JURNAL PERIKANAN DAN KELAUTAN
Volume 29 No. 1, February 2024: 1-10

e-issn : 2721-8902
p-issn : 0853-7607

The Quality of Oceanographic Parameters in the Waters of Setan Island, West Sumatra

Kualitas Parameter Oseanografi di Perairan Pulau Setan, Sumatra Barat

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Received
December 1, 2023

Accepted
January 17, 2024

Abstract

This research was conducted from February to March 2023 in Setan island, West Sumatra. This study aimed to determine the sediment accumulation rate and coral cover, as well as the correlation between sediment accumulation rate and coral cover. The survey method was used in this research. The sediment accumulation rate was measured using a sediment trap. At the same time, the coral cover was observed using the underwater photo transect (UPT) method with a transect length of 50 m. The total suspended solid was analyzed using the Gravimetric method. Observations were made at four sampling points at depths of 3 and 6 m. The sediment accumulation rate at a depth of 3 m ranged from 0.946315 to 1.534992 mg/cm²/day, while at a depth of 6 meters, it ranged from 1.357756 to 1.607786 mg/cm²/day. The percentage of live coral cover at a depth of 3 meters ranged from 3.40% to 31.36%, and at a depth of 6 m, it ranged from 0.33% to 30.50%. The total suspended solids values ranged from 23 to 96 mg/L. Regression analysis showed that the sediment accumulation rate negatively influenced the percentage of live coral cover.

Keywords: Coral, Oceanographic parameters, Sediment accumulation.

Abstrak

Penelitian ini dilakukan dari Februari hingga Maret 2023 di perairan Pulau Setan, Sumatera Barat. Tujuan dari penelitian ini adalah untuk menentukan laju akumulasi sedimen dan tutupan karang, serta hubungan antara laju akumulasi sedimen dengan tutupan karang. Metode survei digunakan dalam penelitian ini. Laju akumulasi sedimen diukur menggunakan perangkap sedimen, sementara pengamatan tutupan karang dilakukan menggunakan metode *Underwater Photo Transect* (UPT) dengan panjang transek 50 m. *Total suspended solid* dianalisis menggunakan metode Gravimetri. Pengamatan dilakukan pada empat titik sampling pada kedalaman 3 dan 6 meter. Laju akumulasi sedimen pada kedalaman 3 m berkisar antara 0,946315 hingga 1,534992 mg/cm²/hari, sedangkan pada kedalaman 6 m, berkisar antara 1,357756 hingga 1,607786 mg/cm²/hari. Persentase tutupan karang hidup pada kedalaman 3 m berkisar antara 3,40% hingga 31,36%, dan pada kedalaman 6 m, berkisar antara 0,33% hingga 30,50%. Nilai total suspended solids berkisar antara 23 hingga 96 mg/L. Melalui analisis regresi, laju akumulasi sedimen menunjukkan pengaruh negatif terhadap persentase tutupan karang hidup.

Kata kunci: Karang, Parameter oseanografi, Akumulasi sedimen.

1. Introduction

Coral reefs are a unique feature among marine ecosystems, entirely formed by biological activities; that is, the formation of calcium carbonate piles (reefs) occurs through interactions between coral animals and zooxanthellae. This interaction is mutual, and corals provide a food source for zooxanthellae in the form of carbon dioxide as photosynthetic material, while providing photosynthesis results from zooxanthellae used by corals for calcification. Scientifically, coral reefs have large deposits of calcium carbonate ($CaCO_3$) produced by animals and 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 oceans, their development is not as well developed as 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 produces calcium carbonate, while ahermatypic coral cannot. Another difference is that in the body tissue of hermatypic corals, there is the 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 a limited period at temperatures slightly below 20 °C and tolerate temperatures ranging from 36-42°C (Nybakken, 2018). Salinity changes can cause coral stress by disrupting the homeostasis process, decreasing the concentration of zooxanthellae and chlorophyll, inhibiting growth and reproduction, and ultimately causing severe coral bleaching (Samlansin et al., 2020). Coral requires sufficient light intensity for their symbionts to carry out photosynthesis, which enables the corals to secrete calcium carbonate effectively (Osinga et al., 2008). The upward growth of corals is restricted by air, as prolonged exposure to air can lead to the death of many corals, causing the upward growth of corals to reach only 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 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, coral 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 significant 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 primary purpose of this study was to determine the effect of sediment accumulation rate on coral cover.

2. Material and Method

2.1. Time and Place

Setan island, located in Kawasan Wisata Bahari Terpadu, Mandeh, Pesisir Selatan, is at 01°07'10" S and 100°22'53" E (Figure 1). It is a hilly island, with rocky beaches on the southeast and northwest 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 the Mandeh estuary

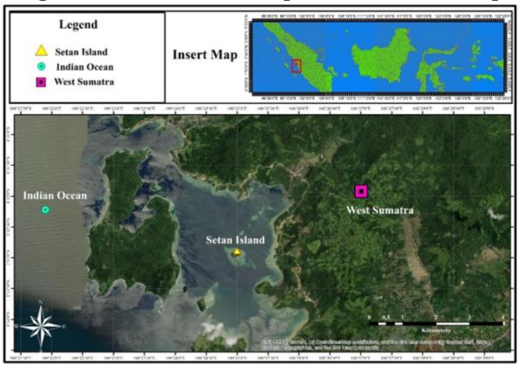

Figure 1. Research location

2.2. Procedure

2.2.1. Sediment Trap Installation

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 length of 11.5 cm. Two sediment traps were attached to a steel rod and placed at each sampling point at 3 and 6 meters depths. 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, were brought to the laboratory for further analysis.

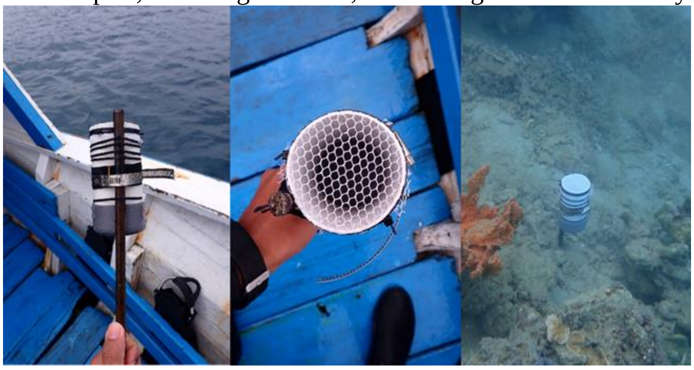

Figure 2. Sediment trap model

2.2.2. Oceanographic Parameters

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

2.2.3. Sediment Accumulation Analysis

Sediment samples were analyzed using the following procedures: 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; and 4) Weigh the dried sediment samples in milligrams. The sediment accumulation is evaluated by calculating the weight of the sediment deposited per unit area divided by the unit time (Rifardi, 2012):

$$KA = \frac{W/V}{t}$$

Description:

KA : accumulation speed (mg/cm^2/day);
W : dry sediment weight;
V : sediment trap volume;
t : trap installation time;

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

Table 1. Estimated degree of the sedimentation impact on coral

Sedimentation rate mg/cm^2/day	Degree of impact
1 - 10	Slight to moderate
10 - 50	Moderate to severe
> 50	Severe to catastrophic

2.2.4. Coral Cover

Coral cover observations are conducted using the underwater photo transect method at four sampling points (Figure 3). This method utilizes the development of digital camera technology and computer software (Giyanto et al., 2018). Sample collection in the field was done by taking underwater photos using an underwater camera. Then, the results were analyzed using coral point count with Excel extension (CPCe) software, which can help identify the coral life forms and determine the percentage of coral cover. At each sampling point (Figure 3), there are two transects at depths 3 and 6 m. So, there are eight transects in the research location.

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

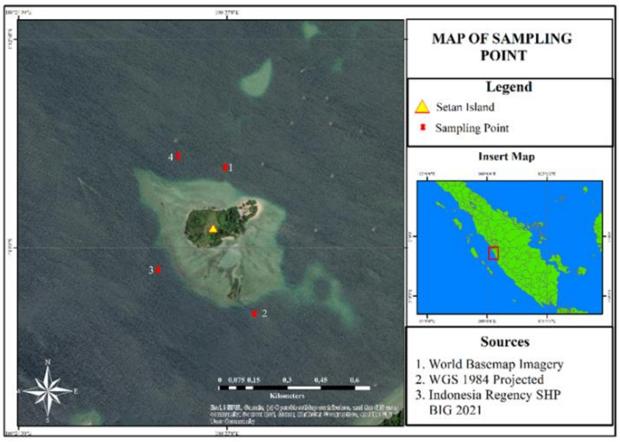

Figure 3. Sampling points

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

2.3. Data Analysis

The correlation 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) is as follows:

$$Y = a + bX$$

The strength of correlation can be seen from the value of the correlation coefficient (*r*), with the categories as follows: 0.00 – 0.20: weak; 0.26-0.50: medium; 0.51 – 0.75: strong; 0.76 – 1.00: perfect.

3. Result and Discussion

3.1. Oceanographic Parameters

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 similar, ranging between 27°C and 31.7°C. The current velocity measurement results were considered slow because the surrounding islands sheltered the area (Cubadak, Sironjong Gadang, Sironjong Ketek, Sumatra). The surface salinity values ranged from 30-33‰. The total suspended solid (TSS) values ranged from 23 - 96 mg/L, exceeding the TSS threshold on corals.

Table 3. Oceanographic parameters measured between 9 m to 3 m

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

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

Based on the in-situ current measurements, the surface current velocity ranges from 1.10 m/s to 0.16 m/s. According to Sari & Usman (2012), those values are classified as slow. Zamani (2015) states that research locations sheltered by surrounding land tend to have slow current velocities. Increased water flow velocity can positively affect coral individual calcification, thereby increasing 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 the 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 ecosystem survival. Many factors 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 macromolecules' structure and the corals' metabolic functions. Therefore, salinity fluctuations can cause significant changes in corals' cellular chemistry and negatively impact their symbiotic correlation with zooxanthellae (True, 2012).

The total suspended solids (TSS) values obtained from laboratory analysis range from 23 to 96 mg/L. The TSS in the waters of Setan Island exceeds the TSS threshold, according to Whitall & Bricker (2021), which is ten mg/L for juveniles and 3.2 mg/L for adult corals. Coral takes at least ten times longer to experience tissue death due to exposure to suspended sediment than equivalent concentrations of settled sediment. However, physiological changes occur ten times faster in response to suspended sediment (Tuttle & Donahue, 2020). The highest TSS concentration is found at sampling point 4, where this sampling point is still affected by the input of suspended material from the Mandeh estuary. This is consistent with research conducted by (Parenden et al., 2021; Rifardi et al., 2020; Winnarsih et al., 2016), which showed that river flows carry suspended materials from the land to the sea. Sampling point 4 also has the lowest percentage of coral cover (Table 6 and Table 7), indicating that TSS impacts coral cover at this sampling point. 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 environment (Carlson et al., 2022).

3.2. The Rate of Sediment Accumulation

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 and Table 5).

Table 4. Sediment accumulation rate at 3 meters

Sampling point	Depth	KA (mg/cm^2/day)	Pastorok & Bilyard 1985 Category	Degree of Impact
1	3 m	0,946315	1 - 10 mg/cm^2/day	Slight to moderate
2		1,243818		
3		1,262808		
4		1,534992		

Table 5. Sediment accumulation rate at 6 meters

Sampling point	Depth	KA (mg/cm^2/day)	Pastorok & Bilyard 1985 Category	Degree of Impact
1	6 m	1,152035	1 - 10 mg/cm^2/day	Slight to moderate
2		1,357756		
3		1,43055		
4		1,607786		

The sediment accumulation rates at a depth of 3 m range from 0.946315 to 1.534992 mg/cm²/day, while at a depth of 6 m, they range from 1.357756 to 1.607786 mg/cm²/day. According to Pastorok & Bilyard (1985), the sediment accumulation rates at each depth have a slight to moderate impact on corals. Sediment distribution is greatly affected by tides and wave strength (Rifardi, 2021). The sediment accumulation values at a depth of 6 meters tend to be higher than those at 3 m. This is in line with the research by Putra et al. (2023), which indicates that the more profound the sea, the more sediment particles are trapped in the water column compared to shallower waters. According to Rifardi & Mubarak (2022), bottom current energy is more substantial in transporting sediment than sediment density energy, meaning that the current erodes the bottom sediment and turns it into suspended sediment. Oceanographic parameters are believed to influence the distribution and dispersion of suspended materials. Tides significantly affect water circulation, allowing sediments to be mixed due to the combined effects of tidal currents and other complex currents (Siswanto & Nugraha, 2014).

There is a significant variation in the tolerance levels of corals to turbidity and sedimentation, which may be attributed to taxonomic differences, geographical locations, sediment types, as well as the concentration, duration, and frequency of exposure (Tuttle et al., 2020). According to Tuttle & Donahue (2020), corals experience physiological responses and potentially lethal effects at concentrations below 10 mg/cm²/day, previously considered slight for coral reefs (Pastorok & Bilyard, 1985).

Sampling point 4 is the sampling point with the highest sediment accumulation rate. In Figure 1, it can be observed that towards the northeast of Setan Island, there is Teluk Mandeh, where sediment movement is directed towards sampling point 4. In a bay, a current called the longshore current commonly occurs. The longshore current is a current that moves parallel to the coastline and typically transports solid sediment materials from one point to another. The TSS concentration at sampling point 4 is the highest among the sampling points (Table 3) and the sediment accumulation rates (Table 4 and Table 5). TSS stands for total suspended solids, which measures the amount of solid particles suspended in water. The sediment accumulation rate is the rate at which sediment accumulates in a particular area or body of water. TSS can trap solid particles in the water column. When the TSS concentration is high, these solid particles become heavier and settle to the bottom, leading to faster sediment accumulation. Therefore, higher TSS concentrations are associated with higher sediment accumulation rates (Rizka et al., 2020; Roswaty et al., 2014).

3.3. Coral Cover Percentage

Based on the diversity of coral growth forms, the waters of Setan Island exhibit various growth forms. Acropora has one growth form, Acropora branching, and six growth forms from non-Acropora. Table 6 and Table 7 show that the highest percentage of coral cover was found at sampling point 1, while the lowest was found at sampling point 4. The coral cover at a depth of 3 meters at sampling points 1 and 2 was grouped into the medium category, while sampling points 3 and 4 were grouped into the poor category. The coral cover at a depth of 6 meters at sampling point 1 falls into the medium category, while sampling points 2, 3, and 4 falls into the poor category.

Table 6. Hard coral cover percentage at a depth of 3 m

Lifeform	Sampling points			
	1	2	3	4
	Depth 3 m			
Acropora branching	0,07	0,47	1,47	0,00
Coral branching	2,91	2,33	0,33	0,00
Coral encrusting	0,20	0,27	4,20	0,27
Coral foliose	0,41	0,20	0,13	0,20
Coral massive	27,56	22,67	17,00	2,93
Coral mushroom	0,07	0,13	0,00	0,00
Coral submassive	0,14	0,40	0,13	0,00
Total percentage	31,36	26,47	23,26	3,40
Categories	Medium	Medium	Poor	Poor

Table 7. Hard coral cover percentage at a depth of 6 m

Lifeform	Sampling points			
	1	2	3	4
	Depth 6 meters			
Acropora branching	0,27	0,07	2,07	0,00
Coral branching	13,58	3,00	0,00	0,00
Coral encrusting	1,00	0,27	2,60	0,13
Coral foliose	1,20	0,07	1,27	0,00
Coral massive	13,98	14,95	11,40	0,20
Coral mushroom	0,07	0,00	0,00	0,00
Coral submassive	0,40	0,00	0,00	0,00
Total percentage	30,50	18,36	17,34	0,33
Categories	Medium	Poor	Poor	Poor

Previous research conducted by Khaidir et al. (2020) reveals that the coral cover percentage in the waters of Setan Island ranges from 1.00% to 45.87%, indicating a decline in coral cover. Several factors contribute to this decrease due to corals' limiting factors, including oceanographic parameters. The water temperature and salinity are generally optimal, so these parameters are unlikely to cause a decline. However, the TSS in the waters of Setan Island has exceeded the threshold, suggesting that TSS is the parameter causing the decrease in coral cover. Another influencing factor is tourism activities. The waters of Setan island are a popular tourist destination with flat coastal contours. Tourists engage in activities such as snorkeling, diving, and more. The high number of tourists affects the high traffic of tourist boats, and the anchoring of those coats is suspected to damage the corals (Nirwan et al., 2017; Paulangan et al., 2019; Perdana et al., 2019; Xin et al., 2016).

Furthermore, sedimentation also has an impact on the decline in coral cover. According to Limmon & Marasabessy (2019); Zurba (2019), sedimentation can affect coral mortality, and corals living in areas with currents tend to fare better because the currents can cleanse the corals from sedimentation pressure. Table 6 and Table 7 show that the coral's massive growth form is the dominant form at each sampling point. The dominance of massive corals in that area can be attributed to their better ability to withstand ecological pressures (Suryono et al., 2018; True, 2012) compared to non-massive coral species (Hennige et al., 2008). Ecomorphs such as massive corals provide an advantage for corals to self-clean from sediment accumulation through water currents (Barus et al., 2018).

Sedimentation is one of the limiting factors for coral growth. The extreme effects of sediment can affect coral mortality. When the sediment load exceeds the coral's ability to remove it, the sediment layer settling on coral colonies can damage the coral tissue and even lead to coral death. Sediment particles can also decrease mucus production in corals, which serves as a defense mechanism against bacterial growth. With reduced mucus production, corals become more susceptible to diseases.

Based on the results of linear regression analysis between the sediment accumulation rate and the coral cover percentage at a depth of 3 m (Figure 4), the coefficient of determination (R^2) value obtained is 0.8595, and the correlation coefficient (*r*) value is 0.9217. The coefficient of determination (R^2) indicates that the sediment accumulation rate can explain approximately 85.95% of the variation in live coral cover percentage at a depth of 3 m. The coefficient (r) value of 0.9217 indicates a very strong or perfect correlation between sediment accumulation rate and live coral cover percentage.

Based on the results of linear regression analysis between sediment accumulation rate and live coral cover percentage at a depth of 6 meters (Figure 5), the coefficient of determination (R^2) value obtained is 0.9604, and the correlation coefficient (r) value is 0.9799. The coefficient of determination (R^2) indicates that the sediment accumulation rate can explain approximately 96.04% of the variation in live coral cover percentage at a depth of 6 m. The correlation coefficient (*r*) value of 0.9799 indicates a very strong or perfect correlation between sediment accumulation rate and live coral cover percentage.

The higher the sediment accumulation rate in a water body, the lower the coral cover. Sediments can cause high turbidity levels, reducing sunlight's penetration into the water. This reduction in light penetration impacts Zooxanthellae's decreased photosynthesis process (Kuanui et al., 2019; Vogel et al., 2015; Widiarti et al., 2016). Additionally, sediment settling on the polyps can lead to coral mortality. From the analysis shown in Figure 4 and Figure 5, it is evident that sedimentation hurts the percentage of live coral cover.

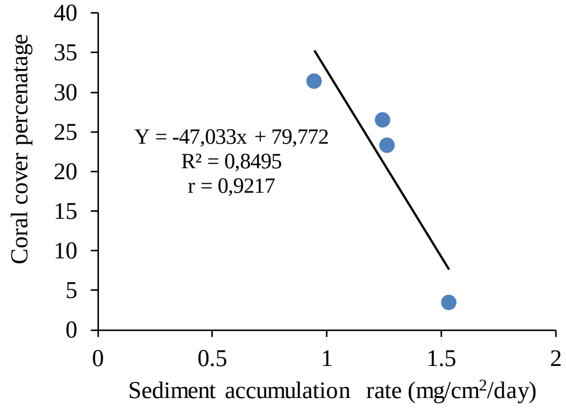

Figure 4. Correlation between sediment accumulation rate and coral cover at a depth of 3 m

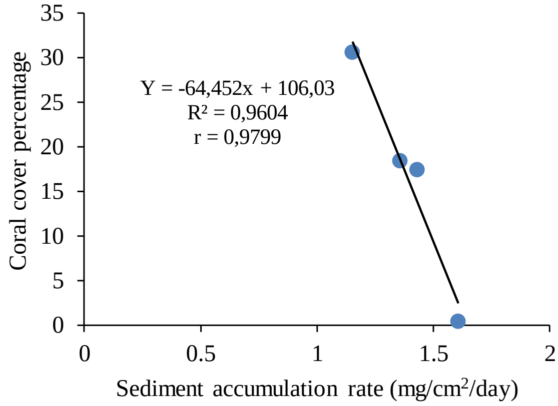

Figure 5. Correlation between sediment accumulation rate and coral cover at a depth of 6 m

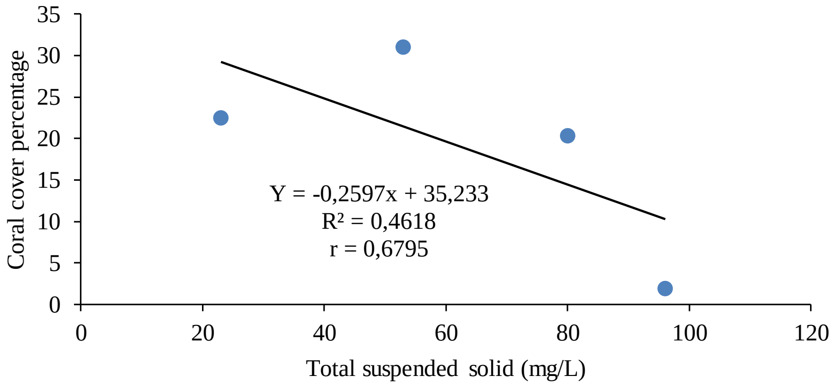

Figure 6. Correlation of total suspended solids concentration and coral cover percentage

4. Conclusions

The rate of sedimentation accumulation has a slight to moderate impact on coral reef cover. In coral reef ecosystems, if there are influence factors that cause coral cover to decrease, the rate of recruitment (growth of new colonies) will also decrease due to influence factors. So, recruitment rates are the recruitment rate (growth of new colonies.

5. References

Adriman, A., Purbayanto, A., Damar, D. (2013). Pengaruh sedimentasi terhadap terumbu karang di Kawasan Konservasi Laut Daerah Bintan Timur Kepulauan Riau. *Berkala Perikanan Terubuk,* 41(1): 90-101.

Ampou, E.E., Susilo, E., Radiarta, I.N. (2020). *Pemutihan karang di Perairan Bali Utara dan sekitarnya (Periode April - Mei 2020).* Balai Riset dan Observasi Laut. 4 p.

Badriana, M.R., Avrionesti., Surya, M.Y., Abdurrahman, U., Pratyaksa, I.F., Hidayatullah, A.I., Wicaksono, M.A.A., Diastomo, H., Suprijo, T., Park, H., Hutahean, A.A. (2021). Potential coral implementation area for Indonesia coral reef garden in Nusa Dua, Bali. IOP Conf. Ser.: Earth Environ. Sci. 925 012024. 15 p.

Barus, B.S., Partono, T., Soedarma, D. (2018). Keterkaitan Sedimentasi dengan persen tutupan terumbu karang di perairan Teluk Lampung. *Jurnal Ilmu dan Teknologi Kelautan Tropis,* 10(1): 49-57.

Calado, R., Olivotto, I., Oliver, M.P., Holt, G.J. (2017). *Marine ornamental species aquaculture.* United Kingdom. 677 p.

Carlson, R.R., Li, J., Crowder, L.B., Asner, G.P. (2022). Large scale effects of turbidity on coral bleaching in the Hawaiian Islands. *Frontiers in Marine Science,* 15 p.

Comeau, S., Edmunds, P.J., Lantz, C.A., Carpenter, R.C. (2014). Water flow modulates the response of coral reef communities to ocean acidification. *Scientific Reports,* 6 p.

Dahlan, K., Haryati, E., Sokoy, Y.D., Togibasa, O., Sa'adah, U. (2021). Characterization of morphological and crystal structure of coral reefs samples from Depapre District, Papua. *J. Phys.: Conf. Ser.* 1940 012029.

Dao, H. N., Vu, H.T., Kay, S., Sailley, S. (2021). Impact of seawater temperature on coral reefs in the context of climate change. A case study of Cu Lao Cham - Hoi an biosphere reserve. *Frontiers in Marine Science*, (8): 10 p.

Ding, D.S., Patel, A.K., Singhania, R.R., Chen, C.W., Dong, C.D. (2022). Effects of temperature and salinity on growth, metabolism and digestive enzymes synthesis of *Goniopora columna*. *Biology*, 19 p.

Fabricius, K.E. (2005). Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin:* 125-146.

Ginoga, D.A., Katili, D.Y., Papu, A. (2016). Kondisi tutupan karang di Desa Ratatotok Timur Kabupaten Minahasa Tenggara. *Jurnal Fmipa Unsrat*, 5(1): 14-19.

Giyanto, G., Mudjianto, M., Hukom, F.D., Picasouw, J., Unyang, S., Haryanto, R., Djuwariah, D., Tanda, L., Alvi, A., Sitepu, B., Sidiq, A., Samsuardi, S., Amrullah, M.Y., Zai, Y., Gea, J., Siregar, A.P. (2018). *Monitoring kesehatan terumbu karang dan ekosistem terkait di Kabupaten Nias Utara Tahun 2018*. P20 LIPI. 97 p.

Hadi, T.A. (2017). Impacts of sedimentation on stony corals. *Oseana*, 42(2): 45-58.

Hadi, T.A., Abrar, M., Giyanto., Prayudha, B., Johan, O., Budiyanto, A., Dzumalek, A.R., Alifatri, L.O., Sulha, S., Suharsono. (2019). *The status of Indonesian corals reefs.* Jakarta: Puslit Oseanografi-LIPI. 88 p.

Hennige, S.J., Smith, D.J., Perkins, R., Consalvey, M., Paterson, D.M., Sugget, D.J. (2008). Photoacclimation, growth and distribution of massive coral species in clear and turbid water. *Marine Ecology Progress Series,* (369): 77-78.

Khaidir, K., Thamrin, T., Tanjung, A. (2020). Kondisi kesehatan terumbu karang di Kawasan Wisata Bahari Terpadu (KWBT) Mandeh Kabupaten Pesisir Selatan Provinsi Sumatera Barat. *Jurnal Berkala Perikanan Terubuk*, 48(3).

Koroy, K., Alwi, D., Paraisu, N.G. (2020). Pengaruh laju sedimentasi terhadap tutupan terumbu karang di Perairan Kota Daruba, Kabupaten Pulau Morotai. *Jurnal Ilmu-ilmu Perairan, Pesisir dan Perikanan,* 9(2): 193-199.

Kuanui, P., Chavanich, S., Viyakarn, V., Omori, M., Fujita, T., Lin, C. (2019). Effect of light intensity on survival and photosynthetic efficiency of cultured corals of different ages. *Estuarine, Coastal and Shelf Science*, 6 p.

Limmon, G.V., Manuputty, G.D. (2021). Coral reef condition at north coastal of Haruku Island Maluku Tengah. *IOP Conf. Ser.: Earth Environ.* Sci. 777 012042. 10 p.

Limmon, G.V., Marasabessy, A.M. (2019). Impact of sedimentation on coral reefs in inner Ambon Bay, Indonesia. IOP. Conf. Ser.: Earth Environ. Sci. 339 012035. 7 p.

Miththapala, S. (2008). *Coral reefs coastal ecosystem series*. Colombo Sri Lanka: ecosystem and livelihoods group Asia. IUCN, (1): 1-36.

Nirwan., Syahdan, M., Salim, D. (2017). Studi kerusakan ekosistem terumbu karang di Kawasan Wisata Bahari Pulau Liukang Loe Kabupaten Bulukumba Provinsi Sulawesi Selatan. *Jurnal Kelautan*, 1(1): 12-22.

Nybakken, J.W. (2018). *Marine biology: an ecological approach*. *in* H. Muhammad Eidman., D. Geoffrey Bengen., M. Hutomo., S. Sukardjo. PT Gramedia. Jakarta. 480 p.

Osinga, R., Janssen, M., Jansen, M. (2008). The role of light in coral physiology and its implications for coral husbandry. *Public Aquarium Husbandry Series,* 2: 173-183.

Osinga, R., Schutter, M., Griffioen, B., Wijffels, R.H., Verreth, J.A.J., Shafir, S., Henard, S., Taruffi, M., Gili, C., Lavorano, S. (2011). The biology and economics of coral growth. *Marine Biotechnology*, 13: 658-671.

Parenden, D., Jompa, J., Rani, C. (2021). Condition of hard corals and quality of the turbid waters in Spermonde Islands (case studies in Kayangan Island, Samalono Island and Kondingareng Keke Island). IOP Conf. Ser.: Earth Environ. Sci. 921 012060. 10

Pastorok, R.A., Bilyard, G.R. (1985). Effects of sewage pollution on coral reef communities. *Marine Ecology Progress Series,* (21): 175-189.

Patty, S.I., Akbar, N. (2018). Kondisi suhu, salinitas, pH, dan oksigen terlarut di perairan terumbu karang Ternate, Tidore dan sekitarnya. *Jurnal Ilmu Kelautan Kepulauan*, 1(2): 1-10.

Patty, S.I., Huwae, R., Kainama, F. (2020). Variasi musiman suhu, salinitas dan temperatur air laut di perairan Selat Lembeh, Sulawesi Utara. *Jurnal Ilmiah Platax*, 8(1): 110-117.

Paulangan, Y.P., Fahrudin, A., Sutrisno, D., Bengen, D.G. (2019). Distribution and condition of coral reef ecosystem in Tanah Merah Bay, Jayapura, Papua, Indonesia. *AACL Bioflux*, 12(2): 502-512.

Perdana, M.H., Thamrin., Nursyirwani. (2019). Kondisi terumbu karang di perairan Pulau Tidung Kepulauan Seribu Jakarta. *Jurnal Online Mahasiswa Bidang Perikanan dan Ilmu Kelautan*. 10 p.

Purnomo, T. (2019). *Biodiversity and existing condition of coral reef ecosystem in Kondang Merak Beach Malang.* Antlantis Press. 95: 28-33.

Puryono, S., Anggoro, S., Suryanti, S., Anwar, I.S. (2019). *Pengelolaan pesisir dan laut berbasis ekosistem*. Semarang. Universitas Diponegoro. 284 p.

Putra, R.D., Surinati, D., Mulyono, A., Narulita, I., Djuwansah, M.R., Wirayuhanto, H., Yulada, M.R., Saputra, A.C., Hukom, F.D., Sari, T.E.Y. (2023). Oceanographic conditions and sedimentation in the Kawal River Bintan Island and impact on the prevalence of coral disease. IOP Conf. Ser.: Earth Environ. Sci. 1148 012028. 13 p.

Rifardi. (2012). *Edisi revisi ekologi sedimen laut modern*. Pekanbaru. UR Press. 167 p.

Rifardi. (2021). The bottom surface sediment transport changes in bathymetry in the Rupat Strait, Riau Province, Indonesia. IOP Conf. Ser.: Earth Environ. Sci. 934 012054. 8 p.

Rifardi., Mubarak. (2022). Profile of suspended sediment concentration in narrow channel. *AACL Bioflux*, 15(3): 1435-1443.

Rifardi., Mubarak., Elizal., Nurhuda, A., Aristi, F. (2020). Sediment transport model from Dumai river estuary to the Rupat Strait, Riau Province, Indonesia. *AACL Bioflux,* 13(6): 3447-3458.

Risk, M.J., Endinger, E. (2011). *Impacts of sediment on coral reefs*. Encylopedia of Modern Coral Reefs: 576-586.

Rizka, R.F., Purnomo, P.W., Sabdaningsih, A. (2020). pengaruh total suspended solid (TSS) terhadap densitas zooxanthellae pada karang *Acropora* sp. dalam skala laboratorium. *Jurnal Pasir Laut*, 4(2): 95-101.

Rogers, C.S., Scharron, E.R. (2022). Assesing effects of sediment delivery to coral reefs: a Caribbean watershed perspective. *Frontiers in Marine Science,* (8): 23 p.

Roswaty, S., Muskananfola, M.R., Purnomo, P.W. (2014). Tingkat sedimentasi di muara Sungai Wedung Kecamatan Wedung, Demak. *Journal of Maquares*, 3(2): 129-137.

Samlansin, K., Chawakitchareon, P., Rungsupa, S. (2020). Effects of salinity and nitrate on coral health levels of *Acropora* sp. *Thai Environmental Engineering Journal*, 34(1): 19-26.

Sari, T.E., Usman. (2012). Studi parameter fisika dan kimia daerah penangkapan ikan perairan Selat Asam Kabupaten Kepulauan Meranti Provinsi Riau. *Jurnal Perikanan dan Kelautan*, 17(1): 88-100.

Schoepf, V., Stat, M., Falter, J.L., McCulloch, M.T. (2015). Limits to the thermal tolerance of coral adapted to a highly fluctuating, naturally extreme temperature environment. *Scientific Reports*, 14 p.

Siswanto, A.D., Nugraha, W.A. (2014). Studi parameter oseanografi di perairan Selat Madura Kabupaten Bangkalan. *Jurnal Kelautan*, 7(1): 41-45.

Subhan, S., Afu, L.O.A. (2017). Pengaruh laju sedimentasi terhadap rekrutmen karang di Teluk Kendari, Provinsi Sulawesi Tenggara. *Jurnal Manusia dan Lingkungan,* 24(2): 73-80.

Sukri, A., Effendi, I., Hastuti, R., Ramdani, A., Lukitasari, M. (2020). The effect of coral reef comic media implementation on student environmental care attitude in Indonesia. *J. Phys.: Conf. Ser.* 1464 01028. 7 p.

Sully, S., Burkepile, D.E., Donovan, M.K., Hodgson, G., Woesik, R.V. (2019). A global analysis of coral bleaching over the past two decades. *Nature Communications,* 16 p.

Suryono., Wibowo, E., Ario, R., Taufik, N.S.P.J., Nuraini, R.A.T. (2018). Kondisi terumbu karang di perairan Pantai Empu Rancak, Mlonggo, Kabupaten Jepara. *Jurnal Kelautan Tropis*, 21(1): 49-54.

Tanjung, A. (2014). *Rancangan percobaan*. Bandung: Tantaramesta. 114 p.

Thirukanthan, C.S., Azra, M.N., Lananan, F., Sara, G., Grinfelde, I., Rudovica, V., Gaile, Z.V., Burlakovs, J. (2023). The evolution of coral reef under changing climate a scientometric review. *Animals*, 33 p.

True, J.D. (2012). *Salinity as a structuring force for near shore coral communities.* Proceeding of the 12th International Coral Reef Symposyum, Cairns, Australia. 7 p.

Tuttle, L.J., Donahue, M.J. (2020). *Thresholds for sediment stress on corals.* University of Hawai'I at Manoa Hawai'I Institute of Marine Biology. 75 p.

Tuttle, L.J., Johnson, C., Kolinski, S., Minton, D., Donahue, M.J. (2020). How does sediment exposure affect corals? A systematic review protocol. *Environmental Evidence,* 7 p.

Vogel, N., Meyer, F.W., Wild, C., Uthicke, S. (2015). Decreased light availability can amplify negative impacts of ocean acidification on calcifying coral reef organism. *Marine Ecology Progress Series,* 521: 49-61.

Whitall, D., Bricker, S. (2021). *Examining ambient turbidity and total suspended solid data in South Florida towards development of coral specific water quality criteria*. NOAA Technical Memorandum NOS NCCOS 297. Silver Spring, USA. 22 p.

Widiarti, R., Fadillah, M.F., Johan, O. (2016). Effect of light intensity abundance of zooxanthellae on large polyp stony corals at Panggang Island waters, based on depth differences. International Seminar Sustainable Utilization of Coastal Resources in Tropical Zone, Bengkulu, Indonesia. 82-87.

Wilkinson, C., Salvat, B., Eakin, C.M., Brathwaite, A., Filho, R.F., Webster, N., Ferreira, B.P., Harris, P. (2016). *Chapter 43. Tropical and subtropical coral reefs*. United Nations. 42 p.

Winnarsih, W., Emiyarti, E., Afu, L.O.A. (2016). Distribusi total suspended solid permukaan di perairan Teluk Kendari. *Sapa Laut,* 1(2): 54-59.

Xin, L.H., Adzis, K.A.A., Hyde, J., Cob, Z.C. (2016). Growth performance of *Acropora formosa* in natural reefs and coral nurseries for reef restoration. *AACL Bioflux,* 9(5): 1090-1100.

Zamani, N.P. (2015). Kelimpahan *Acanthaster planci* sebagai indikator kesehatan karang di perairan Pulau Tunda, Kabupaten Serang, Banten. *Jurnal Ilmu dan Teknologi Kelautan Tropis,* 7(11): 273-286

Zurba, N. (2019). *Pengenalan terumbu karang sebagai pondasi utama laut kita.* Unimal Press. Aceh. 23 p.