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Research Article

Coral Reef Degradation Due to Ship Grounding in Indonesia: Case Study of Ship Aground in Bangka-Belitung Waters by Mother Vessel MV Lyric Poet

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Abstract

Ship grounding on coral reefs often results in physical and biological damage, including dislodging and removal of corals from reefs, destruction of coral skeletons, erosion and removal of sediment deposits, and loss of three-dimensional complexity. Indonesia, as an archipelagic country, is very vulnerable to various pressures; for example, the case of ship grounding is a great concern of scientists, managers, divers, and sailors themselves. Most of the damage is very severe. The purpose of the research conducted is to identify the condition of the live coral cover, mapping the type and extent of coral reef damage, affected coral species, their conservation status, and to quantify the extent of the area of coral reef damage. Measuring the extent of damage to coral reef ecosystems using the fishbone method, while the level of damage and its impact was measured using the Underwater Photo Transect (UPT) and belt transect method. The event of the grounding of the MV Lyric Poet on the Bangka Waters, Bangka-Belitung Province, has caused damage to the coral reef ecosystem. There are four damage zones identified, i.e., trajectory, mound, propeller, and dispersion zone. Corals are damaged with a total area of 13.540m2; equivalent to twice that of an international football field. Diversity of hard coral found as many as 49 species included in the CITES-Appendix II. A total of eight protected species are included in the IUCN Red List with extinction-prone status.

1. Introduction

Coral reefs in Indonesia in general only amount to 6.56% of coral reefs in pristine condition, with a total of around 83 families and 569 variants scattered across Indonesian waters (Hadi *et al.*, 2018). Coral reefs are vital to other marine organisms as they act as a habitat and are an important part of the ecosystem, especially to humans living in both tropical and subtropical areas. However, despite being important, the condition of coral reefs has continued to decline over the last few decades due to many reasons.

The condition decline of coral reef is due to natural and anthropogenic causes. The existence of coral reef is currently threatened by sea acidification caused by the increase of carbon dioxide and the rise of sea temperature due to global warming (Hughes, *et al.,* 2003; Kleypas, *et al.,* 2006; Worm, *et al.,* 2006; Hoegh-Guldberg, *et al.,* 2009; UNEP, 2009). Physical damage from natural causes may be caused by earthquakes, tsunami, typhoon, and predatory activity of *Achantaster plancii* and *Drupella* sp. (Tomascik, 1991; Tokeshi and Daud, 2011). Coastal exploitation without consideration of the environment also causes damage to these coral reefs. One such being cruises that often damage coral reef ecosystem and may run aground, causing further significant damage (Negri, 2002; Jones, 2007; Daud and Rattu, 2011).

Ever since humans began building ships and boats, ships sunk by coral reefs have not been uncommon, causing massive biological and physical damage to its surrounding. Massive sunken ships destroy thousands of metres of benthic habitat, primarily coral reefs (Schmahl, *et al.,* 2006). Sunken ships rarely attract attention so there is a lack of data. As an example, sunken ships reported in the Florida Keys reaches 600 cases, but there are many more which remain unaccounted for (Shutler, *et al.,* 2006).

Indonesia as an island nation possesses strategic location as a national and international cruise line. Data from 2017 show that Indonesian waters are traversed by quite a wide variety and number of ships, reaching 327,000 routes/23km^2/year, and Bangka Belitung waters by 92,000 routes/0.4km^2/year (Marinetraffic, 2019). The high activity of cruise lines in Indonesian waters, including Bangka Belitung, causes high chance for ships running aground.

Coral reef damage caused by sunken ships rarely catches many researchers' attention, causing the damage to be overlooked. Therefore, it is crucial to study the impact of these sunken on coral reefs in Indonesia. A single sunken ship may destroy thousands of square meters of coral reefs. The current research is only focused on cases in Bangka waters, Bangka Belitung Isles. The purposes of this study are to identify substrate condition around the sunken ship vicinity, identifying and mapping damage levels of the coral reefs, identifying affected coral reefs and their conservation status, and, last, to quantify the damaged area of the coral reef.

2. Materials and Methods

2.1 Location and Time of Research

Research was done at Bangka Belitung province waters (Figure 1), from 5-10 May 2017, on coral reef group *Gosong Pesawat*. Observation was done for approximately 3-4 days.

2.2 Data Collection Technique

Data collection technique used travel survey; with transect line as a guide. *Swim survey* was done to execute quick observation by marking the scene and the geographical coordinates (Hill and Wilkinson, 2004). Ocean floor substrate data collection was done with *Underwater Photo Transect* (UPT) (Giyanto, 2012a; Giyanto, 2012b). Observation points were set on affected areas (three transects each). Variation data collection was carried out using belt transects and enumeration (English, *et al.,* 1997), 2 x 50 m each transect. Damaged area measurement was done through the Fishbone method (Figure 2) (Hudson and Goodwin, 2001; Collier, *et al.,* 2007).

2.3 Data Analysis

2.3.1 Floor Substrate Condition

Data from UPT for each transect were analyzed using the *Coral Point Counter* extension (CPCe) in Excel (Kohler and Gill, 2006). Floor substrate coverage percentage analysis was calculated with the following formula:

$$\text{Category coverage percentage} = \frac{\text{i Category sum}}{\text{Random point count}} \times 100\%$$

Coral reef condition evaluation was done according to the criteria developed by Zamani and Maduppa, 2011 (Table 1).

Table 1. Coral reef health criteria.

Parameter	Coral Reef Health Criteria			
	Very Good	**Good**	**Sufficient**	**Damaged**
Live Coral Coverage	75-100%	50-74.9%	25-49.9%	0-24.9%
Algae Coverage	0-24.9%	25-49.9%	50-74.9%	75-100%
Sand Coverage	0-24.9%	25-49.9%	50-74.9%	75-100%
Mortallity Index	0.75-1	0.50-0.749	0.25-0.499	0.0-0.249

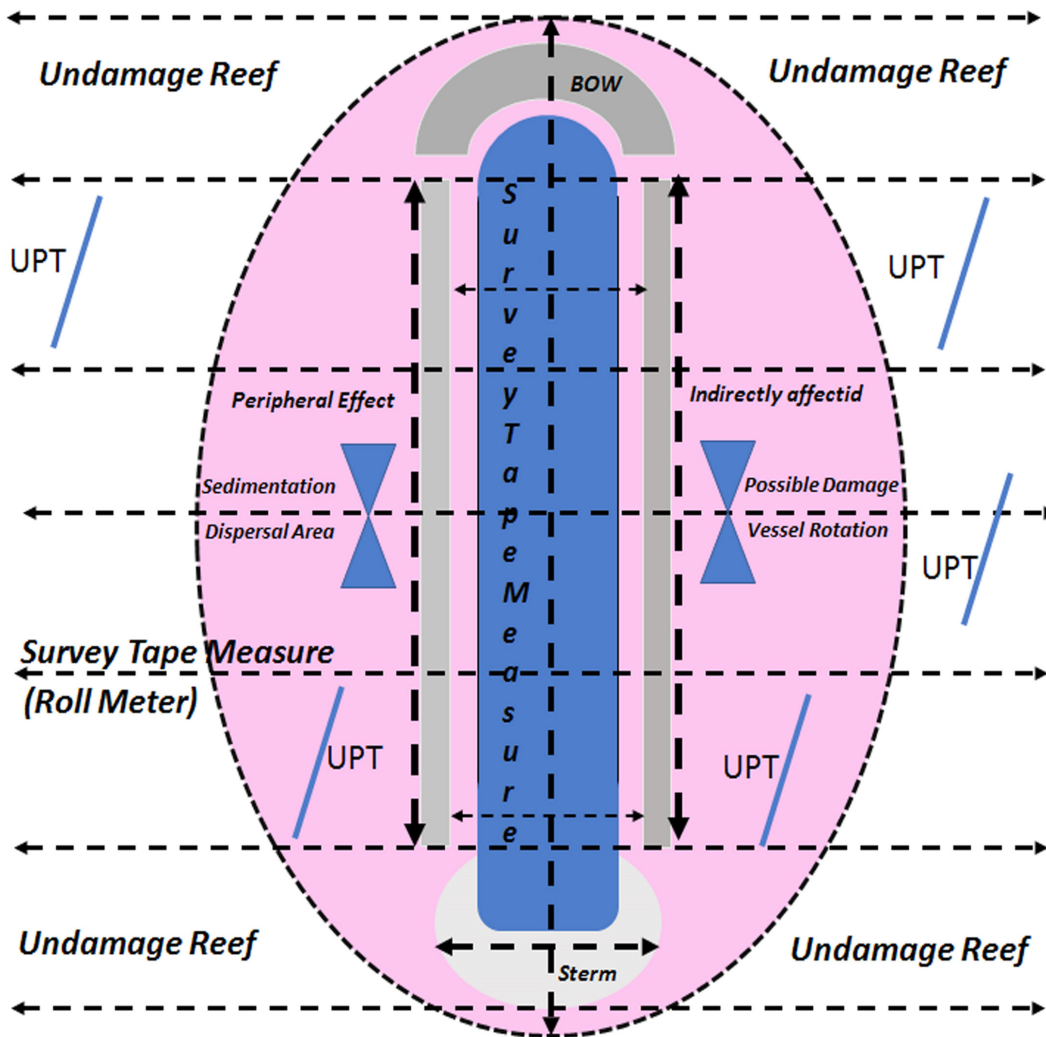**Figure 1**. Sunken ship locations in Bangka Belitung waters.

Figure 2. Fishbone method visualisation to measure damaged area.

Damaged area value was obtained through distance measurement between each point underwater. Values obtained were then calculated with the arbitrary polygon area equation:

$$A_P = \frac{(X_1 \cdot Y_2 - X_2 \cdot Y_1) + (X_2 \cdot Y_3 - X_3 \cdot Y_2) + (X_3 \cdot Y_4 - X_4 \cdot Y_3) + \ldots + (X_n \cdot Y_1 - X_1 \cdot Y_n)}{2}$$

Where:

AP = Polygon area, while X and Y are coordinates.

Distance between points was plotted and analyzed with CPCe. Total damaged area was then acquired.

2.3.2. Live reef coverage changes

Changes in live reef coverage are caused by sunken ships and analysed with single factor ANOVA (Neter, *et al.*, 1996).

3. Results and Discussion

3.1 Affected Area, Level and Coral Reef Damage Area

The grounding of the ship MV Lyric Poet has caused damage in the coral reef ecosystem of *Gosong Pesawat,* Bangka Belitung province. The ship was a cargo ship (mother vessel) with length of 229 m and width of 32.25 m with Bahamas flag. It had grosstonage weight of 44,203 tonnes and deadweight of 81,276 tonnes, draught height of 11.2 m, and last recorded speed before grounding was of 11.6 knots.

Area measurement of damaged coral reef zone was carried out using the ground truth approach and simulation of the grounding was made to obtain the visualization of the damage received. Processes of the ship's grounding up to the re-floating are usually modelled after the 3-step pattern (Tissier, 2010); first

step would be the ship's entry point and grounding with unparalleled bow and steer position, the second step is when the tail of the ship swings outwards (bright red), the last is when the hull is parallel in the rescue process, increasing the damaged area (bright green).

Observation results show the ship's track in the form of whited out corals (abrasion). The track was used as a marker (floater marker) for mapping and evaluation. The sunken ship faced north while its tail faced south (Figure 3). The ship's hull (draught of 11.2m) impact with the coral reef caused the reef to be cut with depth of 9-11 m.

Underwater observation showed cut or damaged coral reef plains at ± 8 m depth by the ship's hull. Damage on coral reefs due to sunken ships may span from minimum damage to total degradation of the corals' structure, affecting the benthic ecosystem. Some research results state that sunken ships may rip off and sweep coral reefs away from its substrate, destruction of coral structure, movement of sediments, and degradation of the three-dimensional structure of the coral (Precht, 1998; Jaap, 2000; Precht, et al., 2001; Jaap, et al., 2006; Precht and Robbart, 2006; Jones, 2007; Lirman, et al., 2010).
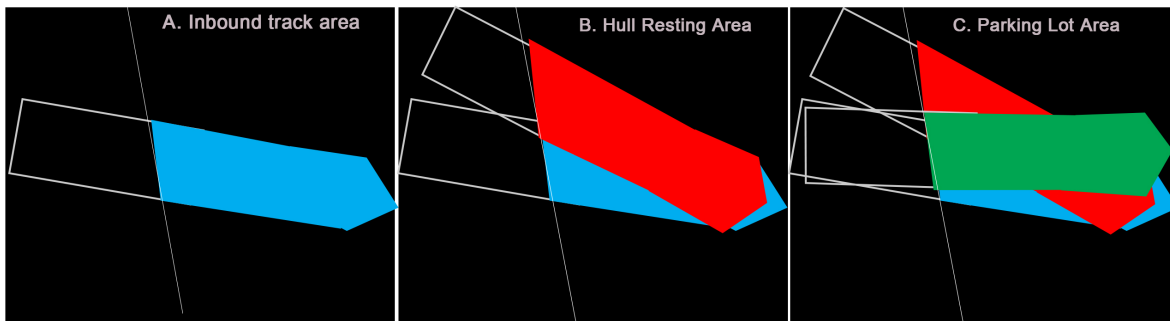

Figure 3. Model of grounding process A. Inbound track area, B. Hull Resting Area, C. Parking area

Figure 4. Coral reef condition on trajectory zone

In this study, four zones of coral damage were identified based on the track, type, and level of damage:

a. Trajectory zone (Figure 4) is the primary zone where the hull impacts the coral reef. The main characteristic was the ground and cut coral reef formation, first seen at 11 m depth to about 9 m depth. This made some kind of canal in the reef formation, leaving mostly rubbles and lumps or mounds of reef debris along the canal walls with average heights of about 3 m. There appears to be a colony of *Porites* sp. with diameter of 4 m, shifted quite far to the left, indicating heavy impact to the reef edge, between the trajectory zone and propeller zone. Reef biota seemed to have died off completely. A number of massive reefs had their top shattered and destroyed by the impact of the ship's bow. This area had the most severe damage; creating unstable pile of reef debris. This reef debris is unsuitable for juvenile reef growth as it is unstable and may shift at any moment, also hindering its restoration capability. The natural recruitment of juvenile reefs on the reef debris is either terribly low or simply unsuitable for recruitment (Fox, *et al.*, 2005; Raymundo, *et al.,* 2007; Edwards and Gomez, 2008), the existence of strong currents or storms renders the natural fusion of coral reefs to be low and may eliminate nearby coral colonies (Bruckner and Bruckner, 2001).

Damaged area measurement was done using arbitrary polygon approach. Trajectory width average was 31 m, which matches with the ship's width of 32.25 m. Trajectory length was 170 m on its left and 150 m for its right with average length of 160 m. mortal coral colonies, coral debris, and coral erosion sediment were in this zone. Total damage area in trajectory zone was 4,960 m^2.

b. Mound zone (Figure 5) was a pile of various coral debris and chalk structure shards mounted on the left and right of the canal walls with average mound height of 3 m and width of 5 m. Similar to the trajectory zone, the damage on coral reefs and benthic biota was severe and benthic lifeforms were not found in this area. Ocean floor substrate was dominated by coral shards and sand lifted by the ship's hull. This type of physical damage is classified as acute and poses a significant threat to the coral reef and its restoration process (Lirman, *et al.*, 2010; Raymundo, *et al.*, 2018). Aside from that, flung coral fractures will also damage corals around it and proves to be a difficult substrate for juvenile coral growth (Idris *et al.*, 2019). Measurement results of the mound zone acquired shows an average width of 5 m for each side, wall height measurement acquired was 2.5 m with length of 160 m. Total damage area for this zone was 1,600 m^2.

c. Propeller zone (Figure 6) as a coral reef "plain" with depth of 14 m and 16 m, forming a con-cave shape, a ditch. Two ditches were likely to form due to the draught height (depth in this case) of 11.2 m, deep enough to dig 16 m down. Damage in this area was also severe, although the damage form differed from the former, being was in the form of split massive corals with size larger than that of rubble. Discerning characteristic of the damage was the coral colonies being ripped off and flung 20 m deep, causing it and another 98.5% of benthic biota to die. Observation results showed two attempts from the ship to dislodge from the parking area; once at the point of impact and once more at the rescue operation.
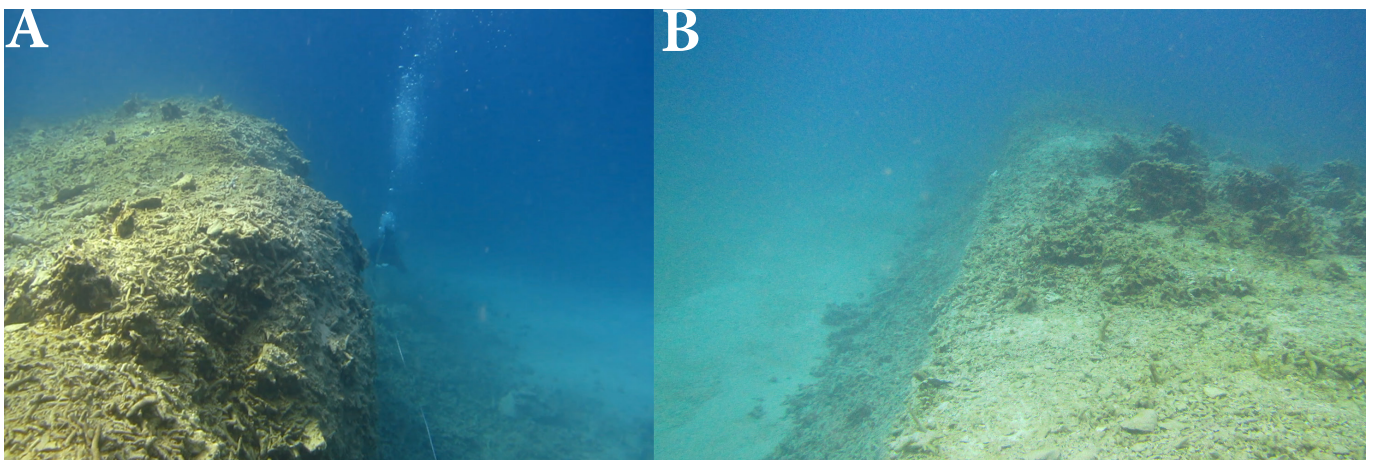

Figure 5. Coral reef condition on Mound zone (A=Left mound and B=right mound).

Those attempts managed to dislodge massive coral colonies with radius up to about 100 m. Some other research results have revealed that a sloppy rescue operation may cause further damage to other supposedly unaffected coral reef; causing acute effects that affects the regenerative process of coral biota (Aronson, 1997; Wakeford, *et al.*, 2008).

Damage area of this zone was an elongated concave ditch; urging the use of ellipse approach. Shortest diameter recorded for the first ditch was about 20 m and the longest was about 40 m. Shortest diameter recorded for the second ditch was about 50 m with the longest about 100 m. Estimated damage area was 3,140 m².

Figure 6. Coral reef condition in propeller zone
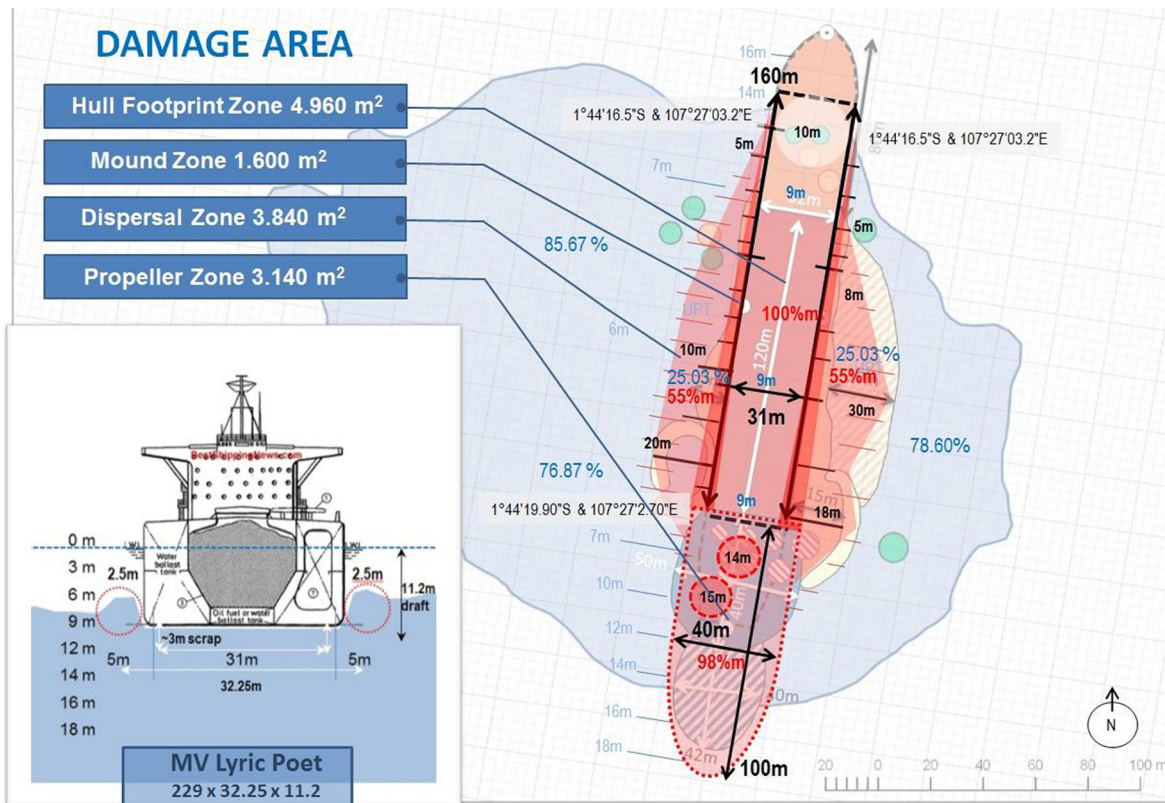

Figure 7. Coral reef damage zonation sketch on *Gosong Pesawat*

e. Dispersion zone was an area on the left and right side of the mound zone indirectly affected by natural factors, such as current dynamics, waves, and storms. These dynamics lifted left-over sediments and unstable coral shards, covering live corals in the vicinity. Damage in this zone was severe, although not so much as to obliterate all corals and benthic lifeforms. Primary damage characteristic was live coral colonies buried under coral shard debris. Observation results found coral death reaching 55.4% although it is expected to increase as time goes due to ocean dynamics. It was also stated by Shutler, et al., (2006), that sunken ships cause coral reefs to shatter, dislodge, destabilize, and may cause incidental casualty or injuries to nearby fauna and flora. Other repercussions from the rescue (ship movements to disengage from crash site) may extend the damage area further from the parking area. Disengagement of the ship may cause wounds on the corals if not treated as soon as possible (Schuhmacher, et al., 2002; Edward and Gomez, 2008). Indirectly, this means "wounds" may expand and kill off other corals.

Measurement result obtained was average width of 12 m on each side although the erosion from coral shards reached 30 m on the right side. Total damage area was 3,840 m². The full summary of damaged area is shown in Table 2, with total area of 13,540 m², equivalent to two international standard football fields. Such massive and vast damage area was caused by large ships with heavy load and high speed. This agrees with a statement by Symons et al., (2006), that large ships (length >75 ft) easily damages thousands of square metre of coral reefs and benthic biota.

3.2 Ocean Floor Substrate Condition

Observation of the floor substrate was divided into two areas; natural area (control zone) located 10 m from crash site and affected area (trajectory zone, propeller zone, mound zone, and dispersion zone). A control zone is necessary to compare substrate changes before and after the crash in order to see the difference in condition.

The observation was based on five main groups, namely Live Coral (LC), Dead Coral (DC), Dead Coral with Algae (DCA), biotic (non-coral lifeform), and abiotic (substrate such as sand, mud, and rocks).

Observation result of the substrate condition in the control zone found live coral coverage of 80.38%; classified as a very good condition; dead coral with algae coverage of 14% and rubbles 0.2%. Directly affected areas such as trajectory zone, propeller zone, and mound zone did not show any benthic lifeform, especially live hard corals, however it was dominated with rubble (99%, 98%, 98.5% for each zone, respectively) and sediment erosion such as chalk, mud, and fine sand (1%, 2%, and 1.5%). At the dispersion zone (indirectly affected), live hard coral coverage found was 20%; classified as damaged, with rubble coverage dominating (69%). Full data of ocean floor substrate coverage of every zone can be seen on Figure 8.

High coverage of rubble on affected area, compared to control area, shows that the damage was massive. Degradation of live coral condition on the crash site was significant, as proven by single factor ANOVA analysis. It was shown that the coral death was significantly different, where $F_c > F_{table}$ ($F_{table} = 5.31$; $F_c = 6.78$, $p < 0.05$); meaning that the grounding of MV Lyric Poet vessel has caused a severe damage to coral reef, where live coral degradation reached 100%. According to a statement by Riegl, (2001) that sunken ship causes significant degradation of live coral coverage up to 58% and leaving behind coral debris that keeps increasing as long as there are no stabilizing attempts by benthic lifeforms. Increasing dominance of coral shards will happen because of the dispersion being dependent on the ocean dynamics; therefore it covers and kills off remaining benthic biota in the vicinity. According to Yusuf, (2014) all corals in affected area will be ground clean (95% dead corals and 5% sand will be left), leaving small, unstable pieces and shards (< 25 cm) that are easily swept away by the current.

Table 2. Damaged coral reef area calculation

No	Damaged zones	Area (m²)	Mortallity (%)
1.	Trajectory Zone	4,960	100
2.	Mound Zone	1,600	100
3.	Propeller Zone	3,140	98.50
4.	Dispersion Zone	3,840	55.35
	Total	13,540	
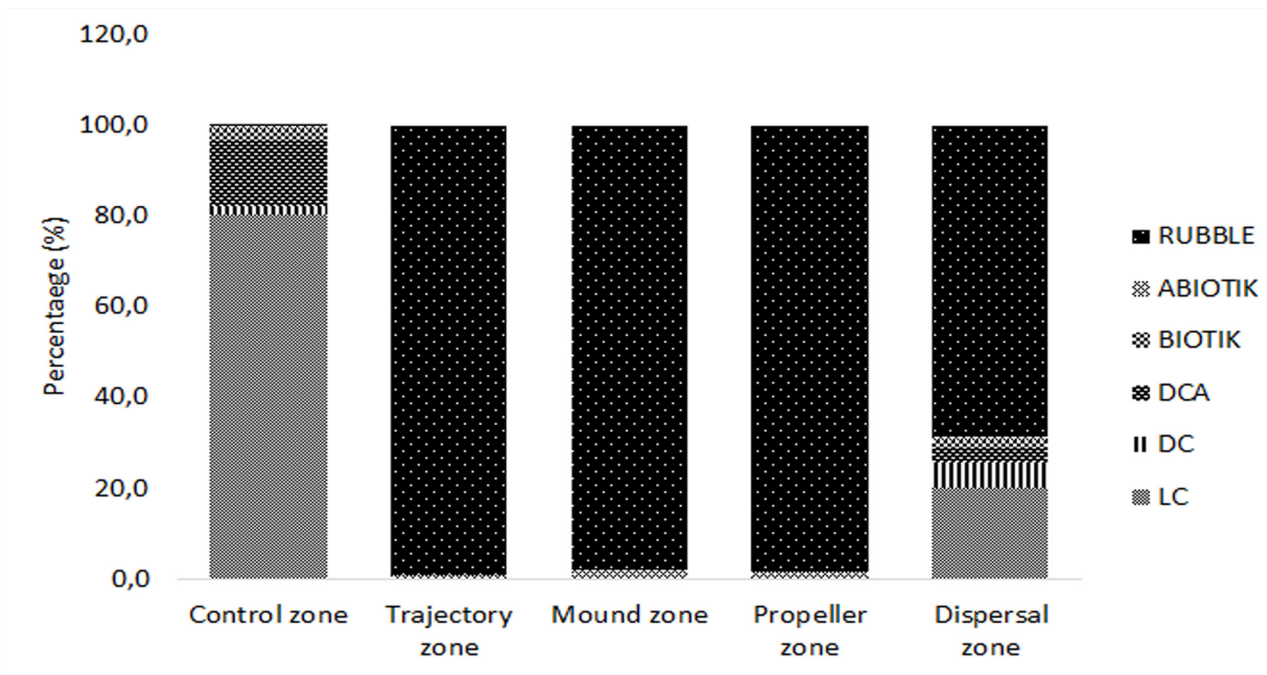
Figure 8. Percentage comparison graph of floor substrate coverage of control and affected area
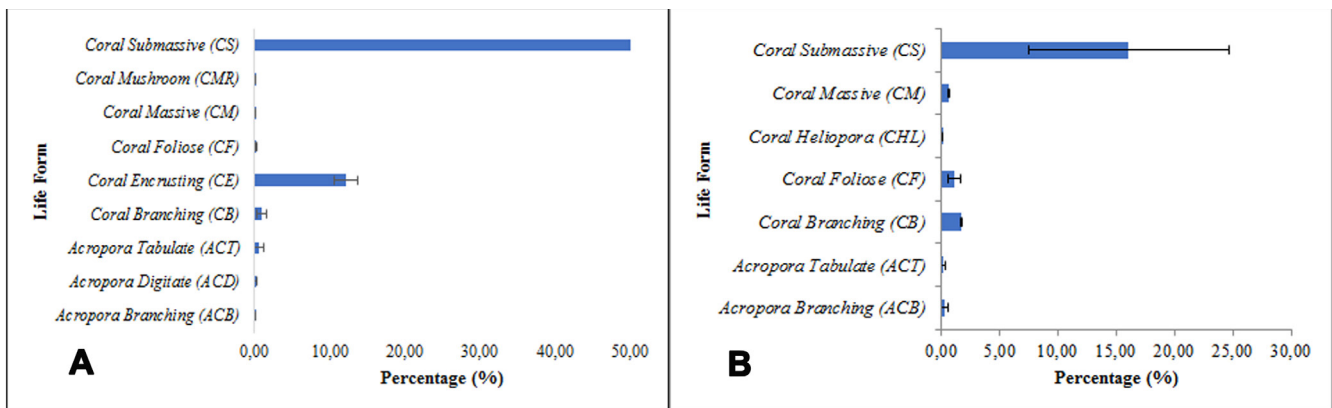
Figure 9. Percentage graph of live coral formation

Corals grow and develop through continuous polyp division. Each polyp produces calcareous substance that is deposited as the coral's structure. The calcium disposition differs based on the coral type, whether the structure or growth rate. Coral growth form varies immensely and so it is used as a criterion on determining corals (Suharsono, 2008).

Live coral growth was used to determine damaged coral type and formation. According to the form, live coral coverage percentage of the control zone was divided into categories; submassive coral as much as 66%, encrusting coral as much as 12.3%, branched coral (CB, ACT, ACD, and ACB) 1.89%, and massive coral 0.04% (Figure 9A). Hard coral coverage on affected location were dominated by submassive coral (16.07%), branched coral (1.7%), foliose coral (1.07%), and helipora coral (0.03%) (Figure 9B).

Coral growth rate varies between 15-200 mm/year depending on its type. Coral types *Porites* spp.*, Favites* spp.*, Goniopora* spp.*, Favia* spp. have growth speed of 1.18-14.88 mm/year with average of 8.41 mm/year (Nugraha, *et al.,* 2008; Tito, *et al.,* 2015; Tito, *et al.,* 2016). Most of those types have a massive and submassive growth form, = categorized as a slow growth. A coral variant with a fast growth is the Acropora variant (branched coral) with growth rate reaching 200 mm/year and average of 65.85 mm/year (Arifin and Luthfi, 2016; Nurcahyani, *et al.,* 2018; Muhlis, 2019; Antou *et al.,* 2019). Growth form of the layered coral Montipora spp. is categorized a fast grower, like branched coral. Growth rate is about 1.48-4.42 mm/month with average of 36.56 mm/year (Johan and Herminawati, 2015; Pratiwi, *et al.,* 2019).

Table 3. Conservation status of hard corals on observation site

No	Family	Species	IUCN Red List
1	Platygira	*Platygyra daedalea (*Ellis and Solander, 1786*)*	
		Platygyra lamellina (Ehrenberg, 1834)	
		Platygyra acuta (Veron, 2000)	
		Platygyra pini (Chevalier, 1975)	
2	Merullina	*Merulina ampliata*	
3	Euphyllia	*Euphyllia divisa*	
		Euphyllia paradivisa	Vulnerable
4	Montipora	*Montipora confusa* (Nemenzo, 1967)	
		Montipora foliosa (Pallas, 1766)	
		Montipora delicatula (Veron, 2000)	Vulnerable
		Montipora digitata (Dana, 1846)	
		Montipora aequituberculata (Bernard,1897)	
5	Porites	*Porites annae* (Crossland, 1952)	
		Porites cumulatus (Nemenzo, 1955)	Vulnerable
		Porites lobata (Dana, 1846)	
		Porites cylindrica (Dana, 1846)	
		*Porites lutea (*Milne Edwards and Haime, 1851*)*	
6	Favia	*Favia pallida (*Dana, 1846*)*	
		Favia matthaii	
8	Favites	*Favites complanata* (Ehrenberg, 1834)	
		*Favites abdita (*Ellis and Solander, 1786*)*	
7	Pacyseris	*Pachyseris speciosa (*Dana, 1846*)*	
		*Pachyseris foliosa (*Veron, 1990*)*	
8	Pavona	*Pavona cactus*	Vulnerable
		Pavona decussata	Vulnerable
9	Hydnopora	*Hydnophora rigida*	
		Hydnophora grandis	
10	Acropora	*Acropora indonesia (*Wallace, 1997*)*	Vulnerable
		*Acropora nobilis (*Dana, 1846*)*	
		*Acropora tenuis (*Dana, 1846*)*	
		*Acropora millepora (*Ehrenberg, 1834*)*	
		*Acropora convexa (*Dana, 1846*)*	
		*Acropora digitifera (*Dana, 1846*)*	
		*Acropora nana (*Studer, 1878*)*	
		*Acropora palifera (*Lamarck, 1816*)*	
11	Fungia	*Fungia granulosa (*Klunzinger, 1879*)*	
		Fungia repanda	
12	Pocillopora	*Pocillopora damicornis*	
		Pocillopora elegans	Vulnerable
		Pocillopora verrucosa	
13	Psamocora	*Psammocora digitata*	
14	Ctenactis	*Ctenactis albitentaculata (*Hoeksema, 1989*)*	
15	Cycloseris	*Cycloseris tenuis (*Dana, 1846*)*	
16	Goniastrea	*Goniastrea pectinata (*Ehrenberg, 1834*)*	
17	Diploastrea	*Diploastrea heliopora*	
18	Galaxea	*Galaxea fascicularis*	
		Galaxea astreata	Vulnerable
19	Gardineroseris	*Gardineroseris planulata*	

Damaged coral formations were dominated by submassive corals, encrusting corals, branched, and layered with the submassive being the most damaged; an efficient and effective approach is mandatory, as their growth is considerably slow

3.3 Rock coral variant diversity and its conservation status

Observation of the location has managed to identify 49 variants of hard corals from 19 families. The Acropora family was the family with the most variant (eight variants), the Montipora and Porites family follow with five variants, and the last was Platygira with four variants. The least abundant families were Gardineroseris, Diploastrea, Psammocora, Cycloseris, and Ctenactis (one variant each) (Table 3).

Conservation criteria for variant and community protection are peculiarity (quirks), threat, and benefit (Law No. 5 of 1990 concerning Conservation of Biological Natural Resources and their Ecosystems. Ecological importance is the pillar for the existence of coral reef diversity all over the world (Veron, 2000; Worm et al.,2006; Veron et al., 2009). Observed hard coral varieties were all categorized in CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora), second Appendix. Eight variants were included in the IUCN Red List (International Union for Conservation of Nature) with vulnerable status or at risk of extinction of extinction.

4. Conclusion

It can be concluded that the hard coral coverage on the control location was 80.38% and on affected area was only 20%. Coral reef damage zones identified were trajectory zone, mound zone, propeller zone, and dispersion zone. Death of coral organisms and other biota reached 100%, leaving behind damaged, shattered, or dislodged coral structure. Hard coral diversity found was of 49 types and all included in the Appendix II-CITES category, eight were classified as vulnerable in the IUCN red list (in risk of extinction). Total damaged coral reef area reached 13,540 m², equal to two international standard football fields.

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Authors' Contributions

Author 's Contribution All authors have contributed to the final manuscript. The contribution of each author as follow, Idris: Conduct research on coral reef ecology and conservation status . Neviaty ; directed writing of manuscripts for coral reef bioecology. Suharsono; directed writing of manuscripts for the impact of damage and condition of coral reef. Ozi ; Survey team that carries out field data collection and analysis

Conflict of Interest

The authors declare that they have no competing interests

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