Using zooplankton for water quality assessment in water bodies inside the Can Gio Biosphere Reserve, Ho Chi Minh City

My Tran Ngoc Diem[1,2]
1. Department of Ecology and Evolutionary Biology, Faculty of Biology and Biotechnology, University of Science, VIETNAM
2. Vietnam National University Ho Chi Minh City, VIETNAM
tndmy@hcmus.edu.vn

Abstract
Zooplankton has rapid responsiveness to environmental fluctuations, provides an accurate reflection of ecosystem well-being and is associated with low economic expenses. The study has recorded 52 species of 29 genera, 21 families, 6 classes, 4 phylum and 7 types of larvae in 24 sampling sites of 3 areas at Can Gio Biophere Reserve. The density of plankton individuals ranged from 49800 individuals/ m^3 to 273862 individuals/ m^3. A majority of the sampling stations (14 out of 24) exhibit a significant level of biodiversity and sustain communities with moderate pollution (β-mesosaprobic). Some sites exhibit zooplankton communities that display lower stability, average biodiversity and a significant amount of pollution (α-mesosaprobic). One of them has an unstable zooplankton community characterized by low biodiversity and a substantial pollution level.

The biological indicators of zooplankton have clearly identified three areas that need additional focus, particularly due to unsustainable zooplankton communities that have a considerable impact on water pollution. This highlights the necessity of employing biological indicators of species inhabiting the environment for the purpose of environmental monitoring. Furthermore, this indicates the necessity for increased focus on the management of wastewater resulting from human activities in highly populated residential areas and aquaculture zones.

Keywords: Zooplankton, Biological indices, Can Gio mangrove.

Introduction

Biological monitoring, which involves the utilization of biological indicators for monitoring changes in environmental quality, is being taken up by many nations worldwide. Every living organism within a biological system serves as an indicator of the overall health of its environment[22]. For example, zooplankton, which is highly responsive to environmental changes, is a crucial biomarker for evaluating water quality and detecting water pollution.

Zooplankton is a primary focus because of high reproductive rate, vast population size and short lifespan, which enables them to assess the water environment's quality[12,20]. Certain species of zooplankton exhibit sensitivity to fluctuations in water quality resulting from either natural or human-induced factors.

Higher water quality is correlated with lower zooplankton abundances and as the trophic state increases, the Shannon-Wiener diversity values fall. The Torrão reservoir is characterized by the prevalence of high-efficiency feed filters and macrofiltrator organisms throughout the year, resulting in poor water quality. The ratio between Calanoida and Cyclopoida exhibits a robust and inverse correlation with the trophic status, as reported[19,20]. The study shows that zooplankton, especially in cases of heavy metal pollution, are highly effective indicators of animals that can be used in ocean ecosystems. Zooplankton has rapid responsiveness to environmental fluctuations, provides an accurate reflection of ecosystem well-being and is associated with low economic expenses.

Subsequently, researchers have undertaken an increasing number of studies on the correlation between environmental parameters and biological composition, leading to the creation of multiple biological indices for rapid assessment of environmental quality[13]. Scientists have examined several zooplankton populations to establish connections between the physicochemical characteristics of water in both flowing and static bodies of water.

Can Gio mangrove became known as Vietnam's first world biosphere reserve throughout the 2000s. Throughout this period, the region has established multiple regular monitoring programs to evaluate the quality of water. Nevertheless, most of these initiatives have primarily concentrated on quantifying physicochemical parameters of water, while just a few investigations have employed biological indices and indicator organisms to evaluate water quality. Moreover, in order to enhance the local economy, it is imperative to make early predictions about the environmental quality due to the growth of tourism and coastal aquaculture.

Material and Methods

Study area: The study was conducted by collecting samples at 24 points divided into 3 areas corresponding to 3 habitat types (mangrove forest, aquaculture and tourism-residential areas) (Figure 1). The mangrove forest consists of the following points: CG01, CG01.1, CG02, CG02.1, CG03, CG03.1, CG04 and CG04.1. The points are situated within the Cần Giờ biosphere reserve, characterized by a low population density and a prohibition on fishing operations.

Coastal aquaculture encompasses the following elements: CG05, CG05.1, CG06, CG06.1, CG07, CG07.1, CG08 and CG08.1. The sampling points are situated throughout the Thạnh An area. An island commune is a diminutive islet located amidst the estuaries of the Lòng Tàu and Thị Vải rivers. There is a prevalence of aquaculture activity in this region. The residential area consists of the points CG09, CG09.1, CG10, CG10.1, CG11, CG11.1, CG12 and CG12.1. The sampling points are situated in the area with the highest population density, where regular tourist activities occur.

Zooplankton sampling and identification: Two samples of zooplankton, one qualitative and one quantitative, were obtained at each location. The collection of zooplankton samples was conducted using a Juday net equipped with a mesh mouth diameter of 30 cm, a net length of 60 cm and a mesh size of 60 µm. The velocity of towing was quantified using a flow meter. For qualitative sampling, the net was dragged about 20 meters at the top layer of the water, ensuring that the whole opening of the net was fully buried beneath the water surface. Quantitative samples were obtained by filtering 100 liters of water through the zooplankton net.

The specimens were placed in 100-milliliter containers, promptly treated with a 5% solution of formaldehyde and appropriately marked. The field logbook encompassed comprehensive data regarding the sampling sites and the attributes of the samples. Samples were identified morphologically according to several references such as: Faunna of Vietnam[4], Rotatoria, Die Rädertiere Mitteleuropas[2], Freshwater Biology[6], Copepoda – Calanoida – Diaptomidae[21] and Free-living Freshwater Protozoa[18].

Method of physio-chemical parameters for water samples: Water samples were collected from 24 sampling sites including parameters such as pH, DO, salinity, turbidity, ammonia, nitrate, phosphate, COD and coliform. The samples were measured according to ISO 5667-6:2014 standards. The samples were preserved and stored following the proper regulations and analyzed at the environmental laboratory.

Data analysis:

Shannon Weiner index[14]: This index serves as a measure of the diversity and complexity of the biological community. It is utilized to examine the structure of the community and to evaluate the characteristics of the water environment in the studied region. The calculation of this index is determined by the following formula:

$$H' = -\sum_{i=1}^{S} p_i . \ln(p_i)$$

where *pi* is the proportion of each species in the sample.

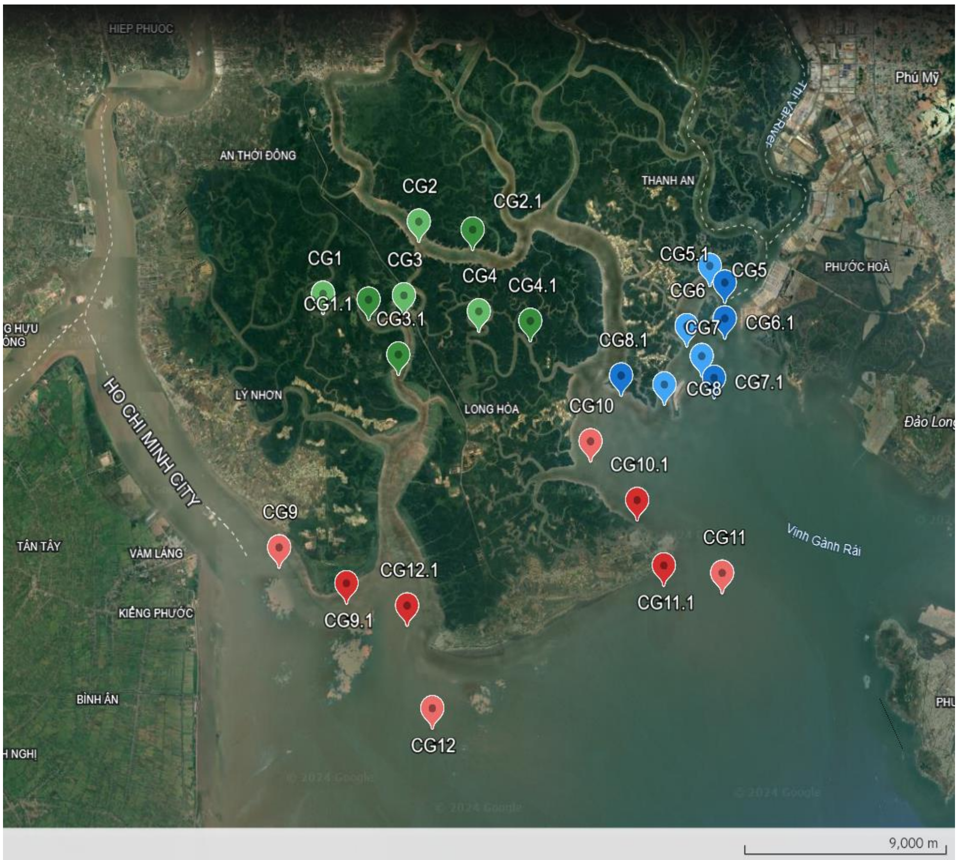

Figure 1: Sampling sites (Google earth, 18/7/2024)

The Shannon-Wiener Index is widely used as a biological index to evaluate the quality of water. Staub et al[23] introduced a water quality categorization scale that correlates species diversity with the pollution level of aquatic systems, using the value of H′ as a basis.

Pielou index (J')[19]:

$$J' = \frac{H'}{\log_2 S}$$

where S is the number of species in the sample.

Dominance index Y (Chen Quing Chao[3]):

$$Y = \frac{n_i}{N} * f_i$$

where ni is the total individuals of species i in the sample and fi is the frequency of occurrence of species i in the samples.

Berger and Parker index[1] (D):

$$D = \frac{N_{max}}{N}$$

where Nmax is the total individuals of the most dominant species and N is the total individuals in each samples.

Data Analysis: The data were processed using Microsoft Excel 2010, Primer 6 and SPSS. Recent research has shown that cluster analysis and correlation analysis are effective ways to use aquatic organism analysis results to measure water quality. They can assist in zoning and classifying the water environment, as well as identifying the appropriate relationship between the organisms and the physical and chemical properties of the water system under study.

After analysis, the data were statistically processed using SPSS 20.0 for Windows. Mean values were compared using one-way ANOVA and t-tests, or non-parametric methods, when the conditions for using parametric methods were not met. All values were statistically analyzed at α = 0.05 and Pearson correlation analysis was also tested at α = 0.05.

Additionally, species composition, population, density and biomass data were analyzed using Primer 6.0. Graphs were generated using Microsoft Excel 2010.

Table 1
Water Quality Scale based on H′ index[23]

Shannon – Wiener index	Pollution scales
0,0 – 1,0	Polysaprobic / high pollution
1,0 – 2,0	Mesosaprobic α / heaviest pollution
2,0 – 3,0	Mesosaprobic β / moderate pollution
3,0 – 4,5	Oligosaprobic / slight pollution

Table 2
Water quality Scale based on J′ index[19]

Peilou[19] index	Pollution scales
E > 0.8	sustainable communities – oligosaprobic
0.6 < E < 0.8	less sustainable communities – Mesosaprobic β / moderate pollution
0.4 < E < 0.6	very less sustainable communities - Mesosaprobic α / heaviest pollution
E < 0.4	unsustainable communities – Polysaprobic / high pollution

Table 3
Water quality scale based on Y′ index[25]

Y index	Pollution scales
Y < 0.2	sustainable communities – oligosaprobic
0.2 < Y < 0.35	less sustainable communities – Mesosaprobic β / moderate pollution
0.35 < Y < 0.5	very less sustainable communities - Mesosaprobic α / heaviest pollution
Y > 0.5	unsustainable communities – Polysaprobic / high pollution

Table 4
Sustainability of the community with pollution scales[23]

Berger – Parker[1] index	Pollution scales
D < 0.3	sustainable communities – oligosaprobic
0.3 < D < 0.4	less sustainable communities – Mesosaprobic β / moderate pollution
0.4 < D < 0.5	very less sustainable communities - Mesosaprobic α / heaviest pollution
D > 0.5	unsustainable communities – Polysaprobic / high pollution

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Results and Discussion

The zooplankton species composition: The survey results of zooplankton at the sampling points recorded 52 species belonging to 29 genera, 21 families, 6 classes, 4 phyla and 7 types of larvae. The Protozoa phylum had 21 species which is 35.59% of all the species; the Arthropoda phylum had 29 species which is 52.54% of all the species; the Copepoda order had 28 species, which is 49.15% and the Ostracoda order had 1 species, which is 3.39% and the other 7 species (11.86%) were made up of 1 species from the Chordata phylum and 1 species from the Chaetognatha phylum and 5 types of larvae (8.66%).

At the 24 sampling points across the three different habitat types, zooplankton species composition ranged from 11 to 28 species. The number of species ranged from 11 to 22 in the mangrove forest area, 20 to 28 in the aquaculture area and 17 to 25 in the residential-tourism area (Figure 2). The results showed a significant difference in the number of species among the three areas with p = 0.001, indicating that the mangrove forest and residential-tourism areas had fewer species compared to the aquaculture area.

The study documented the presence of numerous species that were observed in the majority of the water bodies, namely *Tintinnopsis urnula, Paracalanus crassirostris, Oithona nana* and Nauplius larvae. Only one of the 24 sampling places had species such as *Peridinium willei, Codonella ostenfeldii, Stenosemella sp., Eucalanus subcrassus, Corycaeus* sp., *Laophonte brevifurca* and *Laophonte brevirostris*. Out of these species, *Laophonte brevifurca, Laophonte brevirostris, Codonella ostenfeldii, Stenosemella* sp. and *Peridinium willei* were only discovered in coastal regions whilst *Corycaeus* sp. and *Eucalanus subcrassus* were observed in estuary regions.

Acartia clausi, Acartia tsuensis and *Acartia bispinosa* are zooplankton species that are found in both brackish and marine settings[7,10]. Hence, the existence of these species, in addition to certain members of the Copepoda category, suggests the possibility of saltwater infiltration into freshwater ecosystems. Moreover, *A. clausi* exhibits a high capacity to thrive in settings abundant in nutrients. The study also documented the presence of several species with brackish or marine origins that regularly migrate into coastal regions including *Paracalanus crassirostris, Paracalanus parvus, Paracalanus similis* and *Oithona* sp.[13]. These groups are commonly found in coastal water bodies or regions where saltwater infiltrates the mainland.

Zooplankton density in sampling sites: Zooplankton density ranged from 49,800 individuals/m³ to 273,862 individuals/m³. In the mangrove forest area, the number of individuals ranged from 49,800 individuals/m³ to 106,427 individuals/m³. In the aquaculture area, the density ranged from 73,254 individuals/m³ to 272,862 individuals/m³ and in the residential area, it ranged from 61,032 individuals/m³ to 272,525 individuals/m³ (Figure 3).

The results also showed a statistically significant difference in zooplankton density, with the mangrove forest and residential areas having lower zooplankton densities compared to the aquaculture area (p = 0.003). For economic development, fishermen also cultivate mollusks, crustaceans and fish.

The predominant number of Copepoda individuals in the aquaculture area indicates the area's ability to provide abundant food resources for the growth and development of aquaculture or naturally occurring aquatic species. Regular monitoring of the water environment can prevent significant losses for the local people.

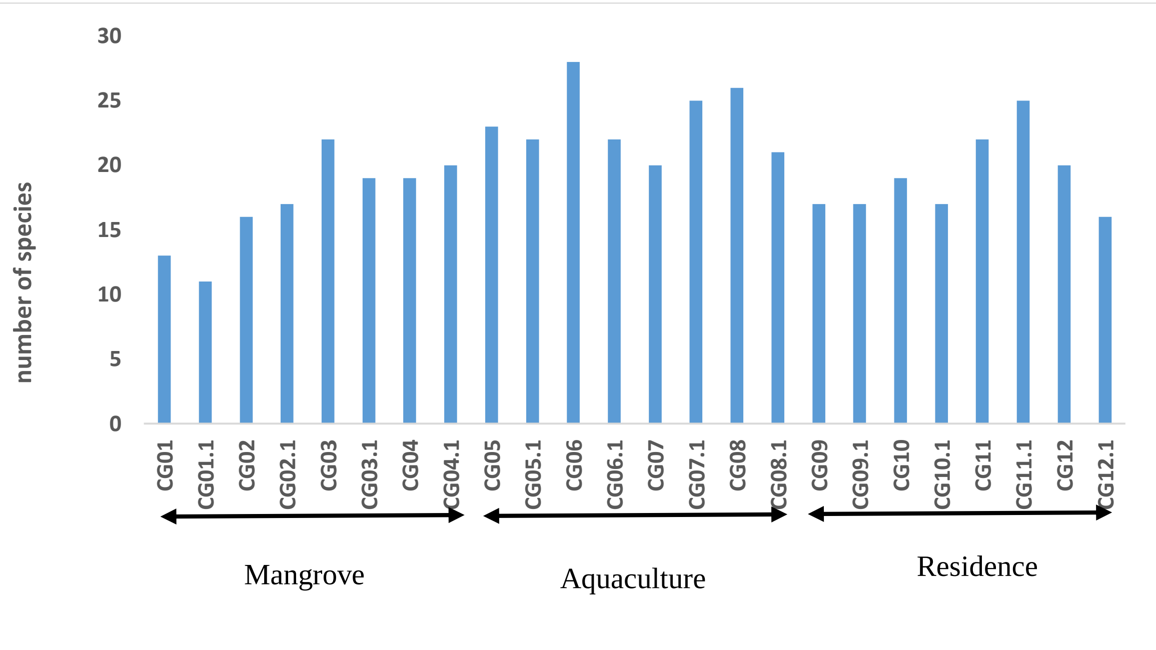

Figure 2: Zooplankton species composition at sampling sites

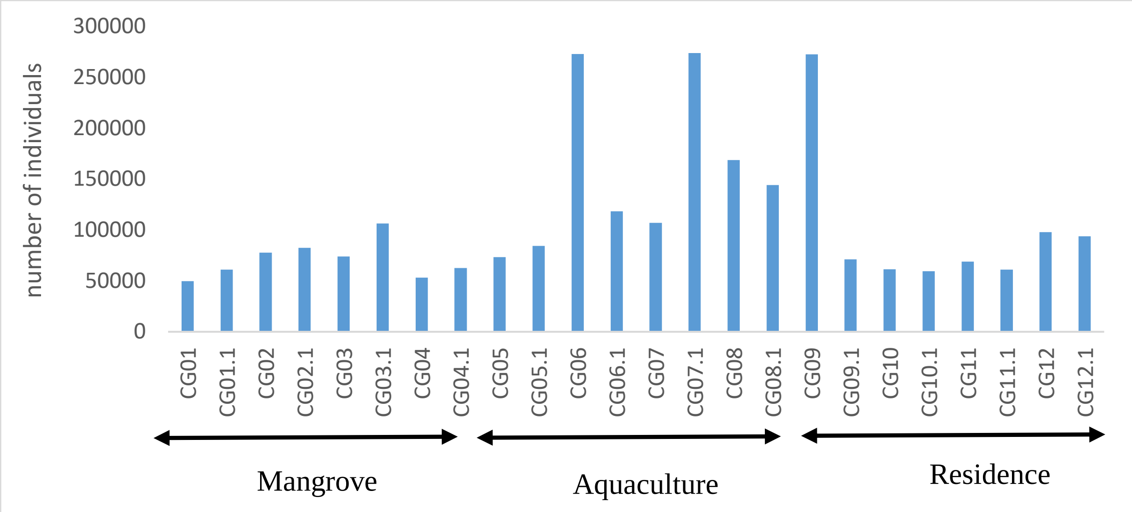

Figure 3: Density of zooplankton at the sample sites

Shannon Weiner diveristy index: The value of the diversity index not only indicates the equilibrium or lack thereof in an ecosystem, but also characterizes the composition of the biological community in an aquatic environment. As the species richness in the community increases, the Shannon-Wiener Index also increases, indicating a more equitable distribution of individuals among species. The investigation indicates that the Shannon-Wiener diversity index varies between 0.85 and 2.82, as shown in figure 4.

The Shannon-Wiener biodiversity index is consistently average across all sampling points, with few variations seen. This suggests that the diversity of the zooplankton community varies from moderately diverse to highly diverse at the surveyed locations. The diversity index H′ indicates that the water quality is highly polluted (β-mesosaprobic) at 15 out of 18 sampling stations. CG09.1 and CG12 have experienced an increase in pollution levels, specifically reaching the α-mesosaprobic level. CG09 is particularly noteworthy for its high pollution level, classified as polysaprobic. These three places are situated in a densely populated residential-tourism zone, suggesting a potential for pollution to spread to other areas due to the presence of an estuarine environment.

The average Shannon-Wiener Index values are higher in the sampling points located in the mangrove forest and aquaculture areas compared to the residential areas ($p = 0.02$). These findings indicate that it is necessary to focus on these specific regions when creating sustainable aquaculture practices in order to reduce the negative effects of aquaculture on the conservation of mangrove forests.

Peilou balance index (J'): The balance index J' ranges from 0 to 1, with values approaching 1 indicating a more stable ecosystem where species have similar individual densities. The balance index for the sampling points varies between 0.3 and 0.91 (Figure 5). The majority of sampling stations exhibit values ranging from 0.6 to 0.8, suggesting that the present water conditions are fostering consistent growth and development of zooplankton species in the ecosystem. The zooplankton community at most sampling stations exhibits a relatively stable condition with a moderate pollution level (β), characterized by a J' value ranging from 0.6 to 0.8. Significantly, the site CG09 is categorized as substantially contaminated (polysaprobic).

On the other hand, according to the Peilou index, mangrove regions are classified as lightly polluted (oligosaprobic), showing a greater level of balance in comparison to aquaculture and residential areas ($p = 0.04$). These findings indicate that the water conditions in mangrove ecosystems are more favorable for the growth and diversity of different zooplankton species.

Y dominance index: Nguyen[17] research on zooplankton in the oil spill-affected areas of Cần Giờ demonstrates that the application of the dominance index Y is a highly effective tool for evaluating environmental quality. Therefore, this study utilizes the Y index to evaluate its suitability in evaluating brackish and marine waters that are contaminated with organic pollution. The Y index has a scale from 0 to 1 where higher values of Y indicate a decrease in community sustainability.

The analysis results indicate that the dominance index Y varies between 0.02 and 0.27 as shown in figure 6. The majority of sampling points exhibit Y values that are less than 0.2, indicating a high degree of community sustainability with slight pollution levels. Sites CG05.1, CG07.1, CG08.1 and CG09 exhibit viable communities with moderate pollution levels (β). The Y index consistently exhibits lower values in mangrove habitats as opposed to aquaculture and residential-tourism regions ($P < 0.05$). The water quality of mangrove areas suggested superior water quality in relative to other habitats.

Berger – Parker[1] dominance index: When a community is dominated by one or two species in terms of individual numbers, it becomes unsustainable. The dominance index is a numerical scale that spans from 0 to 1. As the dominance index approaches 1, the level of community sustainability declines. The index varies from 0.12 to 0.83 across different ecosystems, as seen in figure 7. The Berger-Parker[1] dominance index indicates that 17 out of 24 habitats possess zooplankton communities that are capable of sustaining themselves in the presence of light pollution (oligosaprobic).

Group 2 consists of four habitats out of a total of 24, specifically CG02, CG05.1, CG08.1 and CG12. These habitats are characterized by generally stable communities and low pollution levels (β-mesosaprobic). Group 3 consists of two habitats, specifically CG07.1 and CG09.1 that exhibit less viable populations and significant pollution (α-mesosaprobic). Figure 7 indicates that CG09 possesses an environmentally unsustainable community characterized by significant pollution levels (polysaprobic). Mangrove ecosystems have lower levels of light pollution compared to aquaculture and residential-tourism sectors which had higher levels of pollution ($p < 0.05$).

The water quality study provided different results at each sampling location when relying solely on specific biological indicators. Nevertheless, the amalgamation of these variables offers a more precise evaluation of the sample spots. The sampling points in all three areas exhibit a spectrum of pollution levels, ranging from slight pollution to high pollution. CG01.1, CG02, CG02.1, CG03 (mangrove area), CG06.1, CG07 (aquaculture area) and CG10 (residential area) exhibit significant biodiversity and support sustainable populations with minimal pollution. A majority of the sampling stations (14 out of 24) exhibit a significant level of biodiversity and sustain communities with moderate pollution (β-mesosaprobic).

Points CG09.1 and CG10.1 exhibit zooplankton communities that display lower stability, average biodiversity and a significant amount of pollution (α-mesosaprobic). In contrast, point CG09 has an unstable zooplankton community characterized by low biodiversity and a substantial pollution level (Figure 8). Among the sampling locations, site CG09 displayed the greatest turbidity and TSS concentrations when examining the water physico-chemical characteristics.

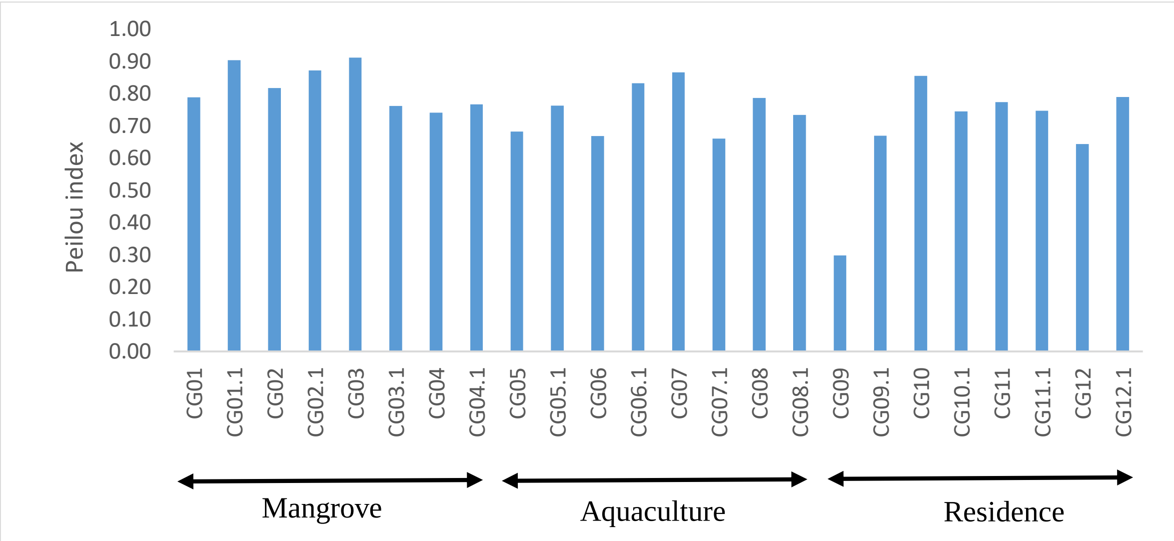

Figure 4: Shannon Weiner index at sampling sites

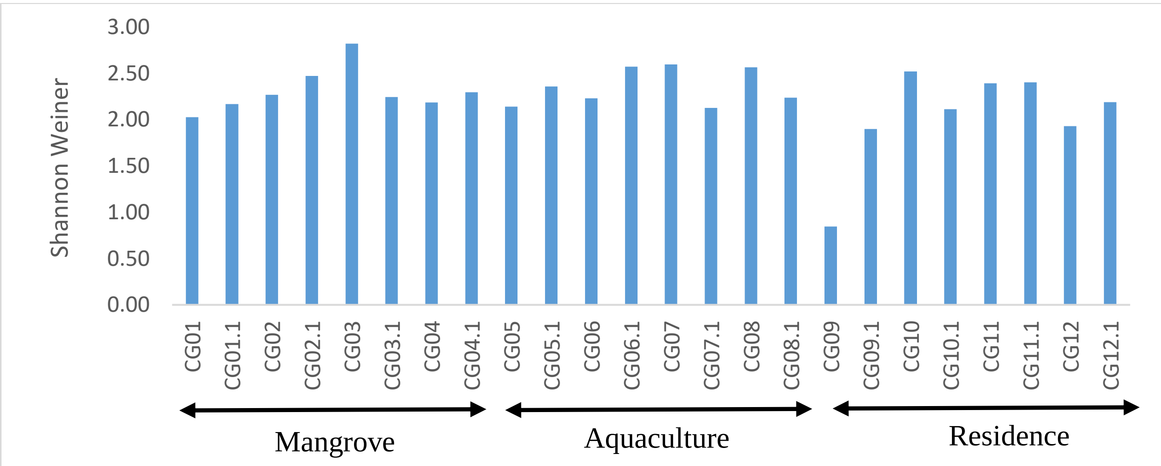

Figure 5: Peilou balance index at sampling sites

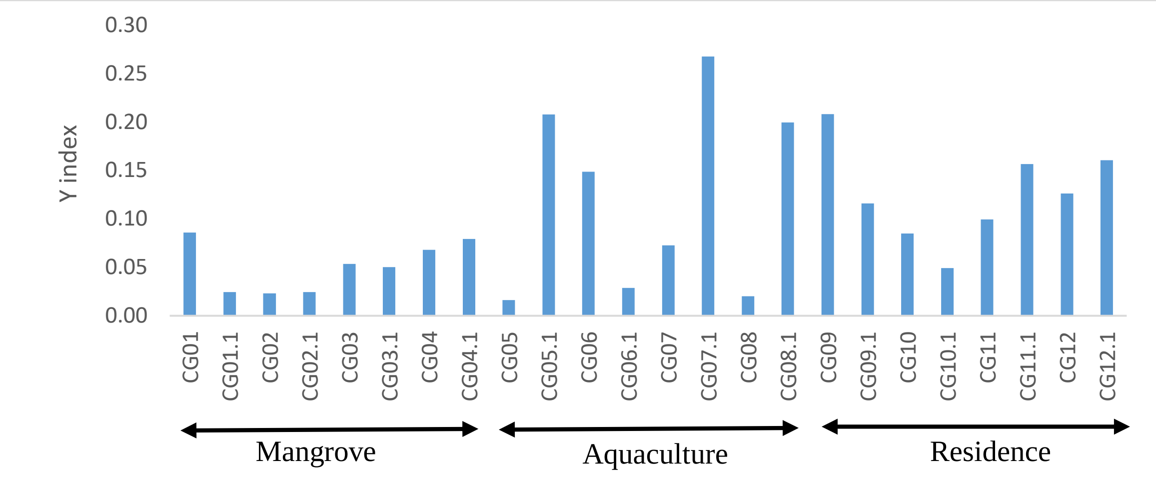

Figure 6: Y dominance index at the sampling sites

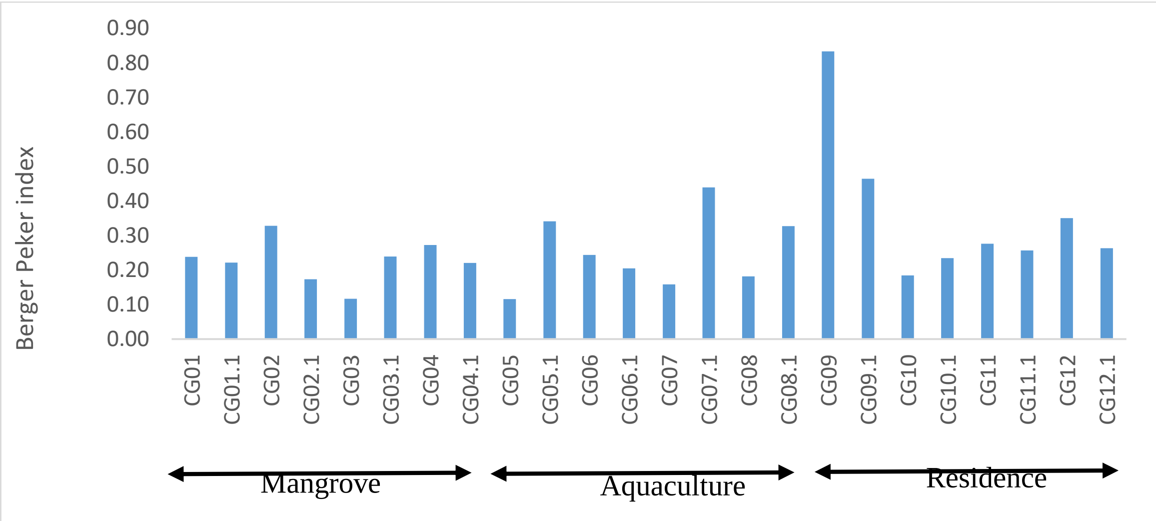

Figure 7: Berger-Parker dominance index at the sampling sites

Although the concentrations of COD, BOD, nitrate and phosphate were not notably elevated, they suggested a rise in the nutritional composition in this region. This phenomenon may be ascribed to the cultivation of shrimp in the upstream region, as well as to the cultivation of blood cockles, clams and oysters utilizing cement boards and the release of wastewater from adjacent residential areas. These findings suggest the necessity for heightened attention on the management of wastewater generated by human activities. Based on the analysis conducted using VN-WQI, as stated in 1460/QĐ-TCMT, it has been determined that out of the 24 points examined, 4 exhibit good water quality that is suitable for domestic use but may require some treatment (specifically CG01, CG01.1, CG07 and CG10).

On the other hand, the remaining 20 points have average water quality that is suitable for irrigation and aquaculture. Meanwhile, the biological indicators of zooplankton have clearly identified three areas that need additional focus, particularly due to unsustainable zooplankton communities that have a considerable impact on water pollution. This highlights the necessity of employing biological indicators of species inhabiting the environment for the purpose of environmental monitoring, in order to obtain more precise assessment outcomes. Furthermore, this indicates the necessity for increased focus on the management of wastewater resulting from human activities in highly populated residential areas and aquaculture zones.

An individual analysis of the species composition of each primary zooplankton group provides more insight into the environmental variables that directly impact the growth and development of these groupings. The Copepoda group had the highest number of species documented at the sampling sites, comprising of 30% to 50% of the species and exhibiting dominance in terms of individual abundance, with greater than 50% of the total individuals. This group had a significant positive connection with dissolved oxygen and salinity ($p = 0.01$).

In addition, the concentrations of NH_4 and PO_4 nutrients showed a positive correlation with salinity. Nitrate and ammonium concentrations in the water had a direct impact on Copepoda. The concentration of nitrite regulated the abundance of phytoplankton which in turn acted as a crucial food supply for the Copepoda group[5,10].

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Figure 8: The map showing water quality at the sampling points
(green: oligosaprobic; yellow: mesosaprobic β; orange: mesosaprobic α; red: polysaprobic).

The observed phenomenon can be attributed to the reduced levels of total suspended solids which facilitate the penetration of sunlight into the water column, leading to an augmentation in phytoplankton density. Elevated phytoplankton density leads to a substantial rise in both the abundance and density of zooplankton. This is because phytoplankton serves as a crucial food supply for zooplankton, especially species belonging to the Cladocera and Copepoda families. Saltwater intrusion is a significant phenomenon during the dry season, as it deeply infiltrates the inland sampling sites. The saline water expanded the distribution of numerous Copepoda species from brackish and saltwater habitats to the inland region. The Copepoda group, particularly the Calanoid, was the predominant group in estuary regions[7,9,27]. Salinity is widely recognized as the primary determinant of tropical zooplankton community structure and the reproductive success of individuals at different phases of growth and development[9].

Furthermore, the proportion of Calanoida to Cyclopoida in the aquatic ecosystem also plays a role in evaluating water quality. When the Calanoida group is the most abundant, the water environment tends to have a low to moderate amount of nutrients. However, when the Cyclopoida group is more dominant, the water environment becomes more eutrophic. Filamentous blue-green algae frequently thrive in habitats with abundant nutrients which can have an impact on the behavior and survival of larger Calanoida species. When the development of this group is at a lower stage, it provides advantageous circumstances for the smaller Cyclopoida group to flourish[8]. This is consistent with the results obtained from the zooplankton study conducted at 24 sampling locations in Can Gio.

CG05.1, CG07.1, CG09, CG09.1, CG10.1, CG12 and CG12.1 were found to have significant pollution levels based on the biological markers of zooplankton. These points showed a larger abundance of Cyclopoida individuals compared to Calanoida. The remaining data points exhibited either a roughly equal distribution or a significantly greater abundance of Calanoida, with a range of 2 to 8 times more individuals.

The reason for this can be attributed to the fact that these places are characterized by estuaries and mangrove ecosystems which make the utilization of this index particularly appropriate for evaluating the quality of water.

Conclusion

The study's findings indicate that zooplankton can serve as a reliable biological indicator for evaluating ecosystem condition, effectively managing and preserving water resources in these vulnerable regions. It is advisable to utilize a variety of biological indicators rather than depending just on one in order to obtain a more objective evaluation in water quality monitoring. The utilization of biological indices for water quality evaluation yields a high level of precision and offers a thorough representation of environmental conditions by examining the composition of the biological community. This approach provides a full understanding of the overall health of the ecosystem.

Species that are susceptible to pollution or environmental changes will become extinct or will experience a decline in population, whereas species that can tolerate pollution will experience an increase in population. This facilitates the timely identification of environmental problems that may not be fully disclosed by simply chemical-physical markers. Furthermore, this approach does not necessitate intricate apparatus or exorbitant charges, hence diminishing the financial burden for evaluating and overseeing water quality.

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