



Evaluating Relationship between Surface Water Quality and Zooplankton Diversity in Coastal Areas of Tien Giang Province, Vietnam

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ABSTRACT: The zooplankton diversity is the most important ecological parameter for water quality assessment, as these small creatures are sensitive to any changes in water quality, hence the objective of this study as to evaluate the relationship between surface water quality and zooplankton diversity in the coastal areas of Tien Giang province, Vietnam using appropriate standard methods. The results showed that the coastal water quality had high concentrations of suspended solids, ammonium and coliforms. A total of 71 zooplankton species with a total density ranging from 3,219,383 to 24,993,634 individuals/m³ were identified. Among the zooplankton species, *Copepoda nauplius* appeared at all monitoring stations, predominating with a density ranging from 740,800 to 7,555,250 individuals/m³. The values of the Shannon-Wiener diversity index (H') ranged from 1.54 to 2.37, reflecting the coastal water quality in the study area from polluted to mildly polluted. The coastal water variables of pH, salinity, DO, NH₄⁺-N and coliform were closely correlated with the density of zooplankton species. The relationship between surface water quality and zooplankton diversity could be a basis for selecting biological indicators to monitor coastal water quality.

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Zooplankton are heterotrophic plankton floating in the water column of seas, oceans and freshwater bodies. Zooplankton plays an essential role in the food chain of aquatic ecosystems because they are not only the main consumers of primary products (plankton) but also secondary producers, which is a natural food for small fish species and the larval stage of many large fish species (Phuoc *et al.*, 2018; Alprol *et al.*, 2021). In addition, zooplankton also plays an important role in the natural cycle of carbon and other elements in the sea (Abo-Taleb *et al.*, 2020). In particular,

zooplankton is very sensitive to water quality; therefore, it could be an important indicator of changes in the water environment (Phuoc *et al.*, 2018; Shen *et al.*, 2021). Environmental factors significantly affect the structure of the zooplankton community, such as abiotic factors (nutrients, light, temperature, transparency and pollutants) and biotic factors (parasite, predator) (Cai *et al.*, 2020; Kyczynska-Kippen *et al.*, 2020), especially in coastal estuary areas where densely populated areas along with the increase in the number of nutrients created by humans have

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severe effects on marine communities (Alprol *et al.*, 2021). At the same time, these areas are also the recipients of pollution sources from the mainland, which are at high risk of environmental pollution (Dung *et al.*, 2022). Tien Giang is a coastal province in Southeast Vietnam, stretching on the north bank of the Tien River with a length of 120 km, extending to the estuaries flowing into the East Sea. The province not only has strengths in tourism but also has economic potential in fisheries with a long coastline and rich river system, namely the Go Cong Dong and Tan Phu Dong districts, where aquaculture and tourism have developed very strongly. Nevertheless, the coastal water environment could be significantly affected, leading to a decrease or change in the composition and density of zooplankton. The relationship between environmental factors and plankton has been studied in many freshwater areas and reservoirs, while it is still limited in the coastal areas. Therefore, the objective of this study as to evaluate the relationship between surface water quality and zooplankton diversity in the coastal areas of Tien Giang province, Vietnam.

MATERIALS AND METHODS

Study site: Tien Giang is a Mekong Delta coastal province located north of the Tien River. The province has a 32 km long coastline, suitable for aquaculture and fishing. In which, Go Cong Dong and Tan Phu Dong are two districts bordering the sea, with a natural area of about 490 km² and a coastline of 21 km and 11

km, respectively. Economic development is mainly based on the marine economy, such as fishing and aquaculture. Tan Phu Dong district has an aquaculture area of about 7,110 hectares, with an output of about 27,855 tons annually. These social-economic activities could influence coastal water quality and the diversity of zooplankton.

Water sampling and analysis: Data on water quality and zooplankton were collected from the Department of Natural Resources and Environment of Tien Giang province, which is the primary agency responsible for carrying out environmental monitoring of land, water, air and biodiversity in all areas of the province. Specifically, 9 water samples and 9 zooplankton samples were collected in the coastal area of Tien Giang province. A total of 9 coastal seawater samples were collected in the Go Cong Dong and Tan Phu Dong districts of Tien Giang province, representing areas affected by aquaculture and tourism activities. In particular, 8 seawater samples were collected in the Go Cong Dong district, including the following locations: B1-B4 and B6-B9. The remaining sample was collected in Tan Phu Dong district (B5). The location of seawater monitoring stations in the coastal area of Tien Giang province is detailed in Figure 1. Seawater samples were monitored five times per year in March, May, July, September, and November of 2022. The method of coastal seawater samples complied with TCVN 5998:1995 (ISO 5667-9:1992) - Water quality - Sampling - Guidance on seawater sampling.

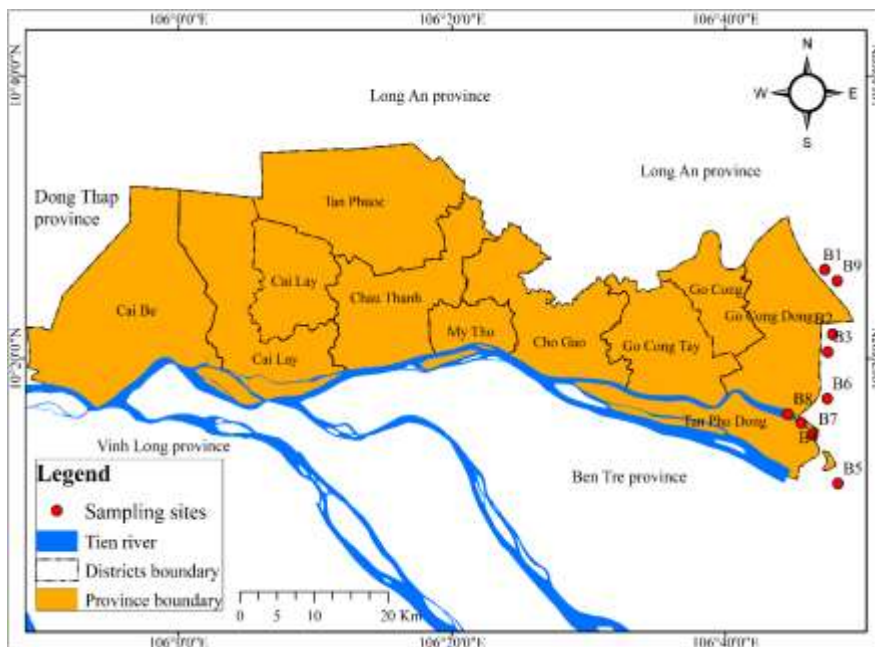


Fig 1. Map of locations of water and zooplankton samplings

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The collected water samples were analyzed for eight physicochemical parameters, including pH, temperature, salinity, dissolved oxygen (DO), total suspended solids (TSS), ammonium ($\text{NH}_4^+\text{-N}$), orthophosphate ($\text{PO}_4^{3-}\text{-P}$) and coliform. The parameters of pH, temperature, salinity and DO were measured directly in the field by the instrument HACH HQ30D (HACH-USA), according to the standard methods of TCVN 6492:2011, SMEWW 2550.B:2017, SMEWW 2520.B:2017 and TCVN 7325:2016, respectively. The remaining parameters (i.e., TSS, $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$ and coliform) were analyzed in the laboratory. TSS was analyzed by filtering through a glass fiber filter (TCVN 6625:2000, ISO 11923:1997). $\text{NH}_4^+\text{-N}$ and $\text{PO}_4^{3-}\text{-P}$ were analyzed using the phenate (SMEWW 4500-NH3.B&F:2017) and the stannous chloride methods (SMEWW 4500-P.D:2017), respectively. Coliforms were analyzed using the multiple tube method (TCVN 6187-2:1996, ISO 9308-2:1990E).

Zooplankton sampling and analysis: Zooplankton samples were collected simultaneously with seawater samples at 9 monitoring stations (B1-B9) in March, May, July, September and November 2022 (Figure 1). Qualitative samples of zooplankton were collected by plankton net with a mesh size of $60\mu\text{m}$, placing the mouth of the net 15 - 20 cm above the water surface and then pulling the net according to zigzag. The collected sample was poured into a plastic bottle (110 mL). Quantitative zooplankton samples were obtained by filtering 200 L of water through a plankton net (mesh size $60\mu\text{m}$), which used a 20 L plastic bucket to collect samples 10 times at each monitoring location. The zooplankton samples were fixed with 4 - 6% formalin solution (Lien *et al.*, 2020; Alprol *et al.*, 2021). For qualitative analysis, the sample after collection was observed under the microscope under different objectives. Then, the name of the genus or species of the zooplankton was identified based on the morphological and structural features. Taxonomic documents such as Shirota (1966), Khoi (2011) and Thanh *et al.* (2018) were used in the study. For quantitative analysis, the volume of all samples was concentrated at 110 mL. After that, count the sample by stirring the sample and aspirating 1 mL into the Sedgwick Rafter counting chamber. Determining the number of species on the microscope using the equation of Dung and Oanh (2011):

$$X = n \times \frac{v}{V} \times 1000 \quad (1)$$

Where X is the density of zooplankton (individuals/ m^3), n is the number of individuals counted in the water sample in 1mL, v is the volume

of zooplankton concentrates (mL) and V is the collected water volume (L) of the sample.

Data processing: The descriptive statistics method was used to show water quality indicators' spatial variation and plankton species' number and density at 9 monitoring stations. One-way ANOVA was performed on water quality parameters to evaluate the difference in water environment properties between monitoring stations ($p < 0.05$). The above analyses were performed using SPSS software version 20.0. In the study, the values of water quality parameters, including pH, DO, TSS, $\text{NH}_4^+\text{-N}$, $\text{PO}_4^{3-}\text{-P}$ and coliform, were compared with QCVN 10-MT:2015/BTNMT national technical regulation on marine water quality. Moreover, Spearman correlation analysis was performed using data on water variables and the density of zooplankton species at nine stations in five monitoring periods. This analysis aimed to determine the relationship between water quality parameters and the zooplankton species in the study area. Spearman correlation analysis has been widely used in evaluating the positive and negative correlations between environmental components and plankton (Lodi *et al.*, 2011; Hanim *et al.*, 2014). Specifically, the correlations between water quality parameters and zooplankton were significant at 0.05 or 0.01. In particular, the degree of correlation is expressed through the coefficient r, which ranges from -1 to 1. When $r = 1$ represents a positive correlation; in contrast, $r = -1$ shows a negative correlation. The absolute value of the correlation coefficient r is used to quantify the strength of the relationship. The correlation coefficients r indicate the significant impact and influence of coastal water quality variables on the change in density of zooplankton species in the coastal area of Tien Giang province. Spearman correlation analysis was performed using SPSS software version 20.0. The Shannon-Wiener Diversity Index (H') was applied to reflect the diversity of zooplankton components and the level of nutrients or water pollution in a specific area (Ren *et al.*, 2011). According to Molvaer *et al.* (1997), water pollution level based on H' index is divided into 5 levels, including (1) $H' > 4$ represents "Very clean", (2) $3 < H' < 4$ represents "Clean", (3) $2 < H' < 3$ indicates "mild pollution", (4) $1 < H' < 2$ indicates "pollution" and (5) $0 < H' < 1$ indicates "very polluted". In the study, the H' was calculated for each monitoring location according to the formula of Shannon and Wiener (1963)

$$H' = - \sum_{i=1}^s \left(\frac{N_i}{N} \right) * \ln \left(\frac{N_i}{N} \right) \quad (2)$$

Where: N_i is the number of individuals of species i , and N is the total number of individuals of all species in the water sample at a given location.

RESULTS AND DISCUSSION

Coastal surface water quality in the study areas: The pH in the water fluctuated relatively stable between

monitoring stations, ranging from 7.32 ± 0.44 - 7.60 ± 0.21 , which characterizes the alkaline environment (Figure 2a). Compared with some other studies conducted in the coastal waters of Vietnam, the pH value in the water in the present study area is relatively lower.

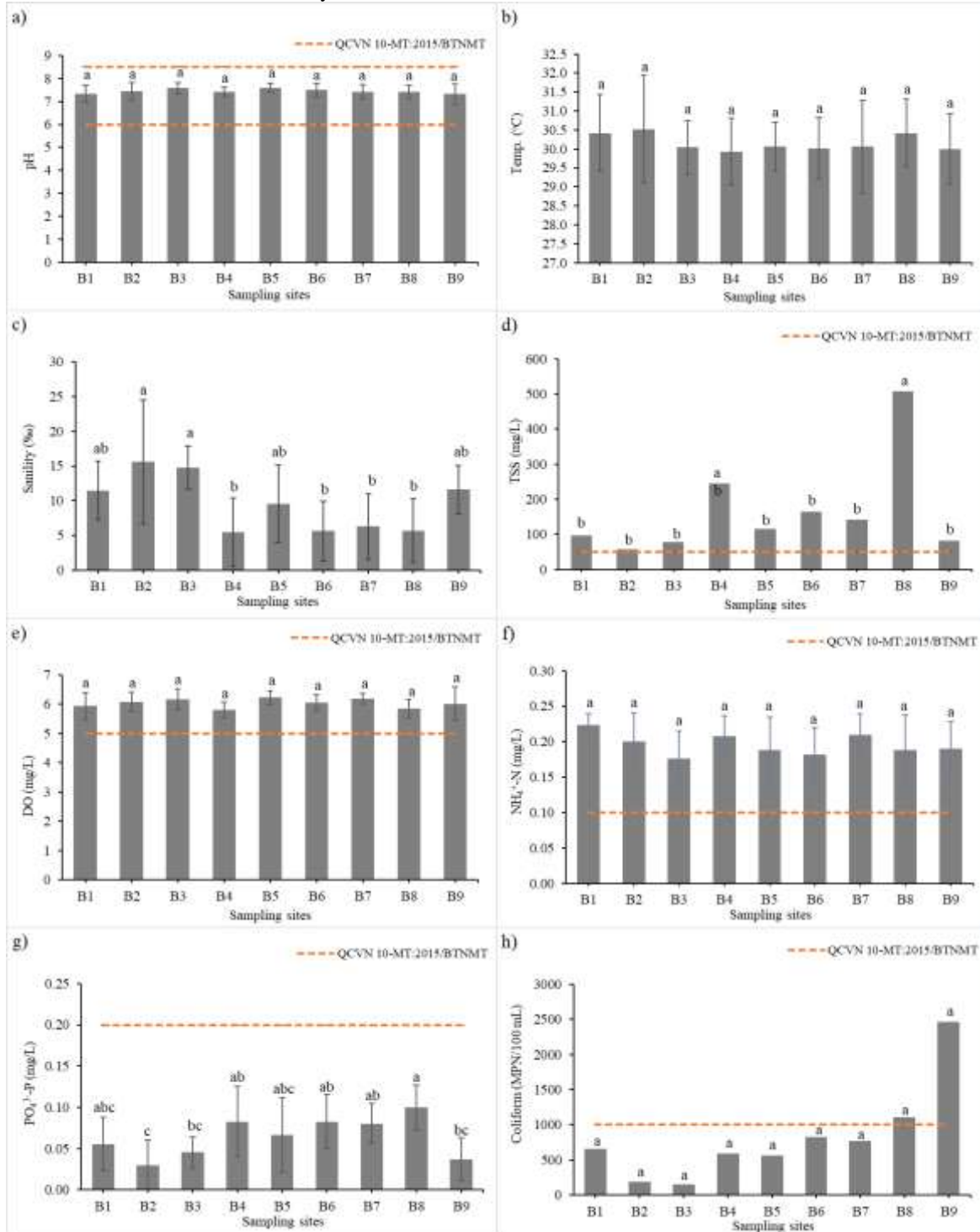


Fig 2. Characteristics of physiochemical parameters of the coastal water in the study areas

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For instance, the pH value in coastal seawater fluctuated from 8.09 ± 0.17 - 8.31 ± 0.05 , 8.03 ± 0.13 - 8.18 ± 0.13 and 7.45 ± 0.34 - 8.32 ± 0.33 in Nha Trang, Vung Tau and Rach Gia monitoring stations, respectively (Tam, 2018). Moreover, the average pH values in coastal seawater in the southern part of the Red River Delta, Can Gio district (Ho Chi Minh City) and northern Vietnam were 8.3 ± 0.1 , 7.43 - 7.62 , and 7.43 - 7.62 , 7.86 - 8.32 , respectively (Dung *et al.*, 2022; Thai *et al.*, 2022; Nghi *et al.*, 2022). Based on QCVN 10-MT:2015/BTNMT on coastal water quality applied to aquaculture and aquatic conservation areas, pH values at monitoring stations were within the limits of water quality permissible limit (6-8.5). The measured temperature was considered suitable for the growth and development of aquatic organisms (Van and My, 2020), ranging from 29.92 ± 0.89 - 30.52 ± 1.41 °C (the average of 30.16 ± 0.91 °C) (Figure 2b). According to the results of the statistical analysis, the study area's water temperature fluctuated relatively stable, and the difference was not statistically significant between monitoring stations ($p>0.05$). However, the temperature recorded in the coastal waters of Tien Giang province in 2022 tended to be higher than in Vietnam's coastal marine environment in 2021. This result was consistent with the annual variation (increase) in sea temperature according to the study of Hien *et al.* (2014).

Salinity reached the minimum and maximum values of 5.47 ± 4.92 ‰ (B4-Cua Tieu) and 15.60 ± 8.87 ‰ (B2-Kieng Phuoc Commune), with the average of 9.58 ± 5.99 ‰ (Figure 2c). There was a statistically significant difference between monitoring stations ($p<0.05$). Salinity was measured in other coastal waters, such as the southern part of the Red River Delta (salinity 26.8 ± 1.8 ‰), Can Gio district (salinity 24.30 - 24.55 ‰), the salinity was relatively higher than that in the Tien Giang province research area (Dung *et al.*, 2022; Thai *et al.*, 2022). Salinity was recorded to be within the tolerance range of some aquatic species, namely shrimp (2-40‰), clams (5.3-42.5‰) and blood cockles (3.8-33‰) (Van and My, 2020). The TSS values did not meet the allowable limit of QCVN 10-MT:2015/BTNMT (50 mg/L). The concentration of TSS fluctuated dramatically from 57.60 ± 23.39 - 508.00 ± 710.07 mg/L and the average was 165.31 ± 39.04 mg/L, exceeding 1.15-10.16 times the standard (Figure 2d). The concentration of TSS was highest at location B8-Den Do fishing port and was significantly different from the other monitoring locations ($p<0.05$), an area affected by aquaculture. According to Hanh *et al.* (2020), high-value TSS in aquaculture areas could be affected by several factors such as algae density, dead algae, rotting leftovers,

waste of farmed shrimp, clams, oysters, microbial carcasses, soil colloids (suspensions) available in the feed. Moreover, the fluctuation of tides, wind direction, wind speed and flow carrying pollutants from inland to sea are among the main factors influencing the variation of TSS concentration in coastal areas (Sas *et al.*, 2022). TSS pollution in coastal water was also recorded in some areas (Vinh, 2011; Tung *et al.*, 2013; Tam, 2018). The concentration of DO varied from 5.81 ± 0.27 to 6.22 ± 0.24 mg/L, reaching an average of 6.03 ± 0.35 mg/L; there was no significant between monitoring stations ($p>0.05$) (Figure 2e). The DO concentration in the study area met the dissolved oxygen conditions for the aquaculture areas according to the regulations of QCVN 10-MT:2015/BTNMT ($DO \geq 5$ mg/L). This result has similarities with some studies of Tam (2018), Tam (2019) and Nghi *et al.* (2022), which were carried out in some other coastal waters of Vietnam.

Nutrient pollution in coastal seawater in the study area was assessed through the concentration of NH_4^+ -N and PO_4^{3-} -P (Figure 2f, g). The measured concentrations of NH_4^+ -N and PO_4^{3-} -P ranged from 0.176 ± 0.04 - 0.224 ± 0.02 mg/L and 0.03 ± 0.03 - 0.1 ± 0.03 mg/L, respectively. The concentration of NH_4^+ -N was not statistically significant between the sampling locations ($p>0.05$), whereas the reverse was true for the concentration of PO_4^{3-} -P ($p<0.05$). Typically, the PO_4^{3-} -P concentration was lowest at B2-Kieng Phuoc Commune and highest at B8- Den Do fishing port. Based on QCVN 10-MT:2015/BTNMT, the study area has been contaminated with nutrients, which may have caused the eutrophication due to the NH_4^+ -N higher than the allowable limit of the regulation (0.1 mg/L). The NH_4^+ -N concentration was high, which may be affected by domestic waste, cultivation, and aquaculture. In domestic wastewater, the concentration of NH_4^+ -N was very high, which was higher than about 6.2 times that regulated in QCVN 14:2008/BTNMT (Anh and Diem, 2016). The concentration of NH_4^+ -N in aquaculture wastewater was 53.21 mg/L (Mao *et al.*, 2015). Ammonium contamination has been reported in a few previous studies, such as in the coastal area of Thai Binh, the southern region of the Red River Delta and the coastal area of Can Gio (Tung *et al.*, 2013; Dung *et al.*, 2022; Thai *et al.*, 2022). Meanwhile, the concentration of PO_4^{3-} -P was lower than the allowable limit of the regulation (0.2 mg/L).

The concentration of coliforms in Tien Giang province fluctuated considerably from 150.60 ± 195.35 - 2463.20 ± 4782.81 MPN/100mL with an average value of 812.67 ± 1842.44 MPN/100mL (Figure 2h).

However, the statistical analysis showed that the variation in the coliform concentration between the monitoring stations was not statistically significant ($p > 0.05$). Compared with QCVN 10-MT:2015/BTNMT, the average coliform density was still within the allowable limits of the regulation. However, coliform concentrations at two sites exceeded the threshold (accounting for 22.22% of the total). The concentration of coliforms in this study area was significantly higher than in other coastal areas in Vietnam, namely Can Gio, Nha Trang and Vung Tau (Thai *et al.*, 2022; Tam, 2016). The presence of coliform in water is considered to be derived from human and warm-blooded animal feces.

Composition of zooplankton in the study areas: The analysis of coastal seawater in Tien Giang province has identified 71 species belonging to 6 phyla and 36 families of zooplankton (Figure 3a). Fluctuating by species number, phylum Arthropoda was considered to have the most significant number of species, with 28 species (accounting for 39.44% of the total). In which, the Copepoda group had the most abundant species (20 species, accounting for 71.43%), representing more than 50% of the zooplankton

biomass in the marine environment and was considered a natural food source rich in nutrients for the marine environment (Abo-Taleb *et al.*, 2020). After that, phylum Ciliophora and Rotifera had 20 species (accounted for 28.17% of the total) and 10 species (accounted for 14.08% of the total species), respectively. The remaining groups (i.e., Larva, Amoebozoa and Chordata) appeared 8 species (11.27% of the total), 3 species (accounting for 4.23% of the total) and 2 species (accounting for 2.82% of the total), respectively. Fluctuating by families, phylum Arthropoda has the highest number of families, with 17 families accounting for more than 47% of the total. The Larva phylum ranked second, with 8 families identified (accounting for 22.22%). Finally, phylum Chordata identified only 1 family, accounting for about 3% of the total. The composition of zooplankton in this area was significantly lower than in the coastal areas of Soc Trang-Bac Lieu (Van *et al.*, 2012), Son Tra Peninsula (Danang) (Trinh and Vinh, 2018) and Khanh Hoa and Vung Ro (Trinh and Vinh, 2017; Vinh and Hai, 2022). This could be explained by the significant difference in nutritional status in the other water bodies.

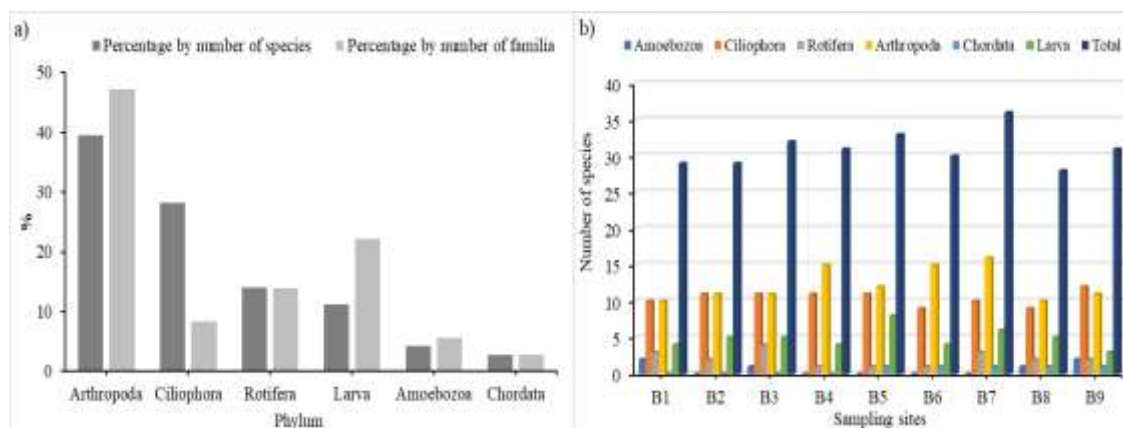


Fig 3. Composition structure of zooplankton species

Figure 3b shows that the number of zooplankton species fluctuated from 28 to 36 species. Position B7-Phu Dong commune area had the richest number of zooplankton species, with 36 species belonging to 4 branches, and the Arthropoda phylum has the highest number of species. Meanwhile, the location B8-Den Do fishing port has the lowest number of zooplankton species. Although there were all 5 phyla, this position only recorded 28 zooplankton species.

The analysis results showed that the Amoebozoa phylum (for example, *Arcella discoides*, *Centropyxis ecornis* and *Centropyxis aculeata*) only appeared at some monitoring stations, namely location B1-Soai

Rap estuary, B2- Kieng Phuoc Commune, B8-Den Do fishing port and B9-Vam Lang fishing port. Similarly, the phylum Chordata has two species (*Oikopleura (Coecaria) fusiformis* and *Oikopleura longicauda*) that occur only from positions B5-B9. Notably, the species *Tintinnopsis fimbriata*, *Tintinnopsis karajacensis*, *Tintinnopsis tentaculata* (Ciliophora), *Brachionus plicatilis* (Rotifera), *Balanus balanoides*, *Paracalanus parvus*, *Paracalanus aculeatus*, *Acartia clausi*, and *Acartia pacifica* (Arthropoda), and *Copepoda nauplius*, *Copepodite sp.* belonging to the Larva group appear at most of the monitoring stations. The occurrence of *Brachionus plicatilis* species was typical for the brackish water environment in the study

area (Lien *et al.*, 2013), and salinity in coastal waters of Tien Giang province ranged from 5.47 ± 0.92 - 15.60 ± 8.87 ‰. In addition, the appearance of *Copepoda nauplius* showed that the coastal seawater environment in this area is rich in nutrients (Du *et al.*, 2019), which is consistent with the recorded results of $\text{NH}_4^+\text{-N}$ concentration in water was higher than the allowable limit of QCVN 10-MT:2015/BTNMT. The dissolved oxygen in the study area was relatively high (5.81 ± 0.27 - 6.22 ± 0.24 mg/L), creating favourable

environmental conditions for species of *Paracalanus parvus*, *Paracalanus aculeatus*, *Acartia clausi*, *Acartia pacifica*, *Oithona similis* and *Oithona nana* of the Copepoda group developed at most monitoring stations. Furthermore, species of the genus *Acartia*, closely related to coastal freshwater habitats, are known to be the most abundant non-migratory, settled species in many coastal habitats (Dorak *et al.*, 2015; Trinh and Vinh, 2017).

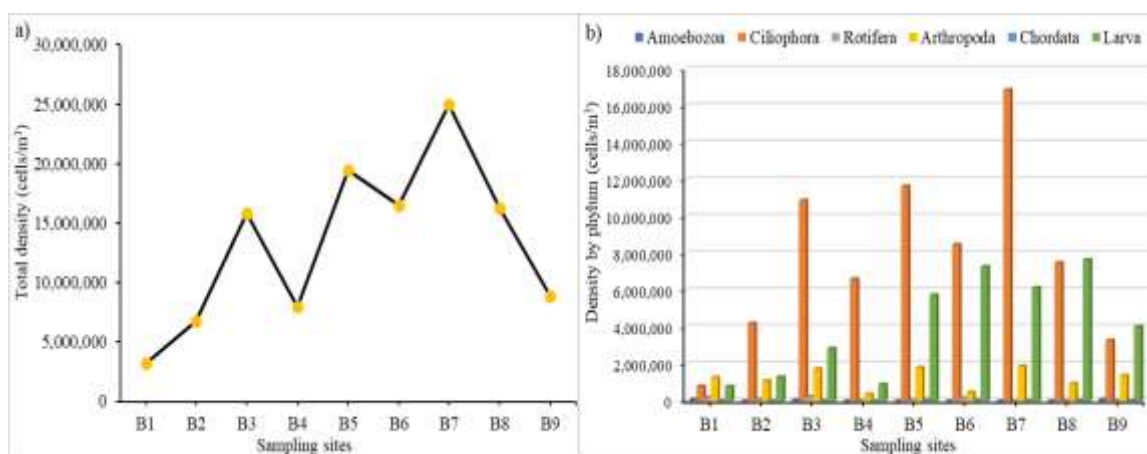


Fig 4. Zooplankton density in the study area

The total density of zooplankton was very rich, ranging from 3,219,383 to 24,993,634 individuals/m³ (Figure 4a). The total density of zooplankton was lowest at location B1-Soai Rap estuary with the density of Amoebozoa, Ciliophora, Rotifera, Arthropoda and Larva at 100,500 individuals/m³, 815,000 individuals/m³, 210,000 individuals/m³, 1,292,583 individuals/m³ and 801,300 individuals/m³, respectively. Meanwhile, the total density of zooplankton was highest at location B7-Phu Dong commune, with the density of phylum Ciliophora, Rotifera, Arthropoda, Chordata and Larva was 16,896,667 individuals/m³, 11,000 individuals/m³, 1,902,667 individuals/m³, 20,000 individuals/m³ and 6,163,300 individuals/m³, respectively. The density of zooplankton in this area was higher than that in the coastal waters of Soc Trang - Bac Lieu (2,650-9,250 individuals/m³) (Van *et al.*, 2012), Son Tra Peninsula (4,906-25,720 individuals/m³) (Trinh and Vinh, 2018), Khanh Hoa (15,412-50,423 individuals/m³) (Trinh and Vinh, 2017). The density of Amoebozoa species appeared at only four locations and was highest at site B1-Soai Rap estuary (Figure 4b). The results also showed that Ciliophora has the highest average density, reaching 7,828,908.4 individuals/m³, accounting for more than 58% of the zooplankton density in this area. During the monitoring periods, *Copepoda nauplius* appeared with the highest density

at most monitoring stations, ranging from 740,800 individuals/m³ to 7,555,250 individuals/m³, representing a rich nutrient environment. In addition, *Polyarthra vulgaris* is often an indicator of eutrophication in water bodies occurring only at location B1-Soai Rap estuary. However, this species was present at a relatively low density compared to the whole region, reaching 10,000 individuals/m³. Similarly, *Brachionus caudatus* also represents a nutrient-rich environment, only appearing at position B7-Phu Dong commune with a density of 10,000 individuals/m³.

Correlation between coastal water quality parameters and zooplankton diversity: The results of Spearman correlation analysis between water quality variables and zooplankton density are detailed in Table 1. The study found a positive correlation between pH and temperature, salinity, Ciliophora, and Larva with correlation coefficients (r) of 0.47, 0.58, 0.31 and 0.32, respectively. At the $p < 0.01$ significance level, the correlation between pH and DO has a correlation coefficient of 0.61. In addition, the study also found an inverse correlation between pH and coliform in coastal seawater in the study area ($r = -0.63$, $p < 0.01$). Salinity formed a positive correlation with the density of species belonging to the phylum Arthropoda ($r = 0.34$, $p < 0.05$) and Larva ($r = 0.33$, $p < 0.05$). This result was

consistent with the recorded occurrence of marine and brackish species in the study area, such as *Paracalanus parvus*, *Acartia clausi*, *Acartia pacifica* and *Oithna nana*. A significant correlation between salinity, number of species and zooplankton biomass was detected in the previous study by Paturej and Gutkows (2015). In addition, water salinity was found to be negatively correlated with TSS, $\text{NH}_4^+\text{-N}$ and coliform at the significance level, with the correlation coefficient of -0.54, -0.34 and -0.59, respectively. TSS positively correlated with coliform ($r=0.33$, $p<0.05$). TSS could facilitate the survival or growth of coliforms by adsorbing coliforms, providing organic and inorganic nutrients to the coliforms from the particles and protecting them from adverse environmental factors (Hong *et al.*, 2010). DO has a positive relationship with the density of zooplankton groups, in which there was a significant positive correlation with the groups of Ciliophora, Rotifera, Arthropoda and Larva with the correlation coefficient of 0.42, 0.30, 0.31 and 0.49, respectively. The presence of optimal dissolved oxygen levels (above 4.5 mg/L) in water is strongly associated with zooplankton abundance (Banerjee *et al.*, 2018), which the density of zooplankton tends to increase. At the same time, DO was negatively correlated with $\text{NH}_4^+\text{-N}$

($r=-0.30$, $p<0.05$) and coliform ($r=-0.52$, $p<0.01$). When the nutrients and microorganisms increase, the decomposition process takes place firmly, thereby reducing the concentration of DO in the water. Both $\text{NH}_4^+\text{-N}$ and coliform were negatively correlated with zooplankton density. From this result, it can be seen that only zooplankton could survive and develop in highly nutrient and eutrophication environments. For example, *Copepoda nauplius* has a very high density, dominating all species at each location. In this study, there was no correlation between temperature, $\text{PO}_4^{3-}\text{-P}$ with water environment variables and zooplankton density. The results of this study were similar to those of Lien *et al.* (2020), which found that temperature was not strongly correlated with the distribution of the composition and density of cetaceans. However, in the study of Dorak *et al.* (2015), a significant positive correlation was found between temperature and DO. At the same time, temperature was identified as one of the environmental variables that directly affects the distribution of zooplankton, typically Rotifera (Thakur *et al.*, 2013; Dorak *et al.*, 2015). In summary, water environmental factors such as pH, salinity, DO, $\text{NH}_4^+\text{-N}$ and coliform influenced the density of zooplankton species

Table 1. Spearman's correlation matrix

Parameters	pH		Temp.		Salinity		TSS		DO		$\text{NH}_4^+\text{-N}$		$\text{PO}_4^{3-}\text{-P}$		Coliform	
	r	p	r	p	r	p	r	p	r	p	r	p	r	p	r	p
pH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temp.	0.47*	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Salinity	0.58*	0.00	0.21	0.16	-	-	-	-	-	-	-	-	-	-	-	-
TSS	-0.16	0.31	-0.01	0.97	-0.54	0.00	-	-	-	-	-	-	-	-	-	-
DO	0.61**	0.00	0.17	0.26	0.45	0.00	-0.29	0.06	-	-	-	-	-	-	-	-
$\text{NH}_4^+\text{-N}$	-0.27	0.07	0.21	0.17	-0.34	0.24	0.12	0.43	-0.30	0.05	-	-	-	-	-	-
$\text{PO}_4^{3-}\text{-P}$	-0.08	0.61	-0.02	0.88	-0.48	0.00	0.29	0.05	0.02	0.88	-0.05	0.74	-	-	-	-
Coliform	-0.63	0.12	0.12	0.43	-0.59	0.00	0.33*	0.03	-0.52	0.00	0.58*	0.00	-0.19	0.90	-	-
Amoebozoa	-0.15	0.33	0.04	0.79	0.16	0.31	-0.09	0.54	0.03	0.83	-0.06	0.68	-0.05	0.75	0.08	0.60
Ciliophora	0.31*	0.04	0.20	0.19	0.28	0.06	-0.05	0.76	0.42**	0.00	-0.53	0.00	0.29	0.05	-0.47	0.00
Rotifera	0.11	0.46	0.21	0.17	0.26	0.09	-0.06	0.71	0.30*	0.05	-0.25	0.00	0.10	0.52	-0.22	0.14
Arthropoda	0.25	0.10	0.27	0.07	0.34*	0.02	-0.11	0.47	0.31*	0.04	-0.53	0.00	0.17	0.27	-0.39	0.01
Chordata	-0.03	0.83	-0.02	0.91	-0.21	0.16	0.09	0.54	0.25	0.10	-0.22	0.15	0.30*	0.05	0.02	0.89
Larva	0.32*	0.04	0.24	0.12	0.33*	0.03	-0.09	0.55	0.49**	0.00	-0.53	0.00	0.27	0.07	-0.46	0.00

Diversity of zooplankton and coastal water quality: Shannon-Wiener diversity index (H') could reflect the overall pollution status of the water. Unpolluted waters are often characterized by a high diversity with a large number of species, and no species is dominant in number or density over the others (Thakur *et al.*, 2013). The H' index in the coastal waters of Tien Giang province ranged from 1.54 to 2.37, indicating that the zooplankton composition varied from medium to moderate (Figure 5). Regarding pollution level, H' reflected the quality of coastal seawater in the study area from polluted to low pollution. There are 6 out of 9 locations with polluted water quality, accounting for more than 66% of the total monitoring locations. Meanwhile, there were only 3 out of 9 monitoring locations at a slight pollution level, accounting for

nearly 34%. In which, B7-Phu Dong commune was assessed to have the most severe water pollution. Although this location appeared the most zooplankton species, it was mainly eutrophication indicator species; typically, *Copepoda nauplius* had a density of 6,118,800 individuals/ m^3 , accounting for nearly 25% of the total density. Similarly, *Tintinnopsis tentaculata* had a density of 9,750,000 individuals/ m^3 , accounting for 39% of the total density.

To assess the nutritional level, the study also relied on the density of zooplankton. Nutrient levels of water based on zooplankton density were divided into three levels: (1) low nutrient ($< 1,000,000$ individuals/ m^3), (2) medium nutrient ($1,000,000 - 3,000,000$ individuals/ m^3) and rich ($> 3,000,000$ individuals/ m^3)

(Zheng *et al.*, 2007). In this study, the total density of zooplankton fluctuated between 3,219,383 - 24,993,634 individuals/m³, indicating the nutrient-rich coastal marine environment of Tien Giang province. The state of water quality and the diversity of zooplankton species composition in this coastal area was relatively worse than in the coastal waters of Son Tra Peninsula (Trinh and Vinh, 2018) but higher than that in Ben Tre province (Van and My, 2020). Compared with the previous study by Chi *et al.* (2020), species composition and biodiversity index values in the current study area tended to be higher.

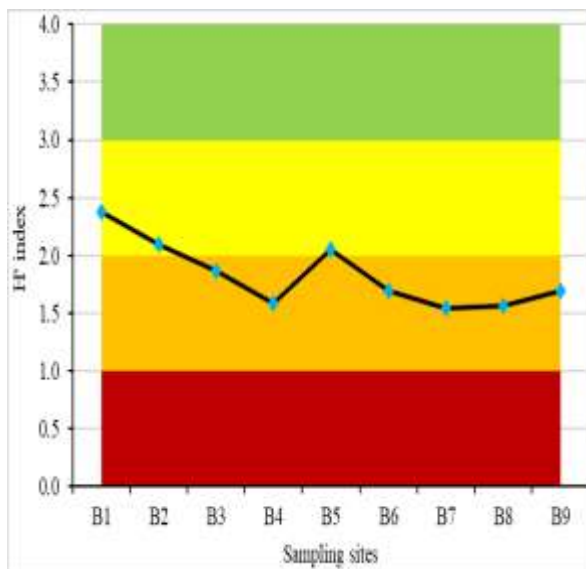


Fig 5. Shannon-Wiener diversity Index (H') of zooplankton in the study area

Conclusions: Concentrations of TSS, NH₄⁺-N and coliform were high in coastal water. The study recorded 71 species belonging to six zooplankton phyla in which Arthropoda phylum was the most abundant. The total zooplankton density ranged from 3,219,383 to 24,993,634 individuals/m³ and *Copepoda nauplius* was dominant and appeared at all monitoring locations. The Spearman correlation results showed that pH, salinity, DO, NH₄⁺-N, and coliform, influenced the density of zooplankton species. The H' index reflected the coastal water quality from slightly polluted to polluted. Future studies should focus on evaluating long-term dynamics of coastal water quality and zooplankton diversity.

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