station 4, 5 and 6 where there was a considerable amount of mud in the sediment (Table 2). The density percentage of bivalves, some representative of the bivalve species, and averages of species density and composition of bivalves, are presented in Figure 2, Figure 3, and Table 3, respectively.

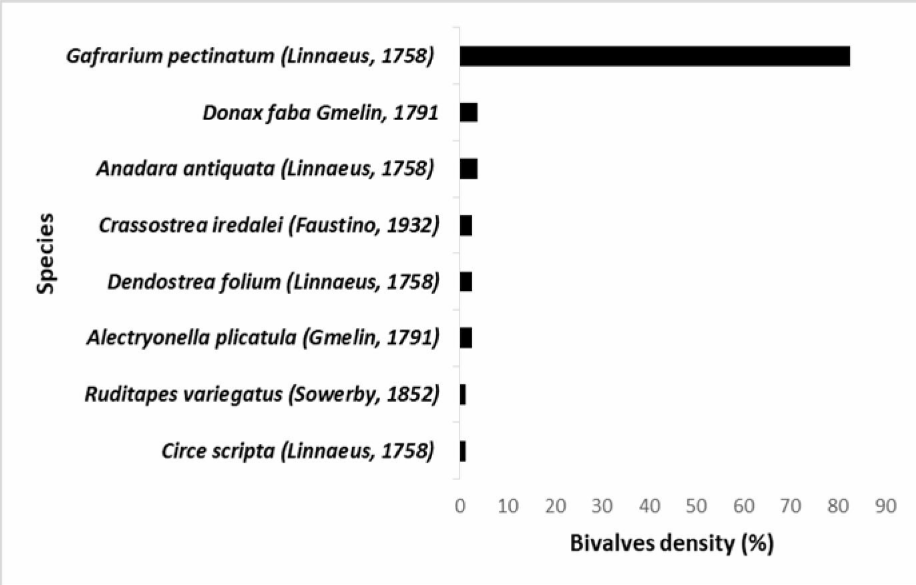

Figure 2. Percentage of bivalves density. Repeated Measures one-way ANOVA p = 0.36.

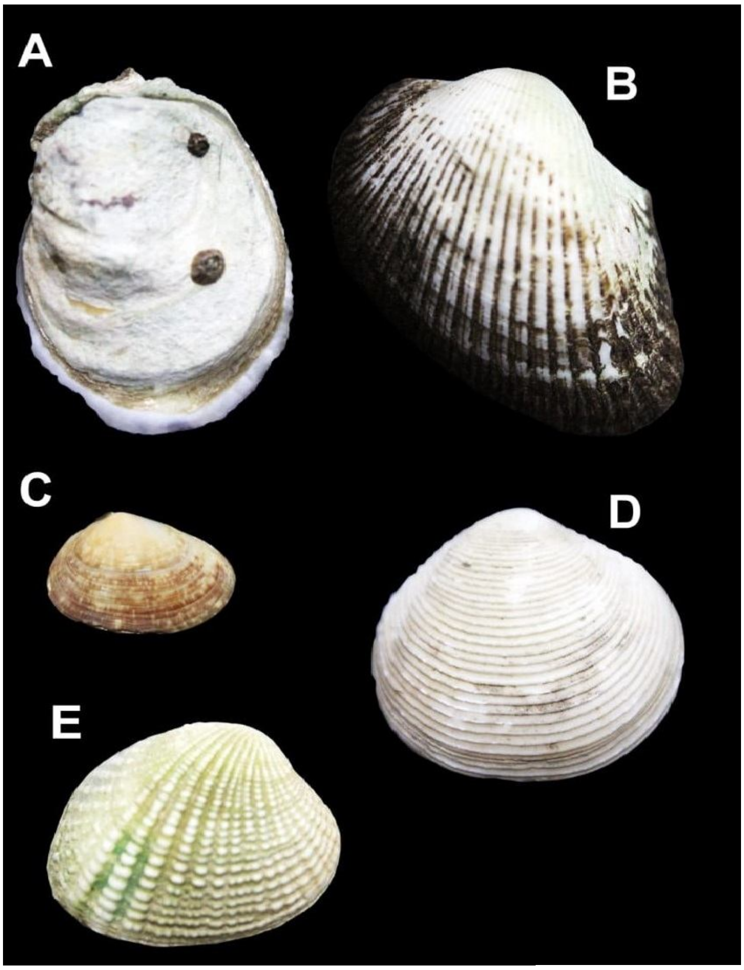

Figure 3. Some representative of the bivalve species: A. *Crassostrea iredalei* (Ostreidae), B. *Anadara antiquata* (Arcidae), C. *Donax faba* (Donacidae), D. *Circe scripta* (Veneridae), E. *Gafrarium pectinatum* (Veneridae).

Table 3

Averages of Bivalves density and richness in study areas (ind m^{-2}) in the coastal areas of Lamongan, East Java, Indonesia in June 2017

Families/species	*Station*					
	1	*2*	*3*	*4*	*5*	*6*
Ostreidae						
Alectryonella plicatula (Gmelin, 1791)	0.2	0	0	0	0	0.2
Dendostrea folium (Linnaeus, 1758)	0.4	0	0	0	0	0
Crassostrea iredalei (Faustino, 1932)	0.2	0	0	0	0	0.2
Arcidae						
Anadara antiquata (Linnaeus, 1758)	0	0	0	0.2	0.2	0.2
Donacidae						
Donax faba Gmelin, 1791	0.6	0	0	0	0	0
Veneridae						
Circe scripta (Linnaeus, 1758)	0	0.2	0	0	0	0
Gafrarium pectinatum (Linnaeus, 1758)	0	2.4	0.6	5.8	0.8	3.8
Ruditapes variegatus (Sowerby, 1852)	0	0	0	0.2	0	0
Average of total density	1.4	2.6	0.6	6.2	1	4.4
Species richness	4	2	1	3	2	4

***Community structure indices**.* Pielou's evenness index (J'), Shannon's diversity index (H') and Simpson's dominance index (D) clearly describe more properties of these communities than the density and richness (S) of bivalves would alone. A diversity index is a quantitative measurement that depends on the species richness and individual distribution of those species (Karydis & Tsirtsis 1996; Asadi et al 2018). The Shannon's diversity index was between 0 and 1.28. Although both station 1 and 6 had 4 bivalve species, the diversity index of station 1 was much higher than that of station 6 (H' = 1.28 and 0.55 respectively). This was due to the distribution of *G. pectinatum* that dominated station 6, which led to the decrease of the diversity index in the station. However, the harsh environment in intertidal areas may limit the diversity index in the areas. In a more stable environment, like in a seagrass ecosystem, diversity index could be higher as the area provides a richer and more stable habitat that promotes more niches to support the sustainability of bivalves (Tomascik et al 1998; Hamsiah et al 2016).

Meanwhile, the evenness index refers to how equal the community is numerically that is constrained between 0 and 1; the lower J', the less evenness in communities is (Morris et al 2014). The evenness value in the research areas ranged from 0 to 0.92. The low J' value (J' = 0) in station 3 was due to the fact that *G. pectinatum* were the only bivalves observed in the station and therefore the area possessed ecological instability. Meanwhile, the high J' value in station 1 indicated that the community is very even, in which the bivalve communities possessed ecological stability. A healthy ecosystem is a relatively equilibrium or stable state that maintains the population size within a sustainable range (Zhang et al 2012; Morris et al 2014).

Furthermore, the Simpson dominance index ranged from 0.3 at the station 1 to 1 at the station 3 with average of 0.74 indicating low dominance to very or completely dominant. The relatively low dominance was at station 1 where the diversity was at the highest level in all research stations. Meanwhile, at station 3, *G. pectinatum* were the only bivalves that observed in the station and therefore the dominance index in the area was completely dominant (D = 1). The higher evenness and diversity index as well as the lower dominance index in station 1 indicated that this station is more suitable for the habitat of bivalves. This station had the highest DO value, a considerable high amount of TOM with moderate turbidity, and ideal pH value and salinity concentration as well as suitable substrate condition. In this station, Ostreidae dominated the species richness, in which extremely high turbidity would limit the growth of oysters. As the intertidal areas are subjected to tidal fluctuation, clay materials would result in high turbidity which in turn limit the growth of oysters (Asadi & Smaal 2015). Shannon's diversity index (H'), the Pielou's evenness index (J'), and the Simpson dominance index (D) of the research stations are presented in Table 4.

Table 4

The community structure indices of each station

Ecological indices	*Station*					
	1	*2*	*3*	*4*	*5*	*6*
Diversity index (H')	1.28	0.27	0.00	0.17	0.18	0.55
Evenness index (J')	0.92	0.39	0.00	0.16	0.26	0.40
Dominance index (D)	0.30	0.85	1	0.87	0.68	0.75

The correlation among biological indices and environmental parameters. The Shannon's diversity index (H') and the evenness index (J') were highly correlated with the richness or number of species ($r = 0.78$, $p > 0.05$ and $r = 0.85$, $p < 0.05$ respectively). These might be due to the fact that stations with higher diversity index (station 1 and 6) also possessed higher species richness, and in both stations, the bivalves were more likely evenly distributed. Meanwhile, the diversity index had a very strong positive correlation with the evenness index but had a very strong negative correlation with the dominance index ($r = 0.92$, $p < 0.05$ and $r = -0.92$, $p < 0.05$ respectively). The calculation of evenness index is based on the diversity index and the species richness, in which the higher diversity index results in the higher evenness index, and the lower species richness results in the higher evenness index. Therefore, the very strong positive correlation between the diversity index and evenness index was also because the bivalves in stations with higher diversities were more likely evenly distributed. The very strong negative correlation between the diversity index and the dominance index was due to the tendency of stations with a higher diversity index having a lower dominance index (Tables 3 and 4).

On the other hand, the evenness index has a very weak correlation with the species density ($r = 0.04$, $p > 0.05$) as the bivalves were not evenly distributed in the station with higher density in which there was a strong dominance of G. pectinatum in the station with higher density. On average, the diversity, the evenness, and the dominance indices of the intertidal areas of Lamongan were H' = 0.4, J' = 0.35, and D = 0.75. The diversity and evenness indices were much lower than those in intertidal areas of Gili Ketapang Island (H' = 1.16, J' = 0.9 respectively). The values also were much lower than those in the seagrass ecosystem of Pangkep, South Sulawesi, Indonesia (H' = 1.8, J' = 0.9 respectively). The bivalves in those areas are evenly distributed, and there are no single species dominated in the research areas; therefore, the diversity and evenness indices values are expected in much higher values (Hamsiah et al 2016; Asadi et al 2018;).

DO and sand sediment had moderate positive correlation (Pearson $r = 0.3$-0.5) with the species density, richness, diversity, and evenness, but negative correlation (Pearson $r = -0.1$) with the species dominance. Higher proportion of sand sediment and higher value of DO definitely could promote the higher diversity, evenness, and species richness as higher values of both environmental parameters are more favorable for the sustainability of bivalves (Long et al 2008; Huber 2015). Meanwhile, mud sediment had a negative correlation with species richness, diversity, and evenness ($r = -0.10$, -0.37, -0.15 respectively). In the research stations, a considerably high amount of mud boosted the density of *G. pectinatum* which prefers habitat with an adequate amount of clay or mud (Gab-Alla et al 2007). With total density of 82%, *G. pectinatum* was significantly responsible for the higher dominance index and the lower species richness, diversity and evenness indices. The Pearson correlation among biological indices and environmental parameters is presented in Table 5.

Table 5

The Pearson correlation among the bivalve's biological indices and environmental parameters of the intertidal areas of Lamongan

	De.	*Ri.*	*Di.*	*Ev.*	*Do.*	*pH*	*DO*	*ToW*	*ToS*	*Te.*	*Sa.*	*Tu.*	*Gr.*	*Sa.*	*Mu.*
Density	1.00														
Richness	0.48	1.00													
Diversity	-0.09	0.78	1.00												
Evenness	0.04	0.85	0.92	1.00											
Dominance	0.22	-0.67	-0.92	-0.82	1.00										
pH	-0.42	-0.13	0.10	0.01	0.08	1.00									
DO	0.47	0.54	0.42	0.35	-0.11	0.43	1.00								
TOM (water)	0.44	0.34	0.23	0.19	0.11	0.48	0.96	1.00							
TOM (sediment)	0.29	-0.07	-0.41	-0.35	0.11	-0.71	-0.58	-0.66	1.00						
Temperature	-0.30	-0.13	0.23	-0.10	-0.12	0.63	0.51	0.48	-0.54	1.00					
Salinity	0.04	-0.44	-0.56	-0.74	0.44	0.19	-0.04	-0.06	0.41	0.37	1.00				
Turbidity	-0.46	-0.43	-0.10	-0.04	0.04	-0.31	-0.56	-0.42	-0.12	-0.28	-0.55	1.00			
Gravel	-0.62	-0.35	0.11	-0.13	-0.01	0.85	0.29	0.34	-0.69	0.87	0.25	-0.06	1.00		
Sand	0.52	0.55	0.46	0.40	-0.15	0.20	0.94	0.91	-0.57	0.42	-0.24	-0.32	0.16	1.00	
Mud	0.09	-0.10	-0.37	-0.15	0.10	-0.70	-0.79	-0.81	0.83	-0.86	-0.01	0.24	-0.78	-0.73	1.00

De. = density; 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; Mu. = mud.

Conclusions. Based on the result and discussion, it can be concluded that the intertidal zone of Lamongan, East Java, Indonesia harbored 8 species of bivalves from 8 genera and 3 families during June 2017, in which the highest species representation were from Ostreidae and Veneridae family. The highest density was in station 3 (6.2 ind m^{-2}) with *G. pectinatum* being the dominant species in the research areas, representing 82% of all individual bivalves. On average, the Shannon's diversity and evenness indices were low (H' = 0.4; J' = 0.35), while the dominance index was high (D = 0.75) due to the high density and dominance of *G. pectinatum*. The high density, density, and dominance of *G. pectinatum* may due to the presence of mud in the sediment of the most research stations, in which there was no *G. pectinatum* recorded in the station without the presence of mud.

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References

Ahmedou-Salem M. V., van der Geest M., Piersma T., Saoud Y., van Gils J. A., 2014 Seasonal changes in mollusc abundance in a tropical intertidal ecosystem, Banc d'Arguin (Mauritania): testing the "depletion by shorebirds" hypothesis. Estuarine, Coastal and Shelf Science 136:26-34.

Asadi M. A., Smaal A., 2015 Effects of high seston concentration on scope for growth of the edible oyster, *Crassotrea madrasensis*. 1st International Symposium on Marine and Fisheries Research, Presented at the ISMFR UGM, Fisheries Department, Gadjah Mada University, Yogyakarta, Indonesia, pp. 91-98.

Asadi M. A., Guntur G., Ricky A. B., Novianti P., Andik I., 2017 Mangrove ecosystem C-stocks of Lamongan, Indonesia and its correlation with forest age. Research Journal of Chemistry and Environment 21(8):1-9.

Asadi M. A., Iranawati F., Andini A. W., 2018 Ecology of bivalves in the intertidal area of Gili Ketapang Island, East Java, Indonesia. AACL Bioflux 11(1):55-65.

Badan Pusat Statistik (BPS), 2018 [Results of 2010 population census]. The Central Bureau of Statistics, Lamongan, Indonesia. Available at: https://lamongankab.bps.go.id/. Accessed: June, 2018. [in Indonesian]

Carpenter K. E., Niem V. H., 1998 The Living Marine Resources of the Western Central Pacific Volume 1: Seaweeds, corals, bivalves and gastropods. FAO Species Identification Guide for Fishery Purposes. Food and Agriculture Oganization of the United Nations, Rome, 686 pp.

Ceballos-Osuna L., Carter H. A., Miller N. A., Stillman J. H., 2013 Effects of ocean acidification on early life-history stages of the intertidal porcelain crab *Petrolisthes cinctipes*. Journal of Experimental Biology 216:1405-1411.

Dewiyanti I., Karina S., 2012 Diversity of gastropods and bivalves in mangrove ecosystem rehabilitation areas in Aceh Besar and Banda Aceh districts, Indonesia. AACL Bioflux 5(2):55-59.

Dharma B., Schwabe E., Schrödl M., 2005 Recent and fossil Indonesian shells. ConchBooks, Germany, 424 pp.

Esqueda-González M. C., Ríos-Jara E., Galván-Villa C. M., Rodríguez-Zaragoza F. A., 2014 Species composition, richness, and distribution of marine bivalve molluscs in Bahía de Mazatlán, México. ZooKeys 399:43-69.

Fenchel T., King G. M., Blackburn T. H., 2012 Aquatic sediments. In: Bacterial biogeochemistry. Third edition, Academic Press, Boston, pp. 121-142.

Gab-Alla A. A. F. A., Mohamed S. Z., Mahmoud M. A. M., Soliman B. A., 2007 Ecological and biological studies on some economic bivalves in Suez Bay, Gulf of Suez, Red Sea, Egypt. Journal of Fisheries and Aquatic Science 2:178-194.

Gosling E., 2008 Bivalve molluscs: biology, ecology and culture. Wiley-Blackwell, Galway, 456 pp.
Hamsiah, Herawati E. Y., Mahmudi M., Sartimbul A., 2016 Seasonal variation of bivalve diversity in seagrass ecosystem of Labakkang coastal water, Pangkep, South Sulawesi, Indonesia. AACL Bioflux 9(4):775-784.
Huber M., 2015 Compendium of bivalves 2. A full-color guide to the remaining seven families. A systematic listing of 8,500 bivalve species and 10,500 synonyms. ConchBooks, Hackenheim, Germany, 907 pp.
Karydis M., Tsirtsis G., 1996 Ecological indices: a biometric approach for assessing eutrophication levels in the marine environment. Science of the Total Environment 186:209-219.
Keast A., 2000 Book review: The ecology of the Indonesian Seas. Part I. The ecology of Indonesia Series, Volume VII. The Quarterly Review of Biology 75:201-201.
Lakani F. B., Sattari M., Falahatkar B., 2013 Effect of different oxygen levels on growth performance, stress response and oxygen consumption in two weight groups of great sturgeon *Huso huso*. Iranian Journal of Fisheries Sciences 12:533-549.
Lamprell K., Healy J., 1998 Bivalves Of Australia Vol. 2, 1st ed. Backhuys, Leiden, The Netherlands, 28 pp.
Leppäkoski E. J., 1991 Introduced species - resource or threat in brackish-water seas? Examples from the Baltic and the Black Sea. Marine Pollution Bulletin 23:219-223.
Levine J. M., HilleRisLambers J., 2009 The importance of niches for the maintenance of species diversity. Nature 461:254-257.
Liu J. Y., 2013 Status of marine biodiversity of the China Seas. PLoS ONE 8:e50719.
Long W. C., Brylawski B. J., Seitz R. D., 2008 Behavioral effects of low dissolved oxygen on the bivalve *Macoma balthica*. Journal of Experimental Marine Biology and Ecology 359:34-39.
Lopez y Royo C., Silvestri C., Pergent G., Casazza G., 2009 Assessing human-induced pressures on coastal areas with publicly available data. Journal of Environmental Management 90:1494-1501.
Merkel E., 2012 Climate: Brondong. Clim. Data Cities Wordwide. Available at: https://en.climate-data.org/location/629795/. Accessed: June, 2018.
Morris E. K., Caruso T., Buscot F., Fischer M., Hancock C., Maier T. S., Meiners T., Müller C., Obermaier E., Prati D., Socher S. A., Sonnemann I., Wäschke N., Wubet T., Wurst S., Rillig M. C., 2014 Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. Ecology and Evolution 4:3514-3524.
Newell R. I. E., Cornwell J. C., Owens M. S., 2002 Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: a laboratory study. Limnology and Oceanography 47:1367-1379.
Oigman-Pszczol S. S., Figueiredo M. A. O., Creed J. C., 2004 Distribution of benthic communities on the tropical rocky subtidal of Armação dos Búzios, southeastern Brazil. Marine Ecology 25:173-190.
Orr J. C., Fabry V. J., Aumont O., Bopp L., Doney S. C., Feely R. A., Gnanadesikan A., Gruber N., Ishida A., Joos F., Key R. M., Lindsay K., Maier-Reimer E., Matear R., Monfray P., Mouchet A., Najjar R. G., Plattner G. K., Rodgers K. B., Sabine C. L., Sarmiento J. L., Schlitzer R., Slater R. D., Totterdell I. J., Weirig M. F., Yamanaka Y., Yool A., 2005 Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437:681-686.
Rudiarto I., Handayani W., Sih Setyono J., 2018 A regional perspective on urbanization and climate-related disasters in the northern coastal region of Central Java, Indonesia. Land 7(1):34.
Sassa S., Watabe Y., Yang S., Kuwae T., 2011 Burrowing criteria and burrowing mode adjustment in bivalves to varying geoenvironmental conditions in intertidal flats and beaches. PLoS ONE 6(9):e25041.
Satheeshkumar P., Khan A. B., 2012 Influence of environmental parameters on the distribution and diversity of molluscan composition in Pondicherry mangroves, southeast coast of India. Ocean Science Journal 47:61-71.

Silverman H., Lynn J. W., Dietz T. H., 2000 In vitro studies of particle capture and transport in suspension-feeding bivalves. Limnology and Oceanography 45:1199-1203.
Smaal A. C., Prins T. C., 1993 The uptake of organic matter and the release of inorganic nutrients by bivalve suspension feeder beds. In: Bivalve filter feeders. Dame R. F. (ed), Springer, Berlin Heidelberg, pp. 271-298.
Sudradjat A., 2006 Effect of salinity, temperature, and food value of four microalgae to oyster, *Crassostrea iredalei* larval growth. Indonesian Aquaculture Journal 1:135-143.
Sueiro M. C., Bortolus A., Schwindt E., 2011 Habitat complexity and community composition: relationships between different ecosystem engineers and the associated macroinvertebrate assemblages. Helgoland Marine Research 65:467-477.
Tallarico L. F., Passos F. D., Machado F. M., Campos A., Recco-Pimentel S. M., Introíni G. O., 2014 Bivalves of the São Sebastião Channel, north coast of the São Paulo state, Brazil. Check List 10(1):97-105.
Thorp J. H., Rogers D. C., 2016 Phylum Mollusca. In: Thorp and Covich's freshwater invertebrates (Fourth Edition). Academic Press, Boston, pp. 189-221.
Tomascik T., Mah A. J., Nontji A., Moosa M. K., 1998 The ecology of the Indonesian Seas: Part 2. Periplus Edition, Singapore, 752 pp.
Torreblanca-Ramírez C., Flores-Garza R., Flores-Rodríguez P., García-Ibáñez S., Galeana-Rebolledo L., 2012 [Wealth, composition and diversity of the mollusk community associated with the intertidal rocky substrate of the Parque de la Reina beach, Acapulco, Mexico]. Revista de Biología y Oceanografía 47:283-294. [in Spanish]
Turgeon D. D., Lyons W. G., Mikkelsen P., Rosenberg G., Moretzsohn F., 2009 Bivalvia (Mollusca) of the Gulf of Mexico. In: Gulf of Mexico – origins, waters, and biota. Volume 1. Biodiversity. Felder D. L., Camp D. K. (eds.), Texas A&M University Press, College Station, Texas, pp. 711-744.
Urban H. J., 1994 Upper temperature tolerance of ten bivalve species off Peru and Chile related to El Nino. Marine Ecology Progress Series 107:139-145.
van der Meij S. E., Moolenbeek R. G., Hoeksema B. W., 2009 Decline of the Jakarta Bay molluscan fauna linked to human impact. Marine Pollution Bulletin 59:101-107.
Vannucci M., 2001 What is so special about mangroves? Brazilian Journal of Biology 61:599-603.
Veras D. R. A., Martins I. X., Matthews-Cascon H., 2013 Mollusks: how are they arranged in the rocky intertidal zone? Iheringia. Série Zoologia 103:97-103.
Wilson B., 2013 Patterns of life and the processes that produce them. In: The biogeography of the Australian north west shelf. Elsevier, Boston, pp. 267-369.
Zhang H., John R., Peng Z., Yuan J., Chu C., Du G., Zhou S., 2012 The relationship between species richness and evenness in plant communities along a successional gradient: a study from sub-alpine meadows of the eastern Qinghai-Tibetan Plateau, China. PLoS ONE 7:e49024.

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