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Indication of feeding ground inside the Manta Ray's cleaning station by investigating the zooplankton community composition in Raja Ampat Islands, Indonesia

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Abstract. *Widiastuti, Borumei D. 2024. Indication of feeding ground inside the Manta Ray's cleaning station by investigating the zooplankton community composition in Raja Ampat Islands, Indonesia. Biodiversitas 25: 1239-1245.* Raja Ampat Islands, Indonesia, hosts reef manta ray (*Mobula alfredi*) and oceanic manta ray (*M. birostris*). Studies reported that these areas have functioned as manta ray cleaning and nursery sites. However, food availability is also the main attraction for manta ray aggregation. Thus, this study investigated the zooplankton community composition and abundance in the Manta Sandy Spot, a manta's cleaning station, to indicate its other role as the manta ray's feeding ground. Three sampling sites were located around the cleaning station bordered by mooring. A plankton net collected samples with a 100 µm mesh size, a mouth diameter of 30 cm, and a 1 m length horizontally towed from a boat for 5-10 min at a speed of ~2 knots. Manta ray's behavior was observed by snorkeling in the surface waters. Results demonstrated that the zooplankton was only composed of Copepod, consisting of three orders: Calanoida, Cyclopoida, and Harpacticoida. Among these orders, Calanoids dominated the zooplankton composition (93%). These genera were further grouped according to their body sizes, whereas three genera in Calanoids (*Eucalanus, Calanus,* and *Undinula*) were categorized as large-bodied zooplankton. The presence of the large-bodied zooplankton in the water samples, Calanoids, and Cyclopoids, which have been reported as the manta rays' preferred prey, indicates the area's role as the manta ray's feeding ground. This finding is supported by studies that found these zooplankton in the water where manta rays' feeding activity occurred and were absent in areas with no feeding activity. More indications were demonstrated by the manta ray's behavior, which followed the feeding activity criteria.

Keywords: Feeding and cleaning ground, Manta Ray, Raja Ampat Islands, Zooplankton

INTRODUCTION

Feeding activity can determine the animal's distribution (Fortune et al. 2020), reproductive success (Beltran et al. 2023), food availability (Billard et al. 2020), as well as evolutionary patterns through niche specialization (Dehnhard et al. 2020). Therefore, understanding the feeding activity, particularly that of a threatened organism such as a manta ray, may promote its conservation management effectively. Raja Ampat Islands, Indonesia, hosts two species of reef manta ray (*Mobula alfredi*) and oceanic manta ray (*M. birostris*). *M. birostris* has a global distribution found in tropical and subtropical coastlines that are usually near the more productive deep water (Andrzejaczek et al. 2021). In contrast to its close relative, *M. alfredi* inhabits near the shore, especially tropical reef atolls and barrier reefs (Setyawan and Mambrasar 2018; Germanov et al. 2022). This planktivore organism can migrate long distances to find suitable habitats, leading it to land in targeted or non-targeted fisheries countries such as Indonesia, Philippines, Mozambique, Peru, Mexico, Sri Lanka, and India (Croll et al. 2015). The worldwide declining population of manta rays is mainly due to targeted and bycatch fisheries activities, and this fish is widely used in traditional Asian medicinal products (O'Malley et al. 2017). However, fisheries are not the only pressure on the manta ray's existence. Manta ray tourism is estimated to contribute US$ 140 million annually to the global economy (O'Malley et al. 2013), where dive operators offer diving and swimming experiences with manta rays. Human interaction may interfere with the manta rays' which brings several negative consequences, such as interrupting their natural behavior and degrading their habitat (Venables 2013), inhibiting reproduction and feeding activity, and potentially harming the manta ray through injury because of close contact with the tourist boat (Stevens et al. 2018). Internationally, all Mobulids species, including *M. alfredi* and *M. birostris*, are classified as "Vulnerable" and "Endangered," respectively, on the IUCN's Red List of Threatened Species (IUCN, 2023). Indonesia was the third largest exporter of manta ray gill plates, until the local government of Raja Ampat Regency, West Papua Province, issued Regional Regulation 9/2012 that prohibits the capture of sharks, rays, and certain other fish species in Raja Ampat waters, in explicit recognition of the value of living sharks and manta rays *Manta* spp., in particular, to the local economy, which is based mainly on marine ecotourism (Anon. 2012), followed by the issuing of Regulation of the Minister of Marine Affairs and Fisheries 4/KEPMEN-KP/2014 which established the full protected-status of both species of manta rays, *M. birostris* and *M. alfredi* (Anon. 2014). However, the recovery from continued fishing is low because of the manta ray's slow growth, late maturity, and low number of offspring (Dulvy et al. 2014; Stevens 2016).

Manta rays aggregate around the Raja Ampat Islands due to their function as a cleaning station (Setyawan and Mambrasar 2018) and nursery ground (Setyawan et al. 2022). In contrast, primary productivity plays a vital role in this occurrence. Cleaning behavior is conducted when a manta ray (client) visits the reefs to remove the ectoparasites, fungi, algae, or necrotic tissue by the cleaner fish (host) (Garner 2013; Demairé et al. 2020; Bshary and Noë 2023). It is indicated by the slow motion or even motionless manta rays on the top of the reefs, allowing the small fish to clean its skin and inner gill slots (Germanov et al. 2019; Araujo et al. 2020). This behavior is the most observable in manta rays. However, data on the feeding and prey availabilities in these areas still need to be explored, even though several studies demonstrated that food availability is one of the main attractions for manta ray aggregation besides cleaning habits (Armstrong et al. 2016; Harris et al. 2020; Harris and Stevens 2021). In contrast, there is overlap in the use of cleaning and feeding stations. The manta ray is a planktivorous pelagic organism that feeds on zooplankton (Perryman et al. 2019). Its feeding ground is indicated by the higher zooplankton biomass at the feeding activity locations than at other sites where no feeding activity occurs. Nonetheless, tropical water has low nutrient content (oligotrophic); therefore, it employs several strategies to cope with this. This plasticity strategy, which is demonstrated by the foraging time, swimming into deep water, swimming in circular patterns on the surface water to concentrate the zooplankton (Gadig and Neto 2014), bottom feeding, and concentrating the zooplankton in the movement such as vortex (Stevens 2016). The occurrence of near-surface zooplankton is significant for manta ray diet sources as its foraging behavior is reported in many aggregation sites around the world, such as those in Australia (Couturier et al. 2014; Armstrong et al. 2016), Hawaii (Whitney et al. 2023), Indonesia (Beale et al. 2019; Germanov et al. 2019; Setyawan et al. 2022), the Maldives (Armstrong et al. 2021), Mozambique (Carpenter et al. 2022), Philippine (Rambahiniarison et al. 2023), and New Caledonia (Lassauce et al. 2020). Manta ray aggregates where prey productivity elevates (Armstrong et al. 2016; Lezama-Ochoa et al. 2020; Armstrong et al. 2021). The position of zooplankton as the primary diet source for manta rays is indicated by the study of Couturier et al. (2013) using stable isotope $\delta^{15}N$. This study also revealed that while the near-surface zooplankton biomass decreased or was insufficient to support its energy demands, it feeds the demersal zooplankton as an alternative. Furthermore, *M. alfredi* feeds near the surface (Armstrong et al. 2016); surface-feeding activity occurred during the daytime as the observation was mainly done during the daytime (Harris et al. 2021). This behavior is typical among the Mobulidae family (Paig-Tran et al. 2013).

Determining the manta ray's prey community composition and abundance can be used to estimate its feeding dynamic and the importance of the areas on the aggregation sites observed. Moreover, this study can be applied in planning marine protected areas and fishery management, contributing to sustainable ecotourism in the Manta Sandy Spot in the Raja Ampat Islands by increasing the diving experiences with manta rays. Therefore, this study investigated the zooplankton community composition and abundance in the Manta Sandy Spot, a manta ray's cleaning station, to evaluate its role as the manta ray's feeding ground.

MATERIALS AND METHODS

Study area

The study site was located on Manta Sandy Spot, which is a manta cleaning station located between Arborek and Mansuar Islands in the Dampier Strait, Raja Ampat Islands, Indonesia (0°34'48.5" S and 130°32'31.5" E) (Figure 1).

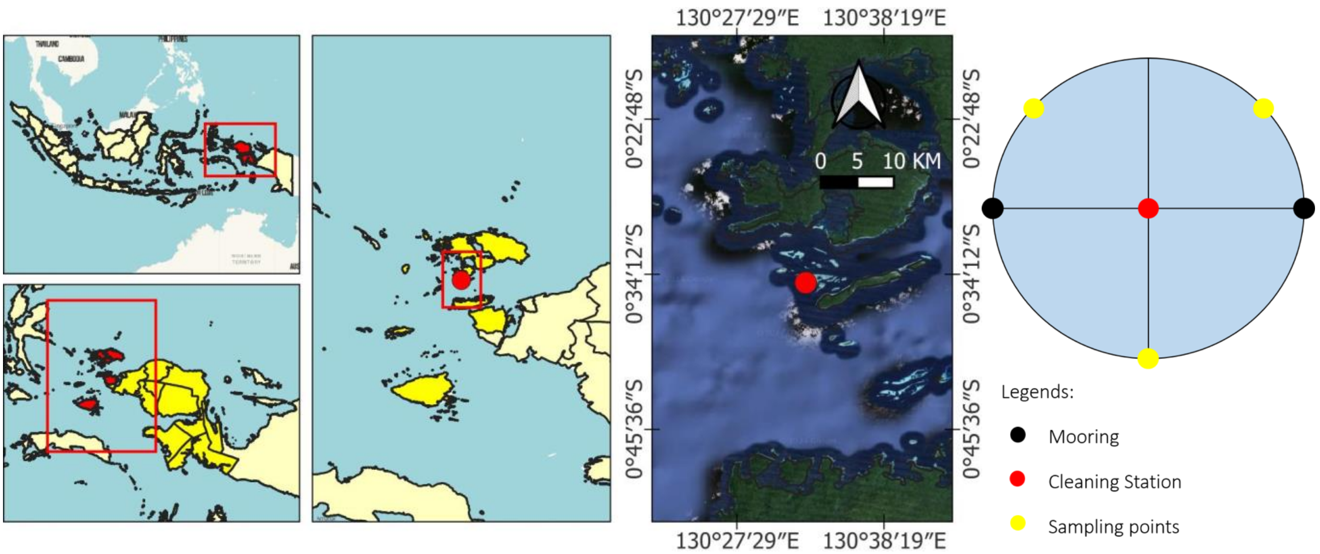

Figure 1. Location of sampling sites around Manta Sandy Spot, Dampier Strait, Raja Ampat Islands, West Papua Province, Indonesia. A. Map of the location of sampling sites. B. Sketch of sampling sites' position in the manta ray's cleaning station

The manta rays' behavior on surface water was observed in January 2018. In comparison, zooplankton samplings were collected in June 2019. There is a gap between zooplankton sampling and observing the manta's swimming behavior. The authors could not collect the zooplankton samples and simultaneously observe the manta's swimming behavior. We used a boat to tow the plankton net, and if we did so, we were afraid it would disturb the mantas that were feeding on the surface.

Sample collection

The sampling sites were determined at three sites in the manta's cleaning station that were bordered by mooring (Figure 1). This location is defined according to the Regional Public Service Agency Regional Technical Implementing Unit (BLUD UPTD) in the Management of the Conservation Area (KKP) of the Raja Ampat Islands where manta reported in the areas. The sampling method was horizontal towing using a plankton net with a mesh size of 100 µm, a 30 cm diameter mouth, and 1 m in length. The plankton net was towed from a boat for 5-10 min at a speed of ~2 knots. Samples were kept in a 100 ml glass bottle sample and preserved in three drops of 4% formalin buffered.

Sample fixation and identification

Samples were identified under a microscope according to their morphology to the genus level according to Newell and Newell (1963), and the abundance was measured at a Sedgwick Rafter cell counter. Due to limited resources, the authors could not further identify the zooplankton at the species level.

Observation of Manta's behavior

The manta ray's behavior was observed by snorkeling on the surface water for five days in a row from 08.00 AM-04.00 PM. Their numbers and behaviors were recorded with the underwater camera by a diver/researcher who snorkeled quietly and kept a distance when the manta rays appeared around the study sites once every hour. The authors did not observe a particular manta's behavior and only counted its presence/absence.

Data analysis

The abundance of zooplankton

According to Eaton et al. (2005), the zooplankton's abundance was calculated using:

$$K = \frac{N}{Ac} \; x \; \frac{At}{Vs} \; x \; \frac{Vt}{As}$$

Where K = abundance (ind/L); N = the number of zooplankton or phytoplankton counted (ind/L), Ac = Sedgwick-Rafter Counting Cell's field of view (mm^2), At = Sedgwick-Rafter Counting Cell's field of view (mm^2); Vs = concentrate volume of Sedgwick-Rafter Counting Cell (ml); Vt = volume's filtered sample; As = volume's filtered water (l).

Diversity Index

The diversity index was calculated according to Shannon and Weiner's diversity index (H'):

$$H' = -\ln \sum_{i=1}^{s} (p_i \;\; ln\, p_i)$$

$$p_i = \frac{n_i}{N}$$

Where p_i = proportion of individuals in the sample belonging to the ith species, H' is the diversity index, i = Counts denoting the ith species ranging from 1 - n, n= the species represents the number of individuals, and N= the total number of individuals in the sampling space.

RESULTS AND DISCUSSION

Results

The zooplankton found in the sites only consisted of members of Class Copepoda, and it was distributed into three different orders: Calanoida, Cyclopoida, and Harpacticoida. The Copepod's genera observed in the samples are presented in Figure 2. The most dominant were the Calanoids that made up 93% of the zooplankton community, which had five genera in the sample sites (*Eucalanus*, *Acartia*, *Calanus*, *Temora*, and *Undinula*), followed by Cyclopoids, which had two genera (*Oithona* and *Corycaeus*) (Figure 3). The least dominant was the Harpacticoida, which had only one genus (*Macrosetella*) (Figure 3). The average abundance of the sample zooplankton was 3.71 x 10^6 ind/L with Shannon and Weiner's diversity index (H'), indicating that the diversity of zooplankton is generally at a moderate level (1.2).

The manta ray's swimming behavior was observed on the surface in January 2018. It showed one of the primary manta ray's behaviors, foraging, which indicated the manta swimming against the currents with its mouth open to sieve the plankton (Figure 4).

Many manta rays were in the surface water in the morning, between 08.00 AM and 12.00 AM. Most swam in the water column after 12.00 AM and reappeared in the surface water after 02.00 PM (Figure 5).

The occurrence of manta rays inside the cleaning station areas increased after 10.00 AM and peaked between 11.00 AM and 12.00 AM, whereas no manta rays were observed outside the cleaning station. After 01.00 PM, neither inside nor outside the cleaning station found manta rays, and they reappeared in both areas in the afternoon (after 02.00 PM) but in tiny numbers (Figure 6).

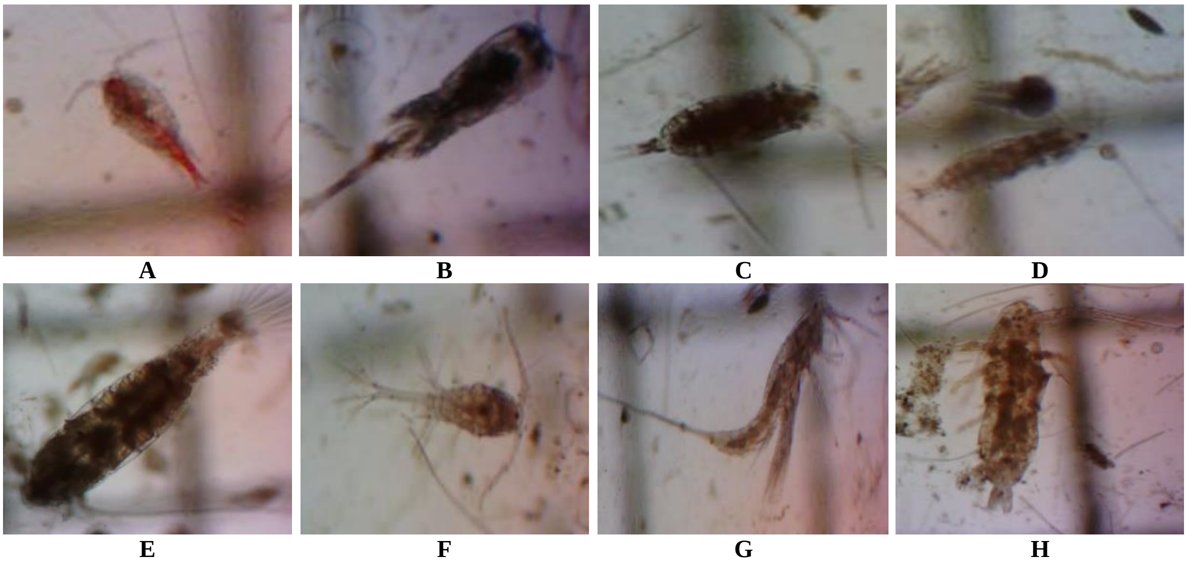

Figure 2. Composition of zooplankton in the study sites, Dampier Strait, Raja Ampat Islands, Indonesia using an Olympus CX21 (10x). A. *Temora* (Calanoida, Copepoda). B. *Corycaeus* (Cyclopoida, Copepoda). C. *Calanus* (Calanoida, Copepoda). D. *Acartia* (Calanoida, Copepoda). E. *Undinula* (Calanoida, Copepoda). F. *Oithona* (Cyclopoida, Copepoda). G. *Macrosetella* (Harpacticoida, Copepoda). H. *Eucalanus* (Calanoida, Copepoda)

Figure 4. Manta ray behaviors were spotted in the Manta Sandy Spot, Dampier Strait, Raja Ampat Islands, Indonesia. Photos were taken in January 2018

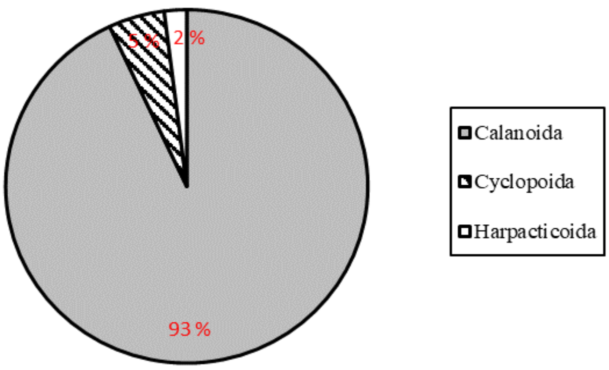

Figure 3. Zooplankton community composition around the Manta Sandy Spot cleaning station, Dampier Strait, Raja Ampat Islands, Indonesia

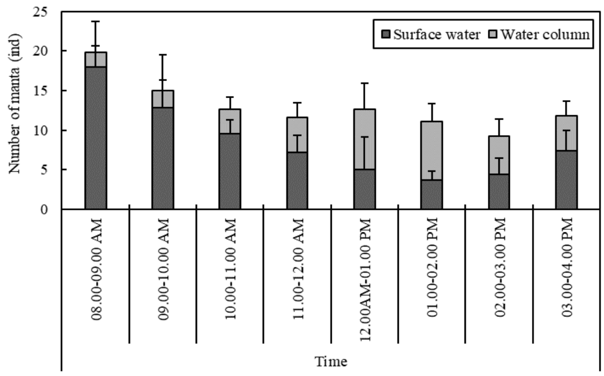

Figure 5. The number of mantas observed and recorded using an underwater camera once per hour by a snorkeled diver on the surface and in the water column. Surface water is defined as the top meter (0-1 m)

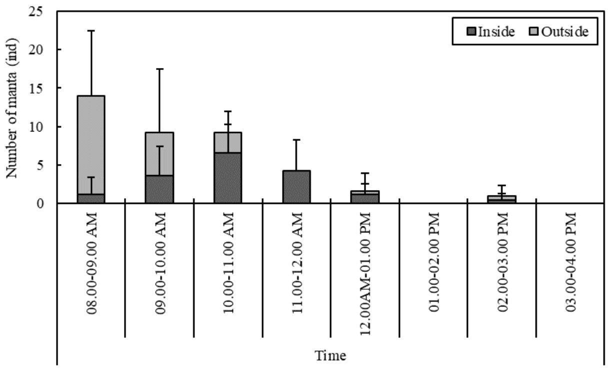

Figure 6. The numbers of mantas observed and recorded inside and outside the cleaning station areas using an underwater camera once per hour by a snorkeled diver. The inside/outside areas of the manta ray's cleaning station are defined according to the Regional Public Service Agency Regional Technical Implementing Unit (BLUD UPTD) in the Management of the Conservation Area (KKP) of the Raja Ampat Islands

Discussion

Copepod is a crustacean that dominates zooplankton biomass, with a body size ranging from 0.2-2 mm (mesozooplankton) (Steinberg and Landry 2017; Dyomin et al. 2023). There were three categories of body size of Copepod: large-bodied (>1.4 mm prosome length), medium-bodied (0.45-1.4 mm prosome length) and small-bodied (<0.5 mm prosome length) (Hopcroft et al. 2001). The large-bodied zooplankton is the main prey for economically and ecologically fish and other marine organisms, such as manta rays (Dalpadado and Mowbray 2013; Orlova et al. 2013). Some Calanoids found in this study are large-bodied zooplankton, such as *Eucalanus* and *Calanus*, with body size ranges of 6.8 ± 2.15 mm, which are subsequently categorized as herbivorous and omnivorous (Benedetti et al. 2023). Another genus in this order, *Undinula*, is also classified as the large-bodied Copepod. It was composed mainly in the water where the feeding activity of *M. alfredi* was observed in the Maldives (Armstrong et al. 2021). Additionally, the zooplankton community samples during the feeding activity of *M. alfredi* in the Maldives showed that it has a prey preference toward large-bodied zooplankton. The other zooplankton observed in the samples were the small-bodied zooplankton. For example, the small-bodied Calanoids consisted of *Acartia*, which is omnivorous and herbivorous with a body size of 1.5 ± 0.67 mm (Skjoldal and Aarflot 2023)**,** and *Temora* (a body size of 0.56 ± 0.003 mm) (Genelt-Yanovskaya et al. 2023). All the members of Cyclopoid and Harpacticoid were composed of small-bodied zooplankton, such as *Corycaeus*, which is carnivorous with a body size of 1.2 ± 0.7 mm, *Oithona* is omnivorous with a body size of 1.1 ± 0.52 mm (Benedetti et al. 2023) and *Macrosetella*, a herbivorous (Perry et al. 2021) that was present at 80 µm mesh net-samples (Chen et al. 2021). Despite the large-bodied-sized zooplankton preferences of manta rays, the small Copepod is crucial in the ecosystem to become prey on various predators, such as carnivorous-omnivorous zooplankton and other economic fishes (Chen et al. 2021).

The average zooplankton abundance around the cleaning station in this study was significantly higher than another study in the same areas that collected samples in March and July 2017 (~15 ind L^{-1}) (Thovyan et al. 2020) and also compared to other sites in Indonesian waters, such as in Kodek Bay, Lombok Island, that was 9.8 x 10^{-5} L^{-1} (Widiastuti et al. 2023) where no manta ray sighting reported in that area. The difference in zooplankton abundance between this study and those of Thovyan et al. (2020) might be due to the mesh sizes of plankton net used, whereas they used a smaller mesh size (20 µm). This study's 100 µm mesh size selection followed the minimal mesh size recommended for the mesozooplankton sampling procedure, such as the Copepoda (Bode-Dalby et al. 2023). Moreover, the hydro-oceanography dynamic in the sampling site areas might nourish the abundance and diversity of zooplankton. The warm waters yet poor nutrients from the West Pacific Ocean that flow through Indonesia Through Flow (ITF) to the Indian Ocean are pushed down to the Seram and Halmahera seas and mix vertically by the southeast monsoon (Purba and Khan 2019; Setiawan et al. 2020). Those streams further generate upwelling in this area that supplies high nutrients for the phytoplankton to grow, eventually leading to the abundance of zooplankton from August to January.

Direct observation is one of the non-lethal methods suggested to examine the manta ray's prey preferences (Armstrong et al. 2016; McInturf et al. 2023). Through this method, it is argued that the high composition of Calanoids and small amounts of Cyclopoids in the zooplankton community indicates the role of the Manta Sandy Spot that not only serves as a cleaning station but also as a manta ray's feeding ground. This finding is in line with Armstrong et al. (2016) and Burgess (2017), that examined the presence of Calanoids and Cyclopoids in the water samples where the feeding activity of manta rays was observed. The indication of the role of a feeding ground inside the manta ray's cleaning station is also supported by the manta ray's behavior in January 2018. The observation revealed the feeding activity behavior criteria, such as swimming on the surface with an open mouth, visible gill rakers, and unfolded cephalic fins (Paig-Tran et al. 2013; Garzon et al. 2023) (Figure 4). Another indication as a feeding ground was demonstrated by the higher numbers of manta rays observed near the surface from 08.00 AM-12.00 AM (Figure 5). It is suggested that they followed the aggregation of zooplankton in this area, where the number lowered at noon as the sea surface temperature increased. The sea surface temperature reduces the growth of phytoplankton and eventually affects the biomass of the zooplankton (Roxy et al. 2016). This finding agrees with those of Stewart et al. (2016), where more manta rays aggregated on the area near the surface. Conversely, more manta rays were found at a 0-250 m depth from 00.00 PM-12.00 AM. However, the manta ray started being detectable inside the cleaning station after 10.00 AM, which assumed that the manta ray had started the feeding activity outside the cleaning station or foraging in the deeper water, where the environmental conditions around that time might have promoted the abundance of zooplankton (Figure 6). Manta ray tends to shift its foraging activity according to ecological conditions (Barr and Abelson 2019). For example, foraging increased during high to ebbing tides in Hanifaru Bay, Maldives (Armstrong et al. 2021).

This study revealed the presence of large-bodied zooplankton in the water samples, which have been reported as the manta rays' preferred prey, indicating the area's role as the manta ray's feeding ground. This finding is supported by studies that found these zooplankton in the water where manta rays' feeding activity occurred and were absent in areas with no feeding activity. Since there are several spots of manta ray cleaning stations across the Raja Ampat Islands, more zooplankton community composition and abundance data is necessary to be collected in each area to determine the manta ray's feeding ground and compare it with areas with no observable feeding activity. Furthermore, the study of environmental parameter measurements has been revealed to show their effect on the manta ray's foraging behavior in each manta ray's cleaning station. Those environmental parameter measurements are required to elucidate their impact on the dynamics of the zooplankton community structure. Further observations on manta rays' behaviors in the cleaning stations are needed and thus would resume its synchronous functions as cleaning, nursery, and feeding grounds.

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