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Possible Effects of Shipping Routes on Coral Reef Degradation and Diversity in Karimunjawa Marine National Park, Java Sea

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Abstract

The Karimunjawa Marine National Park, situated in the Java Sea, Indonesia, is renowned for its rich biodiversity and lively coral reefs. However, amidst the backdrop of this natural beauty, concerns have been raised regarding the potential impacts of shipping activities on the health and diversity of these fragile ecosystems.The increase in maritime traffic, including commercial vessels, tourist boats, and fishing vessels, traversing through the Karimunjawa Marine National Park raises significant environmental concerns. The movement of these vessels, especially along specific shipping routes, has the potential to disturb and damage coral reefs through various mechanisms. Hence, the aim of this study was to investigate the possible impacts of shipping routes on the coral abundance and diversity and the coral health in the Karimunjawa Islands, Java Sea, Indonesia.

In this study, the ship routes were grouped into 3 categories (west, east, and non-routes). The West Route, East Route, and Non-Route including a total of 15 islands were investigated for their % prevalence of coral disease, % coral cover, diversity index, species richness, relative abundance, and evenness. At each island, a 15x2 m belt transect was established at 3 and 8 m in depth with 3 repetitions. The statistical analyses showed that there were significant differences in coral abundance and species richness among the ship-route groups. Nonetheless, there were no significant differences in all parameters observed between 3 m and 8 m in depths. These findings suggest that while certain aspects of coral health and diversity are not influenced by shipping routes, other factors or mechanisms may play a more dominant role in determining disease prevalence, coral cover, and overall diversity in the Karimunjawa coral reefs.

Keywords: Shipping route, coral reefs, biodiversity, degradation, Karimunjawa

1. Introduction

More than fifty thousand ships move around the world every year, lugging millions of containers (Sinay, 2022). As global trade continues to expand, maritime shipping is poised for rapid growth. The primary shipping routes are expected to experience heightened congestion and a potentially unprecedented increase in traffic in the coming years (International Maritime Organization/IMO, 2019). As a result, all stakeholders in the maritime sector explore more effective methods for managing ships, trade routes, transit times, cargo ports, and containers (Lind et al., 2016).

In the context of environmental concerns, cruise ships are frequently observed discharging substantial amounts of sewage, food waste, and oily bilge water, containing insoluble particles, into the ocean. Byrnes and Dunn (2020) reported addressing pollution discharge from cruise ships and highlighted that the decomposition of these wastes and ocean dumping contributes to water acidification and a significant reduction in oxygen levels. This, in turn, leads to the proliferation of toxic algae blooms, posing a substantial threat to coral reefs (Lioret et al., 2021). Additionally, with the cruise industry's shift towards increasingly larger ships, tourist destinations face the challenge of adapting to the latest generation of ships. These ships require deeper and wider shipping lanes, which presents a dilemma for many tourist destinations. The location of shipping lanes close to shore, through which cruise ships pass, has significant environmental and economic impacts. Larger tract dredging can damage habitat, while ship traffic can result in sediment buildup that has the potential to cover sensitive habitats such as coral reefs and seagrass beds. Additionally, dredging costs tend to vary spatially (Sinay, 2022).

Coral reefs are one of the seabed ecosystems that are very beneficial for human life because of their enchanting aesthetic beauty as a recreation area, their ecological function as a coastal barrier from waves and erosion, and are a fish habitat for spawning, rearing, and fishing grounds for various types of fish and other marine organisms, as well as providing active compounds for various pharmaceutical and medicinal purposes (Hoegh-Guldberg, 2011; Gracia et al., 2018; Zhao et al., 2019; Reguero et al., 2018).

Shipping routes are the navigating lanes, both natural and man-made, in wide waterways used by large vessels to connect major ports and carry cargo (Sinay, 2022; Pirotta et al., 2019). These routes allow efficient, safe, and economical transportation of goods while offering the shortest sailing times. Karimunjawa Marine National Park (KMNP) which is composed of 27 islands is one of seven marine national parks in Indonesia. This archipelago is located about 100 km north of Semarang, Central Java. The richness of coral and coral fish species in Karimunjawa consists of about 100 species of corals documented from more than 50 genera and approximately 250 species of fish (Edinger et al., 2000). Consequently, tourism in KMNP has increased remarkably in the last decade. Since the early 2010s, cruise ship travel has experienced nearly continuous growth, exceeding 25% annually (Sabdono, 2019[b]). Associated with the increasing tourism boom has been an increase in the total number of cruise ships and the routes of ship traffic (Sabdono et al., 2019). This situation in the vicinity of coral reefs is not always benevolent and corals are subject to continuous stress. The negative impacts can include coral degradation and loss of marine life.

The increasing volume of ship traffic, water pollution from ships, and increased direct physical pressure on coral reefs due to ship groundings and anchoring activities are factors that allow damage to coral reefs (Satya et al., 2023; Walker et al., 2019; Zhang et al., 2019; Kostianaia et al. 2020). Today, the study on the impact of increasing shipping routes on the existence and health of coral reefs is limited. Few previous studies reported that damage to coral reef ecosystems has long-term impacts that cause reduced marine biodiversity, decreased fish populations, and loss of habitat for marine organisms (Eddy et al., 2021; Veron et al., 2009). Increasing human activity around KMNP due to the ever more crowded shipping traffic traversed by commercial ships, tourist ships, and local transport has become an important part of the economic life of the community and the environment in Karimunjawa. This is because the impact of increasing shipping routes on the existence and health of coral reefs is not yet fully understood. Hence in this study, the possible effects of shipping routes on coral reef degradation and diversity were investigated.

2. Materials and Methods

2.1. Experiment Design

Based on the tourism destinations and geographic locations, the ship routes were grouped into 3 categories (west, east, and non-routes). The West Route refers to regular arrival in these islands that are situated in the western part of Karimun island including Menjangan Kecil, Burung, Geleang, Cemara Besar, and Cemara Kecil islands. The East Route refers to regular arrival in these islands that are situated in the western part of Karimun island including Menjangan Besar, Gosong Saloka, Kecil, Tengah, and Sintok islands. Non-route refers to irregular arrivals of tourism in these islands including Sambangan, Seruni. Genting, Cendekia, and Menyawakan islands (Fig. 1). Three belt transects, with 2x15 meters (30 m^2) in size, were randomly establshed on each of the 15 islands. These transects were located at depths of 3 meters and 8 meters. Hence the total number of belt transects established is 90 transects. Within each belt transect, all scleractinian coral colonies exceeding 5 centimeters in diameter were recorded based on their genus. Corals were further classified as either healthy or diseased. Diseased colonies exhibited manifestations such as changes in color or structure, tissue loss, necrosis, and abnormal growth. Conversely, healthy colonies displayed no signs of lesions or other indications of compromised health. The prevalence of coral diseases was determined for each belt transect by dividing the number of colonies showing signs of each disease by the total number of colonies present in each transect. The other variables measured for reef degradation was % coral cover, H-index (H’), species richness (SR), and evenness (E).

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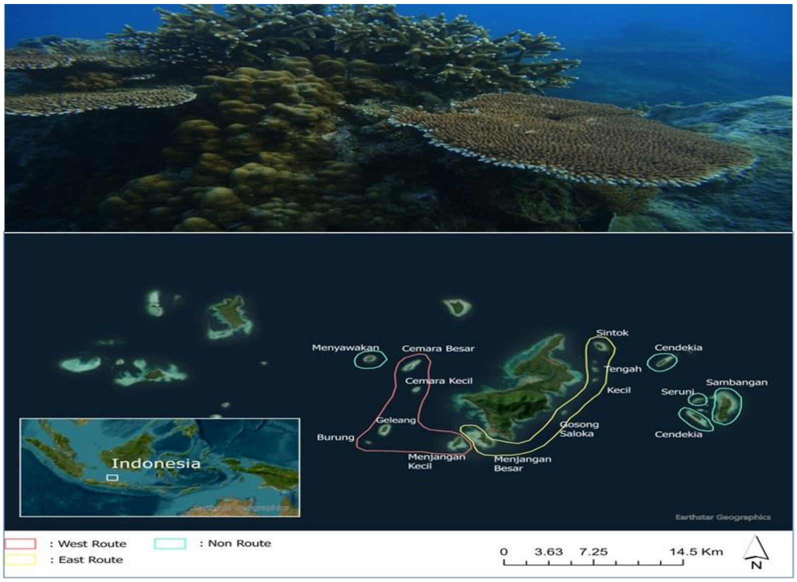

Figure 1. Route ships of Karimunjawa (Note- red: east shipping route; green: west shipping route; blue: non-route)

2.2. Data analyses

Parameters observed included coral damage, underwater photography, oceanographic parameters, type and number of corals per transect, number (healthy/sick coral), and percent coral cover. To determine the prevalence and coral cover, the formula used was adopted from Raymundo *et al*. 2008)):

$$Percent\ Prevalence = \frac{\sum Diseased\ coral\ colonies}{\sum Total\ colonies} \times 100 \qquad (1)$$

$$Percent\ Coverage = \frac{Lifeform\ coverage\ length}{Total\ transect\ length} \times 100 \qquad (2)$$

The Shannon-Weaver index was used to measure the H', GR, and E of coral reefs (Odum, 1971; Creb, 1994):

$$H' = \sum_{i=1}^{S} \text{Pi}\ lnPi \qquad (3); \qquad E = \frac{H'}{lnS} \qquad (4)$$

where: *pi*= relative abundance, S= species richness; H'= diversity index, and E-evenness.

Analyses of Variance-one way was used to analyze the impact of shipping routes on disease prevalence, coral cover, and biological diversity of corals among islands by using SPSS-22 software.

3. Results and Discussion

3.1. Impact of shipping-route traffic on the prevalence of coral diseases

The mean prevalences of coral disease in the west, east, and non-route are 7.5, 5.8, and 5.2 %, respectively (Fig. 2). White Syndrome (WS), White Blotch (WB), Black Band Disease (BBD), Pigmentation Response (PR), White Plague (WP), Ulcerative White Spot (UWS), Black Disease (BD), Growth Anomaly (GA) and Skeleton Erode (SE) were detected in all routes (Fig. 3.). It indicates a widespread issue affecting coral reefs in these areas. Statistically, there were no significant differences among them. However, the prevalence of coral disease in the west cruise line tends to be high and the non-cruise lines are the lowest one. Some previous studies of Karimunjawa coral diseases reported that coral disease prevalence in Menjangan Besar ranged between 10.6 and 43.61 % and found BBD, BrBD, UWP, WS, YBD, PR, WP and WBD (Nursalim et al., 2022). A swift evaluation of coral disease across three islands—Genting, Seruni, and Sambangan—in the Karimunjawa revealed that human activities, specifically coastal settlement, and floating cage mariculture, were responsible for the onset of coral disease. However, there was no notable difference in coral disease prevalence among areas frequented by cruise lines and those that were not (Sabdono *et al.*, 2019[a]; 2019[b]).

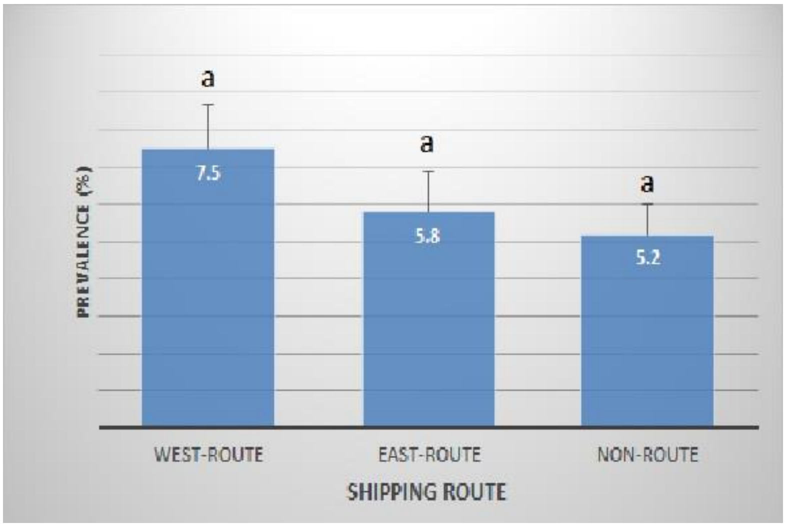

Figure 2. Coral diseases prevalence of Karimunjawa on three shipping routes (Note: the same word characters means no significant differences)

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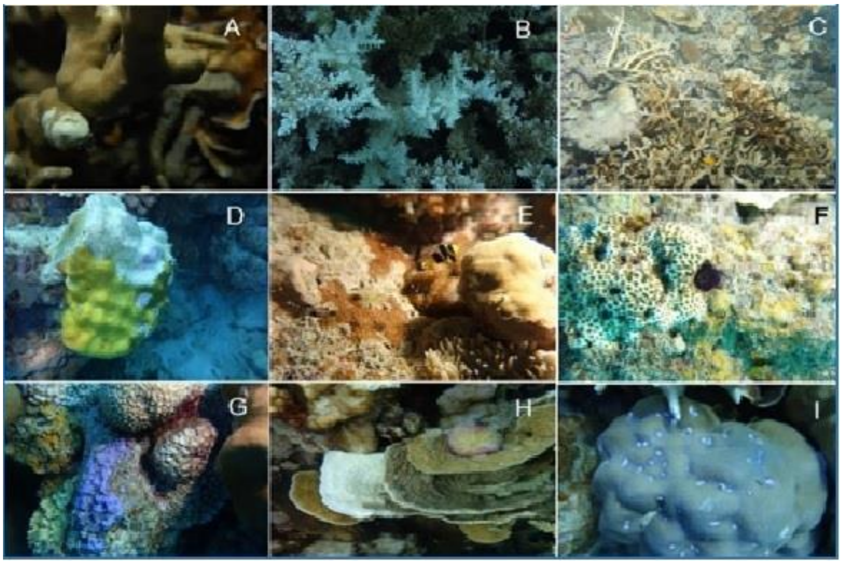

Figure 3. Coral diseases prevalence of Karimunjawa [Note: A- White Blotch (WB), B-White Syndrome (WS), C-Sedimental Eroding (SE), D-White Plague (WP), E-Skeletal Erode (SE), F-Bleaching Syndrome (BS), G-Growth Anomaly (GA), Black Band Disease (BBD), and Pigmentation Response (PR)].

3.2. Impact of shipping-line activity on % coral cover

Fig. 4. demonstrated that the % coral cover in the west, east and non-cruise line were 68.14, 64.9, 61.18 %, respectively. Statistically showed no significant difference among routes in % coral cover.

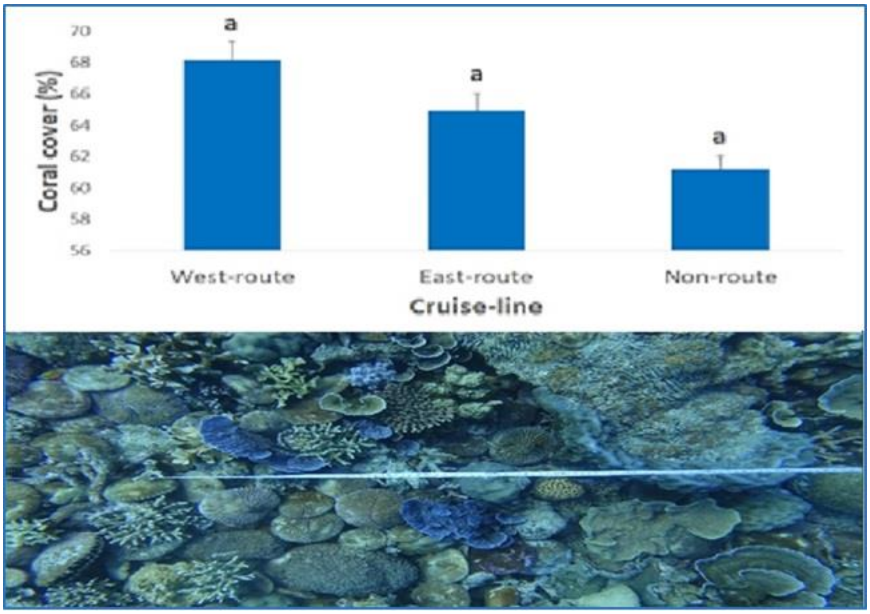

Figure 4. Percent coral cover of line-transect on cruise route.

Even the cruise line has no significant difference in this study, however, shipping lines have detrimental effects on coral reef ecosystems in Southeast Florida (Walker *et al.*, 2012). Additionally, the Great Barrier Reefs (GBR) have been changed by human activities, and live coral cover has declined overall (Sweatmanet et al. 2011). In this study, the west route is the most visited by tourists, vessels, and cruise, ships, however, it has the highest % of coral cover. Based on the data available, the differences observed in coral cover between the west, east, and non-cruise lines are not significant enough to conclude that one category has significantly more or less coral cover compared to the others. However, by knowing that there were no significant differences between the pathways, environmental management can detail conservation efforts evenly across the region, without focusing too much on one pathway. It is important to continuously monitor and analyze data to support conservation policies and sustainable environmental management. Further research may be needed to understand the factors behind the differences in % coral covers in each pathway.

3.3. Impact of shipping-route activity on abundance and diversity

Statistical analysis showed that the impact of shipping-line activity on coral abundance and species richness are significantly different (Fig. 5.). However, there are no significant differences in terms of diversity and evenness. Post-hoc test $LSD_{5\%}$ revealed that the coral abundance and species richness on the west route were significantly different to the east route, and no significant difference to the non-shipping route. These differences could be multifaceted and may include factors like vessel-related disturbances, water quality changes, or specific environmental conditions. Numerous prior investigations have indicated that water quality controls the relative abundance and physiology of dominant soft corals and contributes to phase shifts from hard to soft coral dominance (Baum et al, 2018). In addition, a study of the effect of anthropogenic activity on corals in Jakarta Bay showed pronounced differences in composition and coral cover among zones (Harahap et al 2021). Moreover, Kunzmann et al (2018) reported that anthropogenic pressure from local as well as regional sources is responsible for the spatial structure and health of reefs. Shifting from massive morphologies toward more complex foliose and branching corals were apparent across all zones (Denis et al, 2017).

Shipping route	Diversity (H')	Relative Abundance (RA)	Species Richness	Evenness
West route	2.18 ± 0.7[a]	36.6 % [a]	17.86 ± 0.65[a]	0.76 ± 0.02[a]
East route	2.02 ± 0.9[a]	26,5 %[b]	14.04 ± 1.01[b]	0.78 ± 0.02[a]
Non-route	2.20 ± 0.8[a]	37,0 %[a]	17.12 ± 0.61[a]	0.79 ± 0.01[a]

Fig. 5. Impact of shipping-line activity on abundance and diversity

3.4. Depth effect on the prevalence of coral diseases, % coral cover, abundance, and diversity

The effect of shipping-route activity in response to increases in depth, specifically, whether relationships exist between depth and prevalence of coral diseases, coral cover, and diversity was presented in Table 1. This table showed that there were no significant differences between depths of 3 m and 8 m in prevalence of coral diseases, % coral cover, abundance, species richness, and diversity. However, the % coral cover tends to decrease with depth, likely due to reduced light. Meanwhile, reduced light exposure at greater depths can constrain the photosynthetic activities of zooxanthellae (Kahng et al., 2019; López-Londoño et al., 2024). Additionally, very low water flow may result in the formation of boundary layers around the coral surface, hindering nutrient absorption and consequently suppressing coral respiration and growth (Hughes et al., 2020; Nelson & Altieri, 2019).

Table 1. The effects of shipping-route activity on the prevalence of coral diseases, % coral cover, and abundance and diversity on different depth

No.	Depth	Prevalence (%)	Coral Cover (%)	H-Index	Species Richness	Evenness
1.	3 m	6.18 ± .94 a	67.07 ± 2.42 a	2.15 ± .06 a	16.22 ± .59 a	.79 ± .01 a
2.	8 m	6.43 ± .73 a	62.85 ± 2.89 a	2.13 ± .04 a	17.07 ± .72 a	.76 ± .01 a

It is important to note that each location has unique conditions, and human impacts on coral reefs are highly dependent on the local context. Additionally, effective conservation and management efforts can help reduce the negative impacts of human activities on coral reefs at various depths.

4. Conclusions

In conclusion, the management of the KMNP area is quite good, even though the shipping lanes are quite congested, coral cover is still maintained. The most important result was that between the non-route route and the west route, there were no significant differences in coral abundance and species richness. However, it is necessary to consider again the limited data obtained and the limited research time available, so that it cannot capture long-term trends or changes in coral cover. So, it is necessary to carry out further research to find out the specific causes of differences in coral abundance and species richness in the context of shipping route activities.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

A. Sabdono, conceived and designed the study methodology, analyzed and interpreted the data, drafted the manuscript, visualization, supervision, project administration, and funding acquisition. D.P. Wijayanti, conceived and designed the study methodology, analyzed and interpreted the data, and wrote—reviewed, and edited the manuscript. M. Helmi, analyzed and interpreted the data, writing—reviewing, and editing. E.D. Satya analyzed and interpreted the data, and data curation.

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Data availability

All of the data that support the findings of this study are available in the main text. The data underpinning the analysis reported in this paper are deposited at “Data repository” at https://doi.org/10.3897/biorisk.xx.xxxxxx.

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