Effect of sediment accumulation rate on coral cover in the waters of Setan Island, West Sumatra, Indonesia

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Abstract. The waters around Setan Island are a habitat for coral reef ecosystems. Unfortunately these waters receive sediment inflows from the surrounding coast and affect the ecosystem. The study was conducted in March 2023 in the waters of Setan Island, West Sumatra, Indonesia. The aim of the study was to determine the sediment accumulation rate and live hard coral cover, as well as the relationship between sediment accumulation rate and coral cover. Four sampling points were determined for conducting the study. Sediment accumulation rate was measured using a sediment trap. Coral cover observations were conducted using underwater photo transect (UPT) method with a transect length of 50 meters. Total suspended solid was analyzed using the Gravimetric method. Oceanographic observations were also performed at each sampling points. The sediment accumulation rate had a slight to moderate impact on the percentage of live coral cover, with a loss average value of 1.3170075 mg cm^{-2} day^{-1}. The average percentage of live coral cover is 18.87%. Through a simple linear regression analysis, the sediment accumulation rate shows a negative effect on the percentage of live coral cover.
Key Words: sedimentation, live hard coral , oceanographic parameters, relationship, growth forms.

Introduction. Coral reefs are a unique feature among marine ecosystems, entirely formed by biological activities. Scientifically, coral reefs have large deposits of calcium carbonate ($CaCO_3$) produced by animals, in addition to calcifying algae and other organisms that can produce calcium carbonate (Puryono et al 2019; Dahlan et al 2021). Coral can live in tropical and subtropical waters. Although coral can survive in subtropical ocean, they are not as well developed as coral living in tropical waters. This is due to the presence of two different groups of coral, namely the group of coral called hermatypic and the group of coral called ahermatypic (Ginoga et al 2016). Hermatypic coral able to produce calcium carbonate while ahermatypic coral cannot. Another difference is that in the body tissue of hermatypic corals, there is presence of zooxanthellae algae, while in ahermatypic corals the opposite is true (Miththapala 2008).

The growth of hermatypic coral is constrained by several factors, including temperature, salinity, light, air, and sedimentation (Limmon & Manuputty 2021). Hermatypic coral can survive for limited period at temperatures slightly below 20°C and can tolerate temperatures ranging from 36-42°C (Eidman et al 2020). Changes in salinity can cause stress to the coral by disrupting the homeostasis process, relsulting in a decrease in the concentration of zooxanthellae and chlorophyll, inhibiting growth and reproduction and ultimately causing severe coral bleaching (Samlansin et al 2020).

Coral require sufficient light intensity to be available for their symbionts to carry out photosynthesis, which enable the corals to effectively secrete calcium carbonate (Osinga et al 2008). The upward growth of corals is restricted by air, as prolonged exposure to air can lead to death, therefore the upward growth of corals only reaches the level of the lowest tide.

Sedimentation or deposition is known to cause coral growth hindrance and even death (Adriman et al 2013; Fabricius 2005; Koroy et al 2020). Many hermatypic corals cannot survive under heavy sedimentation conditions as sediment covers their mouth structure. Sedimentation also affects the turbidity of the water, and the consequences of can be lethal or harmful to corals (Hadi 2017; Rogers & Scharron 2022). Corals respond to environmental changes and pressures by striving to survive (resistance) and showing signs of recovery until a stable community is formed (resilience) and returns after damage (Subhan & Afu 2017). Currently corals reefs are experiencing degradation caused by various environmental changes such as excessive exploitation, anthropogenic impacts (Sukri et al 2020; Thirukanthan et al 2023) and sediment pollution from upstream areas (Wilkinson et al 2016). Therefore sedimentation must be considered as one of the major causes of coral death (Risk & Endinger 2011).

A study on the percentage of coral cover in the waters of Setan island has been carried out before by Khaidir et al (2020). The study only investigated coral cover without examining the bioecological effects. However, there has been no study regarding the effect of sediment accumulation rate on coral cover in the waters of Setan island. The main purpose of this study was to determine the effect of sediment accumulation rate on coral cover.

Material and Method

Study location. Setan island located in Kawasan Wisata Bahari Terpadu, Mandeh, Pesisir Selatan, situated at 01°07’10” south latitude and 100°22’53” east longitude (Figure 1). It is a hilly island, with rocky beaches on the southeast and norwest directions and sandy beaches on the north and east directions. The waters surrounding the island are home to various biotas such as clams (*Tridacna*), *Acanthaster planci*, sea cucumbers, sea urchins, lionfish, morray eels, and groupers. Due to its proximity to the Sumatra mainland, Setan island is affected by sedimentation from the land. Additionally, the waters surrounding the island receive suspended materials input from Mandeh estuary.

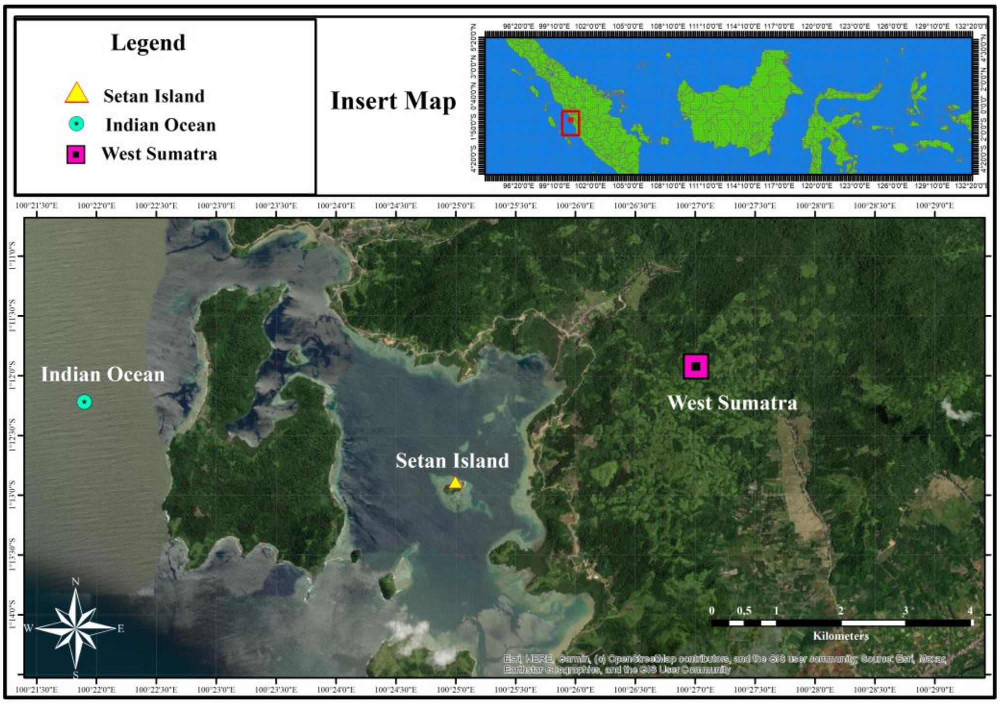

Figure 1. The location of Setan Island, West Sumatra, Indonesia.

Sediment trap installation procedure. The sediment accumulation rate was measured using a sediment trap (Figure 2). The sediment trap was made of PVC with a diameter of 5 cm and a length of 11.5 cm. Two sediment traps were attached to a steel rod and placed at each sampling point at depths 3 and 6 m. The base of the traps should be 20 cm above the substrate. The sediment traps were installed for 14 days. After 14 days, the sediment trap could be retrieved. Before bringing them to the surface, the top part of the sediment trap was closed to prevent the loss of material inside the sediment trap. All samples, including seawater contained in them were taken to laboratory for further analysis.

Figure 2. Sediment trap model (original photos).

Sediment accumulation analysis. Sediment samples were analyzed using the following procedure:

1. Open the sediment trap in the laboratory and transfer the sediment sample that has been trapped into a beaker;
2. Let the sample settle for a day so that the sediment settles down again, and separate the sediment from the water contained in each beaker;
3. The collected sediment is then dried in an oven at 105°C for 24 hours;
4. Weigh the dried sediment samples (miligrams).

The sediment accumulation calculated is the weight of the sediment deposited per unit area per unit time (Rifardi 2012):

$$KA = W\ V^{-1}\ t^{-1}$$

Where:
KA-sediment accumulation rate (mg cm^{-2} day^{-1});
W-dry sediment weight;
V-sediment trap area;
t-trap installation time;

Based on sediment accumulation rate values, there are three categories ofeffects of sediment accumulation on corals, according to Pastorok & Bilyard (1985). The categories of effects of the sediment accumulation rate on coral can be seen in Table 1.

Table 1

Estimated degree of impact on coral by sedimentation

Sediment accumulation rate (mg cm^{-2} day^{-1})	*Degree of impact*
1 – 10	Slight to moderate
10 – 50	Moderate to severe
> 50	Severe to catastrophic

Coral cover. Coral cover observations are conducted using the underwater photo transect method at four sampling points (Figure 3). This method utilizes the developments of digital camera technology and computer software (Giyanto et al 2018). Sample collection in the field is done by taking underwater photos using an underwater camera. The resulting are then analyzed using coral point count with excel extension (CPCe) software, which can help identify coral life forms and determine the percentage of coral cover. At each sampling point (Figure 3), there are 2 transects at depths 3 and 6 m.

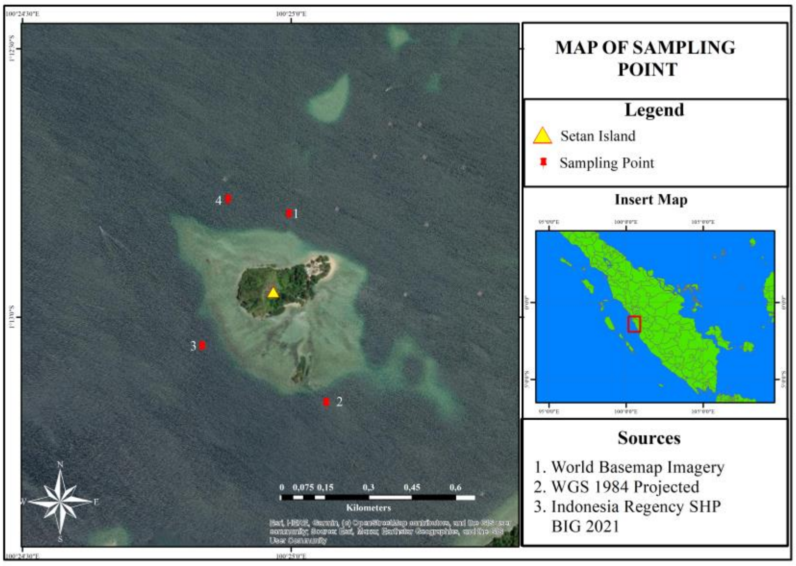

Figure 3. Sampling points.

The photos were analyzed using a computer and the CPCe software. In each photo frame, 30 random points were selected using the intermediate coral code. Each point was assigned a code according to the life form of the coral. Based on the live coral cover values, the coral cover condition is categorized into four criteria as determined by Hadi et al (2019). The categories of coral cover can be seen in Table 2.

Table 2

Criteria for coral cover based on live hard coral percentage

Hard coral percentage (%)	*Criteria*
HC ≤ 25	Poor
25< HC ≤ 50	Medium
50 < HC ≤ 75	Good
HC > 75	Very good

Oceanographic parameters. The parameters are measured using appropriate instruments. Temperature is measured using a thermometer, while current velocity is measured using a current drogue. Salinity is measured using a refractometer, while brightness is measured using a Secchi disk. Total suspended solid (TSS) are measured by filtering a known volume of water and weighing the residue after drying in an oven at 105°C. The measurement of these parameters is important to understand the environmental conditions that may affect the coral growth and survival.

Simple linear regression. The relationship between sediment accumulation rate and coral cover is calculated by finding the regression value (Y). The general equation for simple linear regression found in Tanjung (2014) as follows:

$$Y = a + bX$$

The strength of relationship can be seen from the value of the correlation coefficient (r), with the categories as follows:

1. 0 – 0.25 means weak relationship;
2. 0.26 - 0.50 means medium relationship;
3. 0.51 - 0.75 means strong relationship;
4. 0.76 - 1.00 means perfect relationship.

Results. The values of the measured oceanographic parameters at each sampling point are presented in Table 3. The parameters were measured directly (in situ) during the research in March 2023. The surface temperature measurements in the waters of Setan island were relatively similiar, ranging between 27°C and 31.7°C. The current velocity measurement results were considered slow because the area is sheltered by the surrounding islands (Cubadak, Sironjong Gadang, Sironjong Ketek, Sumatra). The surface salinity values ranged from 30 to 33‰. Brightness at all sampling points indicated a depth of 6 m, which indicates good water transparency. The TSS values ranged from 23 to 96 mg L^{-1}, which exceeded the treshold for TSS on corals.

Table 3

Oceanographic parameters measured between 9 am to 3 pm

Parameters	*Sampling point*			
	1	*2*	*3*	*4*
Temperature (°C)	30.9	27	30.5	31.7
Current velocity (m s^{-1})	0.13	0.10	0.16	0.10
Salinity (‰)	30	33	31	30
Brightness (m)	6	6	6	6
TSS (mg L^{-1})	53	23	80	96

Accumulation rate. According to Pastorok & Bilyard (1985), the average level of sediment accumulation rate at all sampling points has a slight to moderate impact on coral (Table 4).

Table 4

Sediment accumulation rate

Sampling points	*Depths (m)*	Accumulation rate *(mg cm^{-2} day^{-1})*	*Average*	*Accumulation rate categories*	*Degree of impact*
1	3	0.946315	1.049175	1 - 10 mg cm^{-2} day^{-1}	Slight to moderate
	6	1.152035			
2	3	1.243818	1.300787		
	6	1.357756			
3	3	1.262808	1.346679		
	6	1.430550			
4	3	1.534992	1.571389		
	6	1.607786			

Live coral percentage. Table 5 shows that the waters of Setan island have a diverse range of coral growth forms.

Table 5

Hard coral cover percentage

Growth forms	*Sampling points*							
	1		*2*		*3*		*4*	
	Depths							
	3 m	6 m	3 m	6 m	3 m	6 m	3 m	6 m
Acropora branching	0.07	0.27	0.47	0.07	1.47	2.07	0.00	0.00
Coral branching	2.91	13.58	2.33	3.00	0.33	0.00	0.00	0.00
Coral encrusting	0.20	1.00	0.27	0.27	4.20	2.60	0.27	0.13
Coral foliose	0.41	1.20	0.20	0.07	0.13	1.27	0.20	0.00
Coral massive	27.56	13.98	22.67	14.95	17.00	11.40	2.93	0.20
Coral mushroom	0.07	0.07	0.13	0.00	0.00	0.00	0.00	0.00
Coral submassive	0.14	0.40	0.40	0.00	0.13	0.00	0.00	0.00
Total percentage	31.36	30.50	26.47	18,36	23.26	17.34	3.40	0.33
Average	30.93		22.41		20.3		1.86	
Criteria	Medium		Poor		Poor		Poor	

There is one growth form of the Acropora genus, namely Acropora branching, and six growth forms from non-Acropora genera. Among the sampling points, the highest average percentage of live coral cover is found at sampling point 1, while the lowest is found at sampling point 4. It can also be observed that the cCoral massive growth form is the most dominant form at each sampling point.

Relationship analysis. In order to observe the relationship between sediment accumulation rate and the percentage of live hard coral cover, a simple linear regression analysis needs to be conducted. The sediment accumulation rate in the waters of Setan island ranges from 0.946315 to 1.607786 mg cm^{-2} day^{-1}, while the live coral cover percentage ranges from 0.33 to 31.36%. The results of the simple linear regression analysis of the sediment accumulation rate and live hard coral cover can be seen in Figure 4.

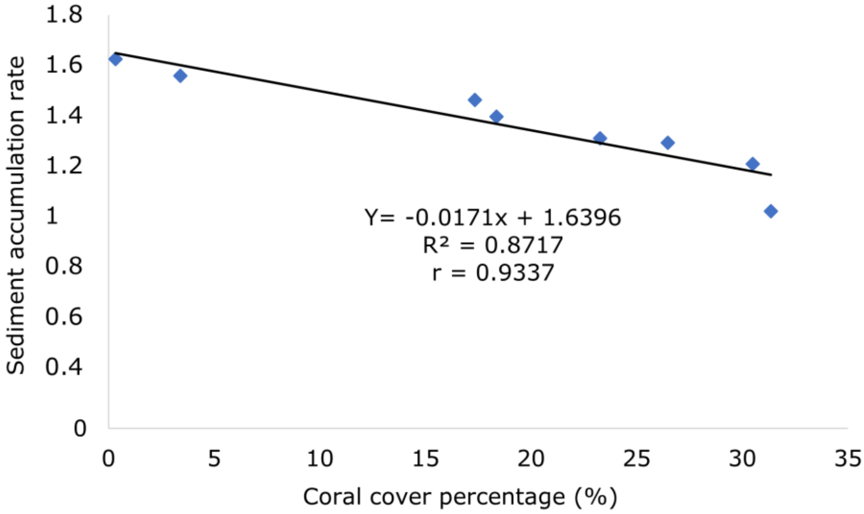

Figure 4. Regression analysis of relationship sediment accumulation rate with live hard coral cover percentage.

Based on the obtained Significance F value of 0.0006 (Table 6), it can be said that sediments have a negative effect on the percentage of live hard coral cover. The results of simple linear regression analysis of the sediment accumulation rate and the percentage of live hard coral cover yielded a coefficient of determination (R^2) value of 0.8717 and correlation coefficient (r) value of 0.9337. The magnitude of the effect of the sediment accumulation rate can be seen from coefficient of determination, which is 81.17%. The correlation coefficient value of 0.9337 indicates that the relationship between the sediment accumulation rate and the percentage of live hard coral cover falls into the category of very strong or perfect.

Table 6

Significance F value

ANOVA

	df	*SS*	*MS*	*F*	*Significance (P)*
Regression	1	0.083152	0.083152	40.75187	0.000695
Residual	6	0.012243	0.00204		
Total	7	0.095394			

Discussion. Measurement of oceanographic parameters is one way to asses the condition of a water, whether is it good or bad. Oceanographic parameters are supporting factors as well as limitations that can affect coral reef ecosystem. Temperature is one of the parameters that plays an important role in coral growth. Corals can be found growing optimally at water temperature between 25-30°C, some can tolerate higher temperatures but only for a short period (Badriana et al 2021; Bussapakorn et al 2019; Schoepf et al 2015). The main cause of coral bleaching today is the increase in seawater temperature due to global warming (Ampou et al 2020). Bleached coral do not die immediately, but if the temperature is too high for a long time, they will die due to starvation or disease (Dao et al 2021). During this process corals lose their endosymbiotic algae as the main source of energy for most reef-building corals (Sully et al 2019).

Based on the results of in situ current measurements, the surface current velocity ranges from 0.10 to 0.16 m s^{-1}. According to Sari & Usman (2012), currents with those values are classsified as slow. As stated by Zamani (2015), research locations that are sheltered by surrounding land tend to have slow current velocities. Increased water flow velocity can have a positive effect on coral individual calcification, also increasing the primary production (Comeau et al 2014). Currents affect the success of corals in capturing particles, and they can indirectly enhance coral growth by removing sediments and preventing settlement of disruptive organisms (Calado et al 2017; Osinga et al 2011).

The salinity in Indonesian waters generally ranges from 28 to 33‰ (Patty et al 2020). The optimal condition for coral survival ranges from 30 to 35‰ (Ding et al 2022; Purnomo 2019). Based on previous research references, the salinity value in the waters of Setan island is considered suitable for the standard of coral reef ecosytem survival. There are many factors that can cause changes in salinity, such as water circulation patterns, evaporation, rainfall, and river flows (Patty & Akbar 2018). A significant shift from the ideal osmolarity can cause changes in the structure of macromolecules and the metabolic functions of corals. Therefore, salinity fluctuations can cause significant changes in the cellular chemistry of corals and have negative impacts in their symbiotic relationship with zooxanthellae (True 2012). The Secchi disk reading is conducted to observe the ability of light to penetrate the water. Light plays an essential role in the growth of coral that symbiotically hosts zooxanthellae (Kuanui et al 2019; Vogel et al 2015; Widiarti et al 2016). Coral hosts are highly adapted to facilitate light capture by their symbiotic algae due to the optimal light reflective properties of their calcium carbonate framework, increasing light absorption by symbiotic algae (Osinga et al 2011). The percentage of coral cover generally decreased with the increase of depth due to the lack of light penetration.

The TSS in the waters of Setan island exceeds the treshold, according to Whitall & Bricker (2021), which is 10 mg L^{-1} for juveniles and 3.3 mg L^{-1} for adult coral. The effects of suspended sediment include the blockage of polyps, excessive light restriction, increased coral competitors, changes in oxygenation, and changes in the chemical composition of the coral enviroment (Carlson et al 2022). Coral takes at least ten times longer to experience tissue death due to exposure to suspended sediment than to equivalent concentrations of settled sediment, although physiological changes occur ten times faster in response to suspended sediment (Tuttle & Donahue 2020). The highest TSS concentration is found at sampling point 4, due to the input of suspended material from Mandeh estuary. This is consistent with researches conducted by Winnarsih et al (2016), Parenden et al (2021), Rifardi et al (2020), which showed that suspended materials from the land are carried by river flows to the sea.

Sediment distribution and sedimentation is greatly affected by tides and wave strength (Rifardi 2021). Al all sampling points, the sediment accumulation rate values at a depth of 6 meters were higher than at 3 meters. This is in line with the research of Putra et al (2023), which shows that deeper waters tend to have more sediment particles trapped in the water column compared to shallower waters. According to Rifardi & Mubarak (2022), the energy of bottom current is stronger than the aggregation energy of the solid sediment. In other words, the current erodes and trasports the bottom deposit, transforming it into suspended sediment.

The measurement of oceanographic parameters is crucial for understanding the transport and sinking velocity of the sediment particles in the study area. According to Febriyanti et al (2017), current pressure is expected to decrease with increasing depth. Additionally, Siswanto & Nugraha (2014) suggest that oceanographic conditions such as water circulation and tides can greatly affect the distribution and dispersion of suspended material. The combination of currents caused by tides can cause sediment to be mixed, making the transport and distribution of the sediment particles even more complex.

There is a significant variation in the level of exposure to turbidity and sedimentation that coral can tolerate, which may be due to taxonomic differences, geographic location, sediment type and concentration, as well as to the duration and frequency of exposure (Tuttle et al 2020). According to Tuttle & Donahue (2020), corals experience physiological and potentially lethal responses at concentrationsabove 10 mg cm^{-2} day^{-1}, a level that was previously considered slight to moderate on coral reefs by Pastorok & Bilyard (1985).

According to the coral cover criteria of Hadi et al (2019), the coral cover at sampling point 1 is classified as medium, while at sampling points 2, 3, 4 it is classified as poor. Previous research conducted by Khaidir et al (2020) found that the percentage of coral cover in the waters of Setan island ranged from 1.00% to 45.87%. Based on their research, it can be said that there has been a decrease in the percentage of coral cover in these waters. There are several factors that may have contributed to this decrease. Corals are limited by oceanographic parameters such as temperature, brightness and salinity. Since these parameters are generally good, the author suspects that they are not the primary factors contributing to the decrease in coral cover. According to Whitall & Bricker (2021), TSS may be the parameter responsible for this decrease. Another factor that may be contributing to the decrease in coral cover is tourism activities.

The waters around Setan island are a popular tourist destination due to its flat beach contour. Tourists typically engage in activities such as snorkeling, diving and the high number of visitors is directly proportional to the high traffic of tourist boats, which are believed to damage the corals through anchor throwing (Nirwan et al 2017; Paulangan et al 2019; Perdana et al 2019; Xin et al 2016). The sedimentation may also contribute to the decrease in coral cover, as it can cause coral death (Limmon & Marasabessy 2019; Zurba 2019). The dominance of massive coral in area can occur because these coral colonies have better survival abilities against ecological pressures (Suryono et al 2018; True 2012) compared to non-massive coral species (Hennige et al 2008). Ectomorph forms of coral, such as massive corals, provide them the ability to clean themselves from the accumulated sediment carried by currents (Barus et al 2018).

Conclusions. Sedimentation has a slight to moderate impact on live coral. The higher the sediment accumulation rate, the lower the percentage of live hard coral cover. In other words, recruitment rates of corals tend to decrease with increasing sedimentation rates.

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Conflict of interest. The authors declare no conflict of interest.

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