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Short time changes of zooplankton communities in Cam Ranh Bay

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ABSTRACT

Coastal embayments are ecologically significant ecosystems increasingly affected by human activities and climate change pressures. This study investigated the spatial and temporal dynamics of the zooplankton community in Cam Ranh Bay under varying environmental conditions by chronically sampling in consecutive days, weeks and seasons. The bay exhibited high zooplankton diversity, with 188 species recorded across seven phyla. Arthropoda, particularly Copepoda, contributed over 65% of the total species richness. Notable changes were observed in the zooplankton community, particularly within Copepoda families, even over short periods (e.g., day or week). At a seasonal scale, the zooplankton community shifted with increased densities of larval groups during the rainy season, coinciding with a relative decrease in arthropods. Biodiversity indices indicated greater stability during the rainy season, while canonical correspondence analysis (CCA) revealed distinct seasonal relationships between species and environmental variables, such as nutrient fluxes and salinity. These findings underscore the ecological complexity of Cam Ranh Bay, providing a critical baseline for monitoring environmental changes and managing human impacts on this biodiverse ecosystem.

1. INTRODUCTION

Coastal lagoons and bays are transitional zones between land and sea, often characterized as shallow water bodies partially isolated from the sea by natural or artificial barriers. Despite covering only about 13% of the global coastlines (Kennish & Paerl, 2010), these ecosystems are recognized as biodiversity hotspots and among the most productive ecological systems in the world (Boudouresque, 2004; Basset et al., 2013). Moreover, lagoons are natural bio-filters, processing organic matter and nutrients transported from terrestrial sources (McGlathery et al., 2007). Consequently, they play an essential role in biogeochemical cycles while providing significant economic benefits such as food production (fishing and aquaculture), hydrological balance, climate regulation, flood prevention, water purification, recreation, and ecotourism (Newton et al., 2018).

The ecological integrity and biodiversity of lagoons and bays face significant threats due to global changes, including anthropogenic pressures (Holmer et al., 2008; Kemp & Boynton, 2012; Lapointe et al., 2015). These studies have explored the impact of environmental and human factors on tropical and subtropical ecosystems. For example, Tarafdar et al. (2021) documented that human-induced alterations in temperature and salinity impacted autotrophic biomass in Chilika Lagoon, India. Similarly, long-term studies in Patos Lagoon, Brazil, which revealed that freshwater inflow variability, primarily impacted by climate change, was a key factor influencing primary productivity (Ducrotoy et al., 2019), and hence zooplankton. In general, lagoon ecosystems are inherently complex, with each aquatic system exhibiting unique biotic and abiotic characteristics shaped by diverse natural and anthropogenic drivers (Anufriieva et al., 2022). Faunal communities also exhibit significant interannual changes (Kennish & Paerl, 2010) or even short-term (weekly) shifts in response to nutrient dynamics in the water body (D'Alelio et al., 2016; D'Alelio et al., 2019).

Indeed, zooplankton perform a critical role in driving the nutritional dynamics and ecological succession within aquatic ecosystems (Iqbal et al., 2014; Abdullah Al et al., 2018) through top-down (Micheli, 1999; Winder & Jassby, 2011) or bottom-up (D'Alelio et al., 2016; D'Alelio et al., 2019) control processes. Therefore, alterations in the diversity of these groups can significantly disrupt normal ecosystem functioning. Zooplankton abundance and composition are dependent on various ecological conditions, including water temperature, transparency, food availability, and nutrient supply (Arashkevich et al., 2002; Lo et al., 2004; Sullivan et al., 2007; Mk et al., 2016; Abdullah Al et al., 2018). Furthermore, due to their short life cycles and rapid responses to environmental disturbances make zooplankton effective bioindicators of water quality and climate change (Bianchi et al., 2003; Uriarte & Villate, 2004; Sullivan et al., 2007; Ferdous & Muktadir, 2009; Liu et al., 2013). Among zooplankton, certain copepods serve as indicators of pollution (e.g., *Acartia clausi*), rising temperatures (e.g., *Acartia tonsa* and *Acartia hudsonica*), and salinity shifts (Hirst et al., 1999; Bianchi et al., 2003; Mulyadi, 2004; Hooff & Peterson, 2006). Copepod distribution patterns have been used as indicators of salinity changes (Hirst et al., 1999; Bianchi et al., 2003; Thompson et al., 2012; Vineetha et al., 2015; Fontana et al., 2016; Mk et al., 2016).

In Viet Nam, zooplankton research dates back to the early 20th century, with foundational studies conducted between 1924 and 1960 (Rose, 1926; Serène, 1937; Dawydoff, 1952; Hamon, 1956; Leloup, 1956). Coastal lagoons and bays in Central Viet Nam have been investigated for zooplankton diversity since 1978, with more research conducted in 1990s (Cho & Ky, 1994; Khoi, 1994). However, these studies largely focused on species composition at specific times and locations. Since 1996, research on zooplankton in lagoons and bays has mainly been conducted by the Institute of Oceanography (Cho, 2001; Cho & Hai Trinh, 2006; Cho et al., 2013; Trinh et al., 2013). Recently, there have been some assessments of zooplankton community changes in lagoons and bays over time (Trinh & Vinh, 2015b, 2015a; Vinh & Hai, 2020, 2021, 2022). Nevertheless, comprehensive studies on zooplankton communities in different embayments along the coast of Viet Nam is still scares. Cam Ranh Bay, like many other coastal waters in Viet Nam, aquaculture and anthropogenic pressure has become, and will continue to be, an issue requiring attention and management. In 2018, Cam Ranh Bay had a designated aquaculture area of 260 hectares (equivalent to 20,000 cages) (Vietnam Fisheries Magazine). For the Khanh Hoa Province plan, in 2022, a strategy was implemented to transition to and adopt high-tech aquaculture practices to address climate change, maintain biological safety, and enhance economic efficiency. Therefore, understand the bay's ecosystem, particularly its zooplankton communities, is necessary. The present study analysis data sets from a study conducted in Cam Ranh Bay to provide baseline knowledge of zooplankton communities in biodiversity, structure, and abundance. Moreover, the present study also further reveals any changes of zooplankton communities over short-term (days, weeks) and long-term (seasons).

2. MATERIALS AND METHODS

2.1. Study area and sampling

Qualitative and quantitative samples were collected using a Juday with a mouth diameter of 37 cm, 200 µm of mesh size, and equipped with a closing mechanism. At stations with depths of less than 10 meters, single-layer sampling was conducted from 1 meter above the seabed to the surface layer. At stations with depths greater than 10 meters, the net was lowered to the desired depth (typically 1 meter above the seabed, based on actual depth measurements), and manually slowly towed to the targeted position. A heavy object (or drop passenger) will be dropped along the wire where connected to the sampling net, will hit the switch to activate the closing mechanism. This will cause the net to fold and prevent water filtration. The collected samples were stored in 500 mL plastic bottles and preserved with formaldehyde, ensuring a final concentration of approximately 5%.

Environmental parameters like temperature, salinity, fluorescence were measured by a Seabird CTD 19+ system (USA).

This study was conducted in Cam Ranh Bay, Khanh Hoa province, Viet Nam (Figure 1). Samples were taken during 2006 in June (day 1, 3, 5, 10, 15, 20 and 30), dry season, and in October (day 20, 21, 22 and 24 and in November (day 8 and 18), wet season.

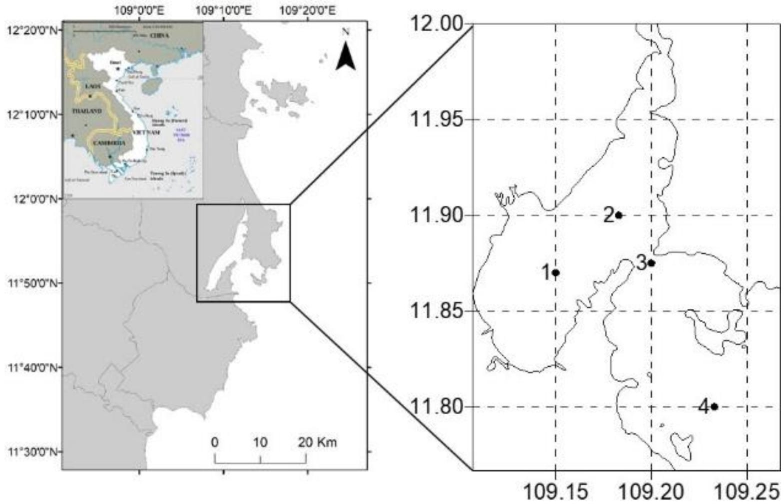

Figure 1. Maps showing the studied area (left) and sampling stations in Cam Ranh Bay (right) in 2006

2.2. Sample analysis

In the laboratory, zooplankton samples were rinsed with fresh water, then filtered through a 500 µm sieve and divided into two portions. The portion retained on the sieve (>500 µm) was further divided into subsamples, depending on the sample quantity, using a Folsom splitter. Subsamples were used for species identification and individual counting. The portion that passed through the sieve (<500 µm) was diluted with distilled water, and 1 mL was taken for counting. The entire process of counting and analyzing zooplankton samples was conducted using a Bogorov counting chamber and stereo-microscope (ICES, 1999; HELCOM, 2021). Identification was done based on morphological key followed by Chen (1965), Owre & Foyo (1967), Chen (1974), Nishida (1985), Boltovskoy (1999), Mulyadi (2002), Al-Yamani et al. (2011), Prusova et al. (2012), Conway (2012).

2.3. Data analysis

The species richness (Margalef, d), Evenness (Pielous, J') and species diversity (Shannon-Weiner, H') indices were used to summerize the biodiversity of zooplankton communities (Shannon, 1948; Margalef, 1958; Pielou, 1966). These measures were computed using PRIMER package (v6 version):

$$d = (S-1)/Log(N)$$

$$J' = H'/ Log(S)$$

$$H' = - sum (Pi*Ln(Pi))$$

where,

Pi = proportion of the total counted arising from ith species,

S = total species number,

N = total number of individuals.

The temporal pattern of species distribution was clustered by using Bray-Curtis similarity index (Bray & Curtis, 1957) from square root transformed species abundance data. The species contribution on each sample was computed using SIMPER analysis (similarity percentage). Canonical Correspondence Analysis (CCA) were carried out using R with "vegan package" to elucidate the relationships between biological assemblages of species and their environment (Oksanen et al., 2010). Nutrient data using in CCA is provided by HABViet project, and the data archive was described in Huynh et al. (2025, submitting).

3. RESULTS

3.1. Species composition and diversity

There were 188 zooplankton species belonging to seven phyla in the Cam Ranh Bay area during 2006 identified. Arthropoda, primarily represented by Copepoda, remained the dominant group with 129 species, contributing to over 65% of the regional diversity. Figure 2 illustrates changes in chronological sampling dates and seasons in species numbers observed in the study area. The lower figure (Figure 2) was excluded dominated Arthropoda to able the clearer variation of other groups. While Annelida was represented by only one species during the rainy season (Fig. 2, lower), the species counts for Ctenophora and Chordata remained constant across seasons. The species numbers of Mollusc and Chaetognath were the most variation among the sampling dates. Cnidaria, and Arthropoda exhibited slight differences in species number among sampling dates and seasons, however insignificant (Figure 2).

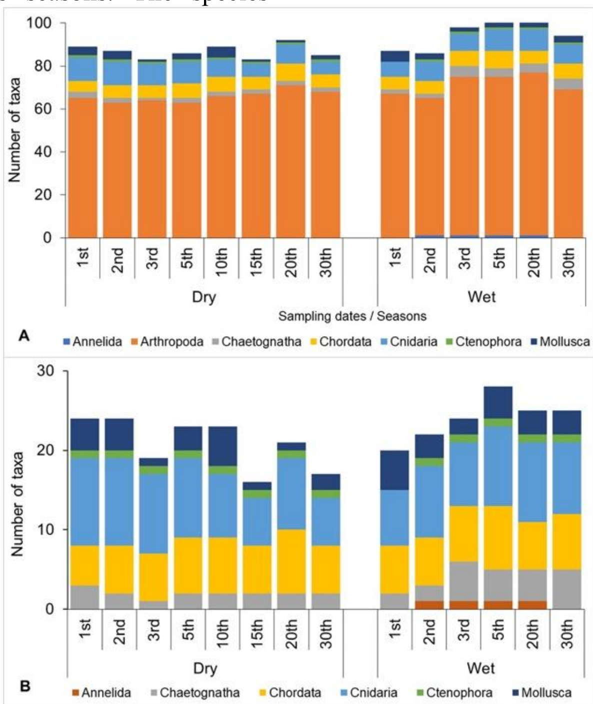

Figure 2. Zooplankton community structure (species number) changes among the chroconical sampling dates at two seasons included Arthropoda (2A) and excluded Arthropoda (2B) in Cam Ranh Bay

The lower figure (Figure 2B) was excluded dominated Arthropoda to able the clearer variation of other groups. While Annelida was represented by only one species during the rainy season, the species counts for Ctenophora and Chordata remained constant across seasons. The species numbers of Molluscs and Chaetognaths varied the most among the sampling dates. Cnidaria and Arthropoda exhibited slight differences in species number among sampling dates and seasons, however insignificant (Figure 2A).

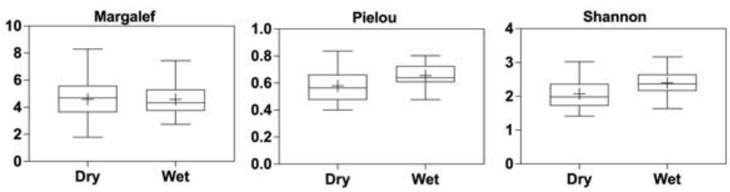

Figure 3. Seasonal biodiversity indices

The boxplots illustrate (Figure 3) seasonal variation in zooplankton biodiversity indices, including species richness (Margalef), evenness (Pielou), and community diversity (Shannon-Weiner), across the dry and wet seasons. All three indices exhibited relatively small differences. The species richness showed greater variability during the dry season compared to the wet season.

3.2. Changes in zooplankton abundance and dominance

The zooplankton composition across stations reveals both short-term (day scale) and long-term (seasonal) variations. In the short-term variation, daily change was particularly clear in the Larvae group, which shows intermittent peaks during the wet season, especially at Stations 1 and 3. Long-term (seasonal) variations, however, exhibited more consistent patterns: the percentage of Larvae increased during the wet season, accompanied by a relative decline in Arthropoda dominance inside the bay. This trend was less pronounced at Station 2, and at Station 4 (outside Cam Ranh Bay), which remains stable across seasons (Figure 4).

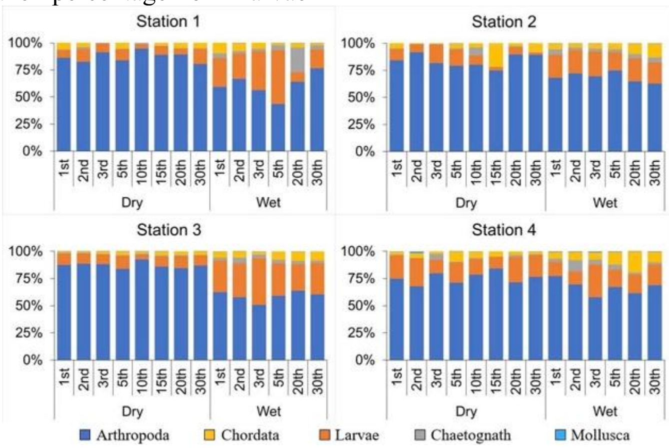

Figure 4. Variations of Zooplankton major phyla and larvae (in density percentage) in chroconical sampling days and seasons

Figure 5 illustrates the spatial and temporal variations in the composition of the Copepoda's orders in 2006. Calanoida and Cyclopoida were the most dominant of all 4 orders. Spatial variations were clearly shown among stations. Station 4 (outside the bay) directly influenced by the open sea, exhibited significant different changes in the composition of Copepoda groups across surveyed days. Stations located inside the bay, however, demonstrated notable seasonal changes. The proportion of Calanoida in Station 1 decreased remarkedly during the wet season.

At Station 2, which is relatively close to Station 1, such changes were only observed toward the sampling dates 20th and 30th of the wet season, suggesting either slower environmental responses or localized conditions affecting this station. Interestingly, Station 3, situated at the narrow part of the bay where strong hydrodynamics were theoretically expected, showed remarkable stability in the proportion of the two main families, Calanoida and Cyclopoida.

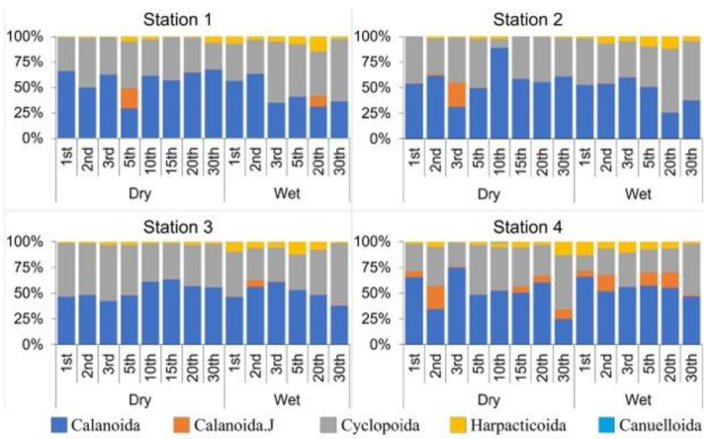

Figure 5. Variations of zooplankton major orders of Copepoda and calanoid juvenile (in density percentage) in chronological sampling days and seasons

3.3. Community changes and dominance of zooplankton

3.3.1. Community changes

Hierarchical cluster analysis identified two distinct groups of zooplankton communities in Cam Ranh Bay, showing up to 80% dissimilarity between the inner and outer bay regions. In the outer bay (Station 4), community structure exhibited substantial variability over both short-term (daily) and long-term (seasonal) timescales, with similarity ranging from roughly 40% to 70%. There were clearly seasonal changes, with zooplankton community composition differing by as much as 70% between the seasons. Furthermore, noticeable daily variations within the month were observed in the inner bay, particularly at Stations 1, 2, and 3 (Figure 5).

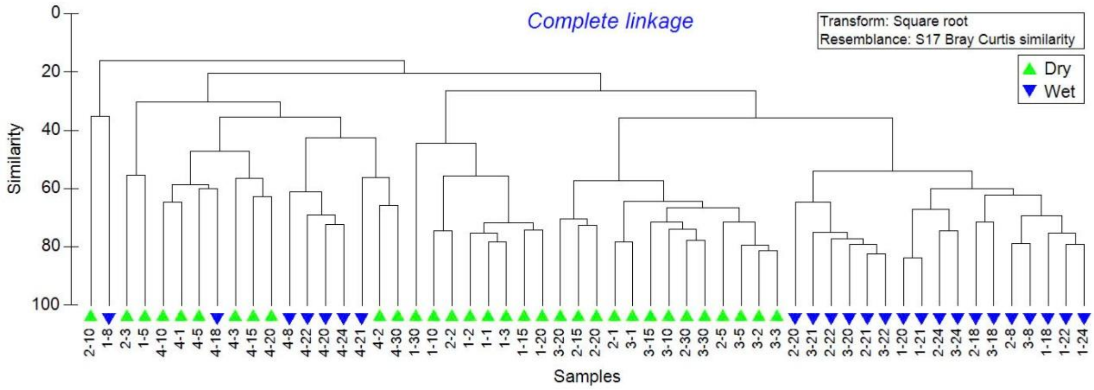

Figure 6. Hierarchical cluster graph presenting similarity of zooplankton communities among stations, sampling days and seasons. Number indicates station-sampling date, triangular symbols for the dry season and inverted triangle for the wet season

3.3.2. Variations of dominant zooplankton

Dominant analysis using Similarity Percentage (SIMPER) showed copepod species from the genera *Paracalanus* and *Oithona* were the most dominant, followed by larval groups and *Oikopleura (Coecaria) fusiformis* (Fig. 7). There was a clear seasonal variation with a significant increase of larvae during the rainy season, while copepod abundance decreased from 74% in the dry season to approximately 44% in the rainy season, indicating a notable shift in the zooplankton community structure.

Detailed analysis revealed small changes in the zooplankton community during the dry season, where *Paracalanus* and *Oithona* dominated the community on all sampling days. In contrast, during the wet season, bivalve larvae became predominant on October 20 and 22, reaching 8,630 individuals /m³, the highest density observed in this study. *Paracalanus parvus*, juvenile of Paracalanus and *Oithona nana* were dominant in the whole sampling times but these three species contributed much lower in the wet season.

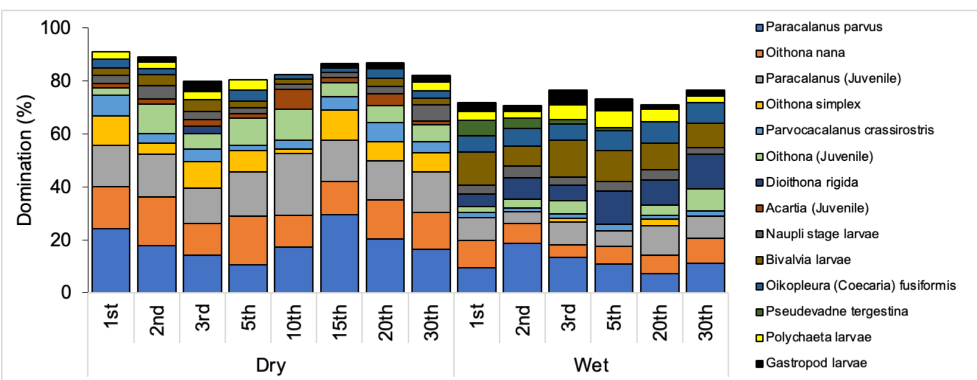

Figure 7. Dominance of main species groups of zooplankton in chroconical sampling days and seasons in Cam Ranh Bay

3.3.3. Variations in environment elements among sampling sites

The two CCA plots (Figure 8) represent the relationships between zooplankton species (blue dots) and environmental variables (red arrows) during dry and wet seasons, respectively. Each axis (CCA1 and CCA2) accounts for part of the variation in species composition explained by the environmental variables. The relative positions of species and environmental arrows indicate how species are influenced by those factors.

In the dry season (Figure 8, left), temperature (Temp) and phosphate have strong positive associations with species located toward the top-right quadrant of the graph. Fluorescence (Flo) and Ammonia are moderately influential but align closely with Silicate, suggesting a co-dependence between these factors. *Dioithona rigida* (ORI) was isolated and strongly influenced by unknown factors, as it doesn't align with measured variables. Groups like Echinodermata larvae (ECH) and *Euterpina acutifrons* (EAC) are moderately influenced by nitrate, implying these species thrive in nutrient-enriched conditions. The juveniles of Paracalanus (PJU), *Paracalanus parvus* (PPA), and *Oithona simplex* (OSI) are more closely linked to silicate and phosphate, and temperature.

In the wet season (Figure 8, right), fluorescence was a highly influential variable. Ammonia and silicate were strongly correlated, significantly impacting species positioned in the top-right quadrant. Temperature showed a negative correlation with species closer to salinity (Sal), reflecting reduced temperature impacts in areas influenced by higher salinity levels during the rainy season. *Dioithona rigida* (ORI) (top-right quadrant) is strongly associated with Ammonia, Silicate, and Fluorescence, indicating its preference for conditions that include high nutrient and phytoplankton biomass. Echinodermata (ECH) and Naupli stage larvae (NAU), similar to the dry season, were linked to nitrate-rich conditions. *Oikopleura (Coecaria) fusiformis* (FUSI) and the juvenile of Paracalanus (PJU) showed no clear adaptability to any environmental condition. *Oithona simplex* (OSI) and Polychaeta larvae (POL), positioned far from any environmental arrow, likely indicate a lesser dependence on these factors.

4. DISCUSSION

The zooplankton community in Cam Ranh Bay, as revealed in this study with high species richness, in which Copepoda contributed more than 65%, highlights that the bay host a rich copepod community, similar to other tropical bays such as Chilika Lagoon, India (Tarafdar et al., 2021) and Patos Lagoon, Brazil (Ducrotoy et al., 2019). Previous reports from adjacent areas in Viet Nam such as Thi Nai Lagoon, De Gi, Da Nang Bay (Trinh & Vinh, 2018; Vinh & Hai, 2020, 2021, 2022) also show similar patterns, emphasizing copepod important role in coastal waters (Micheli, 1999; Arashkevich et al., 2002).

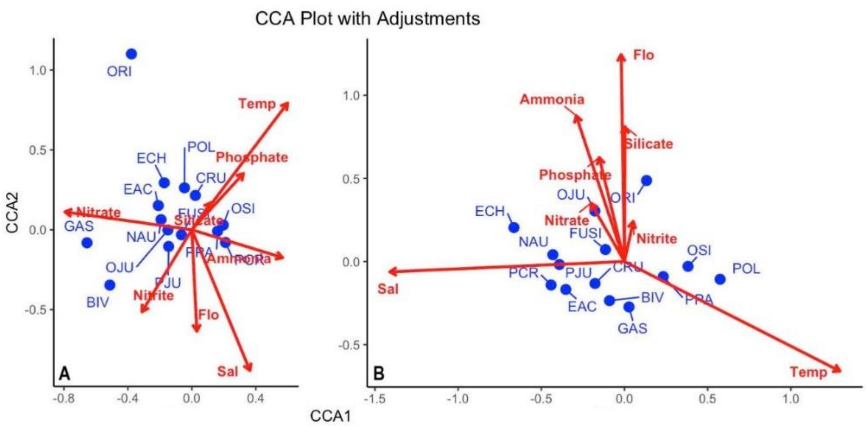

Figure 8. Canonical Correspondence Analysis (CCA) ordination of environmental factors and dominant groups in the dry (A) and wet season (B) in Cam Ranh Bay

(ORI: Dioithona rigida, EAC: Euterpina acutifrons, OJU: Juvenile of Oithona, OSI: Oithona simplex, PJU: Juvenile of Paracalanus, PPA: Paracalanus parvus, PCR: Parvocalanus crassirostris, FUSI: Oikopleura (Coecaria) fusiformis; Planktonic larvae include BIV: bivalve, CRU: crustacean, ECH: Echinodermata, GAS: gastropoda, NAU: nauplii stage, POL: polychaeta)

On the other hand, variations in zooplankton richness and species diversity indicated ecological complexity in such coastal bay areas. These variations, besides the seasonal influence, were possibly due to anthropogenic influences. Recent research by Phu Le (2022) showed a clear difference between areas with and without aquaculture activities in terms of environmental parameters (BOD5, Nitrogen, Nitrate, Phosphate) in Cam Ranh Bay from April 2019 to March 2020. Studies in other bays and lagoons, such as Chesapeake Bay in the United States and Manila Bay in the Philippines, also reveal significant seasonal and anthropogenic influences on zooplankton dynamics. For example, eutrophication in Chesapeake Bay has led to hypoxic zones that profoundly impact zooplankton and their predators (Kimmel et al., 2006). Similarly, Manila Bay's zooplankton communities have been affected by urbanization and nutrient runoff, resulting in altered community structures (Sotto et al., 2015). Besides anthropogenic pressures, seasonal habitat changes are also a factor influencing zooplankton communities. Like Cam Ranh Bay, studies in Daya Bay (China) show a strong seasonal influence on zooplankton abundance and diversity. Environmental variables such as temperature, salinity, and nutrient levels (e.g., nitrate and phosphate) are major determinants of species composition (Liu et al., 2013). The findings from Chilika Bay and Manila Bay have also experienced community shifts due to a combination of freshwater influx and nutrient loading, demonstrating similar patterns of eutrophication-driven changes (Sotto et al., 2015; Muduli et al., 2022).

Our statistics, CCA analysis, reveals that certain species exhibit distinct affinities toward specific environmental factors such as salinity and nutrient levels, with some showing tolerance for elevated temperatures and phosphate concentrations. The increased influence of fluorescence and ammonia during the wet season likely corresponds to nutrient supplied from influx, significantly affecting phytoplankton and consequently zooplankton species distribution. The negative correlation between salinity and nitrate/nitrite concentrations aligns with the dilution effect caused by freshwater during this period.

These findings were similar to previous studies in tropical coastal systems (Liu et al., 2022; Mohammed et al., 2023), highlighted the interplay between environmental factors and zooplankton distributions. The observed temporal shifts in the zooplankton community, particularly the increased density of larval groups during the wet season, underscore the critical role of nutrient dynamics and hydrological changes (Liu et al., 2022; Mohammed et al., 2023). Similar conclusions were drawn by Hirst et al. (1999) and Lo et al. (2004), who identified salinity, temperature, and nutrient concentrations as primary drivers of community structure in dynamic environments. This is particularly evident in ecosystems like Cam Ranh Bay, where species such as *Dioithona rigida* and *Paracalanus parvus* respond to these environmental variables.

Additionally, we observed temporal changes in zooplankton populations. Specifically, we found an increase in the density of larval groups, particularly bivalves and Oithonidae species (*Oithona nana* and *Dioithona rigida*), on certain days during the wet season, while Paracalanus was the most dominant group in the dry season. This underscores the important roles of nutrient and hydrological dynamics (e.g., salinity, temperature) as primary drivers of zooplankton community structure (Hirst et al., 1999; Lo et al., 2004).

5. CONCLUSIONS

This study provides a comprehensive assessment of the short-term and seasonal variations in zooplankton communities in Cam Ranh Bay, revealing significant temporal shifts influenced by both environmental and anthropogenic factors. The high species richness observed, particularly the dominance of Copepoda, underscores the bay's role as a biologically diverse and ecologically significant coastal system. Seasonal variations, including the increased dominance of larval groups during the wet season and fluctuations in biodiversity indices, highlight the dynamic nature of the zooplankton community in response to changing environmental conditions such as salinity, nutrient availability, and hydrodynamic forces.

Our findings emphasize the necessity of continuous monitoring to assess the impact of nutrient dynamics, hydrological changes, and human activities on coastal zooplankton assemblages. Understanding these variations is essential for effective marine resource management and conservation efforts in Cam Ranh Bay. Future research should further investigate long-term trends and the influence of climate change on zooplankton dynamics, contributing to a broader understanding of the ecological processes shaping coastal ecosystems in Vietnam and beyond.

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