CHARACTERISTICS OF RECEIVING WATERS IN A SHRIMP AQUACULTURE AREA IN CAI NUOC, CA MAU

NGUYỄN THỌ, NGUYỄN THỊ ÁNH
Email: ntho@vast-hcm.ac.vn
Viện Địa lý Tài nguyên Tp. HCM - Viện Khoa học và Công nghệ Việt Nam
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1. Introduction

Shrimp aquaculture has been expanding rapidly, mainly in tropical coastal lowlands [7]. Impacts of the shrimp industry to the surroundings have widely been discussed [5, 7, 10, 14]. It can degrade the environment, jeopardize the integrity of ecosystems, and compete for food and habitat with natural populations [8]. The impacts of the industry can also be indirect through the loss of habitat and niche space, changes in food webs, and depletion of wild shrimp/fish stocks [5, 20]. Impacts of shrimp farm effluent on plankton biomass in the receiving waters have been reported [12, 21].

In the Mekong delta of Vietnam, shrimp aquaculture boomed in 2000 [4, 23] and the improved extensive shrimp system predominates [23]. In view of a single farm, this system does not provide significant amounts of wastes to the receiving waters [15,17]. While discharge of a single shrimp farm is of little environmental concern, effluents from a vast number of farms can be worth noticing as a result of accumulation effect. Impacts of shrimp aquaculture to the receiving waters in the area has still been poorly understood [13, 15]. To clarify the impacts of shrimp aquaculture, this paper documented the characteristics of the receiving waters in the Cai Nuoc district - a shrimp aquaculture area of the Mekong delta of Vietnam where shrimp farms expanded rapidly since 2000 [23]. This was conducted in comparison with a non-impacted freshwater rice dominated reference site.

2. Material and methods

2.1. Description of the study area and the shrimp systems

The 395,14km^2 coastal Cai Nuoc area (8°50’20’’ - 9°10’20’’N and 104°56’48’’- 105°10’40’’E) is located in the South-west of Ca Mau province, Mekong delta of Vietnam (*Fig. 1*). A wet season (May - October, average rainfall of 2,100mm) and a dry season (November - April, average rainfall of 200mm) was reported in the district [19]. A dense network of rivers and canals connects the area to its neighbouring districts and the seas. The area is affected by a complicated water regime as affected by combined tidal impacts from the South China Sea and the Gulf of Thailand. In the Mekong delta of Vietnam, mean water level is monsoon-driven and usually peaks in December [24].

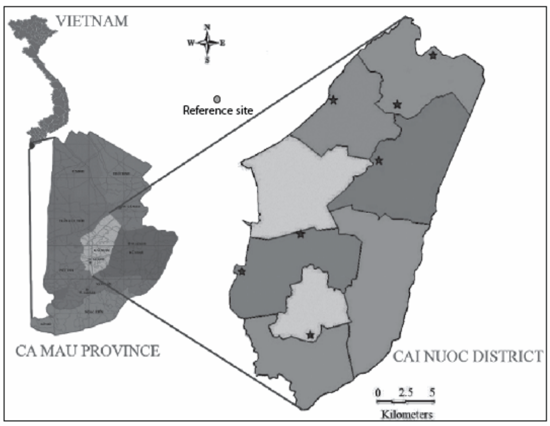

Fig. 1. Location of the aquaculture sites and the reference site

Shrimp aquaculture in the area can be categorized as "extensive", "improved extensive", and "intensive" systems. In the first system, shrimps are usually cultured in mangrove forests, relying mostly on natural seedstocks, sometimes with supplementary stocking (1 - 1.5 postlarvae m^2). The improved extensive shrimp farming system can be characterized by: (1) shrimp is reared in a monoculture system in earthen ponds, (2) stocking of 1 - 7 ind m^{-2}, (3) sediment dredging and subsequent pond liming, and (4) low survival rate (3 - 20%). The intensive shrimp farming system witnesses the highest level of intensification (mechanical pond preparation, stocking density of 15 - 45 postlarvae m^{-2}, use of industrial feed and chemicals) [17]. In Cai Nuoc district, the improved extensive shrimp farming system is the most predominant culture system [23].

2.2. Sampling and analysis

Sampling was conducted on 3rd November 2011, right at the transition period between the wet and the dry season in the Mekong delta of Vietnam. At this time of the year, the receiving waters can be considered least impacted by aquaculture discharge as a result of dilution impact. As impacted by the Southwest monsoon, water levels in the rivers remain constantly high during the day. Samples were taken in the middle of the rivers at 7 sites in the Cai Nuoc district (the aquaculture sites) and a reference site in the neighbouring Tran Van Thoi district. The aquaculture sites were characterised by (1) being covered by brackish/saline water all year round, (2) a domination of the improved extensive system, and (3) free movement of tidal water. The reference site was characterized by (1) all year round freshwater, (2) rice was the major crop, (3) rainwater was the only source of input water, and (4) water was almost blocked (Fig. 1).

2.2.1. Physico - chemical parameters

The parameters pH, EC, salinity, turbidity, temperature, and dissolved oxygen (DO) were measured in situ using a TOA instrument (Water Quality Checker-22A, Japan). The other parameters were collected at 20cm depth with 3 replicas, stored at approx. 4°C, and transported to the lab the same day. Water analysis was performed using the following procedures: Cl^- (Mohr method), SO_4^{2-} (Turbidity method), TSS (Weight method, dried at 105°C), BOD (5-Day BOD Test), COD (oxidation by $KMnO_4$, Titration method), NO_2-N (Diazo method), NO_3-N (Salicylate method), NH_4-N (Indophenol blue method), PO_4-P (Ascorbic acid method), total N (digested by Kjeldahl Digestion System, Indophenol blue method), total P (Ascorbic acid method), and total Fe (Phenanthroline method, Colorimetric method, 510nm) [1]. River sediment was sampled, also with 3 replicas using a sediment trap. Sediment pH and redox potential (Eh) were measured in situ using a combined Eh/pH meter (pH 62K, APEL). Samples were analysed for organic matter (OM) (loss-on-ignition method, 550°C, 4 hours), hydrogen sulfide (H_2S) (Methylene blue method), and particle sizes (Robinson method).

2.2.2. Biological parameters

Qualitative sampling of phytoplankton and zooplankton was performed by dragging the plankton nets (25 μm and 75 μm mesh size, respectively) in the water surface to a depth of 20cm along a distance of about 50m. Quantitative sampling of phytoplankton was conducted by filling up a 20-litre plastic bucket with river water (0-20cm depth) at 10 nearby locations. The 20-litre water sample was stirred and poured into a 1-litre plastic bottle for analysis. Quantitative sampling of zooplankton was conducted by filtering a total water volume of 200 litres collected at 10 nearby locations through a 75μm mesh size net into a 100-ml ending plastic bottle. Zoobenthos was sampled by an Ekma equipment with a surface area of $0.025m^2$. In each site, samples were taken at 4 nearby locations, making the total area for a zoobenthos sample was $0.1m^2$. The samples were sieved through a 2-layered screen (0.5 mm and 0.25mm in size) and stored in plastic bags. All samples were fixed by a formalin solution of 4%. Total bacteria and Vibrios were sampled in both the water and the sediment. In the river water, sampling was conducted at 4 nearby locations using 250-ml sterilized plastic bottles [1]. The 4 sub-samples were then mixed into a 1.5-litre sterilized plastic bottle from which a final 50-ml sample was extracted into a sterilized Falcon bottle for analysis. Total bacteria and Vibrios in the sediment were sampled 4 times using the Ekma equipment. All samples were kept at approximately

4°C and transported to the lab the same day for analysis. Determination of phytoplankton, zooplankton, and zoobenthos was conducted using the standard methods [1]. Total bacteria and Vibrios were analysed using the Standard Operating Procedure [9].

2.3. Statistical analysis

Totally 8 samples were analysed. Values in the aquaculture sites were averaged and compared with that of the reference site. Data of plankton and benthos were standardised prior to being analysed. Bacterial data was log-transformed and plotted. A Pearson correlation matrix was applied to elucidate the correlations between physic-chemical and biological characteristics. Biodiversity indexes were also applied for comparison between the aquaculture sites and the reference site.

The Simpson's index of diversity $= 1 - \frac{\sum n(n-1)}{N(N-1)}$

Where n=the total number of organisms of a particular species.

N=the total number of organisms of all species.

Shannon - Wiener Diversity index $H' = -\sum_{i=1}^{S} Pi(\ln Pi)$

Where P_i is the proportion of each species in the sample.

3. Results and discussion

3.1. Physic-chemical variables

3.1.1. Salinity and pH

Salinity in the aquaculture sites were very high (17.23 g l^{-1}) compared to that of the reference site (0.60 g l^{-1}) even at the end of the wet season. In the wet season of 2002 - 2 years after the shrimp boom - a salinity value of only 10.6 g l^{-1} was reported in the receiving waters of Cai Nuoc and its neighbouring Phu Tan districts [15]. Saline intrusion is becoming more serious in the shrimp aquaculture area as a direct consequence of allowing saline water to the interior fields [15, 16]. The same situation was observed for river sediment (*Fig. 2*). Salinity intrusion also enhanced pH values in the aquaculture sites *(Fig. 2)*. High pH values in these sites can also be attributed to lime-containing shrimp farm effluents.

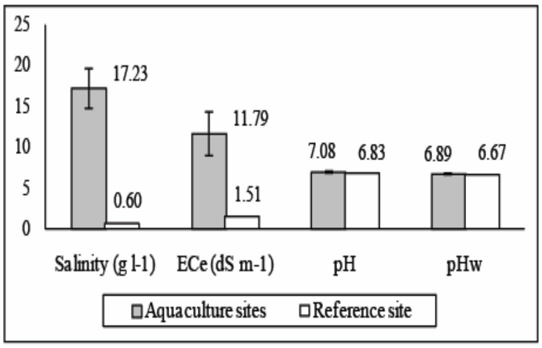

Fig. 2. Comparison of salinity and pH between the aquaculture sites and the reference site. Vertical bars denote standard deviation

In the Mekong Delta of Vietnam, saline intrusion was a naturally occurring phenomenon and exacerbated by shrimp aquaculture [15]. Saline intrusion to shrimp aquaculture areas have been widely reported [5, 13, 15].

3.1.2. Organic loadings, TSS, turbidity, and total Fe

The aquaculture sites showed a higher level of organic loadings (BOD, COD, NH_4-N) (*Fig.3, 4*). These sites also had a higher OM content (11.07 ± 0.80%) compared to that of the reference site (10.35%). Higher organic loadings in the aquaculture sites may be derived from shrimp farm discharge and run-off. TSS values in the aquaculture sites (21.84 ± 9.37 mg l^{-1}) were also higher compared to that of the reference site (13.9 mg l^{-1}), indicating a more severe run - off in the former. The finding was consistent with Tho et al. (2011a) [17]. Increased run-off caused by shrimp aquaculture has been reported [5].

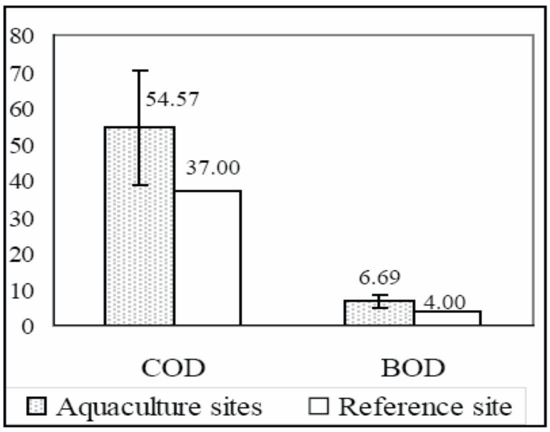

Fig. 3. Comparison of COD and BOD between the aquaculture sites and the reference site

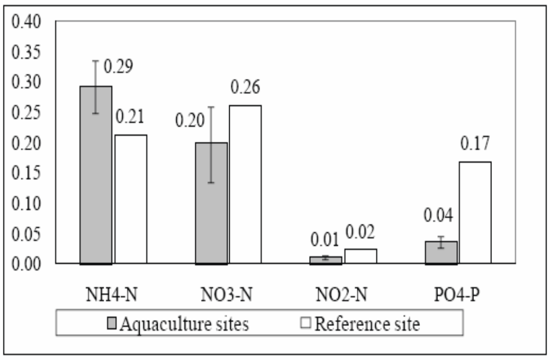

Fig. 4. Comparison of soluble N and P between the aquaculture sites and the reference site

The other indicators of organic loadings (NO_3 - N, NO_2 - N, and PO_4 - P) in the aquaculture sites, however, were lower than those of the reference site *(Fig. 4)*. This might be explained by the use of inorganic fertilizers for rice farming in the reference site. Total N and total P did not show clear differences between the aquaculture sites (respectively 2.21 ± 0.41 mg l^{-1} and 0.35 ± 0.40 mg l^{-1}) and the reference site (respectively 2.41 mg l^{-1} and 0.26 mg l^{-1}).

DO values in the aquaculture sites (3.77 ± 0.66 mg l^{-1}) were higher than that of the reference site (1.48 mg l^{-1}) due to the effect of highly exchanged tidal water and waterway traffic. Low DO in the reference site was the consequence of stagnant water and a localized pollution by rice field discharge. Total Fe in the aquaculture sites (0.17 ± 0.11 mg l^{-1}) was much lower than that of the reference site (2.76 mg l^{-1}). This was because iron in the latter can be released from acid sulfate soils and accumulated over time as water was blocked for most of the time. Concentrations of NO_3-N (0.20 ± 0.06 mg l^{-1}) and NH_4 - N (0.29 ± 0.04 mg l^{-1}) in the aquaculture sites were much higher than those reported in the wet season of 2002 (respectively 0.08 and 0.01 mg l^{-1}) [15], indicating a recent increase in nutrients in the receiving waters.

Among the aquaculture sites, turbidity varied remarkably between small channels (23 - 80 NTU) and the major rivers (> 600 NTU) due to a more intense waterway traffic and sediment dredging in the major rivers. In the reference site, a turbidity value of 89 NTU was recorded. High variability of turbidity among the aquaculture sites may mask the difference between them and the reference site. Simultaneously, low turbidity values (4 - 66 NTU) were reported in the most dominant shrimp system in the area [17], indicating that shrimp farms' contribution to river turbidity was of little importance. Waterway transport and markets may have important impacts on regional water quality [2]. Total P were positively correlated with turbidity ($p < 0.001$), suggesting that a majority of phosphorus was adsorbed in the suspended materials.

3.1.3. Redox potential, particle sizes, and hydrogen sulfide (H_2S) in the sediment

River sediment of the aquaculture sites were less anaerobic (Eh-274.14 ± 101.31mV) compared to the reference site (-376 mV). The clay content (<0.002mm) of the aquaculture sites (5.12 - 47.12%) were lower compared to that of the reference site (51.6%). The silt content (0.002 - 0.05mm), however, showed an opposite trend (*Fig. 5*). This difference can be explained by a higher flocculation rate of silt particles compared to clay particles at increasing salinities in the aquaculture sites [26]. High velocity of water flows in the aquaculture sites might also be involved.

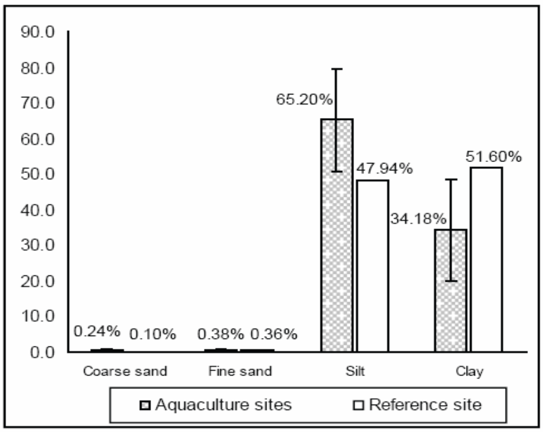

Fig. 5. Particle size composition of river sediment

Some of the aquaculture sites accommodated more H_2S (154.21 ± 119.61 mg kg^{-1}) compared to that of the reference site (70.3 mg kg^{-1}). Enhanced H_2S concentrations (maximum 357.5 mg kg^{-1}) can negatively impact the benthic community in the aquaculture sites.

3.2. Biological variables

3.2.1. Phytoplankton

The total number of phyla in the aquaculture sites (3) was lower than that in the reference site (5) **(***Fig. 6*). The number of species and density in the former (11 - 6 species, 24 - 445 cells l^{-1}) were also lower compared to those of the latter (16 species, 531 cells l^{-1}). Both the Simpson's index of diversity and the Shannon-Wiener Diversity index revealed a reduction in phytoplankton diversity in the aquaculture sites (*Fig. 7*), most probably the effects of higher salinity and lower concentrations of dissolved nutrients (N,P).

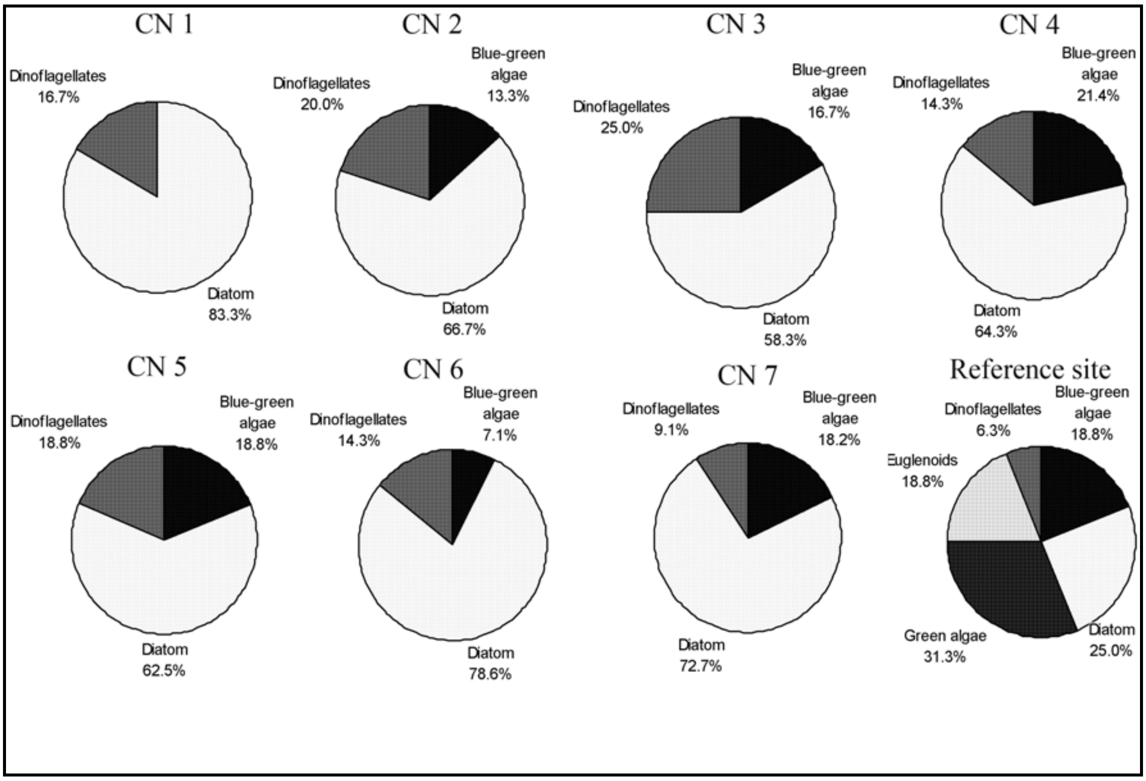

Fig. 6. Species composition of phytoplankton

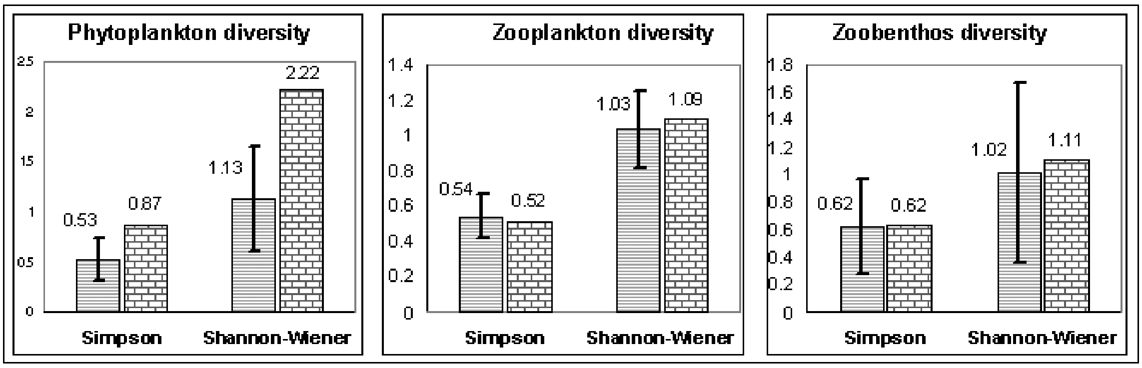

Fig. 7. Simpson's index of diversity and the Shannon-Wiener Diversity index

Diatoms were the most dominant (> 58 %) in the aquaculture sites but not in the reference site (*Fig. 6*). This was because diatoms are the most desirable phytoplankton in coastal waters [11]. In Cai Nuoc's improved extensive shrimp system, diatoms were also the most dominant [18]. Diatoms were positively correlated with salinity ($p < 0.01$). Enhanced concentrations of diatoms in the aquaculture sites were linked to higher salinities.

The number of Blue-green algae in the aquaculture sites (1 - 2 species) was lower than that of the reference site (3 species). Euglenoids were absent in the aquaculture sites but appeared at the reference site (2 species). These suggested a localized pollution by slightly enhanced dissolved nutrients (N, P) in the reference site. Green algae and Euglenoids showed an inverse correlation with salinity ($p < 0.01$) but positive correlations with PO_4 - P and total Fe ($p < 0.001$), which explained their abundance in the reference site (respectively 5 and 2 species).

3.2.2. Zooplankton

The number of species and density in the aquaculture sites ranged respectively from 6-14 species and 7,500 - 162,000 ind l^{-1}. In the reference site, 10 species were recorded at a density of 35,500 ind l^{-1}. Copepoda accounted for the majority of species (33.3 - 66.7 %) in the aquaculture sites, with the most widely found species being *Acartia pacifica* Steuer (5/7 sites), *Oithona simplex* Farran (5/7 sites), and *Paracalanus parvus* Claus (6/7 sites). Copepods were also most dominant in Cai Nuoc's improved extensive shrimp system [18]. In the reference site, Rotifera took the lead (*Fig. 8*). The number of Copepod species ranged between 4 - 7 among the aquaculture sites while only *Thermocyclops hyalinus* Rehberg (2,500 ind m^{-3}) and *Tropocyclops prasinus* Fischer, indicators of freshwater environment, were found in the reference site.

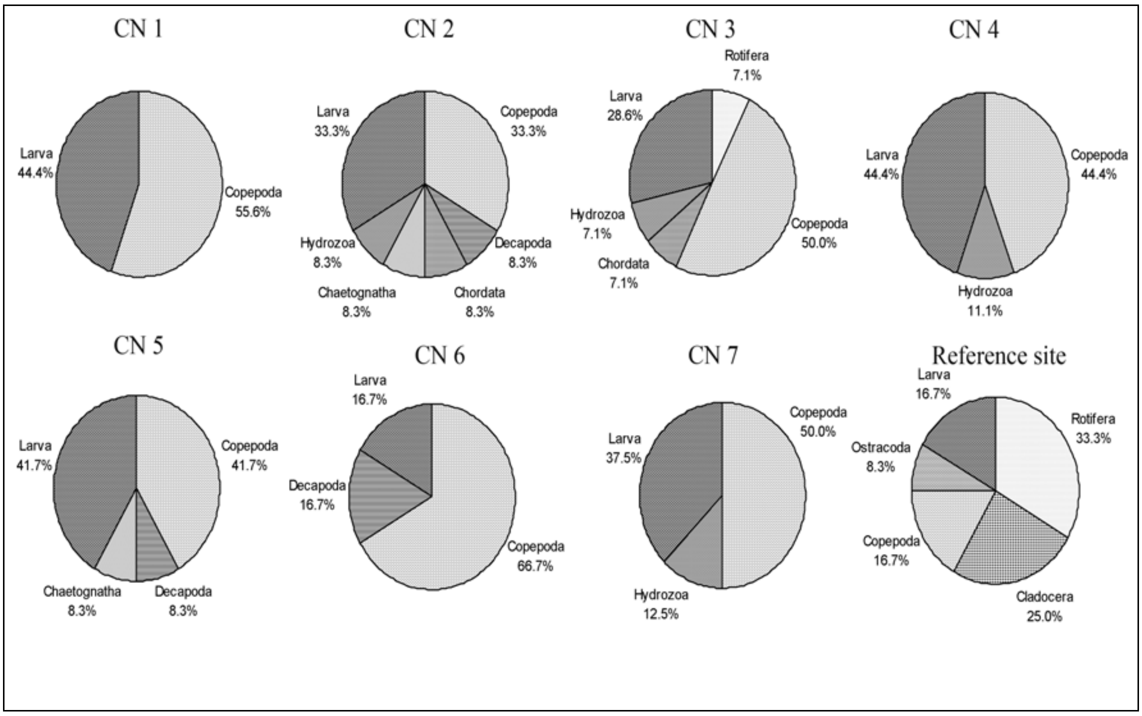

Fig. 8. Species composition of zooplankton

Rotifers can serve as indicators of trophic conditions [25]. Density of rotifers were positively correlated with PO_4-P and total Fe ($p < 0.001$), which explained their abundance in the reference site but not in the aquaculture sites. *Filinia longiseta* Ehrenberg, a rotifer species - indicator of eutrophic waters [3] was found in the reference site (4,500 ind m^{-3}). The only rotifer species found at one of the aquaculture sites was *Brachionus plicatilis* Müller, a typical indicator of saline waters [6]. A similar situation was observed for cladocerans, with 3 species being found in the reference site (*Ceriodaphnia rigaudi* Richard, *Diaphanosoma sarsi* Richard, and *Moina macrocopa* Straus) but none in the aquaculture sites. Salinisation of the water bodies in the aquaculture sites has restructured the zooplankton community.

3.2.3. Zoobenthos

Most of the aquaculture sites (6/7) had a higher number of species (7 - 11) compared to that of the reference site (6). Zoobenthos density varied largely among the aquaculture sites (70 - 5,430 ind m^{-2}) as compared to 1,180 ind m^{-2} in the reference site. Both the Simpson's index of diversity and Shannon-Wiener diversity index showed no difference between the aquaculture sites and the reference site *(Fig. 6)*.

Differences in zoobenthos community between the aquaculture sites and the reference site, however, did exist. Dominant zoobenthos species varied among the aquaculture sites, with Branchiomma sp. being dominated at 2 sites, Apseudes vietnamensis at 3 sites, Amphioplus acutus and Melita vietnamica each at 1 site. The reference site also showed different dominant species. The freshwater snail Melanoides granifera was dominated in the reference site (540 ind m^{-2}, 45.8 %) but scarcely found in the aquaculture sites (at 1 site, 60 ind m^{-2}).

Similarly, not any individuals of the freshwater bivalve Scaphula pinna was found in the aquaculture sites but in the reference site (460 ind m^{-2}, 38.98 %). It was obvious that shrimp aquaculture practices did not change zoobenthos diversity. However, severe saline intrusion has altered the structure of the benthos community.

3.2.4. Bacteria

Total bacteria in the aquaculture sites were slightly higher than those of the reference site (*Fig. 9*), most probably because of higher organic loadings in the former. In the water column, total bacteria were positively correlated with BOD ($r = 0.77$, $p < 0.05$). In the sediment, they showed a positive correlation with OM ($r = 0.77$, $p < 0.05$).

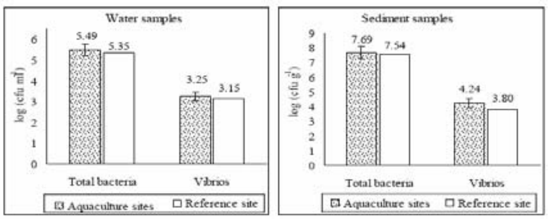

Fig. 9. Bacterial comparison between the aquaculture sites and the reference site

Vibrios in the water column of the aquaculture sites were slightly higher than that of the reference site. In the sediment, however, Vibrios of the aquaculture sites were distintly higher than that of the reference site *(Fig. 8)*. Elevated salinity in the aquaculture sites may be one of the factors that favour the development of Vibrios. In the sediment, the counts were positively correlated with ECe ($r = 0.82$, $p < 0.05$). In the water column, counts of Vibrios showed negative correlations with turbidity ($r = - 0.78$, $p < 0.05$), total N ($r = - 0.77$, $p < 0.05$), and total P ($r = - 0.80$, $p < 0.05$). Vibrios are widely accepted as opportunistic pathogens associated with penaeid shrimp [22]. High values of total bacteria and Vibrios were also reported in the Cai Nuoc shrimp ponds [18].

4. Conclusions

The receiving waters were characterized by enhanced salinity and organic loadings, a high variability of TSS and turbidity, and changes in particle size distribution. Phytoplankton diversity was reduced while zooplankton and zoobenthos communities were altered on account of elevated salinity. Bacterial concentrations in the area were enhanced as a result of high organic loadings and salinity. It can be concluded that shrimp aquaculture development has changed the physico-chemical and biological characteristics of the receiving environment.

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SUMMARY

Unregulated shrimp aquaculture development has posed several negative impacts to the receiving waters of the coastal Cai Nuoc district, Mekong delta of Vietnam where most of the land area was converted to shrimp farms since 2000. Enhanced organic loadings and salinisation of surface water and sediment are the major physico-chemical impacts. Increasing levels of organic loadings and suspended solids were found in the receiving waters, mainly as a result of shrimp farm discharge and run-off. The salinization has been caused by the irrigation of saltwater to the interior fields for shrimp culture. The shrimp aquaculture practice has also caused a reduction in phytoplankton diversity and changes in the structures of zooplankton and zoobenthos community. The bacterial community in the receiving waters has also been enriched as a result of enhanced organic loadings. Shrimp aquaculture practices might deteriorate the quality of the receiving waters, which is used as input water for shrimp farms.

TÓM TẮT

Đặc trưng của môi trường nước sông rạch khu vực nuôi tôm tại huyện Cái Nước, Cà Mau

Việc chuyển sang nuôi tôm ồ ạt đã gây ra một số tác động tiêu cực đối với môi trường ở huyện ven biển Cái Nước, ĐBSCL nơi hầu hết diện tích đất được chuyển sang nuôi tôm từ năm 2000. Gia tăng vật liệu hữu cơ và xâm nhập mặn vào nước mặt và trầm tích của hệ thống sông rạch là những tác động chính về phương diện lý hoá. Sự gia tăng vật liệu hữu cơ và chất rắn lơ lửng trong nước mặt chủ yếu do nước thải từ ao nuôi tôm và do xói mòn. Xâm nhập mặn vào môi trường nước gây ra do dẫn nước mặn vào sâu trong nội đồng để phục vụ cho hoạt động nuôi tôm. Hoạt động nuôi tôm ồ ạt cũng làm giảm đa dạng phiêu sinh thực vật và làm biến đổi cấu trúc quần thể phiêu sinh động vật và động vật đáy trong hệ thống sông rạch. Quần thể vi sinh vật trong nước và bùn đáy sông rạch cũng gia tăng do việc tăng cao vật liệu hữu cơ trong môi trường. Hoạt động nuôi tôm có thể làm suy thoái chất lượng nước mặt của hệ thống sông rạch, vốn được sử dụng làm nước cấp trong hoạt động nuôi tôm.