Ecology of bivalves in the intertidal area of Gili Ketapang Island, East Java, Indonesia

Muhammad A. Asadi, Feni Iranawati, Ajeng W. Andini

Marine Science Department, Brawijaya University, Malang, Indonesia.
Corresponding author: M. A. Asadi, asadi@ub.ac.id

Abstract. Bivalves provide a range of ecosystem services such as turbidity reduction, denitrification induction, and habitat complexity provision. This study aimed to assess the diversity and the community structure of bivalves in the intertidal areas of Gili Ketapang Island, East Java, Indonesia, as well as analyze the environmental parameters that might influence their biological community. Three (15-m long) transects with five 1x1-m quadrant plots in each transect line of each research station were established seawards perpendicular to the coast line. The bivalves were composed of 5 families, 8 genera and 10 species of which *Gafrarium tumidum* had the highest density and distribution. On average, the Shannon's diversity index (H') and the Simpson dominance index (D) were moderate with the values of 1.12 and 3.13 respectively. The Evenness Index (J') was high with value of 0.90, which indicated that the bivalve communities possessed ecological stability. Moreover, physico-chemical parameters of water and sediment were still in the range of the tolerant level to sustain bivalves life.
Key Words: Gili Ketapang, bivalves, *Gafrarium tumidum*, community structure, *Periglypta puerpera*.

Introduction. Bivalvia is a class of marine and freshwater mollusks that is a soft-bodied invertebrate enclosed by a two-part hinged shell. Bivalves play important roles in regulating estuarine and coastal marine ecosystems by filtering large volumes of water containing plankton, planktonic larvae, particulate organic matter, and inorganic particles. As a result of pumping and filtering processes through the gills, bivalves eject both pseudofeces and feces which transfer inorganic, organic and nutrient-rich particulate to the bottom (Newell et al 2002; Prins et al 1991; Silverman et al 2000). Hence, the bivalves promote ecosystem services such as stabilizing substrates, decreasing erosion, and enhancing habitat complexity (Asadi & Smaal 2015; Newell et al 2002).

Bivalvia is the second largest taxonomic class within the phylum Mollusca with about 10,000 living species known throughout the world (Rahman et al 2015). Bivalve can be found on the head of tide to the deepest abyss, buried in the sand and mud, attached to shells and rocks, burrowing in wood and coral rock, crawling on seagrass blades (Turgeon et al 2009), and even attached to mangrove leaves in the mangrove forest (Keast 2000). Marine bivalves (including estuarine and brackish water species) represent about 8,000 species, with the South China Sea having the most diverse bivalve fauna in the world with about 802 species (Liu 2013). There were 197 documented species of class Bivalvia in Malaysian waters from various sources (Wong & Arshad 2011), while the Gulf of Thailand and Vietnam have 594 and 814 bivalve species respectively. In the Tubbataha Reefs Natural Park (TRNP), Palawan, Philippines, there were recorded 17 species of bivalves in seven families (Dolorosa et al 2015). In Indonesia, as many as 37 bivalves species are known to inhabit the Jakarta Bay (van der Meij et al 2009), while the seagrass ecosystem of Labakkang coastal water, Pangkep, South Sulawesi has 21 bivalves species (Hamsiah et al 2016). However, little information on East Java marine bivalve mollusks is available.

In ecological studies, abundance, species composition, and species distribution are among the basic elements to analyze the structure of biological communities, which may change over time in response to disturbances (Veras et al 2013). In marine environments, bivalves seem to be diversified in the intertidal zone, where microhabitats and microclimates support a large number of epifauna species (Oigman-Pszczol et al 2004). Thus, the aims of this study were to assess the community structure of bivalves of intertidal zone of Gili Ketapang Island, Probolinggo, East Java, and to analyze the environment parameters that might influence their biological communities.

Material and Method

Description of the study sites. Gili Ketapang is a small island located on Madura Strait about 8 km north of the coast of Probolinggo (Figure 1). The island is influenced by anthropogenic activities as it is a highly populated island with more than 8,000 residents within only 68 ha areas (Juniarta et al 2013). The intertidal zone of the island is characterized predominantly by sand with minor gravel. According to the Köppen-Geiger climate classification, Gili Ketapang Island has tropical savanna climate, with a temperature average of 26.7°C, and the rainy season is from November to May, with average rainfall of 1197 mm (Merkel 2012). The station coordinates and its characteristics are presented in Table 1.

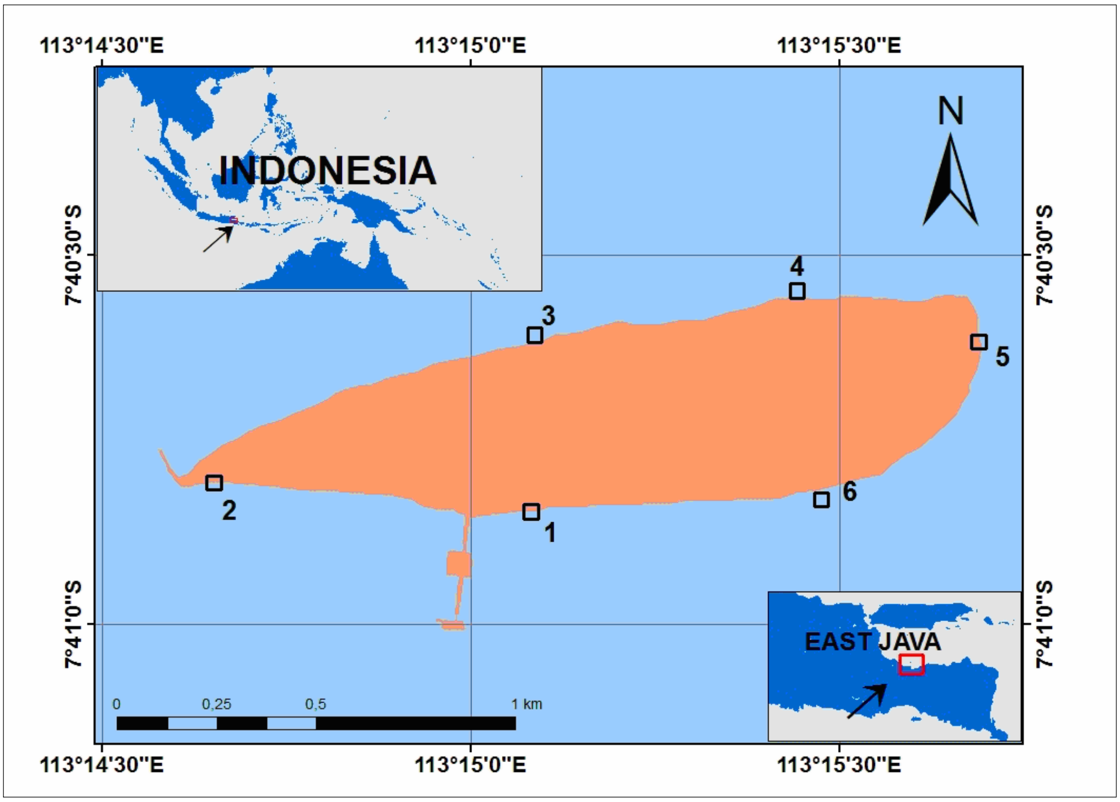

Figure 1. Study area and sampling sites in the intertidal areas of Gili Ketapang Island, East Java, Indonesia.

Table 1

Coordinates and characteristics of study sites

Station	*Coordinate*	*Characteristics*
1	7°40'51.96"S, 113°15'9.42"E	Close to harbor for medium-size fishing vessels
2	7°40'50.29"S, 113°14'40.77"E	Far from both harbors and houses
3	7°40'36.71"S, 113°15'9.37"E	Close to the densely populated area of the island
4	7°40'33.84"S, 113°15'25.50"E	Close to harbor for small-size fishing vessels
5	7°40'39.12"S, 113°15'42.06"E	Close to the densely populated area of the island
6	7°40'49.98"S 113°15'29.88"E	Close to landfill site

Sampling procedure and laboratory. Sampling occurred in May 2016 during the late rainy season and periods of low tide. Three transects were established seawards perpendicular to the coastal line in the intertidal zone of each station. In each 15-m long transect, five 1x1 m plots were laid with plot and transect intervals of 2 m and 25 m respectively, totaling 15 plots per station. Bivalves from the surface to 20 cm below the substrate within the plot were counted; only living organisms were considered. Some bivalves were identified in the field, and others were preserved in 4% formalin for further identification in laboratory; the identification followed Lamprell & Healy (1998), Dharma et a (2005), and Huber (2015).

Furthermore, approximately one kilogram of sediment sample was taken from each station. The samples were then dried using a Memmert drying oven at 60^{o}C for 4 days for further particle size analysis using a sieve shaker in the laboratory of Department of Soil Science, University of Brawijaya (Asadi et al 2017). After the shaking was complete, the material on each sieve was weighed and calculated using Microsoft Excel. The percentages of sediment were then grouped using the Shepard Sediment Classification Diagram. Moreover, dissolved oxygen (DO), salinity, pH, temperature, and turbidity were measured in situ to support oceanographic parameters; meanwhile, total organic matter (TOM) were measured in the laboratory of PT. Jasa Tirta Malang and Department of Chemistry, University of Brawijaya respectively.

Data analysis. The bivalve abundance was expressed as the number of individuals per species per square meter. The Shannon-Wiener index was used to compute the bivalve diversity index (H') and the evenness index (E). Meanwhile, dominance was determined using Simpson's dominance index (C). Moreover, the relationship between the bivalve community structure and its environmental parameters was performed using Pearson Correlation processed with GraphPad Prism 7 software.

Results and Discussion

Water quality parameters and sediment characteristics. Various environmental parameters such as DO, TOM, pH, temperature, salinity and substrate govern the abundance and diversity of benthic molluscs (Satheeshkumar & Khan 2012). The level of DO (5.5±0.1 - 6.4±0.1 mg L^{-1}) in all stations was suitable for the respiration of benthic organisms. Those organisms are unable to move to avoid the hypoxic area (DO<2 mgL^{-1}) which is a significant stressor in many benthic ecosystems (Long et al 2008).

The average of surface water temperatures in the study areas was 32.9±0.1^{o}C. In the tropical zones, temperature fluctuations are less pronounced. This could stabilize tropical intertidal benthic communities throughout the year, even in areas with distinct dry and rainy seasons (Ahmedou Salem et al 2014).

The turbidity and salinity varied from 0.56±0.05 to 1.25±0.05 NTU and 32.3±0.1 to 34.2±0.1 ‰ respectively. Suspension-feeding bivalves can tolerate a range of salinity and turbid water. They help buffer shallow waters of coastal oceans and estuaries against excessive turbidity and phytoplankton concentrations in the water column (National Research Council 2010; Satheeshkumar & Khan 2012).

The average pH of the intertidal area of Gili Ketapang Island was lower than the average ocean pH that is slightly basic, averaging about 8.1 (Orr et al 2005). The research was conducted in the rainy season that may decrease the pH and salinity level. However, the pH level in the research stations was still in range of optimum pH for the survival of bivalves (Hamsiah et al 2016).

Furthermore, based on particle size analysis, the substrate of intertidal area of Gili Ketapang Island was dominated by sand (< 98%) with a low percentage of gravel and mud in some stations (0.11-2.1%). Sand sediments, high levels of TOM and phosphate were found to be favorable to bivalves in the intertidal areas (Huber 2015). The physico-chemical parameters of water and sediment characteristics are presented as mean and standard deviation (Table 2).

Table 2
Physico-chemical parameters of water and sediment characteristics of each station

Parameters	Station					
	1	*2*	*3*	*4*	*5*	*6*
Water qualities						
pH	7.31±0.01	7.75±0.00	7.50±0.01	7.49±0.01	7.50±0.00	7.36±0.01
DO (mg L^{-1})	5.5±0.1	6.5±0.1	5.8±0.2	6.2±0.1	5.9±0.1	5.5±0.1
TOM (mg L^{-1})	27.2±0.2	15.4±0.2	26.4±0.1	18.5±0.1	24.1±0.2	27.8±0.3
Temperature (^{o}C)	32.3±0.1	33.3±0.1	33.0±0.0	33.3±0.1	33.0±0.0	32.3±0.1
Salinity (‰)	33.3±0.1	33.8±0.2	34.2±0.1	32.3±0.1	33.3±0.1	33.3±0.1
Turbidity (NTU)	0.85±0.07	0.56±0.05	0.75±0.08	0.61±0.10	0.93±0.06	1.25±0.05
Substrates						
Gravel (%)	2.1	0	0.49	0.11	1.24	0.76
Sand (%)	96.7	100	99.5	99.76	98.75	99.23
Mud (%)	1.2	0	0	0.11	0	0

Species composition and abundance. Bivalvia class associated with the intertidal zone of Gili Ketapang Island was composed of 5 families, 8 genera and 10 species. The species richness was lower than that found on the Rocky Intertidal Zone of Marine Priority Region 32, Mexico, and the intertidal and subtidal zones of the São Sebastião Channel, Brazil, 32 and 52 species respectively. The study in both locations encompassed wider and longer lengths area than that of Gili Ketapang Island. Therefore, they had higher species richness as these sites had more variety in type and stability of substrate, as well as wave exposure (Tallarico et al 2014; Torreblanca-Ramírez et al 2012), which in turn promoted different niches for the maintenance of species diversity (Levine & HilleRisLambers 2009). This is also supported by the study of bivalve distribution in Bahía de Mazatlán, México that recorded the species increase from the upper (44 species) and lower intertidal (53 species) to the shallow subtidal (76 species) (Esqueda-González et al 2014).

Although the Indonesia archipelago is estimated to harbor over at least 1000 species of bivalves, little information on bivalve species diversity of Indonesia is available (Nontji 1993). Moreover, the researches have been focused on intertidal and mangrove areas as they are much easier to cover than those in lower intertidal and deeper shallow subtidal where the species diversity is higher (Esqueda-González et al 2014). For example, Dewiyanti & Sofyatuddin (2012) recorded bivalves in mangrove ecosystem rehabilitation areas of Aceh Besar and Banda Aceh district, Hamsiah et al (2016) covered the shallow seagrass beds of Pangkep regency, Ambarwati & Trijoko (2015) recorded mactrid bivalves of Sidoarjo coast, and van der Meij et al (2009) covered the Jakarta Bay molluscan fauna.

In this research, the species richness was higher than that found in mangrove ecosystem rehabilitation areas of Aceh Besar and Banda Aceh district, Indonesia that recorded only 5 species of bivalves (Dewiyanti & Sofyatuddin 2012). Mangroves habitats are commonly located in the upper intertidal zone that might limit filtering processes of bivalves, as the water is only available regularly with high tide; thus, only bivalves adapted to an environment of harsh extremes could occupy the area (Vannucci 2001). The high temperature and low oxygen of mangrove soil make bivalves difficult to adapt, thus resulting only a few species of bivalves presented in the area (Tomascik et al 1998). Meanwhile, the seagrass beds of Pangkep regency harbored 14 species of bivalves during rainy season. The seagrass ecosystem is constantly submerged thus providing a better habitat to bivalves than that of intertidal area where the area is exposed during low tide (Hamsiah et al 2016).

Furthermore, the Veneridae family was the best represented in species richness, representing 2 genera and 4 species. The Veneridae or Venus clams are the largest recent marine families with about 765 species (Huber 2015; Lamprell & Healy 1998). The substrate of intertidal zone of Gili Ketapang was dominated by sand (< 98%), and Veneridae is an infauna group of bivalves that lives predominantly in sandy bottoms

(Wilson 2013). One of the Veneridae species found in the research station was *Periglypta puerpera*. The species is common throughout the tropical Indo-Pacific Ocean. However, there were few studies available on this species in Indonesia. A research study by Zoological Museum Amsterdam and National Museum of Natural History Naturalis, The Netherlands, reported that *P. puerpera* was no longer found in Jakarta Bay after 1937/38 and only found as beach material in Kepulauan Seribu. The increased environmental stress has impacted the coral reefs in the areas, declining species richness, and changing the species composition of bivalves (van der Meij et al 2009). Meanwhile, the only Psammobidae family found in the research station was *Asaphis violascens*. These are burrowing suspension feeders, with well-developed siphons and an easily breakable shell. It is common in sand in the intertidal zone (0-30 m) of Moluccas, Australia, The Philippines, Indo-Pacific and South China Sea (Bernard et al 1993).

Based on the research station, the lowest species richness was found on stations 3 and 5 with 2 species in each station. The stations were close to the densely populated area of the island that might elevate the anthropogenic threats, which shaped the biodiversity of bivalves (Coll et al 2010). Meanwhile, station 1 had not only the highest species richness (7 species) but also the highest species density (4.95 ind m^{-2}) among other stations. In the station, mud was also prevalent as substrate thus providing more niches to the bivalves, which in turn supported higher number of species (Esqueda-González et al 2014). Meanwhile*, Gafrarium tumidum* represented 24% of individual bivalves found in 5 of 6 research stations, with the highest density in station 1 (1 ind m^{-2}). *G. tumidum* has a size range from 10 to 40 mm commonly found in sandy intertidal areas with width distribution from Indo-West Pacific to Japan and New Caledonia. The clam is edible and exploited as food sources by local communities in some developing countries (Huber 2015; Islami 2013; Jagadis & Rajagopal 2007). The averages of species composition and abundance of bivalves in each station and the density percentage of bivalves are presented in Table 3 and Figure 2 respectively.

Table 3

Averages of Bivalves abundance and richness in study areas (ind m^{-2})

Families/species	*Station*					
	1	*2*	*3*	*4*	*5*	*6*
Cardiidae						
Acrosterigma impolitum (Sowerby, 1833)	1.5	0.33	0	0	0	1.33
Fragum unedo (Linnaeus, 1758)	0.33	0.33	0	0	0	0
Psammobiidae						
Asaphis violascens (Forsskål in Niebuhr, 1775)	0.4	0	0	0	0	0
Tellinidae						
Jitlada juvenilis (Hanley 1844)	0	0.26	0	0	0	0
Tellinimactra edentula (Spengler, 1798)	0.46	0	0	0	1.2	0.33
Thyasiridae						
Philis cumingi (Fischer, 1861)	0	0	0.26	0	0	0
Veneridae						
Gafrarium aequivocum (Holten, 1802)	0	0.26	0	0.6	0.4	0
Gafrarium pectinatum (Linnaeus, 1758)	0.46	0	0	0	0	0
Gafrarium tumidum (Röding, 1798)	1	0.46	0.6	0.6	0	0.8
Periglypta puerpera (Linnaeus, 1771)	0.8	0.86	0	0.86	0	0
Total of average abundance	4.95	2.5	0.86	2.06	1.6	2.46
Species richness	7	6	2	3	2	3

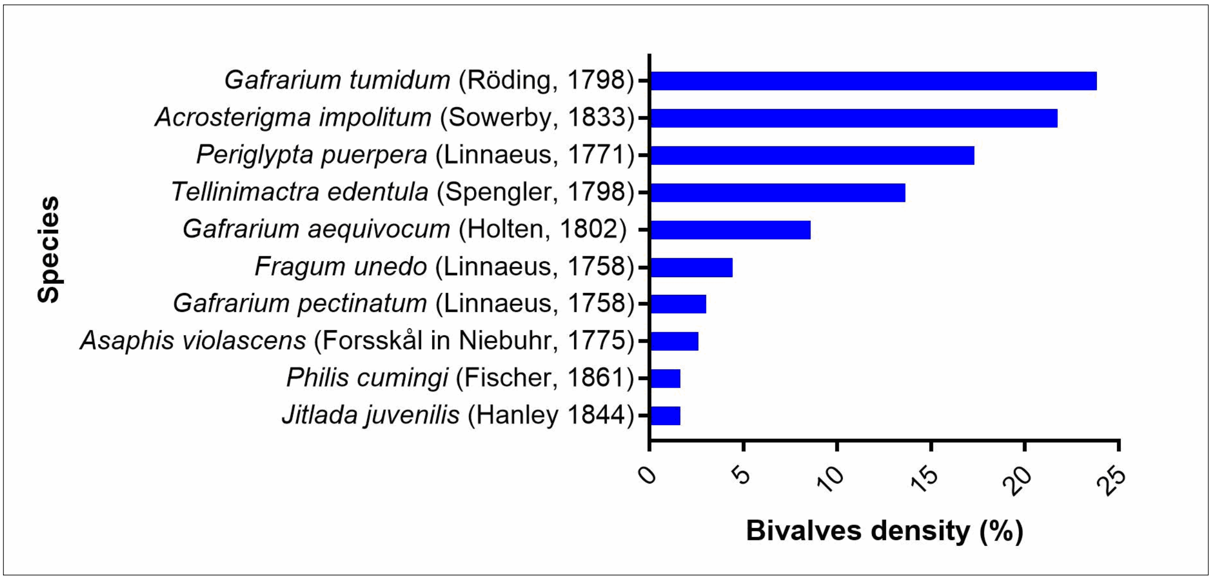

Figure 2. Percentage of bivalves density.

Ecological indices. Shannon's diversity index (H') and Pielou's evenness index (J') clearly give more information about these bivalve communities than solely the number of bivalve species would. The higher number of species found in the research area results the higher diversity index, and the evenness index measures how equal the community is numerically, with zero signifying no even and one, a complete even. On the other hand, the Simpson dominance index gives more weight to dominant species. In this case, a species with a few representatives will not significantly affect the dominance index (Karydis & Tsirtsis 1996).

The average of the diversity index of bivalves of intertidal area of Gili Ketapang was 1.12, in which stations 1 and 2 had the highest diversity index (1.8 and 1.68 respectively) due to higher species richness than that of other stations. Station 1 had substrate of not only sand, but also a considerable amount of mud and gravel thus providing more alternative niches for bivalve to settle; meanwhile, station 2 was less influenced by anthropogenic threat as it was far from the dense settlements of the island, which in turn kept the bivalve diversity in the area (van der Meij et al 2009). However, those values were lower than that found in the seagrass area of Pangkep (1.83 – 2.23). Seagrass areas provide better habitat and more niche to bivalves which in turn result in a higher diversity index than that of intertidal areas that have more harsh environments (Tomascik et al 1998; Vannucci 2001; Hamsiah et al 2016).

Even though the diversity index values of bivalve in the research area were moderate, the evenness index values were high ranged from 0.81 to 0.99 with an average of 0.90. The high values indicate the relatively equal numbers of individual bivalves belonging to each species (Morris et al 2014). It can be interpreted that the bivalve communities possess ecological stability, which a healthy ecosystem is a relatively stable state or equilibrium that keeps bivalve population size within a sustainable range (Zhang et al 2012).

The dominance index ranged from 1.60 at station 5 to 5.35 at station 1 with an average of 3.13. The values were categorized as moderate in which the dominance index values between 2.5 and 4 were interpreted as moderate level of dominance (Jørgensen et al 2005). The indices were quite similar to the Shannon's diversity index values that were also moderate meaning that the dominance and the diversity of the bivalves in the research area were moderately stable or equilibrium. Shannon's diversity index (*H'*), the Pielou's evenness index (*J'*), and the Simpson dominance index (D) of each station are presented in Table 4.

Table 4

The ecological indices of each station

Ecological indices	Station					
	1	*2*	*3*	*4*	*5*	*6*
Diversity index (*H'*)	1.80	1.68	0.61	1.08	0.56	0.97
Evenness Index (*J'*)	0.93	0.94	0.88	0.99	0.81	0.88
Dominance index (D)	5.35	4.79	1.73	2.91	1.60	2.40

Species diversity indices and environmental parameters correlation. The correlations of species diversity indices and environmental parameters are presented in Table 5. The Shannon's diversity index (H') and the Dominance index (D) were very highly correlated with species richness (r = 0.98 and r = 0.99). The Dominance index was also very highly correlated with the diversity index (r = 0.99), which might be due to the fact that the values of both indices had a same category (Table 4). The calculations of both indices were also based on the species richness. Meanwhile, the Evenness Index (*J'*) had a low correlation with species abundance (r = 0.35) as the community was quite evenly distributed, and the index is a biodiversity measurement which quantifies how equal the community is numerically (Karydis & Tsirtsis 1996; Jørgensen et al 2005; Morris et al 2014).

The DO was very highly correlated with pH (r = 0.94), meaning that the higher pH could result the higher DO. The acidic or low pH environment potentially induces dissolution of calcium carbonate that can drop DO to physiologically stressful levels. Meanwhile, the TOM was significantly correlated with the amount of DO (R^2 = 0.94), which higher TOM leads to lower DO as oxygen is removed from the water by respiration and decomposition of organic matter (Mnaya et al 2006).

Furthermore, the distribution patterns of grain size in all research stations were dominated by sand (< 98%). The presence of mud in the substrates added available niches, which in turn increased the species abundance and richness as mud was highly correlated with species abundance and richness (r = 0.9 and r = 0.72 respectively). This is supported by the fact that the majority of bivalves adopt a sedentary lifestyle, with many burying in soft substrate like mud (Huber 2015). Moreover, finer sediment could hold higher organic content (Asadi et al 2017), and the vast majority of bivalves are certainly a detritivore (consumer of organic materials) in addition to feeding on bacteria and algae (Gosling 2008).

Conclusions. The intertidal zone of Gili Ketapang, East Java, Indonesia harbored 10 species of bivalves from 8 genera and 5 families. The highest abundance was in station 1 (4.95 ind m^{-2}), while the lowest was in station 3 (0.86 ind m^{-2}). *G. tumidum* was the most spread-out species found in 5 out of 6 research stations that represented 24% of individual bivalves. On average, Shannon's diversity index (*H'*) and Simpson dominance index (D) were moderate with the values of 1.12 and 3.13 respectively in which both indices were very highly correlated with species richness (r = 0.98 and r = 0.99). Meanwhile, the Evenness Index (*J'*) was categorized as high with the average value of 0.90. All of the environmental parameters were still in the range of the tolerant level for bivalves to sustain.

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Table 5

Pearson Correlation of species diversity indices and environmental parameters

	Abu.	*Ric.*	*Div.*	*Eve.*	*Dom.*	*pH*	*DO*	*TOM*	*Tem.*	*Sal.*	*Tur.*	*Gra.*	*Sand*	*Mud*
Abundance	1.00													
Richness	0.86	1.00												
Diversity	0.83	0.98	1.00											
Evenness	0.35	0.49	0.63	1.00										
Dominance	0.84	0.99	0.99	0.60	1.00									
pH	-0.44	0.04	0.08	0.14	0.08	1.00								
DO	-0.34	0.07	0.16	0.40	0.15	0.92	1.00							
TOM	0.16	-0.21	-0.32	-0.54	-0.30	-0.84	-0.97	1.00						
Temperature	-0.59	-0.25	-0.18	0.25	-0.17	0.83	0.92	-0.83	1.00					
Salinity	-0.23	0.04	-0.08	-0.45	-0.04	0.29	-0.07	0.22	-0.07	1.00				
Turbidity	0.10	-0.27	-0.32	-0.59	-0.35	-0.67	-0.80	0.78	-0.80	0.02	1.00			
Gravel	0.66	0.33	0.18	-0.36	0.24	-0.72	-0.75	0.69	-0.74	0.01	0.45	1.00		
Sand	-0.79	-0.50	-0.38	0.13	-0.43	0.70	0.68	-0.59	0.71	0.05	-0.30	-0.97	1.00	
Mud	0.90	0.72	0.64	0.26	0.69	-0.57	-0.47	0.34	-0.57	-0.13	0.01	0.79	-0.92	1.00

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Authors:
Muhammad Arif Asadi, Marine Science Department, Brawijaya University, Jl. Veteran no. 16, Malang 65144, Indonesia, e-mail: asadi@ub.ac.id
Feni Iranawati, Marine Science Department, Brawijaya University, Jl. Veteran no. 16, Malang 65144, Indonesia, e-mail: dzimi2012@gmail.com
Ajeng Widi Andini, Marine Science Department, Brawijaya University, Jl. Veteran no. 16, Malang 65144, Indonesia, e-mail: ajengwidiandini@gmail.com

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