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Zooplankton communities in Cenderawasih Bay National Park, West Papua: can their composition be used to predict whale shark Rhincodon typus Smith, 1828 appearance frequencies?

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Abstract. The use of lift net fishing vessels in Cenderawasih Bay National Park (CBNP) along with the increased popularity of CBNP as an ecotourism area is suspected to have an impact on the behavior and population of its whale sharks Rhincodon typus Smith, 1828. The differing frequency of whale shark appearances along the waters of CBNP has been alleged to be related to the distribution of the whale sharks' food sources, one of which is zooplankton. This preliminary research aimed to investigate the composition of the zooplankton community in CBNP based on distance from the coast and difference in locations, and to use the pattern of zooplankton compositional variation as a basis for indication of the frequency of whale shark appearances. There were clear differences in the composition and diversity of zooplankton communities among sampling stations, but these differences were not strong enough to infer the cause of the different whale shark appearance frequencies in different locations. Nevertheless, the waters of CBNP had an equal availability of zooplankton for whale sharks. With the increasing popularity of whale shark tourism, understanding the species' feeding habits is critical to the sustainability of both the industry and the enigmatic species on which it depends.

1. Introduction

Located in Indonesia's West Papua Province, Cenderawasih Bay National Park (CBNP) has been identified as one of the aggregation sites of the whale shark Rhincodon typus Smith, 1828 in the Indo- Pacific region. Previous long-term monitoring of whale sharks conducted in CBNP waters has provided an overview of the sex composition and size of the population inhabiting this area [1, 2]. Nevertheless, knowledge of this population is still very limited compared with that in other areas [3], such as in Australia [4, 5, 6, 7], Mexico [8, 9], Belize [10], or Seychelles [11, 12]. In recent years, whale sharks have been reported to often roam near CBNP's coasts, allegedly as a response to the booming of bagan (stationary fishing vessels with lift nets) along the coast. This has resulted in CBNP gaining popularity as a tourist destination, the results of which has been both economically rewarding and potentially damaging to the whale shark population itself. An increasing number of tourists visit the bay for a glimpse of the whale sharks around the lift net vessels. These sharks are lured to the surface by small fish being used as bait, a method that may cause a direct disturbance to whale sharks by altering their natural feeding behavior, along with accustoming them to interactions with humans, which can make them an easier target for poachers. The whale sharks may also be indirectly disturbed due to the vulnerability of their habitat to increased human activity in the water and along the mainland, as pollutants entering the ocean affect the survival of the marine organisms on which the sharks feed.

The impact of both the use of lift net vessels for fishing and the increasing popularity of CBNP as a whale shark ecotourism site on the behavior and population of its whale sharks has not been studied in depth [3]. Previous studies indicated a correlation between the number of vessels and frequency of whale shark sightings [1, 2]. They also reported differences in the frequency of whale shark sightings in different parts of CBNP, specifically along the waters of the villages of Kwatisore and Napan Yaur. Between 2013 and 2016, there were reportedly no sightings of whale sharks in Napan Yaur, in contrast with Kwatisore, where sightings were frequent. The prevailing speculation that this disparity is related to the abundance and distribution of one of the whale shark's food sources, anchovies, known locally as puri is supported by one study whose catch data revealed that anchovies composed a very small fraction of Napan Yaur's annual catch, whereas in Kwatisore, they were the major fish caught by fishermen [2].

Baseline data on whale sharks' preferred food sources and their availability in CBNP is essential for monitoring the national park's water quality and the impact of human activities on its whale shark population, as well as providing a basis for estimating the carrying capacity of its ecosystem. This preliminary research aimed to investigate the background composition of zooplankton in CBNP, along with the pattern of variations in composition, which could be used as an indicator of whale shark sighting frequencies.

2. Methods

Research was carried out in Cenderawasih Bay National Park, in the waters off the coast of Nabire District, West Papua Province, Indonesia (approximately 2°53'04.5"S 134°50'15.4"E to 3°13'47.2"S 134°57'43.5"E), in August 2016. Zooplankton sampling was performed following the procedures described in Motta et al. and Taylor, with modifications [5, 10]. Because of the darkness of the water, a search for naturally feeding whale sharks to directly collect the zooplankton samples on which they were feeding was not possible. We therefore opted for an indirect approach. Zooplankton samples were collected from eight stations located between the villages of Kwatisore and Napan Yaur (Figure 1). In each station, a transect was laid out perpendicular to the shoreline, and zooplankton samples were taken at four sampling points at distances of 0.5, 1.0, 2.0 and 4.0 nautical miles from the coastline. Sampling was carried out in the morning between 8:00 and 11:00 a.m., except for the 0.5 nautical mile sampling point on the first transect, where sampling was carried out at 3:00 p.m. because of bad weather. Samples were collected by horizontally towing a 125 µm mesh conical plankton net with a 450 mm opening just under the water surface behind the boat for 2 minutes at a constant speed of 2 knots. Each zooplankton sample was then homogenized in the cod end, concentrated to 10 ml, then fixed with 1 cc of 4 % formaldehyde and 2 to 3 drops of Lugol's iodine solution. In total, 32 zooplankton samples were collected from all sampling sites. Zooplankton identification was conducted according to Shirota [13]. Using the program SPADE [14], Morisita's index of similarity was used to measure the similarity of zooplankton community composition between sampling sites, while diversity estimates were performed using Shannon's index and the inverse Simpson's index.

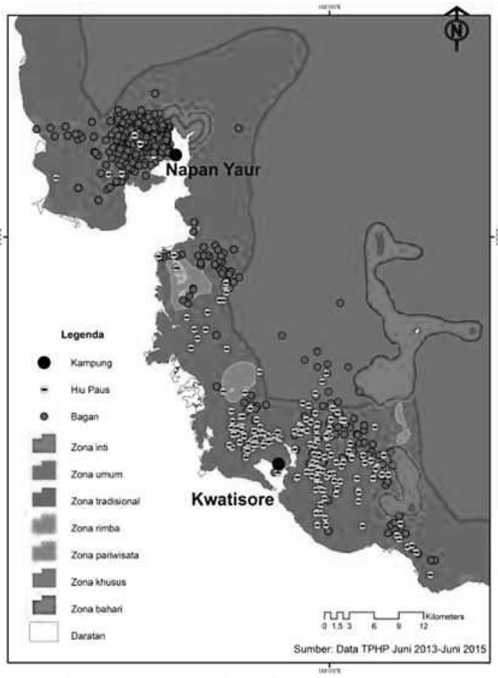

Figure 1. Approximate placement of plankton sampling stations and transects. Yellow lines represent transects, numbers indicate station number. (Source of map: Tania 2015, with modifications)

3. Results and Discussion

3.1. Result

3.1.1. Zooplankton communities composition in Cenderawasih Bay National Park

Across distances (0.5, 1.0, 2.0, and 4.0 nautical miles), the zooplankton communities were found to have almost the same taxonomic group composition. Crustaceans dominated CBNP at all distances, with a proportion of 78–88 %, 59–65 % of which were copepods (Figure 2). This result is in accordance with Tait [15], who reported that at least 70 % of marine zooplankton are crustacean, with Copepoda as the predominant group. The dominance of crustaceans and similarity in taxonomic composition was also found in the majority of sampling stations (Figure 3). Crustaceans dominated the composition of seven of the eight stations, ranging from 76 to 97 %, whereas rotifers had the lowest proportion, ranging from 2 to 20 %. The only station in which this was not the case, Station 4, was composed of 51 % crustaceans and 34 % rotifers, respectively the lowest and highest proportions among the stations. The zooplankton community in Stations 7 and 8, located in Napan Yaur, was composed almost entirely of crustaceans 91 % and 97 %, respectively. Sergestids were not found in Stations 4 and 5, while barnacles were not found in Stations 2, 4 and 5 (Figure 4). Copepods and branchiopods were ubiquitous in all sampling points, except for a couple in Station 8 where both groups were absent.

In general, all of the sampling sites were highly similar in zooplankton community composition. Morisita's similarity index for multiple communities estimated a pronounced similarity level of 0.97 among sampling points based on distance, while the similarity of communities among stations was comparatively lower with 0.75 (Table 1). The conspicuously high similarity across distances was consistent with the pairwise similarities between the sampling points, whose values ranged from 0.94

to 0.98 (Table 2). Pairwise similarity values between sampling stations showed greater variations, ranging from 0.43 to 0.93, with the lowest values found between Station 8 and the other stations (Table 3).

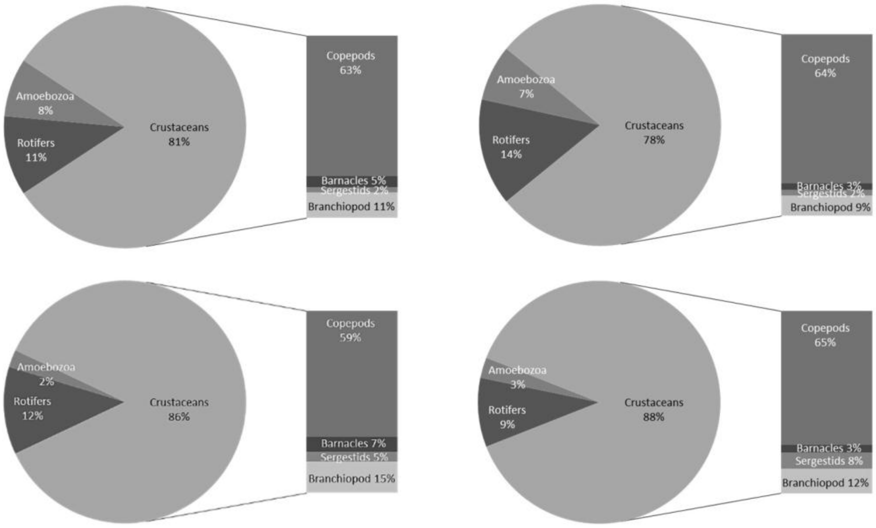

Figure 2. Composition of zooplankton taxonomic groups in Cenderawasih Bay National Park based on distance from the coast: a) 0.5 nautical miles; b) 1.0 nautical miles; c) 2.0 nautical miles; d) 4.0 nautical miles.

Table 1. Morisita's similarity index for multiple zooplankton communities in Cenderawasih Bay National Park. SE, standard error.

Zooplankton communities similarity	Estimate (SE)	95% Confidence interval	Zooplankton communities similarity
Among stations	0.75 (0.03)	(0.70; 0.81)	Among stations
Among distances	0.97 (0.02)	(0.94; 1.00)	Among distances

Table 2. Pairwise Morisita's similarity indices for zooplankton communities found in various distances in Cenderawasih Bay National Park. NM, nautical miles.

Sampling distance	0.5 NM	1.0 NM	2.0 NM	4.0 NM
0.5 NM	1.00	0.98	0.94	0.98
1.0 NM		1.00	0.94	0.98
2.0 NM			1.00	0.95
4.0 NM				1.00

Table 3. Pairwise Morisita's similarity indices for zooplankton communities found in various sampling stations in Cenderawasih Bay National Park.

Station	1	2	3	4	5	6	7	8
1	1.00	0.91	0.78	0.78	0.90	0.86	0.87	0.58
2		1.00	0.84	0.85	0.94	0.93	0.87	0.54
3			1.00	0.58	0.66	0.83	0.88	0.84
4				1.00	0.89	0.82	0.58	0.43
5					1.00	0.81	0.77	0.43
6						1.00	0.85	0.67
7							1.00	0.76
8								1.00

3.1.2. Zooplankton communities diversity in Cenderawasih Bay National Park

A total of 11 zooplankton genera from three phyla and six taxonomic groups were identified from the samples. Both Shannon's and Inversed Simpson's diversity indices resulted in similar values in six of the eight stations, with Station 6 having the highest diversity (Table 4). Stations 5 and 8 were noticeably less diverse than the other stations, based on both indices. Both indices also showed similar levels of community diversity at all four distances examined, with the highest diversity being found at a distance of 2.0 nautical miles (Table 5).

3.2. Discussion

3.2.1. Potential factors influencing the sighting frequency of whale sharks

Whale shark monitoring in the CBNP area revealed that whale sharks were often seen near lift net vessels stationed around the Kwatisore area, but not in Napan Yaur. People associated this behavioral pattern with the low quantity of anchovies caught in Napan Yaur compared with Kwatisore, where they made up the largest proportion of fish caught by lift net vessels. This resulted in a public perception that anchovies were the main food source of whale sharks in CBNP. In order to prove this assumption, information on the natural diet of both the anchovies and whale sharks in this region is required; however, to date no such data have been made available.

In general, anchovies are known to prey on small zooplankton, especially crustaceans [16]. Based on 20 specimens of anchovies taken during the study, all were identified to belong to one species, *Encrasicholina punctifer* Fowler, 1938 (buccaneer anchovy). This anchovy species is commonly found near coasts in the Indian Ocean, and spawns continuously throughout the year [17]. Buccaneer anchovies are the most important food source for large pelagic fish [18]. Thus, it is possible that, in the CBNP area, buccaneer anchovies have become whale sharks' main source of food. On the other hand, it is also possible that the emergence of whale sharks at sites where the anchovies form the majority of the catch is merely due to both species sharing the same food preferences. Both possibilities require further research if the location and frequency of whale shark sightings is to be more clearly understood.

3.2.2. Composition and diversity of zooplankton as an indicator of whale shark appearances

Kwatisore and Napan Yaur's different whale shark sighting frequencies has previously been attributed to either the presence of anchovies or the type of zooplankton on which the whale sharks feed. Our results showed that the zooplankton communities' similarities in composition and diversity at different distances were very high. This suggests that, up to 4.0 nautical miles from the coast, physicochemical factors in CBNP did not play a deterministic role in zooplankton distribution, as well as that CBNP's waters ensured the availability of zooplankton as a food source for whale sharks with a relatively uniform abundance and diversity. Thus, within that range, zooplankton composition and diversity were not a reliable indicator or predictor of the appearance of whale sharks in CBNP.

The similarities in zooplankton composition between Station 8 in Napan Yaur and the other stations were low. If this were assumed to be an indicator of the lack of whale shark sightings around this station, then the main constituents of the whale sharks' diet in CBNP and in this case, also the anchovies' diet could not possibly be crustaceans, especially copepods, as they were the group that dominated the zooplankton communities in the Napan Yaur region. More data are needed to substantiate this hypothesis, as studies on whale shark diets in various locations around the world have generated highly variable results. In Mexico, it was reported that nearly 85 % of whale sharks' diet consisted of copepods [8]. In Australia, whale sharks were found to feed primarily on krill (Pseudeuphausia latifrons), copepods, and schools of small fish [5], while in Tanzania, sergestid shrimp Lucifer hanseni composed over 50 % the whale sharks' diet [19]. There is an indication that whale sharks have no preference for certain types of prey, but rather show preference for the quantity of biomass of their prey. Generalizations therefore cannot be made based on our results.

Given that this preliminary study aimed to get a general idea of whale sharks' natural diet in CBNP, further research should be conducted on the differences in zooplankton biomass at various locations in CBNP in relation to the frequency of whale shark appearances. It is also important that zooplankton samples are taken on the spot where whale sharks are feeding, so that the composition and biomass of prey can be identified and estimated more accurately. There is no reliable information on the daily distribution of plankton and CBNP's whale sharks' natural feeding behavior, so the results of this study leave a gap of information in terms of the actual availability of whale shark food sources. Research on the temporal abundance of anchovies in CBNP's waters should also be carried out, since there is a possibility that the frequency of occurrence of whale sharks will be positively correlated with the abundance of anchovies at any given time.

3.2.3. Implications for Whale Shark Habitat Management in CBNP

The wide gap of information on the ecology of whale sharks in CBNP could have a negative impact on the sustainability of the population. Efforts to safeguard whale shark populations in CBNP need to be based on knowledge of their natural diet and how to maintain it. Ignorance of their natural diet has also driven negative and conservational damaging stereotypes of the whale sharks among some fisherman in CBNP, who hold that the sharks harm their livelihood by preying on their catches. Any solution to this problem requires collaboration between stakeholders so as to align the economic and ecological interests of the parties involved, education of the public on whale shark ecology and its importance to the local economy, and of course more extensive research on the whale shark itself, all of which will ensure a sustainable, environmentally friendly, and mutually beneficial whale shark-based tourism industry.

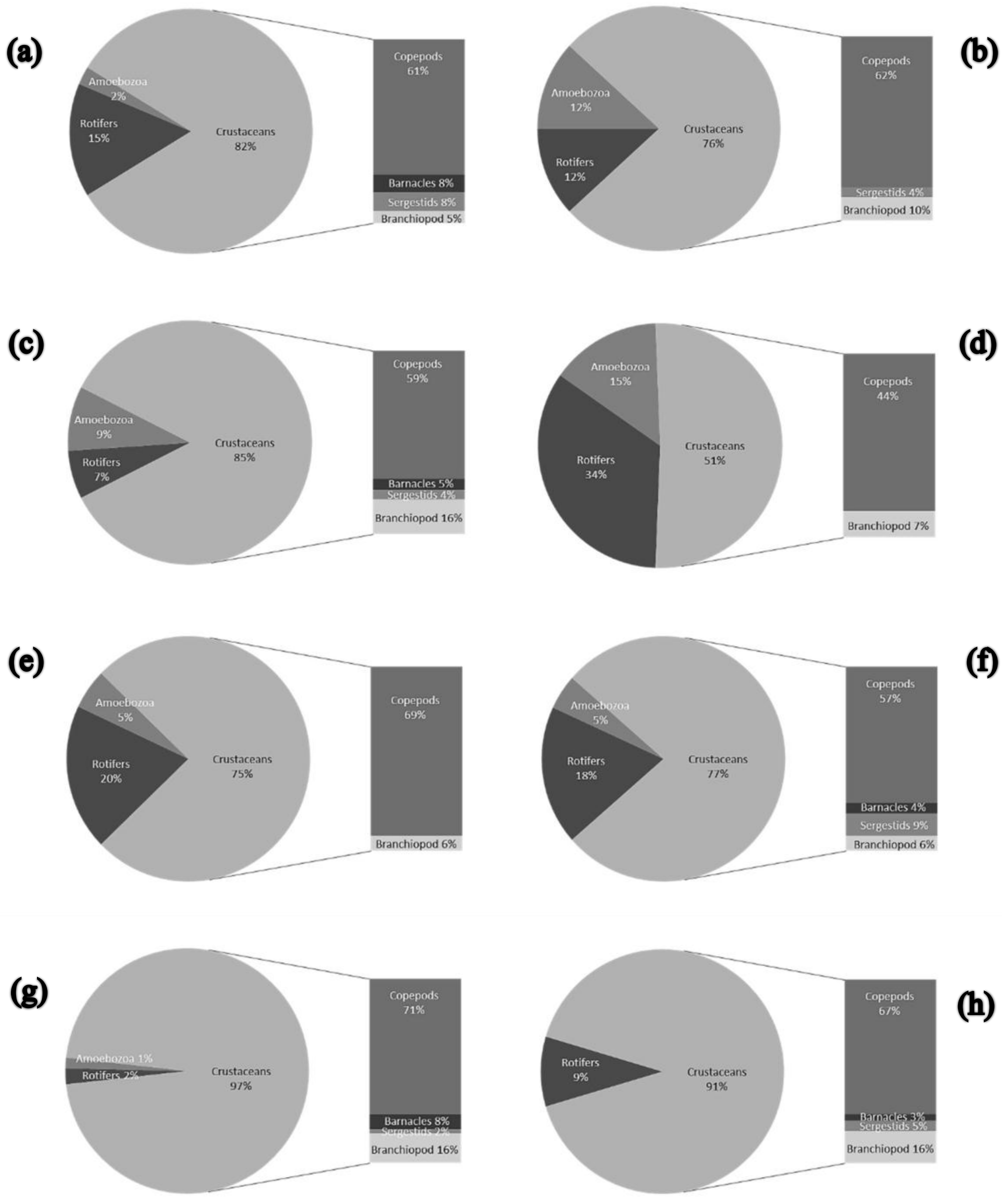

Figure 3. Composition of zooplankton taxonomic groups in Cenderawasih Bay National Park in Nabire, from the east (Kwatisore) to the west (Napan Yaur): (a) Station 1; (b) Station 2; (c) Station 3; (d) Station 4; (e) Station 5; (f) Station 6; (g) Station 7; (h) Station 8.

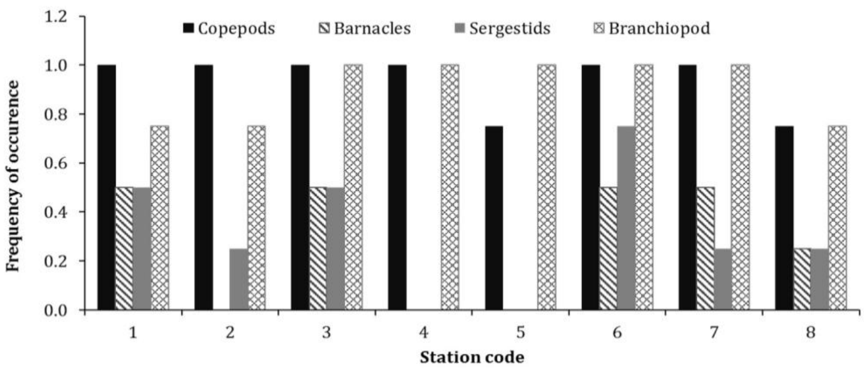

Figure 4. Distribution of crustaceans, the dominant zooplankton group in Cenderawasih Bay National Park, in various sampling stations based on their occurrence in four sampling points of each transect.

Table 4. Zooplankton community diversity of various sampling stations in Cenderawasih Bay National Park. SE, standard error.

Location	Diversity estimator	
	Shannon Index (SE)	Inversed Simpson Index (SE)
Station 1	2.15	7.64 (0.11)
Station 2	2.22	8.30 (0.11)
Station 3	2.29	8.74 (0.08)
Station 4	2.02	6.41 (0.12)
Station 5	1.78	5.37 (0.10)
Station 6	2.34	10.04 (0.09)
Station 7	2.11	7.16 (0.13)
Station 8	1.88	5.01 (0.14)

Table 5. Zooplankton community diversity at various distances in Cenderawasih Bay National Park. NM, nautical mile; SE, standard error.

Sampling distance	Diversity estimator	
	Shannon Index (SE)	Inversed Simpson Index (SE)
0.5 NM	2.26 (0.03)	8.27 (0.11)
1.0 NM	2.26 (0.03)	8.51 (0.12)
2.0 NM	2.32 (0.03)	9.21 (0.09)
4.0 NM	2.30 (0.03)	8.94 (0.09)

4. Conclusions

From Kwatisore to Napan Yaur, Cenderawasih Bay National Park was found to have uniform potential to provide zooplankton as a whale shark food source. Although there was a clear distinction in the composition and diversity of the zooplankton community at one station in Napan Yaur, this study could not provide conclusive results on what causes differences in the frequency of whale shark sightings at various locations in CBNP. With an increasing number of people visiting CBNP to see its whale sharks, understanding their feeding habits is critical to sustaining both the industry and the enigmatic species on which it depends. The manipulation of whale shark appearances for the sake of tourism, such as using bait to lure the sharks to the surface, should be also done in accordance with their natural feeding habits, so as not to potentially alter the behavior of the whale sharks and disrupt their natural habits and habitat.

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