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Loss of Coral Reefs due to Ship Grounding in Indonesian Water: Case Study on Karimun Jawa National Park (TNKj)

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Abstract. A ship grounding on coral reefs can cause severe physical and biological damage, including coral dislodgement and removal, skeleton destruction, sediment erosion, and loss of three-dimensional complexity. The event of a ship grounding in Karimunjawa National Park caused live coral degradation of 100% and massive damage to foliose and branched coral. The total loss of hard coral biodiversity reached 261,274 colonies in an area of ±2687.87 square meters. This destruction has reduced the biodiversity of coral reefs, necessitating urgent conservation and restoration efforts in the affected area. The specific data provided, such as variations in population and density, helps provide a comprehensive understanding of the ecological damage caused by the ship grounding.

1 Introduction

The Indonesian Institute of Sciences (LIPI) issued the status of Indonesia's coral reef which is only left 6.39 percent in convenient condition [1]. Coral cover for the western region is about 8.97 percent with a very good condition; the center is about 4.91 percent and the eastern section 4.05 percent. The causes of high coral reef damage are due to destructive utility activity such, pollution, ship grounding, coral diseases, climate change phenomena, and other natural factors [2,3].

Human activities in the field of transportation (marine transportation) can disrupt and damage coral reef ecosystems such as pollution and massive damage due to ship grounded [3-5]. Ship groundings on coral reefs often result in severe localized biological and physical damage, including the dislodgement of corals, pulverization of coral skeletons, displacement of sediment deposits, and loss of 3-dimensional complexity [6-10]. Some of ship grounding crack the surface

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of coral reef, the framework generally becomes the stabilized and prone to subsequent mobilization and destruction. Reef hard can be destroyed and topography altered. Mobile reef hard can cause incidental injury to nearby animals and plants [11]. Salvage operations usually add to reef damages, without counting damages by fuel and cargo slicking from the ruptured hull. This causes acute and long-lasting effects on the regenerative processes of coral communities [12]. Resulting from low natural fusion levels of fragments to substrates, virtually complete removal of living coral colonies fragments may occur during subsequent storms [13,14]. Injury to coral reefs by groundings can range from relatively minor injuries to the degradation of the structural complexity of the reefs.

Indonesia as an archipelago has a strategic position in the national and international shipping channel. Various cases of damage to coral reefs due to ships running aground have gone unnoticed by scientists, coral reef managers, divers, and sailors themselves. The intricate interplay between sea utilization and transportation infrastructure often intersects with delicate marine ecosystems, presenting a complex challenge for regions such as Indonesia, characterized by its extensive archipelagic expanse. According to data from marine traffic commercial ship density that crossed the area around of Indonesian waters were passed by various types and sizes reaching 327 thousand routes/23km^2/year and TNKj reached 118,000 routes/0.005 km^2/ year. The elevated density of sea shipping routes in Indonesian waters could risk of accidental groundings, posing a substantial threat to the fragile coral ecosystems that populate the TNKj.

The impact of coral damage caused by ships running aground in TNKj waters is currently rarely known. This is lacked research regarding the loss of coral reef diversity due to ships running aground. For this reason, it is necessary to study the impact of ships running aground on the condition of coral reefs in the TNKj area. This research aims to identify changes in the percentage of live coral cover, community structure, and coral reef diversity, identify loss of coral reef diversity, identify affected species, and measure the extent of coral reef damage. It is hoped that the study in this paper can fill the information gap regarding the impact of ship strandings on coral loss in the National Park area.

2 Material and method

2.1 Study site

The study was conducted in the TNKj, from 2017-2019. TNKj was designated as a nature conservation area with native ecosystems. TNKj consists of a group of 22 islands located 60 nautical miles north of Central Java with an area of ±111,625 ha, with sea waters spanning 110,117.3 ha and positioned at coordinates 5°40'39"-5°55'00" South Latitude and 110°05'57"-110°31'15" East Longitude [15]. The administrative position of the TNKj is one of the sub-districts in Jepara Regency, Central Java Province, which is the Karimunjawa Subdistrict which consists of 3 villages: Karimunjawa, Parang, and Nyamuk. Observations carried out for ±3-4 days. Location of observation were in 4 location (1) Gosong Seloka 1; (2) Gosong Seloka; (3) Legon Ipik and (4) Kemujan Island. The total number of transects at 4 locations are 24 (Figure 1).

2.2 Data Collection

Data collection was conducted with the SCUBA diving equipment on reef slopes with depth 3-5 m. Live coral cover and coral popultion were taken by Underwater Photo Transect (UPT) method [16]. Identification of hard coral was carried out to the genera level using the guidebook of Indo Pacific Coral Finder [17]. Observation points were taken in unaffected area (2-3 transect) and affected areas (2-3 transects) at all observation sites. Unaffected areas serve as controls, representing the natural condition of the coral reefs around the incident site. On the other hand, the affected area represents the location where the ship ran aground, encompassing both direct and indirect impacts. The extent of damage was measured using the Fishbone Method [18,19].

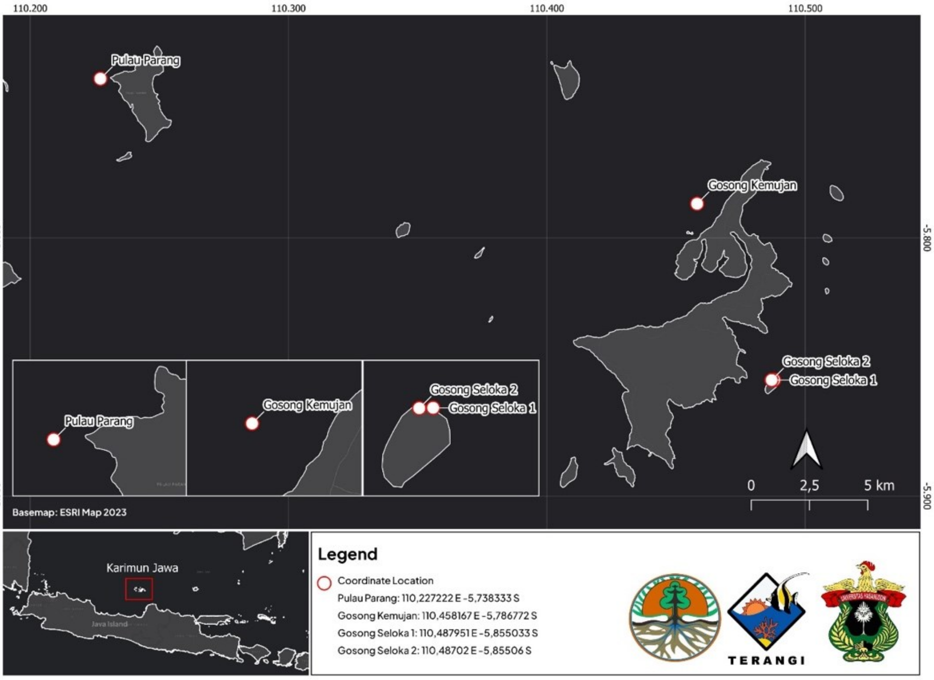

Fig. 1. Map of the location of the ship that ran aground in TNKj waters.

2.3 Data analysis

Table 1. Criteria for coral reef health.

Parameters	Criteria for coral reef health			
	Very Good	Good	Fair	Bad
Live coral cover	75-100%	50-74.9%	25-49.9%	0-24.9%
Algae cover	0-24.9%	25-49.9%	50-74.9%	75-100%
Sand cover	0-24.9%	25-49.9%	50-74.9%	75-100%
Mortality index	0.75-1	0.50-0.749	0.25-0.499	0-0.249

2.3.1 Coral coverage condition

Condition of live coral coverage was analyzed using CPCe (Coral Point Counted with Excel extensions) [20]. The percentage analysis of biota cover referred to [21] by calculating the percentage of substrate cover categories obtained from the formula:

$$Percentage\ of\ cover\ category = \frac{Sum\ of\ cover\ category\ to{-}i}{The\ number\ of\ random\ points} x\ 100\% \quad (1)$$

The assessment of coral reef condition using the criteria that developed by Zamani and Madduppa [22].

2.3.2 Coral community structure

The community structure is analyzed using the following equations: (1) The Diversity Index (H') describes the diversity of the community in terms of the number of species and reflects the individuals within the species (Equation 2). Diversity is known using the Shannon-Wiener index, which takes into account species richness and evenness [23] Pi is the proportion of abundance of species i; (2) Evenness is calculated by the Equation 3 with H' is the diversity index, and H'max= H'/Ln S, and S is the species richness; (3) Density is calculated by the equation 4 [24] with N= Coral recruitment density (Colonies/m^2) ni= number of coral colonies of genus- I and A= sampling area (m^2).

$$\text{Hi'} = \sum \text{Pi Ln Pi} \tag{2}$$

$$\text{Ei'} = \text{Hi'}/\text{H' max} \tag{3}$$

$$\text{N} = \sum \text{ni}/\text{A} \tag{4}$$

2.3.3 Area of damage

The extent of damage is measured by measuring the distance between the "fishbone" points under the water. Then use the irregular polygon area calculation equation, which is:

$$\text{Ap} = \frac{(\text{X1.Y2} - \text{X2.Y1}) + (\text{X2.Y3} - \text{X3.Y2}) + (\text{X3.Y4} - \text{X4.Y3}) + \cdots + (\text{Xn.Y1} - \text{X1.Yn})}{2} \tag{5}$$

Where AP = area of polygon; X and Y are coordinates and the distance between points is plotted and analyzed with CPCe software.

2.3.4 Statistical analysis

The statistical analysis was used the ANOVA Single Factor analysis and two factor without reflication [25]. This analysis was able to analyze of changes in diversity of coral populations and live coral cover were significant or not.

3 Result and discussion

Observation of the condition of live coral cover is crucial to determining the condition of coral reefs in an area. The observations of live coral cover were done, in two different zones the first is a natural area or control area and the second one is an affected area, it is imperative to establish a control zone. This control zone is instrumental in detecting changes in the living coral's state before the ship runs aground, allowing for the identification of changes in that location.

The results of observations of the condition of live coral cover in the control area were in the moderate to good category (40-66% ± 5.32) with an average of 52.98% ± 4.92, including good criteria 22. Dead coral cover with algae was 12.95% ± 10.63 and coral fragments 2% ± 0.86. The condition of coral cover in the control area is still to the results of several previous studies which stated that the condition of coral reefs in Karimunjawa was in poor to moderate condition (20.15% - 69%), with an average of 54.6%. Furthermore, in the affected area, a dominant stretch of dead coral and debris was found at 45.79% ± 5.33 and 31.69% ± 11.62 respectively, while remaining live coral cover only ranged between 1.3-22.84% ± 4.92 or an average of 8.51% ± 4.92 (Figure 3).

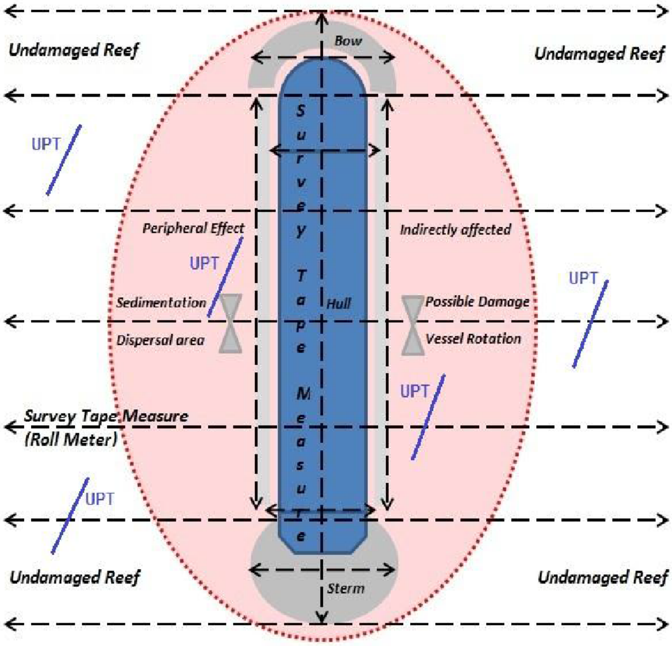

Fig. 2. The visualization for observation using fishbone and UPT method, which included coral cover, coral diversity, and area of damage.

The high coverage of rubble in the affected area, compared to the control area, shows that the damage was massive. The degradation of live coral conditions on the crash site was significant, as proven by single-factor ANOVA analysis. It was shown that the coral death was significantly different, where Fc > Ftable (Ftable = 5.31; Fc = 6.78, $p < 0.05$). It means that the grounding vessel has caused severe damage to coral reefs, where live coral degradation reached 100%. [26] stated that sunken ships can cause significant degradation of live coral coverage, reducing it by up to 58%. This leads to the formation of rubble beds that continue to grow unless stabilized by benthic life forms. The dispersion of rubble is dependent on ocean dynamics, which causes it to cover and direct declination of the remaining benthic biota in the area [28]. Found that all corals in the affected area will be destroyed, leaving behind small, unstable pieces and shards (< 25 cm) that are easily swept away by the current.

Changes in hard coral cover at each observation location varied quite widely from 1% to 22% (Table 2). Parang Island was the location with the most serious damage, reaching 97%, followed by damage at 92.5%, Gosong Seloka 2 at 89%, and Gosong Seloka 1 at 54.4%. Apart from decreasing the condition of live coral cover, there was a significant increase in rubble cover reaching 54% (Kemujan), which will reduce the resilience of the coral reef ecosystem [27]. According to other research findings, this condition predicts complete erosion of all coral in the affected area, resulting in a plain consisting of 95% dead coral and 5% sand [26-28]. Apart from that, it is estimated that the dead coral will break into small pieces with a size of less than 25 cm so that it will be easily carried away by currents and waves [1]. This at least shows the effect of distance impact due to ship collisions that ran aground on the coral reef 'Gosong Panjang'.

Fragments or coral fractional particles are dispersed following the dynamics of oceanography and shuttle down the survival of benthic biota around the primary grounding area [28].

Coral damage caused by a ship running aground can be compared to that caused by a bomb. Based on the research conducted in Komodo on 2002, it is a fact that bombs as small as a soda bottle have the capability to destroy 10-20 sq. meters of reef [29]. Studies have found that coral mortality rates can reach 50-80% in reefs that are frequently bombed or blast fishing, in Indonesia results in the loss of 3.75 m^2 of reef per 100 square meters per year according to [28]. Coral reefs damaged by ship grounding exhibit similar effects to those impacted by bombing activities, including increased rubble cover, damage to the 3-dimensional structure, removal of coral from the substrate, and limestone debris. The recovery period for both cases is prolonged, taking approximately 50 years for reefs to regain 50% of the original coral cover and restore their functionality [30].

Table 2. Changes in the condition of the bottom water substrate at each observation area.

No	Category	Gosong Seloka 1		Gosong Seloka 2		Kemujan		Parang Island	
		T0	T1	T0	T1	T0	T1	T0	T1
1	Live Coral (LC)	50,13	22,84	66,17	6,87	40,53	3,06	49,78	1,26
2	Rubble (R)	0,00	0,00	2,38	38,20	0,96	55,61	3,93	32,96
3	Dead Coral with Algae (DCA)	44,40	23,93	0,00	0,00	7,40	0,00	0,00	0,00
4	Dead Coral (DC)	3,40	51,34	28,77	54,80	10,40	30,65	35,41	46,37
5	Abiotic	0,30	0,70	0,10	0,00	30,80	8,74	7,93	19,33
6	Biotic	1,77	1,20	2,58	0,13	9,91	1,94	2,96	0,07

Coral life forms were used to determine the type and formation of damaged coral reefs. The results of this study found that the percentage of life forms of massive coral was a fairly large decline in coverage for massive coral life forms, reaching 79.2%, while other life forms were below 75% (Figure 4). On the other hand, this also needs to be a concern because the massive coral group is a slow growth coral, in line with the opinion of several researchers who state that massive corals have an average growth speed of 8.41 mm/yr., where these corals have a slow growth rate compared to other types of coral from the branching group [31-36]. Concerns arise about the damage to this massive type of coral, considering that coral growth is very slow. Therefore, an appropriate and efficient restoration approach is needed to overcome this problem.

The abundance and density of hard corals varied quite widely in the observation area, ranging from 784 colonies per ha (D: 1 colony/m^2) to 305,904 colonies/ha (D: 20 colonies/m^2) with a total of 972,048 colonies/ha (D: 97 colonies /m^2). The hard coral genera with the highest abundance (>150 thousand colonies/ha) are Montipora, Porites, and Acropora, while the others have an abundance of less than 75,000 colonies/ha (D: 10 colonies/m^2). The decline in hard coral abundance occurred quite significantly, namely 69.69% of the total abundance in the control area (Figure 5).

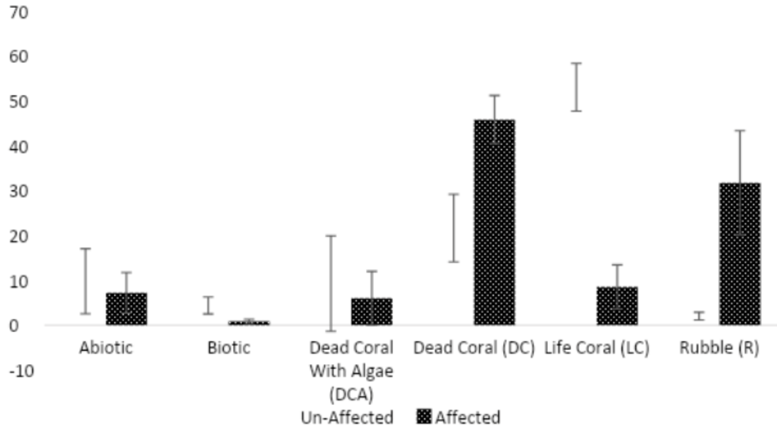

Fig. 3. Changes of underwater subtract in control area and affected area.

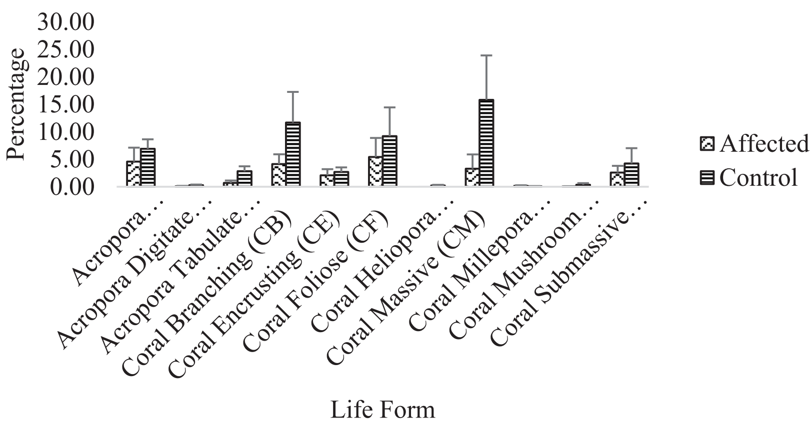

Fig. 4. Changes in the percentage of live coral based on life form.

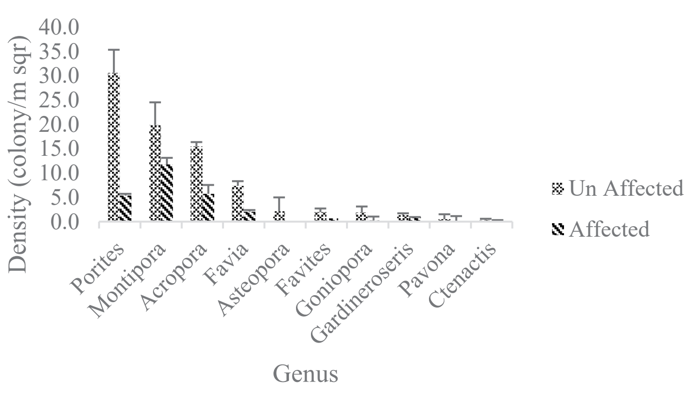

Fig. 5. Changes in ten coral genera with the highest density.

There were 30 hard coral genera found in the control area, while only 18 genera remained in the affected area. All hard coral genera identified are encompassed within the Anthozoa class, excluding Millepora and Heliopora, which are classified under Hydrozoa. The observed reduction in genera exhibited a substantial range, spanning from 21% to 100%, with an average decline of 84.03% ± 4.74%. The number of hard coral genera found in the control and affected areas exhibited a substantial alteration, retaining 18 genera (40%) of the total genera in the control area (Table 3).

The results of observations at the control location had a diversity index of 3.31 (high category) and the affected location was 1.94 (low category) (Table 3). This indicated that ship grounding affected significantly on coral reefs. This is in accordance with the results of the Two-Factor ANOVA Without Replication analysis showed that there were significant differences in changes in abundance per hard coral genera, where FC (2.67) > F table (1.82); P<0.05 and there was a real change in abundance between the control and affected areas F_C (7.02) > F table (4.16); P<0.05. This means that the ship that ran aground at TNKj has caused a decline in the condition of coral as a species and as a habitat for other marine animals.

Table 3. Changes of coral reef community structure in location.

Indeks	T0 (Un Affected)	T1(Affected)
Diversity (H')	3.31	1.94
Evenness (E)	0.97	0.67
Density (D)	97 (colony/ m^2sqr)	29 (colony/m^2)
Species Richness (S)	30	18

Table 4. Loss of hard coral diversity compared to the compensated area of damage in each location.

No.	Location	Compensated Area of Damage (m^2)	Loss Of coral Colony
1	Gosong Seloka 1	184.45	446
2	Gosong Seloka 2	4,239.20	8.643
3	Kemujan Island	52.46	164
4	Parang Island	3,188.73	101.234
5	Total	7,427.93	261.274

Apart from that, the damage caused by ships is the dumping of ship's belongings onto coral reef areas such as sand or coal. This was found on Parang Island, where there was a spill of quartz sand loaded by ships, causing coral to die because it was covered by the sand (Table 4). Meanwhile, on Kemujan Island the level of damage was smaller compared to other islands, this was because the ship's body only hit the top of the massive coral reef so the damage caused was only partial. Based on the level of damage, it can be said that there are three types of damage caused by ships running aground in the TNKj area, namely damage to the 3-dimensional structure of coral reefs, damage and death of coral colonies, and damage to parts of coral reefs. coral colony. Several studies have shown that sunken ships can dislodge coral reefs from their substrates, causing damage to coral structures, sediment movement, and degradation of the three-dimensional shape of corals [37, 18].

Overall, the loss of hard coral biodiversity is associated with the extent of damage to the coral reef ecosystem, which has reached 261,274 colonies in a damaged area of 2687.87 m^2. Based on each ship at each location, the numbers were quite varied, it was from 164 colonies (Kemujan) to 101,234 colonies (Parang Island) (Table 4). The results of observations at 4 locations where ships ran aground in TNKj waters have caused damage to coral reefs reaching 7,427.93 m^2 and made the loss of coral colonies reach 261,274 colonies. By analyzing the information presented in Table 4, it is evident that the ship running aground in TNKj has resulted in the loss of 35 coral colonies every 1 square meter of damage area, as observed through a comparison of the extent of coral damage and the number of colonies lost or deceased.

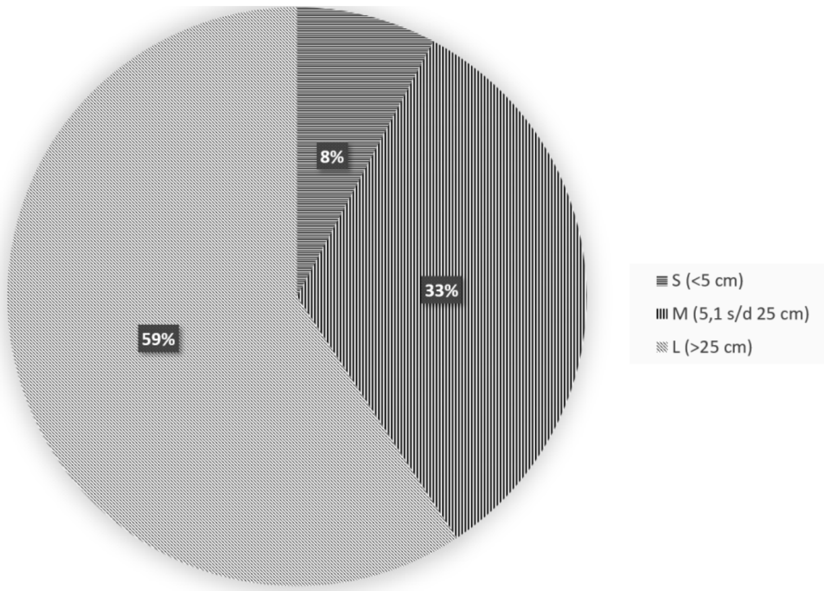

Fig. 6. Percentage of coral abundance based on size. (S=Small, M=Medium, L=Large).

The survival of coral reefs depends on the successful recruitment and attachment of coral larvae and, the filling and blending of coral structures. Hard Coral communities in the control area were dominated by hard coral with L size (~59%), then size M (~41%) and S Size (~8%). The dominant size L is mostly coral colonies that form beds (usually Acropora or Montipora beds) and large, massive boulders (usually from the genus Porites) (Figure 6). Size S is categorized as a juvenile coral size because the maximum size is 5 cm. This size is used by several experts who state that the size of coral juveniles size is 0.5-5.0 cm and a maximum diameter of 5cm [40-42].

The number of colonies in the smallest (S) colony size class can reflect the recruitment process on the coral reef. The smallest proportion of coral colony size was 8%, indicating that the coral reef community at the control location has the potential for natural recruitment. The proportion of smallest and largest colony sizes has a fairly large range and relatively large numbers of small colonies (< 5cm) were found, indicating that the natural recruitment process is going well [42-44]. On the other hand, some researcher stated that coral reef communities will have sustainable recruitment if the coral community structure has many colony sizes, or if the size range between the smallest and largest colonies is large enough.

Natural recruitment at the affected location will depend on the condition of the basic substrate. If a stable basic substrate is available then there will be a high natural recruitment process, conversely, if the basic substrate is unstable then natural recruitment will be very little. This was confirmed based on a study which stated that the density of hard coral juveniles was relatively low in the affected locations because the substrate was in the form of smooth rock scours, thus strengthening the attachment of coral larvae. The type of substrate influences recruitment success, such as the availability of hard substrate for larval attachment, the availability of coral larvae, and water conditions that support the attachment of coral larvae [46]. Based on data on changes in the bottom substrate of the waters and the existing recovery potential, it can be said that the impact of the ship running aground has reduced the potential for natural recovery of coral reefs in the affected area.

4 Conclusion

The grounding vessel has caused a significant impact on the coral reef ecosystem as same as the impact of blast fishing, leading to a notable reduction in live coral cover and an increase in dead coral and rubble. However, the ship's grounding also caused the loss of hard coral biodiversity, totaling 261,274 colonies on an area of around 2,687.87m². The study highlighted a substantial decline in hard coral abundance, amounting to 69.69% of the total abundance in the control area. On the other hand, the potential for natural recovery of coral reefs will decrease. This decline in condition illustrates the serious impact of ships running aground on the changing condition of coral reef ecosystems in TNKj, this makes it very important to immediately carry out conservation and restoration efforts to mitigate further degradation and encourage the recovery of ecologically important coral life forms and this sensitivity.

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References

1. T.A. Hadi, Giyanto, B. Prayudha, M. Hafizt, A. Budiyanto dan Suharsono, Status Terumbu Karang Indonesia (Puslit Oseanografi-LIPI, Jakarta, 2018)
2. A.P. Negri, L.D. Smith, N.S. Webster, A.J. Heyward, Mar. Poll. Bulletin, **44**, 109-115 (2002)
3. R.J. Jones, Mar. Poll. Bulletin, **54**, 905-911 (2007)
4. A.J. Edwards, E.D. Gomez, Reef Restoration Concepts and Guidelines: Making Sensible Management Choices in the Face of Uncertainty (St. Lucia: The Coral Reef Targeted Research & Capacity Building for Management Program, Queensland, 2008)
5. J.R.P. Daud, F.V. Rattu, The impact of land filled (coastal reclamation) on coral reefs in Kalasey-Bulo (Manado Bay Ekowisata, Manado, Indonesia, 1978)
6. W.F. Precht, Geotimes, **1**, 16-20 (1998)
7. W.C. Jaap, Ecol. Eng, **15**, 345–364 (2000)
8. W.F. Precht, R.B. Aronson, D.W.B. Swanson, Mar. Sci, **69**, 1001-1012 (2001)
9. W.F. Precht, Coral Reef Restoration Handbook (Taylor & Francis, Florida, 2006)
10. I.M. Cote, J.D. Reynolds, Coral Reef Conservation (Cambridge University Press, Zoological Society, London, 2006)
11. W.F. Precht, Coral reef restoration handbook (CRC Press, Florida, 2006)
12. B. Rinkevich, Curr. Opin. Env. Sus., **7**, 28-36 (2014)
13. B. Rinkevich, Environ. Sci. Technol, **39**, 12, 4333-4342 (2005)
14. Idris, N.P. Zamani, Suharsono, Fakhrurrozi, Jurnal Ilmiah Perikanan dan Kelautan, **12**, 2, 263–275 (2020)

15. A.N. Magfiroh, A. Fahrudin, Jurnal Ilmu dan Teknologi Kelautan Tropis, **12**, 2, 367-381 (2020)
16. Giyanto, Oseanologi dan Limnologi di Indonesia, **38**, 3, 377-390 (2012)
17. R. Kelley, Coral Finder 2022 - Indo Pacific Coral Finder. 5th (Byoguides, Townsville, 2022)
18. J.H. Hudson, W.B. Goodwin, Mar. Sci, **69**, 2, 509-516 (2001)
19. C. Collier, R. Dodge, D. Gilliam, K. Gracie, L. Grgg, W. Jaap, M. Mastry, N. Poulos, Rapid Response and Restoration for Coral Reef Injuries in Southeast Florida - Guidelines and Recommendations (Florida Department of Environmental, Florida, 2007)
20. K.E. Kohler, M. Gill. Computer Geoscience, **32**, 9, 1259-1269 (2006)
21. S. English, C. Wilkinson, V. Baker, Survey Manual for Tropical Marine Resources, 2nd ed, (Australian Institute of Marine Science, Australia, 1997)
22. N.P. Zamani, H.A. Maduppa, Journal of Indonesia Coral Reefs, **1**, 137-146 (2011)
23. A.E. Magurran, Ecological Diversity and Its Measurement (University College of North Wales, Bangor, 1988)
24. E.P. Odum, G.W. Barrett, Fundamentals of ecology (Saunders, Philadelphia, 1971).
25. J. Neter, M.H. Kutner, C.J. Nachtscheim, W. Wasserman, Applied Linear Statistical Models: Fourth Edition. (Mc. Graw Hill, New York, 1996)
26. S. Yusuf, Investigation of Coral Reef Degradation due to 'Ship Grounding' (Identitas Publications, Makassar, Indonesia, 2014)
27. O. Johan, Idris, Fakhrurrozi, O. Sianipar. *The impact of Manta Mae Phinisi ship grounding at Gili Lawa Darat Marine National Park of Komodo, West Manggarai, East Nusa Tenggara* in Proceedings of the 3rd International Conference on ICMMBT, IOP Conf. Series: Earth and Environmental Science, 11- 12 August 2021, Bogor, Indonesia (2022)
28. L. Pet-Soede, M. Erdmann, An overview and comparison of destructive fishing practices in Indonesia (SPC Live Reef Fish Information Bulletin, 1998)
29. B.B. Riegl, Mar. Sci, **69**, 2, 595-611 (2001)
30. L. Burke, K. Reytar, M. Spalding, A. Perry, Reefs at Risk Revisited (World Resources Institute, Washington DC, US, 2011)
31. Suharsono, Jenis-Jenis Karang di Indonesia (LIPI Press, Jakarta, Indonesia, 2008)
32. K.J.P. Antou, B.R. Ari, D.M. Ruddy, Jurnal Ilmiah Platax, **7**, 1 (2019)
33. W.A. Nugraha, in Proceedings of Embryo, **1**, 5. (2008)
34. C. Tito, A. Setiawan, S.Y. Cahyarini, S.C. Nugroho, A.R. Zaky, A.J. Saputra, *Analisis pertumbuhan karang porites di Pulau Siladen Utara, Bunaken, Sulawesi Utara*, In Proceedings Seminar Nasional Tahunan XII Hasil Penelitian Perikanan dan Kelautan, 2015, Universitas Gajah Mada, Indonesia (2015)
35. L.P.A.D. Nurcahyani, I.G.A.K. Wayan, K. Widiastuti, Journal of Marine and Aquatic Science, **4**, 2, 297-303 (2018)
36. D.B. Pratiwi, E. Yarsi, SIMBIOSA, **8**, 1, 10-19 (2019)
37. D. Lirman, N. Gracias, B. Gintert, A.C.R. Gleason, G. Deangelo, M. Dick, E. Martinez, R. P. Reid. Methods, **8**, 88–97, (2010)
38. C.S. Rogers, H.C. Fitz, M. Gilnack, J. Beets, J. Hardin, Coral Reefs, **3**, 69-76, (1984)
39. P.J. Edmunds, J.F. Bruno, D.B. Carlon, Mar. Ecol. Prog. Ser., **278**, 115–124, (2004)
40. L. Penin, F. Michonneau, A.H. Baird, S.R. Connolly, M.S. Pratchett, M. Kayal, M. Adjeroud, Mar. Ecol. Prog. Ser. **408**, 55-64 (2010)

41. I. Bachtiar, M. Abrar, A. Budiyanto, Indonesian Journal of Marine Sciences, **17**, 1, 1-7. (2012)
42. M.L. Trapon, S.P. Morgan, A.S. Hoey, PLoS ONE, **8**, 2 (2013)
43. Idris, Fakhrurrozi, O. Johan, J.S.R. Ninef, E. Jefri, M.R. Himawan, Jurnal Biologi Tropis, **2**, 23, 434 – 441 (2023)
44. B.F. Alam, D.P.W. Munasik, Buletin Oseanografi Marina, **11**, 1, 41–50 (2022)
45. A.P. Oli, K A. Roeroe, C.P. Paruntu, J.D. Kusen, I.S. Manembu, S.V. Mandagi, Jurnal Ilmiah Platax, **10**, 1 (2022)
46. P.L. Harrison, Coral Reefs, **3**, 59-85 (2011)