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Copepod distribution and diversity in the coastal areas of Ban-ao and Lambajon, Davao Oriental, Philippines: Environmental influences and conservation implications

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ABSTRACT

Copepods are essential components of marine ecosystems, facilitating energy transfer within these complex systems. The study investigates copepod diversity and distribution in Ban-ao and Lambajon coastal areas in Baganga, Davao Oriental, highlighting the environmental factors influencing copepod populations. Four copepod families representing different orders were identified, with Harpacticoida, Calanoida, and Cyclopoida prevalent in both sites, while Misophrioida was exclusive to Lambajon. Physico-chemical parameters such as dissolved oxygen (DO), pH, salinity, sediment composition, water depth, and temperature were analyzed to understand their correlation with copepod density. The study reveals variations in copepod density and abundance between the sites, with Lambajon showing a higher total density (49 ind/cm^3) compared to Ban-ao (35 ind/cm^3). The Pearson correlation matrix illustrates complex relationships between copepod density and environmental parameters in each site. In Ban-ao, strong positive correlations were found between copepod density and DO ($r = 0.65$) and temperature ($r = 0.36$). In Lambajon, positive correlations existed between water depth and copepod density ($r = 0.20$). Both sites exhibit low copepod diversity overall, potentially due to anthropogenic pressures. These findings emphasize the need for further research to understand the interactions between environmental factors and copepod diversity, essential for effective conservation and management strategies in these coastal ecosystems.

Keywords: Copepods, correlation, decantation, diversity, physico-chemical parameters

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INTRODUCTION

Copepods, a taxonomically diverse group comprising ten distinct orders, represent a cornerstone of marine ecosystems (Steck et al., 2023). With approximately 12,000 recognized species, including 2,500 thriving in marine environments, they emerge as pivotal members of the zooplankton community and are categorized as meiofauna (Fernández de Puelles et al., 2019). Typically characterized by their diminutive size, ranging from 0.2 to 5.0 mm, copepods possess compact, segmented bodies, featuring a distinctive rounded head section adorned with elongated antennae, ingeniously designed to mitigate sinking rates (Lenz et al., 2015).

These fascinating organisms reveal their significance through a myriad of biological features. Notably, their unique attributes encompass the degree of segmentation in endopods and pereiopods, the presence of lenses on the cephalosome, metasomal spines, and the number of setae on the caudal rami (Santhanam et al., 2019). Many of these features exhibit sexual dimorphism, allowing for the differentiation between male and female copepods, characterized by size disparities and specialized antennules in males (Yildiz & Karaytuğ, 2018). The pereiopods also play a remarkable role, undergoing substantial modifications to facilitate the transfer of sperm packets, known as spermatophores, during mating (Zupo & Hodgson, 2022).

Apart from their taxonomic complexities, copepods hold a vital role in the complex network of marine ecosystems. Their ecological importance transcends mere taxonomy, as they stand as vital components of marine food chains, serving as primary or secondary food sources for a multitude of commercially significantfish species (Behbehani et al., 2022). At the foundational level of aquatic communities, copepods emerge as secondary producers, perpetuating their influence throughout the oceanic ecosystems (Sasaki & Dam, 2021). Their role as proficient grazers of phytoplankton solidifies their status as keystone trophic links, influencing the structure and dynamics of aquatic ecosystems (Kilfoyle, 2017). Furthermore, copepods contribute substantively to the chemical regulation of marine environments, impacting nutrient cycling and overall ecological balance (Ngochera & Bootsma, 2018).

The broader implications of copepods extend to their role as nutritional sources for various marine organisms, thus establishing them as ecological indicators that furnish invaluable insights into ecosystem health (Pitois et al., 2021). Importantly, their contributions transcend the ecological realm, encompassing substantial economic value by virtue of their integral role in marine and freshwater ecosystem services, amounting to an estimated annualvalue of 22.6 trillion USD (Vaughn & Hoellein, 2018).

In the southeastern part of Davao Oriental, Philippines, there is a notable scarcity of data on copepods. Limited studies have been conducted in this area, with only one study mentioned in the literature to the best of our knowledge. A study by De Troch et al. (2008) was conducted on copepods in Pujada Bay, Mati City, Davao Oriental, shedding some light on copepod diversity in the area and further contributing to the understanding of copepod populations in this region. Despite these efforts, the overall body of knowledge on copepods in Davao Oriental and the broader southeastern part of the Philippines remains inadequate. This lack of data hinders a comprehensive understanding of copepod species diversity, distribution, and ecological roles in thesemarine ecosystems.

The current study aims to address this gap by conducting a detailed investigation of copepod species inhabiting the coastal areas of Davao Oriental, specifically in Baganga, providing valuable insights into their distribution and diversity. Building on the previous research, it is hypothesized that the coastal areas of Davao Oriental harbor a diverse range of copepod species, with differing population densities and distributions across the study sites. Furthermore, correlations are expected to be observed between environmental parameters such as DO, pH, salinity, sediment grain size, substrate type, turbidity, water depth, and water temperature, and copepod diversity and abundance. This study aims to identify the different copepods in the study areas up to the lowest possible taxonomic level, determine the population density, abundance, and distribution of copepods in the study site, assess their diversity, and measure and document environmental parameters.

MATERIALS AND METHODS

Study area

The research investigation was conducted in November 2021 in two specific barangays, Ban-ao and Lambajon, located within the Municipality of Baganga, Davao Oriental (Figure 1). To ensure a representative sample, data points were randomly collected within the designated study areas. Precise geographic coordinates were determined with the aid of a Global Positioning System (GPS) device. Ban-ao is geographically positioned atlatitude 7°4 4’08” N and longitude 126°32’22” E, while Lambajon is situated at latitude 7°36’35” N and longitude 126°34’01” E.

The selection of these two sites was based on several factors. Ban-ao, characterized by its sandy-rockysubstrate,

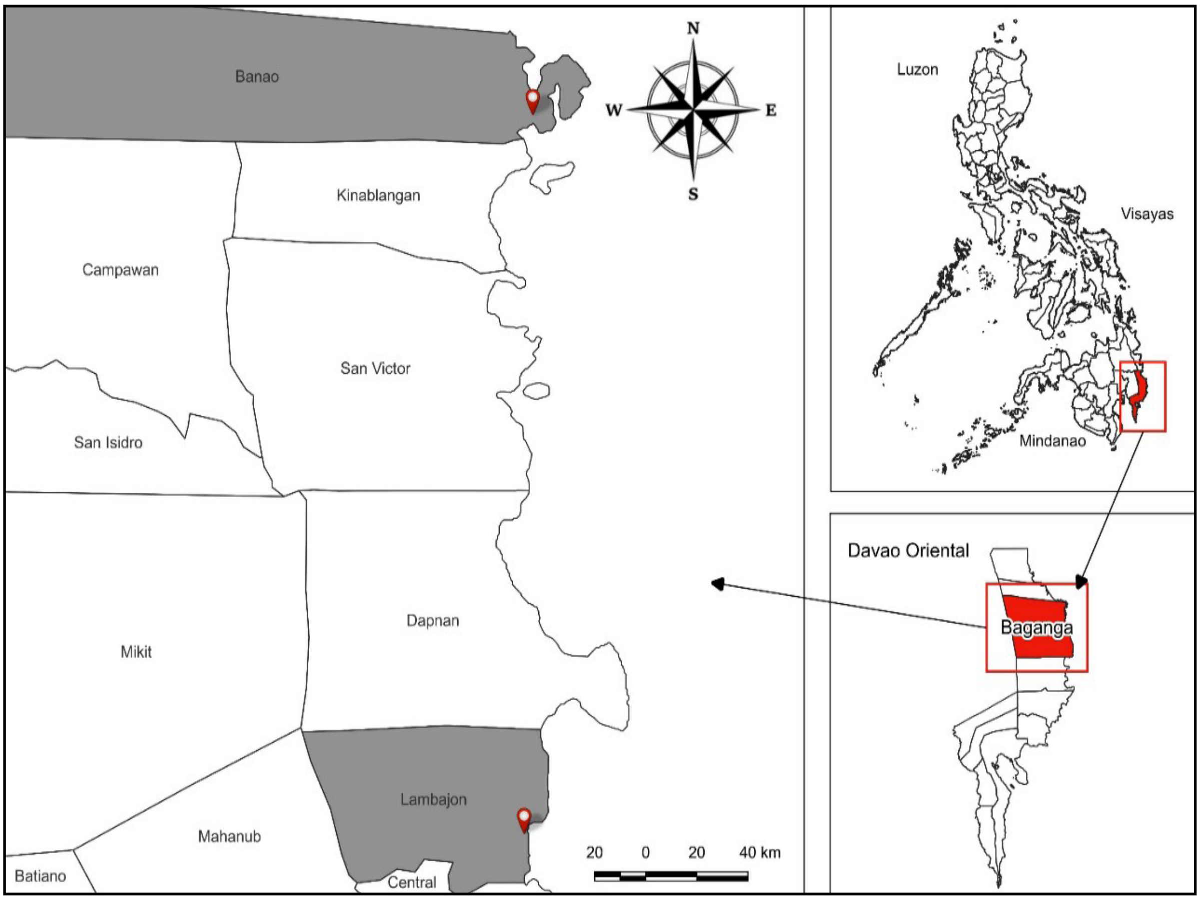

Figure 1. Geographical representation of the study Locations in Ban-ao and Lambajon, Municipality of Baganga, Davao Oriental.

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crystal-clear seawater, and strong waves, offers a unique marine environment with deep waters. Despite a lower abundance of seagrass, this location remains highly appealing to tourists seeking its distinctive features. On the other hand, Lambajon's sandy substrate, turbid water, and considerable depth make it a primary fishing port for local vessels. However, the proximity of commercial and residential areasto Lambajon raises concerns about inappropriate waste disposal practices, potentially threatening marine biodiversity, including copepods. This aspect makes Lambajon unsuitable for recreational swimming, highlighting the negative impacts of human activities on coastal environments. These contrasting environments provide an opportunity to investigate how natural and anthropogenic factors influence copepod populations in 0coastal areas, contributing to our understanding of marine ecosystem dynamics.

Sample collection and processing

At each designated station, a systematic sampling approach was employed. Specifically, six quadrats, each measuring 1 x 1 meter, were positioned in parallel along the shoreline, situated approximately at the waterline. To ensure even distribution, a consistent interval of 25 meters was maintained between each of these quadrats. Furthermore, quadrats that were perpendicular to each other maintained a separation distance of 50 meters.

Sediment samples were collected randomly from each of the sub-quadrats (Felix et al., 2022). Within each quadrat, two sediment cores were extracted for copepod analysis. The sediment corer, measuring 5cm in diameter and 10cm in length, was inserted 5 cm below the ground surface (volume= 98.18 cm3), and the collected sediments were carefully fixed and preserved in small, transparent 500ml PET bottles. Fixation and preservation were facilitated using a 4% buffered formalin solution, applied to preserve the integrity of the samples.

In the laboratory at Davao Oriental State University's Regional Integrated Center for Environmental Research and Development (DOrSU-RIC XI), sediment samples underwent meticulous processing. The samples were initially washed to remove debris, with particular attention to particles smaller than the desired size for copepods. Decantation was then used to separate the sediments, which was repeated 10 times. The sieved sediment samples were transferred to a beaker filled with distilled water for further decantation. The resulting supernatant liquid was carefully poured through a stainless steel sieve with a mesh size of 1000µm. This process utilized four sieves with mesh sizes of 1000, 250, 63, and 38 µm. The copepods were captured on the 250 to 38µm sieve. After extraction, the copepod samples were stored in appropriately labeled plastic containers.

The samples were treated with a few drops of Rose Bengal until they were homogenized into a pink solution, and then incubated for 48 hours. Following incubation, the samples were examined under an Amscope stereomicroscope at 100x magnification, systematically counted, and the data were recorded.

Identification of samples

To identify the collected samples of copepods, specimens were carefully handpicked with the aid of an improvised needle-like tool and subsequently photographed using a mobile phone. The taxonomic classification and identification of these copepod species were carried out by referring to well-established copepod taxonomic references, specifically Higgins and Thiel (1988) and Giere (2009), as well as the World Register of Marine Species (WoRMS) database. These authoritative references and the WoRMS database served as invaluable resources in ensuring accurate and reliable species identification in this study.

Physico-chemical parameters

To characterize the environmental conditions of the study sites, several parameters were carefully measured and recorded such as DO, pH, salinity, sediment grain size, water depth, and temperature.

DO levels were obtained using a DO meter, seawater pH levels were assessed using a pH meter and salinity was measured using refractometer. All readings were done on site in triplicates to ensure the accuracy of each parameter.

The Wentworth grain size classification was followed to characterized thesediments collected in the study sites (Abdulkarim et al., 2021). This was achieved by sieving dried sediment samples through various mesh sizes, resulting in the categorization of the grains into groups such as gravel (2 - 4mm), coarse sand (0.5 - 1mm), fine sand (0.125 – 0.25mm), and silt (0.004 – 0.062mm).

Water depth was measured using a meter stick to determine the vertical distance from the seafloor to the water's surface during low tide. Three readings were taken at each site to ensure data accuracy. The temperature at the sample collection points was measured three times using a mercury thermometer in degrees Celsius (°C).

Data analysis

The data collected from two study sites underwent comprehensive analysis, including the descriptive analysis of physicochemical parameters and Pearson's correlation analysis with copepod density. These analyses were conducted using Microsoft Excel 365. Additionally, population density was expressed as individuals per volume of the corer (volume= 98.18 cm³) (Tuwo & Tresnati, 2015), and abundance was calculated as the number of individuals of a species divided by the total number of individuals of all species in each station, multiplied by 100 (Zakaria et al., 2016).

$$\text{Population density} = \frac{\text{Number of individuals}}{\text{Volume of the corer } (98.18 \text{ cm}^3)}$$

$$\text{Abundance} = \left(\frac{\text{Number of individuals of a species}}{\text{Total number of individuals of all species in each station}} \right) \text{X } 100$$

To assess copepod diversity, the study utilized the Shannon-Wiener Diversity index (*H'*), calculated using Paleontological Statistics (PAST) version 4.10 software (Felix et al., 2022). The index value *H'* can range from 0 (indicating no diversity, where all individuals belong to the same species) to a maximum value that depends on the number of species and their relative abundances. Higher values of the Shannon index indicate higher diversity (Roswell et al., 2021). This index served as a valuable tool for quantifying and comparing copepod diversity across the study locations, providing a robust and standardized measure of biodiversity within the copepod community.

RESULTS

Species composition

The copepods documented in Ban-ao and Lambajon are shown in Table 1. The study identified four families of copepods, each representing different orders: Harpacticoida, Calanoida, Cyclopoida, and Misophrioida (Figure 2). The families Ectinosomatidae (*Ectinosoma* sp.), Acartiidae (*Pseudodiaptomus* sp.), and Oithonidae (*Oithona* sp.), belonging to the orders Harpacticoida, Calanoida, and Cyclopoida respectively, were found in both Ban-ao and Lambajon, indicating a widespread distribution of these copepod species

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within the study area. This suggests that these copepods may thrive in similar environmental conditions present in both locations. However, the family Speleophriidae (*Boxshallia* sp.) under the order Misophrioida was only found in Lambajon.

Table 1. Species composition of copepods recorded in the study area (present +; absent -).

Order	Family	Species	Study site	
			Ban-ao	Lambajon
Harpacticoida	Ectinosomatidae	*Ectinosoma* sp.	+	+
Calanoida	Acartiidae	*Pseudodiaptomus* sp.	+	+
Cyclopoida	Oithonidae	*Oithona* sp.	+	+
Misophrioida	Speleophriidae	*Boxshallia* sp.	-	+

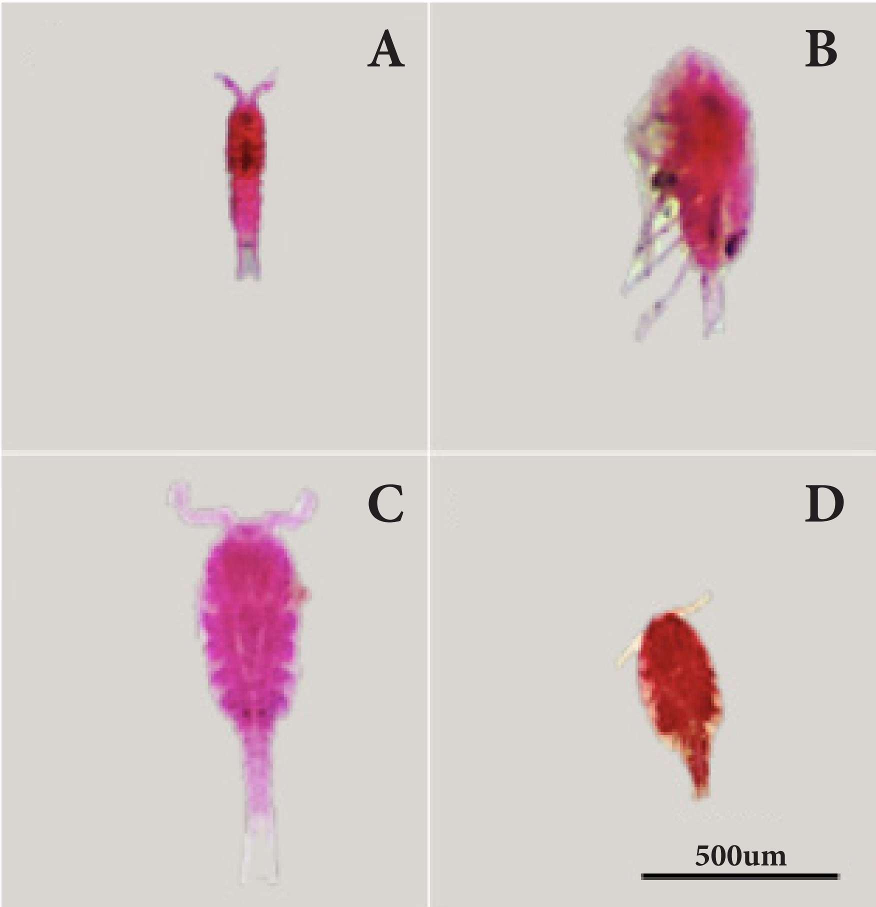

Figure 2. Copepod orders observed: (A) Harpacticoida, (B) Calanoida, (C) Cyclopoida and (D) Misophrioida, (100x, LPO).

Population density, abundance, and diversity

The results indicate variations in copepod density and abundance between Ban-ao and Lambajon (Figure 3). Lambajon exhibited a higher total density (49 ind/cm³) compared to Banao (35 ind/cm³), indicating a denser copepod population in Lambajon. On the other hand, in Ban-ao, Calanoida copepods were the most abundant, comprising % of the total copepod population, followed by Harpacticoida (34%) and Cyclopoida (28%). In contrast, Lambajon showed a different pattern, with Harpacticoida being the most abundant (35%), followed by Cyclopoida (33%) and Calanoida (24%).

Interestingly, Misophrioida copepods were present only in Lambajon, constituting 8% of the total population. This indicates a potential environmental preference or niche for Misophrioida copepods in Lambajon compared to Ban-ao. The Shannon-Weiner Diversity Index further indicates low copepod diversity in both locations (*H'*= 1.09 in Ban-ao, 1.28 in Lambajon), as summarized in Table 2.

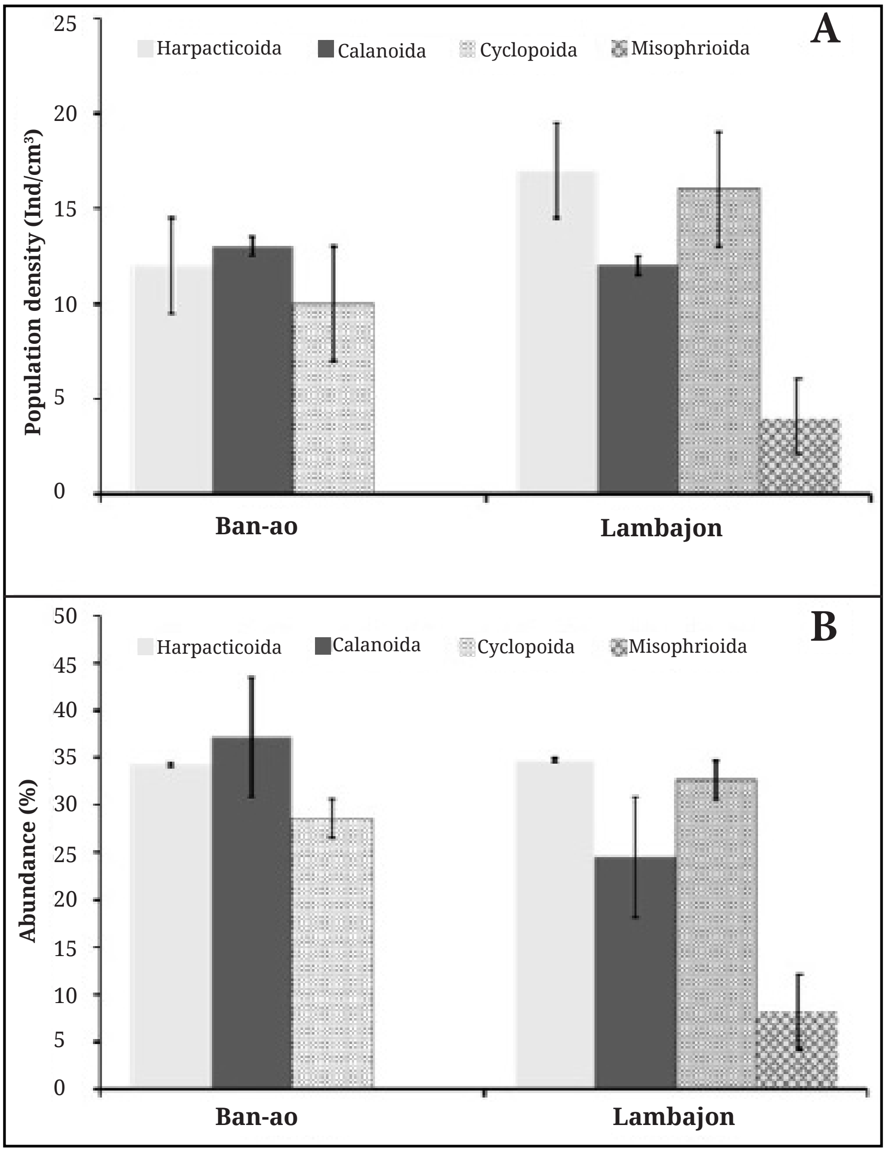

Figure 3. Population density (A) and abundance of copepods (B) in the study areas.

Table 2. The diversity of copepods in two sites using the Shannon Weiner-Diversity Index.

Order	Study site	
	Ban-ao	Lambajon
Harpacticoida	12	17
Calanoida	13	12
Cyclopoida	10	16
Misophrioida	0	4
Total number of individuals	35	49
Shannon-Weiner Diversity Index (*H'*)	1.09	1.28

Physico-chemical parameters

The research results have revealed variations in key environmental parameters that collectively influence the density and distribution of copepods in the study sites. These interactions among parameters shape the copepod communities in the study areas. Table 3 presents the mean values of selected physico-chemical parameters in Ban-ao and Lambajon, along with their standard deviations (SD) to indicate data variability.

The mean DO values in Ban-ao and Lambajon were 3.41±0.34mg/L and 3.77±0.19mg/L, respectively, indicating relatively low variability in DO levels between the two sites. However, these readings were below the standard level of DO, which is 5mg/L (Desa et al., 2005). The pH values are 7.83±0.06 and 7.90±0.08 for Ban-ao and Lambajon, respectively suggesting consistent pH levels at both sites. Salinity levels are slightly higher in Lambajon compared to Ban-ao, with mean values of 34.00±1.10ppt and 35.00±1.13ppt respectively, indicating comparable variability in salinity between the two sites.

Regarding sediment composition, Lambajon exhibits a higher percentage of gravel (56%) compared to Ban-ao (36%), indicating a larger sediment size in Lambajon. Conversely, Ban-ao has a higher percentage of coarse sand (43%) compared to Lambajon (28%), suggesting a coarser substrate in Ban-ao. Both locations have relatively low levels of fine sand and silt. Ban-ao has slightly higher proportions of fine sand (15%) and silt (8%) compared to Lambajon, which has 11% fine sand and 5% silt. The standard deviations for these parameters suggest more variability in substrate composition at Ban-ao than Lambajon. Water depth is greater in Ban-ao (0.70m) compared to Lambajon (0.50m), with standard deviations of 0.20 and 0.14, respectively, indicating higher variability in water depth at Ban-ao. Temperature is slightly higher in Lambajon (29.00±0.82°C) compared to Ban-ao (28.00±0.822°C), suggesting comparable temperature variability between the two sites.

Table 3. Mean values of selected physico-chemical parameters at two study sites.

Study area	Parameters	DO (mg/L)	pH	Salinity (ppt)	Gravel (%)	Coarse sand (%)	Fine sand (%)	Silt (%)	Water depth (m)	Temperature (°C)
Ban-ao	Mean	3.41	7.83	34.00	36.00	43.00	15.00	8.00	0.70	28.00
	SD	0.34	0.06	1.10	1.99	2.00	1.63	1.15	0.20	0.82
Lambajon	Mean	3.77	7.90	35.00	56.00	28.00	11.00	5.00	0.50	29.00
	SD	0.19	0.08	1.13	2.49	0.67	0.82	0.94	0.14	0.82

Correlation analysis

The Pearson correlation matrix in Table 4 illustrates the relationship between copepod density and physico-chemical parameters, as well as among the physico-chemical parameters themselves, in both study sites. In Ban-ao, the strongest positive correlation was found between copepod density and DO (r = 0.65), as well as between copepod density and temperature (r = 0.36). Regarding the correlations among physico-chemical parameters, the strongest positive correlation was observed between pH and temperature (r = 0.76).

Conversely, in Ban-ao, negative correlations were computed between copepod density and salinity (r = -0.45), as well as between copepod density and both gravel and fine sand (both r = -0.32). The most notable negative correlations among physico-chemical parameters were between salinity and pH (r = -0.82), as well as between salinity and temperature (r = -0.86).

In Lambajon, the most significant positive correlation with copepod density among physico-chemical parameters was found in water depth (r = 0.20). In terms of the correlations among physico-chemical parameters, the most substantial positive correlation occurred between salinity and DO (r = 0.60).

In Lambajon, in contrast, the strongest negative correlations were found between copepod density and gravel (r = -0.59), as well as between copepod density and temperature (r = -0.51). On the other hand, the most notable negative correlation among physico-chemical parameters was found between coarse sand and DO (r = -0.26).

Table 4. Pearson's correlation coefficients between physico-chemical parameters and copepod density in two study sites. Darker shades represent stronger correlations: blue for positive, red for negative.

Study Area		Density	DO	pH	Salinity	Gravel	Coarse sand	Fine sand	Silt	Water depth	Temperature
Ban-ao	Density	1.00									
	DO	0.65	1.00								
	pH	0.06	-0.17	1.00							
	Salinity	-0.45	-0.15	-0.82	1.00						
	Gravel	-0.32	-0.32	-0.45	0.40	1.00					
	Coarse sand	0.11	-0.26	0.44	-0.22	-0.27	1.00				
	Fine sand	-0.32	-0.12	0.32	-0.02	0.12	0.37	1.00			
	Silt	-0.06	0.20	0.40	-0.26	-0.05	-0.38	0.35	1.00		
	Water depth	0.00	0.31	0.00	0.07	-0.07	-0.25	0.54	0.67	1.00	
	Temperature	0.36	0.08	0.76	-0.86	-0.07	0.20	0.25	0.47	0.20	1.00
Lambajon	Density	1.00									
	DO	0.14	1.00								
	pH	-0.03	0.58	1.00							
	Salinity	0.02	0.60	0.27	1.00						
	Gravel	-0.59	0.38	-0.11	0.15	1.00					
	Coarse sand	0.10	-0.26	-0.08	0.00	-0.20	1.00				
	Fine sand	-0.17	-0.14	-0.24	0.54	0.11	0.20	1.00			
	Silt	-0.30	0.12	-0.16	0.47	0.14	0.18	0.14	1.00		
	Water depth	0.20	0.37	-0.15	0.38	0.22	0.35	0.29	0.25	1.00	
	Temperature	-0.51	0.14	0.31	0.07	0.11	0.00	-0.17	0.43	0.29	1.00

DISCUSSION

Species composition

The recorded species composition of copepods in the study area provides valuable information about the copepod community structure in Ban-ao and Lambajon. The presence of *Ectinosoma* sp., *Pseudodiaptomus* sp., and *Oithona* sp. in both study sites suggests that these species are common and have adapted to the local environmental conditions in both areas. The presence of *Boxshallia* sp. only in Lambajon indicates a slightly different copepod community composition compared to Ban-ao. The presence of *Ectinosoma* sp. in both study sites is consistent with its known habitat preference for marine and brackish waters (Suárez-Morales & Fuentes-Reinés, 2015). This species is often found in shallow coastal areas, which may explain its presence in both Ban-ao and Lambajon, which are likely to have similar coastal environments. *Pseudodiaptomus* sp. is another common copepod species known to inhabit coastal and estuarine waters (Kayfetz & Kimmerer, 2017). Its presence in both study sites further supports the idea that these areas provide suitable habitats for this species. *Oithona* sp. is a cyclopoid copepod commonly found in shallow coastal habitats (Jaspe et al., 2020). The presence of *Boxshallia* sp. only in Lambajon is interesting and may indicate specific environmental conditions or habitat preferences for this species. The absence of *Boxshallia* sp. may be attributed to the low DO levels recorded in the area. Copepods are known to be sensitive to changes in oxygen levels, with some species being more tolerant to low DO than others (Grodzins et al., 2016). The presence of *Ectinosoma* sp., *Pseudodiaptomus* sp., and *Oithona* sp. in both Ban-ao and Lambajon suggests that these species are more tolerant to low DO levels, allowing them to thrive in both areas despite varying environmental conditions.

Further research is needed to fully understand the relationship between copepod distribution and environmental factors such as DO levels. Investigating the physiological characteristics of different copepod species and their tolerance to low DO could provide valuable insights into the mechanisms driving copepod community composition in coastal areas like Ban-ao and Lambajon.

Population density, abundance, and diversity

The observed variations in copepod density and abundance between Ban-ao and Lambajon may be attributed, in part, to differences in DO levels. Ban-ao exhibited lower copepod density and abundance compared to Lambajon, which could be linked to its lower DO levels. Copepods, like many marine organisms, are highly sensitive to changes in oxygen levels (Soulié et al., 2022), as DO plays a crucial role in their metabolism and overall fitness (Anderson et al., 2021). Low DO levels in Ban-ao could limit the availability of suitable habitats for copepods, particularly those with higher oxygen requirements (Roman & Pierson, 2022). Calanoida copepods, which were the most abundant in Ban-ao, may be more tolerant of lower oxygen levels compared to other copepod groups. This could explain their dominance in Ban-ao despite the suboptimal oxygen conditions.

These findings suggest that DO levels play a significant role in shaping copepod communities in these coastal areas. Further investigation into the specific oxygen requirements of different copepod species and their tolerance to varying oxygen levels could provide valuable insights into the ecological dynamics of these habitats.

The diversity of both areas was found to be low. This observation may be attributed to the low levels of DO in the study sites. Copepods are known to be sensitive to environmental changes, particularly in oxygen levels, which can significantly impact their distribution and abundance. Low DO levels can limit the availability of suitable habitats for copepod survival, consequently leading to lower species diversity (Roman & Pierson, 2022). The observed low species diversity thus warrants an in-depth exploration of the underlying environmental factors contributing to this phenomenon.

Another factor that may contribute to the low diversity is the exposure of both sites to various anthropogenic threats. The coastal site of Ban-ao experiences heightened exposure to human activities such as swimming and other forms of recreation. In contrast, Lambajon contends with significant marine pollution stemming from plastic waste and related sources. Several studies have demonstrated that anthropogenic activities can lead to reduced copepod diversity. For example, Dela Paz et al. (2018) found only three cyclopoid copepods in disturbed sites in Manila coastal areas. Similarly, Fajardo et al. (2022) observed low diversity in Nueva Ecija, likely due to human disturbances. In contrast, pristine environments, such as those studied by De Troch et al. (2008) in dense seagrass areas, Jaspe et al. (2020) in the upwelling zone of Zamboanga, and Angara et al. (2013) in the pristine marine San Ildefonso Cape, have exhibited high copepod diversity. These pristine environments boast good environmental conditions that can support a thriving and diverse copepod population. Further studies are needed to investigate the relationship between anthropogenic threats, environmental factors, and copepod diversity. Such studies could provide valuable insights into the conservation and management of copepod populations in these areas. Understanding the impact of human activities on copepod diversity is crucial for implementing effective conservation strategies and ensuring the long-term health of marine ecosystems.

Physico-chemical parameters

The mean values provide insights into the physico-chemical conditions of Ban-ao and Lambajon, highlighting differences in environmental parameters between the two study sites that may help explain variations in copepod density. The results of the study reveal important insights into the environmental factors influencing copepod density and distribution in two study sites. The relatively low variability in DO levels between Ban-ao and Lambajon suggests that both sites have adequate oxygen levels to support copepod populations. However, it's crucial to note that DO levels in both sites fell below the normal range. This lower-than-optimal oxygen concentration may have had a significant impact on copepod abundance and distribution. DO is vital for the survival of aquatic organisms, including copepods, as they rely on oxygen for respiration (Soulié et al., 2022). Lower-than-normal DO levels can stress copepods, making them more susceptible to diseases and less able to reproduce effectively (Roman et al., 2022). Additionally, inadequate oxygen levels can lead to reduced feeding and growth rates, affecting the overall population size and distribution of copepods in an ecosystem (He et al., 2021).

Consistent pH levels at both sites indicate stable acidity levels, which is important for maintaining a suitable habitat for copepods. Copepods are sensitive to changes in pH, as fluctuations can disrupt their physiological processes and impact their survival and reproduction rates (Halsband et al., 2021). The consistent pH levels indicate a suitable habitat for copepods, supporting their presence and potentially contributing to a diverse copepod community.

The slight difference in salinity levels between the two sites may influence the types of copepod species present, as copepods have varying salinity tolerance levels (Magouz et al., 2021). Some species thrive in freshwater environments while others are more adapted to saline conditions (Suárez-Morales et al., 2020). The observed salinity gradient could create distinct microhabitats within the study area, favoring the dominance of certain copepod species over others. Understanding these salinity-related preferences is crucial for predicting copepod distribution patterns and assessing their ecological roles in these environments.

The sediment composition analysis reveals differences between Lambajon and Ban-ao. Lambajon exhibits a higher percentage of gravel, indicating a larger sediment size compared to Ban-ao. On the other hand, Ban-ao has a higher percentage of coarse sand compared to Lambajon, indicating a coarser substrate in Ban-ao. Both areas show similar percentages of fine sand and silt, with slight differences favoring Ban-ao in fine sand and silt. This information is valuable for understanding the differences in habitat characteristics between the two study areas, which can influence the ecological communities present there, including copepod populations. The high gravel in Lambajon might provide different ecological niches compared to thecoarser substrate in Ban-ao, potentially affecting copepod habitat preferences and distribution patterns. Further analysis and consideration of these substrate differences could enhance the understanding of copepod ecology in these areas.

Water depth variability, with greater variability in Ban-ao compared to Lambajon, may also play a role in shaping copepod communities. The greater variability in water depth in Ban-ao suggests a more dynamic aquatic environment compared to Lambajon. On the other hand, the lower variability in water depth in Lambajon suggests a more uniform and stable habitat structure. This uniformity may limit the availability of diverse microhabitats for copepods, potentially leading to more intense competition for resources among copepod species. However, the stable habitat conditions in Lambajon may also provide copepods with a consistent environment, which could benefit certain species that

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are well-adapted to these conditions. Temperature, though similar between the two sites, it's important to note that copepods are highly sensitive to temperature changes (Roman & Pierson, 2022). The consistent temperature variability observed in both sites indicates stable environmental conditions for copepod populations, which are essential for copepod growth (Fields et al., 2023) and reproduction rates (Behbehani et al., 2023). Fluctuations outside their preferred temperature range can significantly impact copepod populations, affecting their abundance and distribution.

Correlation analysis

The Pearson correlation matrix provides valuable insights into the relationships between copepod density and various physico-chemical parameters in the two study sites. In Ban-ao, the strong positive correlation between copepod density and DO suggests that higher DO levels support increased copepod abundance. This relationship is crucial as DO is essential for the survival and growth of copepods (Jyothibabu et al., 2018), influencing their distribution patterns in aquatic environments. The positive correlation between copepod density and temperature in Ban-ao indicates that higher temperatures may also promote copepod abundance. Temperature influences copepod metabolism, growth, and reproduction rates (Nogueira et al., 2018), highlighting its importance in regulating copepod populations. The strong positive correlation between pH and temperature in Ban-ao indicates a potential interaction between these factors, which could influence copepod abundance indirectly through effects on water quality and nutrient availability (Assis et al., 2018).

However, the negative correlation between copepod density and salinity in Ban-ao suggests that copepods are less abundant in areas with higher salinity levels. Salinity affects osmoregulation in copepods, and extreme salinity levels can be detrimental to their survival (Kim et al., 2022). The negative correlation between copepod density and gravel and fine sand in Ban-ao implies that these substrate types may not provide suitable habitats for copepods.

The strongest negative correlation between salinity and pH, suggests that as salinity increases, pH decreases, and vice versa. This indicates that changes in salinity and pH levels may have a significant impact on copepod distribution and abundance. Similarly, there was a strong negative correlation between temperature and salinity, suggesting that as temperature increases, salinity tends to decrease, and vice versa. This relationship implies that changes in temperature and salinity levels may also significantly influence copepod distribution and abundance.In Lambajon, the positive correlation between copepod density and water depth suggests that deeper waters may provide more favorable conditions for copepod survival and reproduction. Deeper waters often have more stable environmental conditions, which can benefit copepod populations. The positive correlation between salinity and DO in Lambajon suggests an interactive effect on copepod abundance. These two factors are crucial for aquatic ecosystems, and their relationship can influence copepod distribution and abundance.

The negative correlations between copepod density and gravel, and copepod density and temperature in Lambajon, indicate that these factors may negatively impact copepod abundance. High gravel content, characterized by its larger interstitial spaces (Wagner et al., 2013), may not retain enough nutrients, as particles may escape more easily compared to finer sand. This could potentially limit food availability for copepods. Additionally, high temperatures can increase metabolic demands (Low et al., 2018), potentially further limiting copepod populations.

The negative correlation between coarse sand and DO indicates that areas with higher coarse sand content may have lower oxygen levels, which can negatively affect copepod populations. These findings highlight the complex interactions between copepod density and various physico-chemical parameters in the two study sites.

These findings highlight the complex relationship between copepod density and the various physico-chemical parameters in both study sites. The abundance and distribution of copepods are influenced by multiple environmental factors, indicating the intricate interplay within the ecosystem where these organisms exist. This suggests that copepod populations are not solely dependenton one specific factor but are instead shaped by a combination of environmental conditions. This underscores the complexity of the ecosystem and the need for a holistic understanding of the various factors that contribute to the abundance and distribution of copepods in these areas.

CONCLUSION

This study provides valuable insights into the copepod community structure, population density, abundance, diversity, and their correlation with physico-chemical parameters in the Ban-ao and Lambajon coastal areas. The identification of four copepod orders and the widespread distribution of specific copepod families indicate a shared environmental suitability for these species in both areas. However, differences in copepod abundance and composition suggest potential environmental preferences or niche differentiation among species. The observed low copepod diversity in both areas is likely attributed to low DO levels and human-induced impacts, warranting further investigation. The Pearson correlation matrix reveals significant connections between copepod density and environmental characteristics in both sites, underscoring the intricate interactions shaping copepod abundance.

In light of these findings, it is recommended that conservation efforts in the Ban-ao and Lambajon coastal areas focus on improving water quality, particularly in terms of DO levels and the management of anthropogenic activities, to preserve copepod diversity and abundance. Additionally, further research is needed to fully understand the specific ecological roles of different copepod species in these ecosystems and their tolerance levels to environmental stressors, which can inform more targeted conservation strategies.

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