Sedimentation rate implications to water quality and macrozoobenthos community structure in Ciletuh Bay, Sukabumi Regency, West Java, Indonesia

[1]Asia Salsabilla, [2,3]Yuniarti. MS, [2]Yudi N. Ihsan, [2]Mega L. Syamsudin, [2]Lintang P. Yuliadi

[1] Marine Science Study Programme, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung, Jatinangor, West Java, Indonesia; [2] Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung, Jatinangor, West Java, Indonesia; [3] Centre of Conservation Study & Maritime Region Management, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Bandung, Jatinangor, West Java, Indonesia. Corresponding author: A. Salsabilla, asiasalsabilla16@gmail.com

Abstract. Ciletuh Bay is a horseshoe-shaped coastal area with complex geological phenomena. It is part of the UNESCO Global Geopark. Intense human activities in this area contribute to the distribution of domestic waste through rivers that flow into its sea, affecting water quality and sedimentation rate. High sedimentation can cause a decrease in water quality, low diversity of organisms and increase the level of coastal land, which is detrimental for fishermen. This study aims to analyze the rate of sedimentation and see the implications of sedimentation to water quality in this area by observing its macrozoobenthos community structure. This research was conducted in Ciletuh Bay, Sukabumi, West Java. The method used is a survey method with purposive random sampling in five research stations. The results showed four categories of macrozoobenthos, namely *Engina zonalis*, *Trichoptera* larvae*, Conus* sp. and *Donax* sp. The community structure index was abundant, no category was dominant, and uniformity was low. The sedimentation rate in Ciletuh Bay is very high, with an average of 2.421,5 g/cm^2/day and the sediment type that dominated these waters was silt. The structure of macrozoobenthos in these waters is disrupted due to the deteriorating quality because of high sedimentation with silt.
Key Words: environment management, estuary, granulometry analysis, water transparency.

Introduction. A bay is an open beach where various kinds of organisms live; it is an area influenced by two different regional factors, the ocean and land. Administratively, Ciletuh and surrounding areas, including the Sukabumi Regency, West Java Province, is located in the Southern Mountain Zone, according to physiographic classification by Van Bemmelen (1949). Ciletuh Bay itself is an area famous for the beauty and uniqueness of its rocks formed by sedimentary deposits called mélange. The rocks relief shows a distinct composition, morphology and overall structure, making it an exotic sedimentary deposits area. Thus, the Ciletuh-Palabuhanratu area was included in the UNESCO Global Geopark network (CNN Indonesia 2018). However, human activity in the Ciletuh Bay also increased, making the disposal of domestic and fishermen waste a higher environmental problem faced by the area (Environmental Agency of Indonesia 2016).

Siltation is a problem often found at river mouth areas, especially in small bays, due to high sedimentation rates. In coastal engineering, sedimentation is a condition where the coastal sediments move or are transported from one place to another. The transport of coastal sediment will determine the occurrence of sedimentation or erosion in the coastal area. If this process occurs continuously without any measures, the surrounding estuary will gradually get covered by sediment, resulting in an obstruction of the river flow and raise of the water level upstream of the estuary, being detrimental to fishermen (Vironita et al 2012). Even when viewing Ciletuh Bay from Google Earth alone

(Figure 1), it can be seen that the sedimentation issue is clear on its coasts. Utilization of Ciletuh Bay as a tourist area is suspected to increase the sedimentation rate. A high sedimentation rate means a higher chance of erosion or deposition affecting the water body and reducing community structure of organisms living in its water.

Figure 1. Ciletuh Bay (source: Google Earth Pro).

The quality of water can be measured by studying the structure of the macrozoobenthos community that inhabits the area. Macrozoobenthos are aquatic organisms that live at the bottom of the water with relatively slow movements, strongly influenced by the substrate base and water quality. Macrozoobenthos can be used as an indicator in aquatic biology studies in Ciletuh Bay because it is always exposed to seawater and river estuaries. Macrozoobenthos is relatively sedentary with a relatively long life cycle, abundance and diversity, and has the ability to respond to changes in water conditions (Suhanda et al 2019). Therefore, macrozoobenthos can be used to describe water quality through its community structure (Mason 1981). The decrease of the composition and diversity of macrozoobenthos is usually an indicator of ecological disturbance that occurs in the water (Setiawan 2008).

This research aims to analyze the rate of sedimentation and study the implications of the sedimentation rate to water quality by obrserving the structure of the macrozoobenthos community in Ciletuh Bay. Lack of information regarding the implications of the sedimentation rate on the structure of the macrozoobenthos community in the waters of Ciletuh Bay is one of the obstacles in environmental management in this area. Therefore, a study is needed to determine the structure of the macrozoobenthos community, sedimentation rate, and its implications to water qualities in Ciletuh Bay, Sukabumi, West Java.

Material and Method

Description of the study sites. This study was conducted at Ciletuh Bay, Indonesia. Ciletuh Bay (also known as "Zand-baai" or "Pasir Bay" during the Dutch East Indies) is a bay in Palabuhanratu Regency, West Java province. It is located south of Teluk Pelabuhan Ratu, precisely at coordinates 7°11’0” SL and 106°27’0” EL. The name Ciletuh is taken from the name of a large river that flows into the Gulf of Ciletuh, which means "turbid water". The name of the area which is now the first geopark proposed area in West Java describes the natural condition, especially the land and water system. This place presents an easily erodable soil, which causes runoff in muddy rivers, especially when it rains. The turbid water also indicates mining activities in the upstream area, with sediments brought by the rivers to the ocean (Rosana et al 2006). Ciletuh Bay is surrounded by rock cliffs that form a horseshoe with the highest peak of 360 m, on a

stretch 12 km long and 7 km wide. Along the fault, there are 8 waterfalls that empty into four rivers, supplying the substrate bottom waters of the Gulf of Ciletuh with nutrients carried through the sedimentation process (BioFarma 2013). Ciletuh Bay is an area of water strongly influenced by river flows and coastal activities, by both humans and natural processes. Ciletuh and Cimarinjung rivers are the biggest nutrient-supplying rivers and sources of coastal sedimentation by river discharge in Ciletuh Bay (Rosana et al 2006).

5 stations expected to describe Ciletuh Bay water characteristics as a whole were selected in this study. Each station had particular physical differences and surrounding activities that can affect it. Kunti Island, a deserted island, was chosen as the first research station (Station 1) to describe a place with low to none human activity. It also has a coral ecosystem. Station 2 is located on a shrimp farming area to describe water quality affected by aquaculture activities. Station 3 was placed in Mandra Island, an island used as a fishermen port area, highly affected by fishermen activity. Lastly, Stations 4 and 5 are placed in the estuaries of two different rivers, Ciwaru and Cimarinjung to describe the quality of water affected by upper land activities. These different traits of each location were determined as average values that describe Ciletuh Bay's water quality condition. The research location and stations are presented in Figure 2.

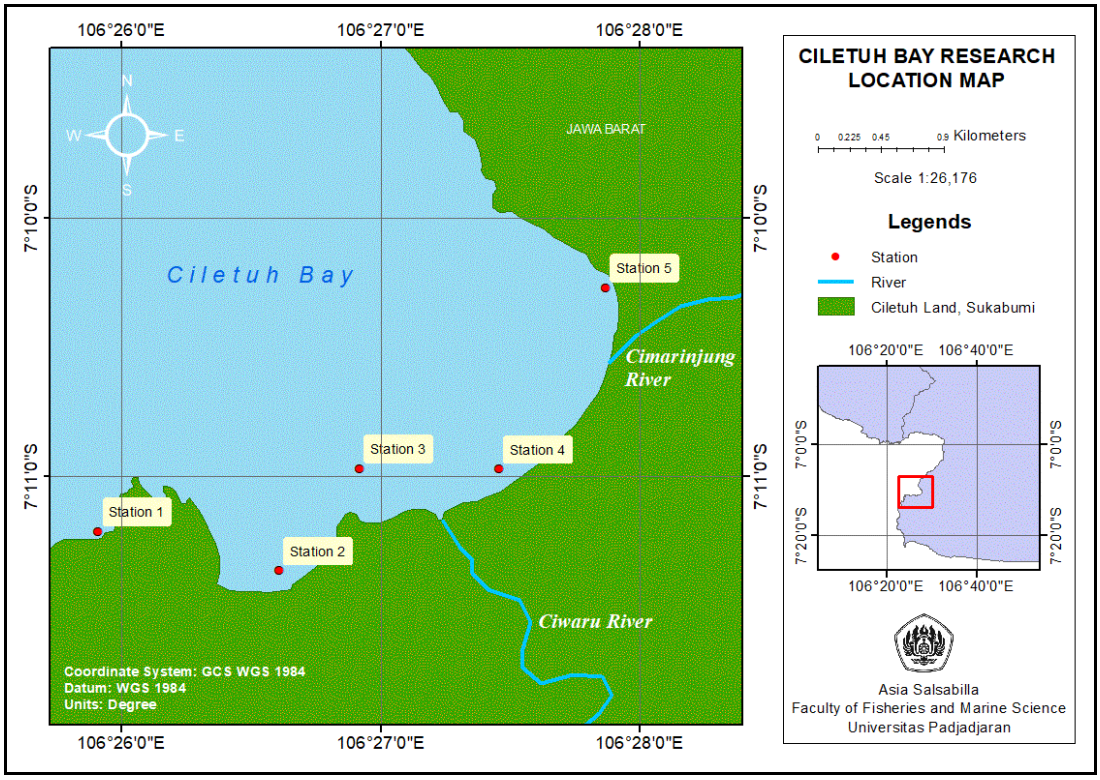

Figure 2. Research location map of Ciletuh Bay, Indonesia.

The study was conducted from April to June 2019 to determine the rate of sedimentation temporarily with repetitions at every 14 days. Sample analysis was carried out at the Hydro Oceanography Laboratory, Padjadjaran University, where sediment transport data was processed and in the Marine Conservation Laboratory, Padjadjaran University, where macrozoobenthos community structure was analyzed.

The location coordinates were determined using GPS (Global Positioning System). The purposive sampling method is a point sampling method considered to have represented the condition of the waters at the study site (Hadi 1979). Each station has one plot where sediment traps were planted on the water bed. The tool was adjusted to capture sediments that move from the four cardinal directions, and one pipe was in the

middle to capture sediments moving through the top of the four cardinal directions. Thus, a total of five inputs were used. Table 1 describes the characteristics of sediment sampling stations and their coordinates.

Table 1

Coordinates and characteristics of each station

Stations	*Station characteristics*	*Coordinates*	
		Latitude	*Longitude*
St. 1	Kunti Island (abandoned island, has coral reef ecosystem)	-7.186861°	106.431861°
St. 2	Shrimp farming (water near shrimp aquaculture activities)	-7.189389°	106.443500°
St. 3	Mandra Island (fishermen port area, highly affected by fishermen activities)	-7.182806°	106.448667°
St. 4	Ciwaru River estuary (affected by sediment originated from the mainland)	-7.182845°	106.457651°
St. 5	Cimarinjung River estuary (affected by sediment originated from the mainland)	-7.171157°	106.464503°

Sampling and analysis methods. Values of physicochemical parameter of water (temperature, salinity, transparency, pH, current speed and dissolved oxygen) were directly measured *in situ* by a thermometer, refractometer, pH meter and DO meter. 3 measurements were conducted at each site. Current speed and water transparency were measured using float tracking and Secchi disks, respectively.

Macrozoobenthos and sediment samples were collected using the Ekman grab at each station. Analysis of the community structure of the macrozoobenthos in the waters of Ciletuh Bay was conducted on samples of the macrozoobenthos living on the surface of sediments (ocean bed) in all five stations. Macrozoobenthos species were identified by after Dharma (2005) and analyzed to determine its community structure using 3 biodiversity indices, namely diversity, evenness, and dominance index (Odum 1993).

Ludwig & Reynolds (1988) classified the diversity value into 3 categories; low, moderate, and high. If the species diversity is less than 1 (H'<1) then species diversity is low; if the value of species diversity is between 1 to 2 (1<H'<2); then the species diversity is classified as moderate; and if the value of species diversity is above 2 (H'>2), the species diversity is classified as high.

The evenness index was obtained after calculation using the formula of Hill (1973). If the index value of evenness is close to 0, it means that uniformity among species in the community is low, which reflects the abundance of each species have a big difference in numbers and vice versa (Basmi 2000).

According to Odum (1993), the dominance index value ranges between 0-1. A closer dominance index value to 0 shows a very small to no impact of the species in the water. On the contrary, if the values is closer to 1, it shows that there is a dominating species habituating the area. The difference in the number of each species is high producing a low dominance index and a high uniformity. The calculated indices are presented in Table 2.

Table 2

Formula of diversity, evenness and dominance indexes

The changes range	*Formula*	*Component*	*Index*
0-1	$H' \equiv -\sum_{i=1}^{s} p_i Ln\, p_i$	Shannon-Wiener (Ludwig & Reynolds 1988)	Diversity
0-1	$D_{max} = 1/s$	(Odum 1993)	Evenness
0-1	$C = \sum (ni/N)^2$	Simpson (Odum 1993)	Dominance

The types of sediment were analyzed using a granulometry analysis by sorting 100 g of sediments with a sieve shaker to differentiate them based on grain size. Weight of sediments with different diameters were then processed using the KUMMOD-SEL software to determine the type of sediment according to species distribution (Shepard 1954). The sedimentation rate was measured with a sediment trap (Figure 3), a tool plugged into each station and left for approximately 14 days.

Figure 3. Sediment trap tool.

Sedimentation rate analysis was conducted by weighing the sediment caught by the sediment trap from the five directions of the PVC pipe. The data obtained were processed according to APHA (1975):

$SR = 10000/(\text{number of days} \times \pi r^2) \times (A-B)$

Where: SR - sedimentation rate ($g/cm^2/day$); A - weight of weighing base + dry sediment; B - weight of the initial weight base; π - 3.14; r^2 - sedimentary circle radius $trap^2$ (cm).

Total sediment weight is the total weight of sediment from 5 PVC pipes of each station and mean sediment weight is the total weight of sediment from 5 PVC pipes divided by 5. Mean sediment weight from each station was divided by diameters of the mouth of PVC pipe; the result was then divided by the number of days the sediment trap was left inside the water column (11 days).

Results and Discussion

Water quality. Water quality data obtained on 24 May 2019 shows that Ciletuh Bay has a water salinity value from 14 to 20‰, water temperature values from 26 to 30.5°C, water pH values of 8 to 8.1, dissolved oxygen from 5.6 mg L^{-1} to 8.5 mg L^{-1}. The visibility ranged from 0.25 m to 0.4 m and current speed ranged from 2.48 m s^{-1} to 5 m s^{-1} (Table 3).

Table 3
Water quality parameters comparison to seawater quality standard by the Ministry of Environment (2004)

Parameter	*Seawater quality standards*		*Station*					*Mean*
	Tourism	*Biotic*	*1*	*2*	*3*	*4*	*5*	
Salinity (‰)	-	33-34	19	16	4	20	18.3	17.46
DO (mg L^{-1})	>5	>5	8.5	8.3	5.6	5.6	8.15	7.23
pH	7-8.5	7-8.5	8.1	8	8	8	8.1	8.04
Temperature (°C)	-	28-30	26	30	28	27	30.5	28.3
Visibility (m)	>6	>5	0.3	0.25	0.35	0.4	0.35	0.33
Visibility (% of total depth)	-	-	21.4	27.8	17.5	13.3	7	-
Current (m s^{-1})	0.2-1.5	0.2-1.5	4.3	5	4	3.81	2.48	3.918
Depth (m)	-	-	1.4	0.9	2	3	5	-

Based on Table 3, it can be seen that the average salinity and visibility values in Ciletuh Bay water are below the standards for both tourism and biotic purposes. Nybakken (1992) stated that salinity in the estuary area ranged from 5 to 30‰, which varies due to the presence of the fresh water entering from rivers, affecting the adaptation pattern and density of benthos. Fluctuations in salinity in the intertidal area are caused by heavy rain that reduces water salinity to a very low level. When it does not rain, the heat in tropical countries causes intense evaporation. Organisms that live in intertidal regions usually have adapted to changes in salinity up to 15‰. Therefore, the salinity in Ciletuh Bay water is low, and according to the water quality standard for biotic ecosystems, it is insufficient for coral reefs.

The average value of visibility in Ciletuh Bay waters was 33 cm. All stations neither exceed nor hit the 100 cm mark as a minimum value. The highest visibility came from station 2 with 27.8% visibility, while the lowest visibility came from station 5, 7% visibility. This result was caused by the influence of the flow of the river, which carries sediment particles that decrease the brightness and visibility of water. In addition, the visibility can also be reduced by the agitating river flow, the influence of tides and currents. Current motion can disseminate suspended solids. River mouth areas have an active current movement, and suspended solids such as sediments continue to spread and affect the water body (Vironita et al 2012). Akromi & Subroto (2002) state that visibility below 1 m is classified as low. Water visibility is largely determined by the number of dissolved particles mixed in the water column. Turbid water, which essentially has a high concentration of suspended material, will reduce feeding efficiency of some organisms (Sembiring 2019).

Water current is influenced by tides, winds, water density and the water input from river mouths. The water current rom the south coast of Java moves eastward from February to June and westward from July to January. In February, the coastal current reached 0.75 m s^{-1} and then weakened to a speed of 0.5 m s^{-1} from April to June. In August, the coast current changed westward at a speed of 0.75 m s^{-1} and then decreased to a speed of 0.5 m s^{-1} until October (Decree of the Minister of Environment 2003). Current velocity at the study site was relatively fast. According to the results presented in Table 3, the highest current velocity was found in Station 1, while the lowest was recorded in Station 2. Water current is classified as fast, if the current speed is above 1 m s^{-1}, relatively fast in the range of 0.5 - 1 m s^{-1}, moderate in the range of 0.25 - 0.5 m s^{-1}, relatively slow in the range of 0.1 - 0.2 m s^{-1} and very slow if it below 0.1 m s^{-1}. Current velocity will affect the composition of the basic substrate that which further affect the life of intertidal organisms, including macrozoobenthos (Vironita et al 2012).

Sediment size, texture and types. Sediment in Ciletuh Bay water is dominated by silt. Stations 3, 4 and 5 have silt sediment, while station 1 has mainly mud type and station 2 presents a sandy mud substrate. Finer types of sediment are more difficult to be deposited compared to coarser sediments and larger grain sizes. Therefore, constant mixing of finer sediment types is bound to happen and will lessen the visibility of the

water and further reduce organism metabolism activities in breathing and producing (as in photosynthesizing). Stations 3, 4 and 5 with silt sediments are suffering for the same reason, resulted in a rapid decrease of organisms habituating these areas. The sediment types are described in Table 4.

Table 4

Sediment types by KUMMOD-SEL software

Stations	*Sediment fraction (%)*				*Sediment type*
	Gravel	*Sand*	*Silt*	*Clay*	
St. 1	5.8	32.8	61.4	0.0	Gravely mud
St. 2	0.3	24.4	75.4	0.0	Sandy mud
St. 3	0.0	0.3	99.7	0.0	Silt
St. 4	0.0	1.7	98.3	0.0	Silt
St. 5	0.0	1.0	99.0	0.0	Silt

The number of living organisms increases with the increasing amount of silt and clay in the sediment because finer type of sediment accumulates more organic matter, benefitting macrozoobenthos. However, the type of substrate is very important to the growth of organisms that live on the coast. Sand substrate makes it easy for shells to move. Finer types of sediment may benefit several intertidal organisms, especially macrozoobenthos who live in the sediment, but coral reefs and others cannot grow on it. This lack leads to an even greater mixture of sedimentation, as there are no barricades to anchor the sediment. Eventually, it leads to the reduction of visibility and dissolved oxygen, causing harm to organisms.

Sedimentation rate analysis. Sedimentation rate results are described in Figure 4. According to Suripin (2002), sedimentation rate that exceeds 340 g cm^{-2} per day is classified as very heavy (destructive to the ecosystem). Stations with high sedimentation rate exposure, which disturb the life of organisms habituating the area are Stations 1, 2 and 5, with recorded sedimentation rate values ranging from 1000-7000 g/cm^2/day. The highest sedimentation rate was obtained at Station 2 (the shrimp farming location) and the lowest sedimentation rate was obtained at Station 3 (Mandra Island). The high rate of sediment in Ciletuh Bay is influenced by sediment deposition and the mixing of fresh water and seawater, making the coastal area a flooded area with shallow water (Yuniarti et al 2019).

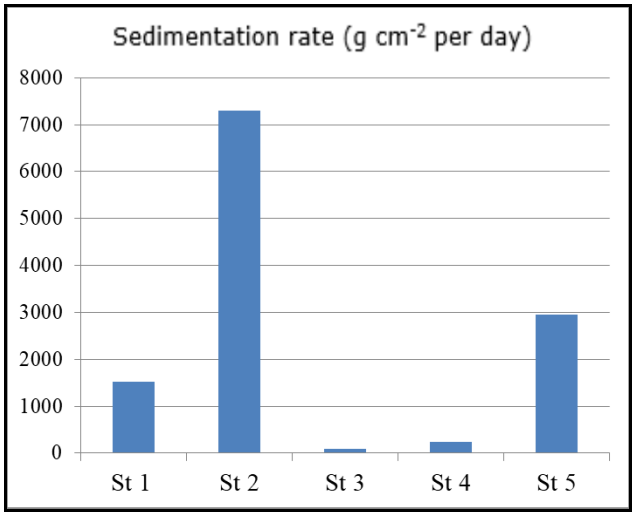

Figure 4. Sedimentation rates in the 5 research stations.

Current velocity can also affect the type and size of substrate, influencing the benthos community (Odum 1993; Yuniarti et al 2018). The high value of the sedimentation rate

at the three stations occurs due to a lower current velocity than in the other 2 stations. Thus, smaller sediment particles settled more easily in calmer waters. This is in accordance with Fernedy (2008), who explains that waters with strong currents deposit large particles, whereas waters with weak currents deposit fine silt particles. High sedimentation rate can adversely affect the substrate condition, especially with a high amount of silt sediment. This process causes high turbidity, lowering light intensity, making it difficult for biota to photosynthesize. Furthermore, the size of the sedimentation rate is also influenced by river discharge because it carries the sediment to the estuary area. Station 5 is influenced by the flow of the Cimarinjung River discharge, but the river has a very small water discharge of 0.00001 $m^3 s^{-1}$ (CNN Indonesia 2019). Therefore, the narrowing makes the water flow at the station to be relatively calm, which creates a condition where the seabed easily deposits more sediment.

Macrozoobenthos community structure. Based on sampled macrozoobenthos, the highest and the only presence of macrozoobenthos was found in Station 1. There are three *Donax* sp., two *Engina zonalis*, and one of each Trichoptera larvae and *Conus* sp., resulting a total of 7 macrozoobenthos individuals found in Ciletuh Bay water. Stations 2, 3, 4 and 5 had no living macrozoobenthos individuals found; however, there were some dead macrozoobenthos shells found during the 3 sampling repetitions with the Ekman Grab.

The sampling results shows that there were 3 taxa classes habituating the area, namely 2 gastropods, 1 bivalve and 1 insect (Figure 5). Nybakken (1992) stated that differences in the texture of the substrate cause differences in the types of organisms living on and inside the sediment. Gastropods enjoy living in mud-type sediments (classified based on the Shepard triangle method). Magfirah & Haya (2014) state that mud-type sediment is highly favored by Gastropoda because of its smooth texture which has a higher nutrient content compared to the coarse-textured substrate. Organic matter is easier to settle in fine particles and is favorable for the survival of gastropods. Ciletuh Bay water is dominated by mud-type sediment and is suitable for gastropod survival.

Bivalves are known to like mud and sand substrates. Hasibuan et al (2009) stated that bivalves live on muddy or sandy substrates. According to Sudarso (2009), most Trichoptera larvae prefer to live in shallow water (5-10 cm) with rock substrate, while a few species are found in fine substrates in deep waters. Beasley & Kneale (2004) mentioned that Trichoptera larvae are relatively tolerant to water contamination.

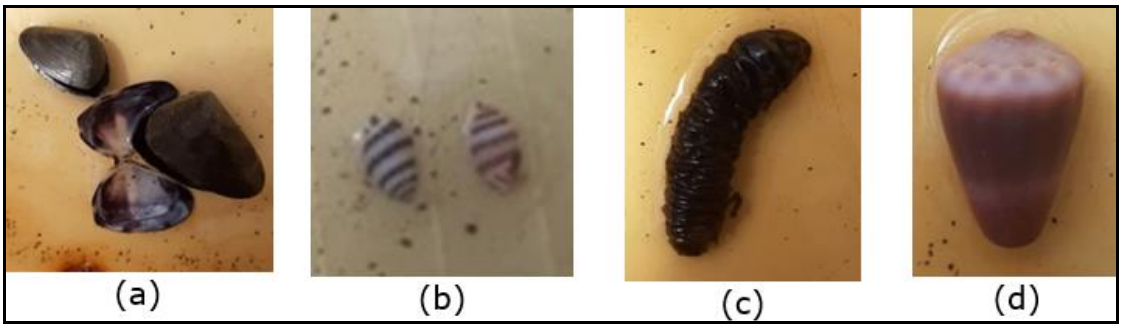

Figure 5. Result of macrozoobenthos sampling; (a) *Donax* sp.; (b) *Engina zonalis*; (c) Trichoptera larvae; (d) *Conus* sp.

Donax sp. could be found more than the other species due to its as bivalves, a passive organisms who tend to live in the same area for a long time, compared to gastropods such as *Conus* sp. and *E. zonalis*. *Donax* sp. is also known to have a good life suitability in the waters of Ciletuh Bay and has a high adaptability (Suhanda et al 2019).

The diversity index results of Station 1 is 1.277, which falls to the 'moderate' category according to Shannon-Wiener classification (Ludwig & Reynolds 1988). The evenness index values range from 0 to 1. If the value of E<0.2, the species distribution is unstable; if the evenness value ranges from 0.21 to 1, the distribution is stable (Krebs

1986). The evenness index is 0.921. This result indicates that the distribution of individuals in Station 1 is even. The dominance index results for all species are below 0.2, with the highest dominance index owned by *Donax* sp. (0.184) followed by *E. zonalis* (0.082) and the lowest dominance index value is for Trichoptera and *Conus* sp., with both having 0.021. These results indicate that there is no dominating species in the water, because the dominance value of each species is close to 0.

The result shows that 3 out of 5 research stations suffer from high sedimentation rates, affecting the quality of water in the area. Station 5 showed the clearest evidence that high sedimentation rate affects water transparency. Sedimentation rate in station 5 was 2949.3 g cm^{-2} per day and it had a visibility value of only 7%. The main sediment in Station 5 was silt; being always agitated by the current, it does not form deposits, endangering living organisms. In fact, there may be no living organism in this area anymore due to its condition; corals or seagrass cannot live in this area because of substrate type incompatibility. Although Stations 1 and 2 both have a high value of sedimentation rate, the two stations have gravely mud and sandy mud as sediment types, which are coarse types of sediment. They are more easily deposited, especially in Station 1, which has corals acting as a barrier to the movement of sediment. Therefore, the life cycle of the organisms within can be maintained.

The structure of the macrozoobenthos community is considered moderate in terms of the ecological index values obtained, but this is due to the lack of living macrozoobenthos found in the area. From the 5 research stations, only one station has surviving macrozoobenthos, while there were no living macrozoobenthos species found in any of the four remaining stations where the water is disturbed by high sedimentation rates. High sedimentation rate is also one of the common causes of poor water quality, which lowers the survival rate of macrozoobenthos. In these research stations especially, the high sedimentation rate visibility affects water quality, gradually affecting dissolved oxygen as well. Station 1 has a very high sedimentation rate, but due to the presence of corals, the water visibility in this area is maintained, as the sediment is easily deposited on the seabed. The type of sediment at Station 1 is quick to be deposited due to its big size; therefore, the life cycle of some organisms within can still be maintained. But, with a continuance of the high organic matter input washed from the mainland (from human activities and river input), the sediment types become finer, smaller in size and softer in texture, especially in Stations 3, 4 and 5.

The results show that other water quality parameter values are in the standard range, but the high sedimentation rate affecting the water and human activities in the mainland that do not seem to decrease (even seem to be increasing over time) will cause a decline of dissolved oxygen, along with water transparency.

Most macrozoobenthos species, especially those known for their endurance and survival rate in poor quality waters, appeared to be non-existent in the water of the four stations aside from Station 1. This shows that the other 4 stations are clearly in an uninhabitable state. Ignoring the problem now, will only allow to create a bigger ecosystem issue in the future. Therefore, coastal management in the Ciletuh area needs to be conducted to prevent the further decline of the biota community, erosion, deposition, and to solve the problem of high sedimentation rates that affect the macrozoobenthos abundance in habituating areas.

Conclusions. Water quality analysis shows that dissolved oxygen, temperature, and pH parameters in Ciletuh Bay water ranged within the standards accepted for aquatic biota, while salinity and visibility parameters ranged below the sufficient standard for living organisms. Low visibility in this area is caused by a high sedimentation rate. Thus, this problem needs to be fixed for a better coastal ecology in Ciletuh Bay. Sedimentation rate values range from 91.2 to 7309.1 g/cm^2/day, with the highest sedimentation rate obtained at Station 2, near a shrimp farm, and the lowest sedimentation rate was obtained at Station 3 (Mandra Island). Based on these data, the sedimentation rates at Stations 1, 2 and 5 are classified as very high, because the sedimentation rate exceeds 340 g cm^{-2} per day, affecting water transparency.

Acknowledgements. Thank you to Hibah Penelitian Universitas Padjadjaran (Universitas Padjadjaran Research Grants) that has funded all activities of this research.

Conflict of Interest. The authors declare that there is no conflict of interest.

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Received: 19 July 2021. Accepted: 30 October 2021. Published online: 02 January 2022.
Authors:
Asia Salsabilla, Marine Science Study Programme, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, Postal code: 45363, West Java, Indonesia, e-mail: asiasalsabilla16@gmail.com
Yuniarti. MS, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, Postal code: 45363, West Java, Indonesia; Centre of Conservation Study & Maritime Region Management, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, Postal code: 45363, West Java, Indonesia, e-mail: yuniarti@unpad.ac.id
Yudi Nurul Ihsan, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, West Java, Indonesia, e-mail: yudinurul@yahoo.com
Mega Laksmini yamsudin, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, West Java, Indonesia, e-mail: vegha16@yahoo.com
Lintang Permatasari Yuliadi, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, West Java, Indonesia, e-mail: elpeesye@gmail.com

How to cite this article:
Salsabilla A., Yuniarti M. S., Ihsan Y. N., Syamsudin M. L., Yuliadi L. P., 2022 Sedimentation rate implications to water quality and macrozoobenthos community structure in Ciletuh Bay, Sukabumi Regency, West Java, Indonesia. AACL Bioflux 15(1):1-11.