Human activities and persistent coral reef degradation in Gaspar Strait, Bangka Belitung Islands, Indonesia [version 1; peer review: 3 approved with reservations]

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Abstract

Background: The aim of the study was to describe the coral reef condition in Bangka Belitung Islands, particularly from Gaspar Strait. This research location is well known for its underwater archaeological discovery and shipwreck sites. Recent increases in mining, fishing and tourism activities in the surrounding islands might have affected the condition of the coral reef.

Methods: Nine islands inside the strait were visited (i.e. Langer, Kembung, Piling, Aur, Salma, Pongok, Celagen, Kelapan, and Lepar Island), and a line transect was used to observed coral reef conditions.

Results: Coral cover was found to be predominantly in fair conditions (25-50%). Coral mortality index also tended to be high, which indicated that the coral reef ecosystem was in threatened conditions. Previous and recent reports also reported the same condition as found by this study.

Conclusion: Degradation of the coral community in Bangka Belitung Islands is likely caused by human activities. This suggests that increasing human activities significantly affects the coral reef condition. Protection of coral reefs with sustainable management for mining activity, tourism and fishing practices are needed.

Keywords
Coral Reef, Degradation, Human Activity, Bangka Belitung, Indonesia
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Introduction
The Research Center for Oceanography (RCO)-LIPI recently reported that Indonesia’s coral reef condition in 2017 was predominantly in fair and poor conditions. Coral reefs are very vulnerable to damage, particularly from human activity, and their degradation is caused by many reasons among them sedimentation, pollution from industrial domestic waste, coral mining, over exploitation, and unsustainable fishing activity. Human activity (e.g. destructive fishing, uncontrolled tourism) can cause dramatic damage in a short period of time to the coral reef ecosystem. Mechanical damage from destructive fishing practices (e.g. anchoring damage and blast-fishing) could dramatically reduce coral cover, and also reduce coral reef resilience to natural perturbations. The higher the decrease in live coral cover in an area, the larger the decrease in coral species diversity. The development of uncontrolled tourism in some areas has already caused substantial damage near reef areas. Sedimentation from mining activity has also impacted coral reefs, and sedimentation is a major controlling factor in reef development. The coral community in high sedimentation sites are relatively similar over a period of time, i.e. stable concerning cover and diversity.

The province of Bangka Belitung Islands is one region of Indonesia that has developed high tourism activity. Tourists visiting the Bangka Belitung Islands are increasing, and has been declared as one tourist area that should be a priority for development in Indonesia. There have been some previous studies on the coral reefs in Bangka Belitung Islands, which have revealed that this coral reef is at threat of a high rate of sedimentation. The sedimentation come from tin mining activities in surrounding islands, which have existed since 1850. The present study describes the coral reef condition in the Gaspar Strait between Belitung and Bangka Island, which is also suffering from the impact of anthropogenic activities. Information on the coral reef condition and distribution in the Gaspar Strait is important for sustainable use of marine resources in this region.

Methods
The Gaspar Strait is the strait separating Belitung Island and Bangka Island and connecting the Natuna Sea (Karimata Strait) to the Java Sea. The sampling sites were located at reef formations in nine islands inside the Gaspar Strait, Bangka Belitung Islands. Those islands are Langer Island (2°48'18.00" S and 107°22'14.00" E), Kembung Island (2°51'36.27" S and 107°20'22.01" E), Piling Island (2°55'17.44" S and 107°21'12.00" E), Aur Island (0°25'920.7" S and 107°13'50.11" E), Salma Island (0°52'26.16" S and 107°06'20.8" E), Pongok Island (2°52'30.12" S and 107°35'58.51" E), Celagen Island (2°52'23.36" S and 107°05'36.36" E), Kelapan Island (0°51'06.57" S and 106°49'89.99" E), Lepar Island (0°53'85.33" S and 106°47'47.51" E) (see Figure 1). The fieldwork was conducted between September and October 2014. This research was approved by Marine and Fisheries Agency (Dinas Kelautan dan Perikanan) of Bangka Belitung Province.

Data was collected using Line Intercept Transect. 3000 centimetres of transect line was placed parallel to the coastline in each site at 5–7 m depth. Coral reefs are identified based on lifeform category. Coral lifeform was counted on every centimetre in line where the lifeform found. Percent cover of living corals (hard corals and soft corals) found along the transect are identified and used to define if the coral reef condition is poor (0–25% coral cover), fair (26–50%), good (51–75%), and excellent (76–100%). A coral mortality index was also calculated, which is a simple ratio of dead coral cover to the sum of dead and hard coral cover. Theoretically, this index would scale the life coral cover values to the amount of space corals could occupy. Statistical values represent means ±SD, with probabilities calculated by one-way ANOVA using Data Analysis function of Microsoft Excel for MAC Version 16.16.2 (180910).

Results and discussion
Coral cover
Percentage live coral cover was calculated from identification of hard and soft corals. Hard corals were presented as a total and broken down to 11 lifeforms, (i.e. acropora branching, acropora digitate, acropora encrusting, acropora sub-massive, acropora tabulate, coral branching, coral encrusting, coral foliose, coral massive, coral mushroom, coral sub-massive) (see Dataset 1). An ANOVA revealed that the lifeforms coral cover between sampling sites were not varied significantly (Supplementary Table 1). On average, coral cover in Gaspar Strait was found in fair conditions (33.1±17.2%), with the lowest coral cover found in Salma Island in poor condition (<25%) and the highest coral cover found in Piling and Lepar Island in good condition (50–75%). Coral cover in the other islands was found in fair and poor conditions (see Table 1).

In total, 89 species of hard corals have been found in Bangka Island, with the most dominant species from the Poritiid and Faviid group. The highest coral cover found in Piling and Lepar Island in the present study was formed from aggregate coverage of Acroporid coral, i.e. tabulate and digitate (Figure 2). Non Acroporid coral found in these two islands commonly from foliose and massive corals. Foliose and massive corals category generally represent Agariciid, Pectiniid, Montiporid, Poritiid corals, which also commonly found in Bangka Island.

Coral mortality
Dead coral cover was calculated as recently dead coral and dead coral with algae. On average, dead coral cover in Gaspar Strait found about 33.0±22.0% (see Table 1). The highest dead coral cover was found in Kembung Island (70.8%), while Aur Island has the lowest dead coral cover (3.9%). The higher the coral’s mortality index value, the worse the condition of the coral reefs (see Figure 3). The coral mortality index was used to describe coral degradation in the research area. The high value of mortality index indicated that the coral reef ecosystem in the Gaspar Strait is in threatened conditions.

Coral reef degradation
The most recent status review of Indonesia’s coral reef was published by Research Center for Oceanography (RCO)-LIPI. Coral reef condition in 2016 from Bangka Belitung Islands was predominantly found in fair conditions. In this research, we
Table 1. Summary of benthic cover and mortality index (CMI) in nine reef sites from Gaspar Strait.

| Sampling Sites | Hard Coral | Dead Coral | Live Coral | CMI | Condition |
|----------------|------------|------------|------------|-----|-----------|
| Langer         | 18.30%     | 37.10%     | 18.30%     | 0.7 | Poor      |
| Kembung        | 21.00%     | 70.80%     | 21.60%     | 0.8 | Poor      |
| Piling         | 58.50%     | 9.20%      | 65.20%     | 0.1 | Good      |
| Aur            | 39.50%     | 3.90%      | 39.50%     | 0.1 | Fair      |
| Salma          | 15.20%     | 54.80%     | 15.20%     | 0.8 | Poor      |
| Pongok         | 36.30%     | 46.10%     | 36.30%     | 0.6 | Fair      |
| Celagen        | 16.30%     | 35.50%     | 16.30%     | 0.7 | Poor      |
| Kelapan        | 33.00%     | 23.30%     | 33.00%     | 0.4 | Fair      |
| Lepar          | 59.70%     | 16.60%     | 59.70%     | 0.2 | Good      |
| Average        | 33.10%     | 33.00%     | 33.90%     | 0.5 | Fair      |
| SD             | 17.20%     | 22.00%     | 18.50%     | 0.3 | -         |

found that the coral reef condition in Gaspar Strait was also predominantly in fair conditions, which is two years on from the RCO-LIPI report. Previously, a report from reef formation in Bangka Island (in 2010) also reported fair condition15. This is in contrast with the condition in an earlier report from 2005 and 200812,21, where the reported coral condition from western and eastern parts of the Gaspar Strait was good condition (see Table 2). This showed us that there have been no significant changes between 2010, 2014 and 2016 of coral cover in Gaspar Strait after coral degradation in 2005–2010.

Causes of degradation

The causes of coral reef degradation in Indonesia has been explained in various papers and reports16,22,23. Since the 1980’s, it has been reported that coral reefs in Indonesia have been severely damaged from sediment and organic pollution as well as excessive exploitation of fishery stocks, with destructive fishing practices24,25. Tin mining activity in the marine waters of Bangka Belitung is legally permitted by the regional government (Supplementary Figure 1), and the coral reef in Bangka Belitung Islands has been allegedly exposed to sedimentation from mining activity15. In the Gaspar Strait, in the present study we found silt substrate under the line transect from four sampling sites. At the ecosystem level, a reef zone with heavy sedimentation will cause lower species diversity with some species absent, greater abundance of forms and species with high resistance to sediment, and lower growth rate10.

Bangka Belitung Islands is one of province in Indonesia that encouraged tourism for regional income12. Tourism activities should have positive impacts on the coral reef in terms of support...
Figure 2. Abundance of benthic cover and abiotic substrate from nine sampling sites in Gaspar Strait, Bangka Belitung Islands. Others represent soft corals, sponges and other animals found. Algae represent algal assemblage, macroalgae, and turf algae. Abiotic represent silt, rubble, rock, and sand substrate.

Figure 3. Coral reef condition in Gaspar Strait. Graphic shows high value of coefficient of determination (R squared) between dead coral cover and coral mortality index value.
and conservation awareness. But, some reports showed direct negative impacts for the reef. Since it was established as one of ten priority tourism destination in Indonesia, tourism development in Bangka Belitung Islands has grown rapidly, seen from growth of tourists which reaches up to 20.5% each year, and also an increase in the number of hotels and restaurants in the tourism area.

Similarly, destructive fishing practices are also one major threat to coral reef degradation. We found fishing practices such as trap fishing with bottom fish pots—made from iron wire—are being placed in the reef flat with the help of corals for anchoring. Fisherman also are still using potassium nitrate to stun fish around Langer Island. Destructive fishing practices are one of major threats for coral development, which in particular may reduce resilience to natural perturbations, leading to assembly of small, sparse corals and reduced patchiness.

Natural perturbation such as predation may also cause coral reef degradation in Gaspar Strait. *Acanthaster planci* (crown-of-thorns starfish, COTS) is recognized as a major cause of coral reef degradation throughout much of the Western Pacific. We found at least two individual COTS around the transect line during fieldwork, in Pongok and Salma Island (see Figure 4).

COTS outbreaks in Indonesia have been reported since the early 1980s. During outbreaks, 90% of coral can be killed in a large area. Another factor that may cause degradation is coral disease. Recently, Nirwanda et al. reported that there are three coral diseases found in Bangka Island; brown-band disease, dark spot disease, and skeletal eroding band are commonly found and generally infect massive coral lifeforms. Improvements in water quality, by minimizing sediments and nutrient pollution, and reduction in fishery exploitation will have definite benefits for the resilience of coral reef ecosystems.

### Dataset 1.

Percent cover of benthic components were found in nine reefs of Gaspar Strait. Value was calculated from 3000 cm line transect.

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### Table 2. Summary of recent coral conditions in Bangka Belitung Islands.

| Locations                  | Number of Sites | Coral Condition | Year | Author                        |
|----------------------------|-----------------|-----------------|------|-------------------------------|
| West Gaspar Strait         | 3               | Good            | 2005 | Siringoringo *et al.*         |
| East Gaspar Strait         | 12              | Good            | 2008 | Sjafrie                       |
| Belitung Island            | 10              | Fair            | 2010 | Siringoringo and Hadi         |
| Gaspar Strait              | 9               | Fair            | 2014 | (this research)               |
| Bangka Belitung Islands    | 21              | Fair            | 2016 | Giyanto *et al.*              |

### Conclusion

The present study found that the coral reef around Bangka Belitung Islands was persistently found to be degraded in fair condition and the mortality index was predominantly high. This indicates that the coral reef ecosystem in this research location is under threatened conditions.

![Figure 4. Coral communities in the sampling sites.](image)

(a) Coral communities in Piling Island; (b) *Acanthaster planci* (crown-of-thorns starfish) found in Salma Island (arrow).
This study identified threats from human activity, such as sedimentation from tin mining activity, tourism development and destructive fishing practices. We also summarized threats to coral degradation from natural perturbations such as predation and disease. Interaction between human activity and other factors (e.g. sedimentation, tourism, predation, and disease) may be critical; thus protective management of island resources in Bangka Belitung Islands, particularly in Gaspar Strait, must be implemented to maintain a healthy coral reef ecosystem in the region. Protection of coral reefs with sustainable management for tourism and fishing practice, and also limitation in the area for tin mining, will increase the resiliency and development of the coral reef community.

Data availability
F1000Research: Dataset 1. Percent cover of benthic components were found in nine reefs of Gaspar Strait. Value was calculated from 3000 cm line transect. https://doi.org/10.5256/f1000research.16519.d229846

Supplementary material
Supplementary Table 1: ANOVA (Single Factor) Analysis result for variance of benthic cover between nine reefs from Gaspar Strait.

Click here to access the data.

Supplementary Figure 1: Map of legal permitted tin mining in the surrounding marine waters of Bangka Belitung Islands. (Source: WALHI 2018; Retrieved from https://walhi.or.id/walhi-dosen-ubb-indra-ambalika-diskreditkan-nelayan/).

Click here to access the data.

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The idea behind the work as presented is valid, and there is a clear need for more field surveys on many reefs, not only in Indonesia, but around the world, and thus this work is a welcome addition to the literature. However, I feel there are many shortcomings that need to be addressed before any indexing. I have refrained from detailed comments on grammar etc. as any revision will likely greatly change this paper. For now, I list only my major concerns:

1. The M&M need many more details. If I read this correctly, only one transect per site? But yet you discuss SD (although it is not shown in the relevant Figure 2 or Table 1). The field methodologies need many more details in order to be reproducible, including a list of "lifeforem" categories - this is listed later in Results incorrectly, images if available, etc. How did you choose sites? Also, why did you merge living coral to include both hard (Scleractinian?) and soft (octocorals?)? I would also like to see a definition of what you clearly mean by hard and soft corals, as there are numerous definitions. Define each category taxonomically. Finally, did you take images while doing LIT? Your work is a single point in time, but after you compare with past work. Detailed information on how comparisons were made is needed.

2. I am not sure I agree with the lumping of categories' health statuses simply by live coral cover. Could you instead look at bleaching, or ratio of live to recently dead, etc.? Some locations are inherently low in cover, and others high. Low cover does not always mean low health.

3. There seems to be some mixing of the different sections. In the Results and Discussion, the first part detailing categories is actually M&M. Also, the statement of 89 spp. of hard coral (hermatypic? Scleractinian?) being listed within your results is a bit misleading, even with the reference, as you did not identify your animals to species-level. The sentence is not even needed here.

4. Are there any environmental (water-quality) data available for this region? This could help your Discussion. I also do not completely agree with the coral mortality without more
details. By Figure 3 inset and your text, it seems many corals may have died recently, yet you state the conditions of the reef are stable compared to 2010, 2012 and 2014. Are these also just 25% bins? In my opinion, Figure 3 is not needed.

5. The authors mention many possible causes of degradation in the Discussion, but provide almost no data or observations, except for some anecdotal ones. This section reads less like a paper and more like a textbook. As a scientific work, it would be good to more clearly link these causes with your field observations, which you do to some degree with the fishing practices. Observing 2 COTS during surveys does not really indicate much, unfortunately.

6. Finally, the English, while very easy to read and generally well-done, could do with a simple brush-up here and there. I imagine a colleague could do this easily for you.

7. Sorry, one more small-ish comment. In Figure 2 - "abiotic" includes rubble - isn't this also biotic if coral rubble? I am a bit confused if some sites do not add up to 100%, as by including all these categories, shouldn't each site = 100%?

The authors are free to contact me with any questions or comments; I am more than happy to help if I can.

Is the work clearly and accurately presented and does it cite the current literature? Partly

Is the study design appropriate and is the work technically sound? Partly

Are sufficient details of methods and analysis provided to allow replication by others? No

If applicable, is the statistical analysis and its interpretation appropriate? Partly

Are all the source data underlying the results available to ensure full reproducibility? Yes

Are the conclusions drawn adequately supported by the results? Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Marine biodiversity, ecology, taxonomy.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
I am normally delighted to see research coming out of Indonesia, particularly coral research produced by Indonesian scientists. This present paper, however, falls short in a number of areas.

First of all, the title is very misleading. Authors have not produced research on “human activities”, they have reported the results of a limited field study. They mention a variety of probable local stresses, some of which have undoubtedly affected these reefs, but nowhere are they able to connect stress with impact. This is quite disappointing, because there is an enormous amount of work that could have led them in the right direction. They mention the possible impact of sediments, but do not attempt to link their data to this putative stress. There have been documented changes in the nature of coral communities in response to the sediments, such as the decrease in Acropora and increase in massives, but this is not investigated. The authors mention the impacts of tin mining, and this would have been interesting to investigate by, for example, trace element analysis of selected corals – but the authors do not even mention this possibility. I could go on, but I will stop with this observation: the authors can say nothing about possible human impacts. What is more, they seem unfamiliar with research that might have allowed them to tease out some of these stresses. I recognize that some techniques, such as isotopic analysis of the coral tissue, might have been beyond their budget limits (although I note that nitrogen ratios can now be had for 20 bucks a pop), but they should at least be aware of the availability of techniques.

Secondly, I have never liked this arbitrary definition of coral reefs into the good, the bad, and the ugly depending on observed percentage of coral cover. This is a particularly bad way in which to track changes over time. I realize this approach was born out of necessity in the Philippines decades ago, but surely we can get past this. A reef that has recently declined from 75% coral to 50% coral is on the way to extinction, whereas one that has happily maintained 30% coral cover throughout the Holocene is quite healthy.

The authors mention Acanthaster as a possible source of reef degradation, and I want to see this entire section removed. It is true that some years ago some Australian COTS experts visited Indonesia and produced a paper that said, lo and behold, COTS are a serious problem. I encourage the authors to read the magnificent Tomascik et al. (2000)¹ book on the reefs of Indonesia, both volumes, cover to cover. Then read all of the papers produced by the McMaster coral reef efforts, by the likes of Jompa, Limmon, Edinger and Risk. Search through this voluminous literature, almost none of which is cited in the present manuscript, which represents
several person-years’ coral reef surveys underwater. Tabulate the number of times Acanthaster is mentioned. I can inform the authors that the answer is zero. It is quite clear that COTS represents no danger to the reefs of Indonesia, especially as compared with the myriad other stresses.

The fieldwork and the reporting thereof seems to have problems. If I am reading the paper correctly, there is only 30m of transect at each location. This is insufficient for an undergraduate student report, let alone a paper in the primary literature. The authors state that measurements were to the nearest centimeter, and all of us who have done underwater surveys recognize that this is an optimistic overestimate of precision. To then report percent cover to two decimal places betrays a fundamental lack of understanding of number theory. The authors are only legitimately allowed to report to the nearest percent.

The literature coverage seems very scattershot. There is copious citation of British research of little relevance, and some glaring holes. The omission of any citation of Tomascik's work is hard to forgive.

References
1. Keast A: The Ecology of the Indonesian Seas. Part I. The Ecology of Indonesia Series, Volume VII. Tomas Tomascik, Anmarie Janice Mah, Anugerah Nontji, Mohammad Kasim Moosa. The Ecology of the Indonesian Seas. Part II. The Ecology of Indonesia Series, Volume VIII. Tomas Tomascik, Anmarie Janice Mah, Anugerah Nontji, Mohammad Kasim Moosa. The Quarterly Review of Biology. 2000; 75 (2). Publisher Full Text

Is the work clearly and accurately presented and does it cite the current literature?
No

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
No

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
No

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Coral reef ecology/Indonesian reefs

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have
The paper on Gaspar Strait coral reef degradation indicates possible threats consisting of tin mining, tourism activities and destructive fisheries but it is not clear how the survey results correspond with the conclusions. I have some comments that may help the authors to clarify their findings:

1. If tin mining has existed in the research area since 1850, how can the effects of destructive fisheries and tourism be recognized as important threats? We may assume that the coral reefs here have been threatened for many years.

2. The data were obtained per location from only one 30-m line transect at 5-7 m depth. This is very little and does not tell much about the condition of the reefs over their whole depth profile. Perhaps the authors can explain how the transects could be considered representative for the localities?

3. A total of 89 species were recorded but there is no information about these species. It is unclear what the meaning of "Poritiid group" and "Faviid group" is, since these are not proper taxonomic units and they do not correspond with life forms. The same counts for "Agariciid, Pectiniid, Montiporiid, Poritiid corals", which does not explain whether this concerns genera or families.

4. How was it determined that changes between 2010, 2014 and 2016 were not significant after 2005-2010? This is perhaps possible if the data were taken in the same way from the exact same spots but the differences are only based on overall conclusions.

5. Sediments can be a natural component of reefs. So, if sediment was found in a transect, this does not necessarily imply that there is a threat.

6. How should tourism activities have positive impact on the reefs? Tourism does not automatically result in awareness and conservation.

7. The authors found "at least two individual COTS" around the transects. Why is it not clear how many individuals were counted? Such a low number does not seem to be threatening.

8. The authors mention the occurrence of coral diseases reported from a previous survey in Bangka but do not mention any disease found in their own transects. How does this
relate to the present results?

9. Conclusion - what kind of management do the authors propose?

Is the work clearly and accurately presented and does it cite the current literature?
Partly

Is the study design appropriate and is the work technically sound?
Partly

Are sufficient details of methods and analysis provided to allow replication by others?
Partly

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No

Are the conclusions drawn adequately supported by the results?
No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Coral reef research, marine biodiversity

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.
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