

MULTI-CORRELATION BETWEEN NEMATODE COMMUNITIES AND ENVIRONMENTAL VARIABLES IN MANGROVE-SHRIMP PONDS, CA MAU PROVINCE, SOUTHERN VIETNAM

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Received 26 October 2019, accepted 28 July 2020

ABSTRACT

Multi-correlation between bio-indices of nematode communities and ecological parameters in mangrove-shrimp farming ponds in Tam Giang commune, Nam Can District, Ca Mau Province, Vietnam were investigated. In which, diversities of nematode communities and several environmental variables in eight ponds were considered to process. Our findings underlined the high diversity of nematode communities in mangrove-shrimp farming ponds compared to other mangrove habitats. Nematode diversities provided more opportunity in natural food for shrimp. Single correlation analyses showed that the species richness index correlated significantly to three variables (salinity, total organic carbon, and total nitrogen), the Margalef diversity index correlated to two variables (salinity, total organic carbon), and the expected number of species for 50 individuals index correlated with one variable (salinity). Results of multi-correlation analyses between the nematode bio-indices and the environmental variables were completely different from those of single-correlation analyses. In multi-correlation analyses, the species richness and the Margalef diversity index correlated to two variables (salinity, total organic carbon), Pielou's evenness index and Hill indices correlated with dissolved oxygen, also the Hurlbert index correlated to total organic carbon. Hence, it is necessary to pay attention to the impact of complex interactions between the multi-environmental variables and nematode communities. This research aims to explain the differences between single- and multi-correlation for evaluation of the effects of environmental factors on nematodes as well as aquatic organisms.

Keywords: Aquaculture, aquatic ecology, benthic fauna, chemical water diversity, mangroves, sediment.

Citation: Thai Thanh Tran, Nguyen Thi My Yen, Hoang Nghia Son, Ngo Xuan Quang, 2020. Multi-correlation between nematode communities and environmental variables in mangrove-shrimp ponds, Ca Mau Province, Southern Vietnam. *Academia Journal of Biology*, 42(3): 15–29. <https://doi.org/10.15625/2615-9023/v42n3.14546>.

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INTRODUCTION

The largest remaining area of mangrove forest in Vietnam is situated in coastal provinces and river mouths of Mekong Delta which covers approximately 100,000 ha. The Ca Mau Province has the largest area of mangroves with over 58,285 ha, followed by Tra Vinh (8,582 ha), Ben Tre (7,153 ha), Bac Lieu (4,142 ha), and Soc Trang (2,943 ha) (Truong & Do, 2018). Ca Mau mangroves are very rich in biodiversity, containing 98 species of mangroves (e.g. *Rhizophora apiculata*, *Kandelia obovata*, *Sonneratia caseolaris* and *Avicennia alba*) with *R. apiculata* being the most abundant (Vu, 2004). Studies on aquatic fauna indicated that Ca Mau mangroves have a fauna of 46 species of fish, 25 species of shrimps and 57 species of birds including 17 migratory species (Phan & Hoang, 1993). Also, the Ca Mau mangroves had 28 species of mammals belonging to 12 families, 5 species are listed in Vietnam's Red Book, 1 species in the IUCN's Red Book (Ca Mau Province Portal, 2013).

In 2017–2018, several studies were conducted to determine the biodiversity of aquatic organisms in mangrove-shrimp farming ponds in Nam Can District, Ca Mau Province. The phytoplankton communities contained 64 species belonging to four groups namely blue-green algae, diatom, green algae and dinoflagellates (Pham et al., 2017). Macrofauna communities contained 22 species of 15 families belonging to 5 classes: Polychaeta, Oligochaeta, Crustacea, Gastropoda, and Bivalvia of 3 phyla: Annelida, Arthropoda and Mollusca (Tran et al., 2017b). Tran et al. (2017c) studied meiofauna assemblages in mangrove-shrimp farming ponds in Ca Mau Province and recorded 15 major taxa, including Nematoda, Copepoda, Turbellaria, Polychaeta, Oligochaeta, Amphipoda, Tardigrada, Ostracoda, Rotifera, Sarcomastigophora, Kinorhyncha, Isopoda, Halacaroida, Thermosbaenacea, and Cladocera.

The nematode communities consisted of 75 genera belonging to 24 families and 7 orders. The density was quite high, ranging from 221 ± 122 (inds/10 cm²) to 7254 ± 5454 (inds/10

cm²) and the Shannon-Wiener index expressed high diversity, ranging from 2.35 ± 1.02 to 3.61 ± 0.24 (Tran et al., 2018c). Thus, nematode communities of Ca Mau mangrove-shrimp farming ponds (CMMSFP) could be characterized by high biodiversity. Nematode communities play a vital role in benthic ecosystems processes. They form a crucial component in benthic food webs with trophic links between microfauna and larger fauna.

Main food sources of nematode communities are organic detritus, bacteria and benthic diatoms. In turn, nematode communities can provide food for a number of predators such as juvenile fish, shellfishes, and also other nematodes (Liu et al., 2014). Chong & Sasekumar (1981) found that the white prawn *Penaeus merguensis* is a carnivore that feeds largely on nematodes and other small organisms. Thus, nematode communities can make a substantial contribution as a food source for shrimps in the CMMSFP. Also, nematode communities play a vital role in the flow of nutrients, materials, and energy in benthic and aquatic ecosystems. Several studies showed that mineralization of organic matter is enhanced and stimulated by the presence of nematode communities (Semprucci et al., 2013).

Ensuring suitable environmental conditions for nematode communities is essential to maintain their diversities and densities, and to provide sufficient food sources for shrimp in the CMMSFP. To optimize this environment, interaction between nematodes and environmental variables should be analyzed. It is well known that densities, diversities, distribution, and functional properties of meiofauna (including nematodes) could be affected by a number of environmental variables such as salinity, temperature, hydrodynamics, granulometrics, dissolved oxygenation level, and food availability (Ingels et al., 2011; Cai et al., 2012; Ngo et al., 2013a; Zeppilli et al., 2013; Górska et al., 2014). According to Tran et al. (2018a), diversities of meiofauna communities in shrimp farm in the CMMSFP showed significant positive correlation with

dissolved oxygen but significant negative correlation with total organic carbon and total nitrogen. Furthermore, abundances of the genera *Sabatieria* and *Terschellingia* showed significant positive correlation with total organic carbon, total nitrogen, and depth. In contrast, *Desmodora*, *Halalaimus* and *Ptycholaimellus* showed negative correlation with organic enrichment (Tran et al., 2018c). However, these correlations were based on single-correlation analyses, which were designed to determine the impact of a single quantitative environmental factor on nematode characteristics. While studies and reviews on the single-correlation between environmental variables and nematodes are increasingly common, to date, few studies have assessed the multi-correlation between environmental variables and the nematode characteristics. Differences between single- vs multi-correlation analyses and the effects of

environmental variables on the nematode characteristics needs to be investigated.

In this study, we provide (i) additional information on the nematode bio-indices in the CMMSFP and (ii) explore multi-factorial interactions between the nematode bio-indices and the environmental variables. Results obtained in this study are valuable for understanding biodiversities of benthic nematofauna and their complex interactions with environmental variables in mangrove forest.

MATERIALS AND METHODS

Study location

The present study was carried out in eight different stations in the CMMSFPs (P1–P8) situated in the Tam Giang Commune, Nam Can District, Ca Mau Province (Fig. 1). Detailed information about the study area has been described by Tran et al. (2018c).

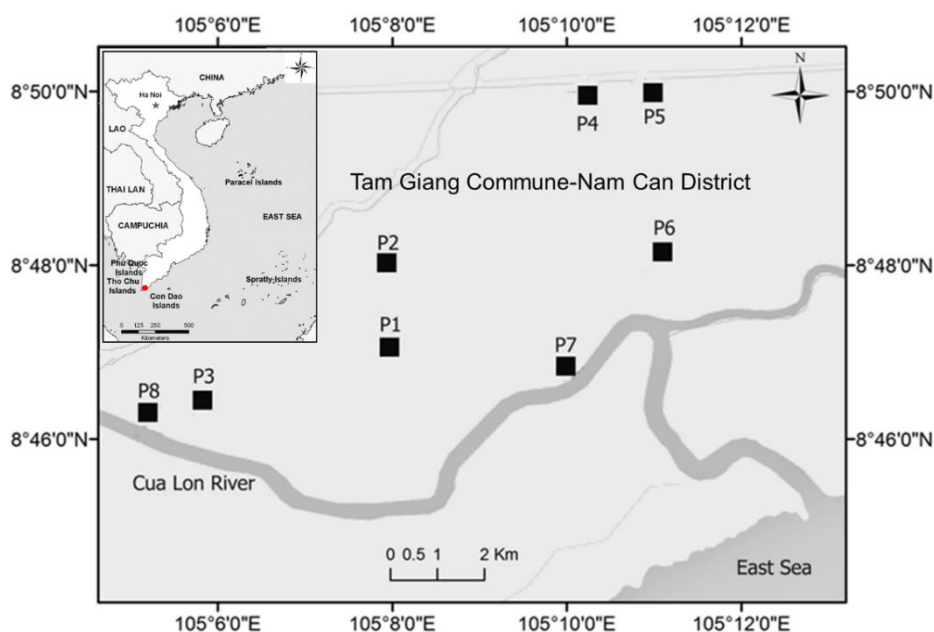


Figure 1. Map and ordinations of sampling stations in eight mangrove-shrimp farming ponds in Tam Giang commune, Nam Can District, Ca Mau Province

Sampling and laboratory activities

Nematode communities in the CMMSFP were investigated in three periods: March-dry season, July-transient season and November-

rainy season of 2015. Nematode samples were collected in triplicate using 10 cm² cores with 3.5 cm in diameter, pushed in the sediment at least 10 cm deep. Only samples with clear overlying water with sediment depth up to 10

cm were retained. Sediment samples were then preserved in 7% neutralized formaldehyde (heated to 60 °C). In the laboratory, nematode specimens were extracted from the sediment using a 1-mm mesh upper sieve and a 38 µm mesh lower sieve. The flotation technique using Ludox-TM50 (specific gravity of 1.18) was applied to separate the specimens from the sediment (Vincx, 1996). To facilitate the sorting and counting of nematodes under a stereo-microscope, the samples were further stained with 1% Rose Bengal solution. About 100 nematodes from each sample (if the sample consists of less than 100, all nematodes in that sample) were picked out randomly and specimens were processed and mounted on permanent slides for identification (De Grisse, 1969). Nematodes were identified to genus level according to Platt & Warwick (1983, 1988), Warwick et al. (1988), Zullini (2005), Nguyen (2007) and the NEMYS database of the Marine Biology Section, Ghent University, Belgium (Bezerra et al., 2018) (www.nemys.ugent.be).

Furthermore, data and methods of sampling of sediment characteristics such as depth (Dep, cm), dissolved oxygen (DO, mg/l), salinity (Sal, ‰), pH, Fe²⁺ (mg/100 g), Fe³⁺ (mg/100 g), total organic carbon (TOC, %), and total nitrogen (TN, %) followed those described by Tran et al. (2018a).

Data analyses

All data of nematode communities was presented as an average $\pm$ standard deviation. The following bio-indices: genera richness (S), Margalef diversity index (d), Pielou's evenness index (J'), the expected number of species at Hurlbert's index (ES(50)), and Hill indices (N₁, N₂, and N_{inf}) were used as biodiversity measures for nematode communities. The software Primer v.6.1.6 was used to calculate the diversity indices.

Non-parametric Spearman's rank correlation coefficient was used to identify the correlation between the environmental variables and the nematode bio-indices (S, d, J', ES(50), N₁, N₂, and N_{inf}). A regression

procedure was applied to construct a statistical model describing the multi-correlation of the multi-quantitative variables (Dep, Sal, pH, Fe²⁺, Fe³⁺, TOC, and TN) on a dependent variable (nematode bio-indices). Moreover, a two-way ANOVA test was carried out to compare the attributes of the nematode communities between seasons and ponds. Tukey's honestly significant difference (Tukey HSD) multiple range test was used when a significant difference ($p < 0.05$) was detected in two-way ANOVA tests. All statistical analysis was performed using the software Statgraphic Centurion XV version 15.1.02.

RESULTS

The nematode bio-indices in the mangrove-shrimp farming pond

Composition and densities of nematode communities in CMMSFP have been described in details by Tran et al. (2018c). The lowest biodiversity value was observed at the dry season in P1 and P2, whereas the highest biodiversity value was observed at the dry season in other ponds (except for Hill indices in P3, P4, and P6). The nematode biodiversity decreased gradually from the dry season to the rainy season (except for ES(50) in P4, Hill indices in P3, P4, and P6). More specifically, the average species richness index (S) ranged from 13.33 ± 0.62 (P1) to 21.33 ± 0.77 (P6) in the dry season, from 16.33 ± 0.83 (P7) to 21.00 ± 0.76 (P6) in the transient season, and from 11.33 ± 0.65 (P7) to 17.33 ± 0.82 (P6) in the rainy season (Fig. 2A). The diversity of nematode communities measured by the Margalef diversity index (d) ranged from 2.35 ± 1.13 (P1) to 4.32 ± 0.32 (P6) in the dry season, ranging from 3.20 ± 1.46 (P7) to 4.25 ± 0.66 (P6) in the transient season and from 2.20 ± 1.50 (P7) to 3.65 ± 0.48 (P6) in the rainy season (Fig. 2B). The Pielou's evenness index (J') ranged from 0.62 ± 0.18 (P1) to 0.83 ± 0.06 (P5) in the dry season but was higher in the transient and rainy seasons, ranging from 0.71 ± 0.05 (P7) to 0.85 ± 0.15 (P3) and from 0.65 ± 0.16 (P7) to 0.85 ± 0.03 (P3), respectively (Fig. 2C). The ES(50) index showed a trend similar to

other indices (S, d, J' index). ES(50) value was highest in the dry season (except for P1 and P2), and gradually decreased from the dry season to the rainy season (except for P6)

(Fig. 2D). Regarding Hill indices, P1, P2, P3, P4, P5, and P6 showed the highest value during the sampling period, whereas P7 showed the lowest value (Figs. 2E–2D).

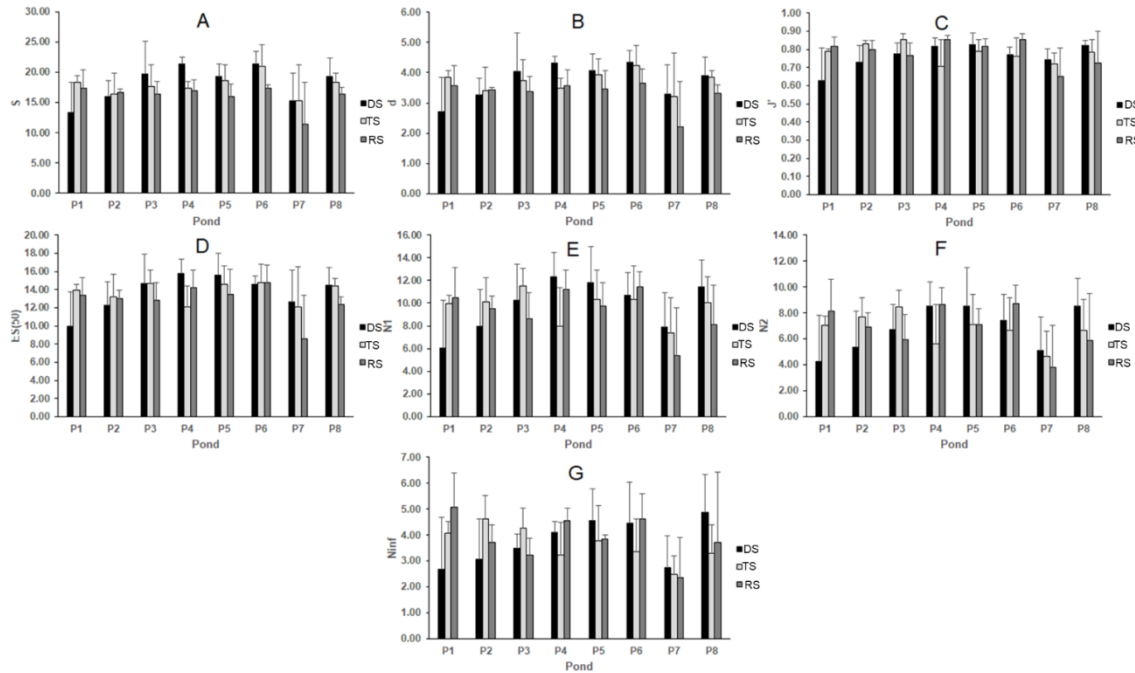


Figure 2. Average and standard deviation of different nematode bio-indices for eight different ponds (P1–P8) during the dry season (DS), transient season (TS), and the rainy season (RS)

Two-way ANOVA test was carried out to compare the biodiversity indices (S, d, J', ES(50) and Hill indices) between seasons and ponds. Results indicated that seasonal factors and the factor interaction between

seasons and ponds (season*pond) have no statistically significant effect on any indexes. In contrast, the pond factor showed statistically significant effect on S, d, ES(50), and N₁ index (Table 1).

Table 1. The p value of the two - way ANOVA for the nematode bio-indices

	S	d	J'	ES(50)	N ₁	N ₂	N _{inf}
Season	0.10	0.14	0.68	0.36	0.78	0.98	0.87
Pond	0.01	0.02	0.17	0.02	0.02	0.06	0.09
Season*Pond	0.62	0.61	0.08	0.31	0.17	0.22	0.27

Tukey HSD tests with a multiple comparison procedure were used to check whether the nematode bio-indices were significantly different between seasons/ponds. With this method, there was a 5.0% risk of calling one or more pairs significantly different when their actual difference equaled 0. Figs. 3–4 showed the

means of the nematode bio-indices with their 95% Tukey HSD intervals. For each index, there was no statistically significant difference between seasons (Fig. 3). Compared to the biodiversity indices between ponds, there were significant differences for S, d, ES(50), and N₁ indices between P6 and P7 (Fig. 4).

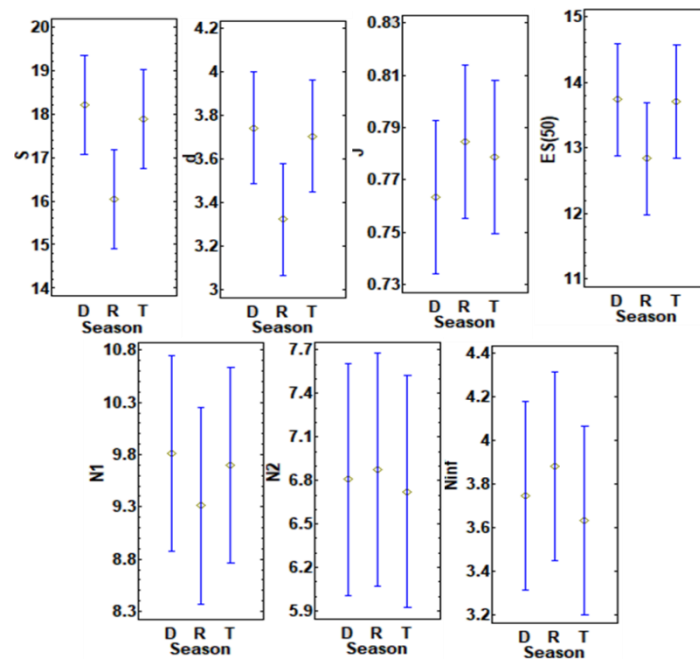


Figure 3. Tukey HSD multiple range tests for nematode community attributes (factor seasons)

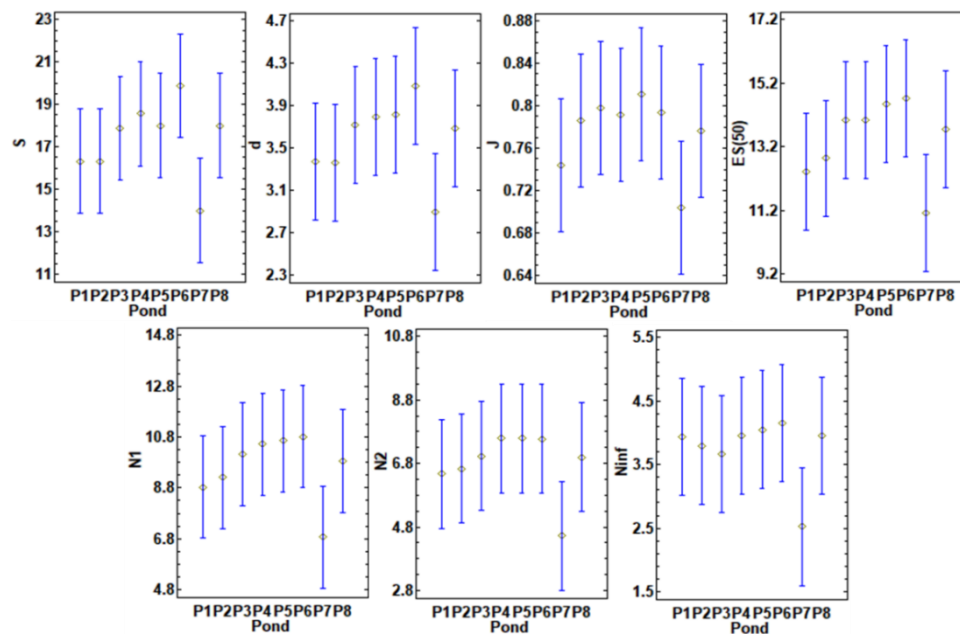


Figure 4. Tukey HSD multiple range tests for the nematode bio-indices (factor ponds)

Correlations between the nematode communities and the environmental variables

In order to investigate a possible significant correlation between the

environmental variables with the characteristics of nematode communities, Spearman rank correlation analysis was conducted between the environmental data and the nematode bio-indices. Results

confirmed that three variables (Sal, TOC, and TN) correlated significantly with three bio-indices of the nematode communities (S, d, and ES(50)). Specifically, salinity was significantly positively correlated with S and d index ($r = 0.31$ and 0.29 , respectively). By

contrast, TOC showed negative correlations with S, d, and ES(50) ($r = -0.32$, -0.32 , and -0.26 , respectively); TN also showed negative correlation with S ($r = -0.25$). Overall, both organic enrichment variables have a negative effect on the nematode bio-indices (Table 2).

Table 2. The r and p -value of Spearman rank correlation between the environmental variables and the nematode bio-indices ($n = 72$) (p -values < 0.05 indicated with bold values)

EnV. variables		S	d	J'	ES(50)	N ₁	N ₂	N _{inf}
Dept.	r	-0.21	-0.16	0.11	-0.07	0.00	0.04	0.06
	p	0.08	0.17	0.37	0.54	1.00	0.75	0.59
DO	r	-0.15	-0.12	-0.15	-0.08	-0.14	-0.19	-0.19
	p	0.20	0.32	0.20	0.48	0.23	0.12	0.11
Sal	r	0.31	0.29	-0.14	0.20	0.09	0.00	-0.01
	p	0.01	0.01	0.23	0.10	0.44	0.98	0.94
pH	r	-0.12	-0.11	0.09	-0.05	0.00	0.04	0.09
	p	0.32	0.35	0.44	0.68	0.99	0.73	0.44
Fe ²⁺	r	-0.05	-0.06	0.03	-0.05	-0.03	-0.01	0.01
	p	0.68	0.62	0.80	0.65	0.81	0.95	0.92
Fe ³⁺	r	-0.17	-0.12	0.19	0.02	0.07	0.11	0.07
	p	0.16	0.29	0.12	0.87	0.57	0.37	0.54
TOC	r	-0.32	-0.32	-0.11	-0.26	-0.21	-0.19	-0.22
	p	0.01	0.01	0.37	0.03	0.08	0.11	0.06
TN	r	-0.25	-0.23	-0.13	-0.16	-0.17	-0.16	-0.15
	p	0.04	0.06	0.29	0.19	0.15	0.19	0.22

Multi-interactions between nematode communities and the environmental variables

Overall, multi-interaction analyses showed that each nematode bio-index was at most affected by independent variables, e.g. S and d were influenced by Sal and TOC. Other bio-indices were affected by only one variable such as DO, except for ES(50). A multiple linear regression model was built to describe the relationship between S and 8 independent environmental variables (Table 3). The equation of the fitted model was $S = 16.82 + 0.17 \cdot \text{Sal} - 0.97 \cdot \text{TOC}$. Since the p -value in the ANOVA test was 0.0002, there is a statistically significant relationship between the variables at a 95.0% confidence level.

The R-Squared statistic indicated that the model fitted explains 22.5% of the variability in S index. The standard error of the estimate

(SE Est.) showed the error range of the residuals to be 3.19. The average value of the residuals (the mean absolute error-MAE) was 2.36. The Durbin-Watson (DW) statistic tests the residuals to see if there are any significant correlation based on the order in which they occur in the data file. Since the p -value of 0.53 was > 0.05 , there is no indication of serial autocorrelation in the residuals at a 95.0% confidence level. Figure 5A showed a plot of the fitted model of S index with salinity and TOC. The multiple regression model of d and the environmental variables (Fig. 5B) were interpreted similarly. The other indices including J', ES(50), Hill indices were affected only by DO. Therefore, a linear regression model was used to describe the relationship between these indices and 8 independent variables. For example, the equation of the fitted model between J' and DO was $J' = 0.86 - 0.01 \cdot \text{DO}$

($p = 0.03 < 0.05$). Moreover, the R-Squared statistic showed that the model as fitted explains 6.4% of the variability in J' . The standard error of the estimate indicated that the range of the error of the residuals was 0.08. Furthermore, the average value of the residuals (MAE) was 0.06. Since the p-value (0.38) of D-W statistic test was > 0.05 , there

was no proof of serial autocorrelation in the residuals at the 95.0% Confidential level (Table 3). The plot of the fitted linear model between J' and DO was presented in Figure 5C. In addition, the single linear regression model of remaining indices and environmental variables was similarly interpreted.

Table 3. Multiple regression coefficients and results of fitting the regression model to describe the relationship between the nematode communities and the environmental variables

Nema.-En.V	Multi-regression model	R ²	SE Est.	MAE	D-W statistic	p-value
S-EnV.F.	$S = 16.82 + 0.17*Sal - 0.97*TOC$	22.49	3.19	2.36	0.53	0.0002
d-EnV.F.	$D = 3.58 + 0.03*Sal - 0.21*TOC$	21.23	0.70	0.52	0.70	0.0003
J' -EnV.F.	$J' = 0.86 - 0.01*DO$	6.38	0.08	0.06	0.38	0.03
ES(50)-EnV.F.	$ES(50) = 16.29 - 0.68*TOC$	13.51	2.44	1.88	0.63	0.001
N_1 -EnV.F.	$N_1 = 13.36 - 0.50*DO$	11.58	2.72	2.23	0.55	0.003
N_2 -EnV.F.	$N_2 = 9.92 - 0.41*DO$	11.46	2.25	1.88	0.61	0.003
N_{inf} -EnV.F.	$N_{inf} = 5.36 - 0.21*DO$	10.63	1.21	0.94	0.60	0.005

Notes: Environmental variables (En.V.); standard error of the estimate (SE Est.); mean absolute error (MAE), Durbin-Watson statistic (D-W statistic).

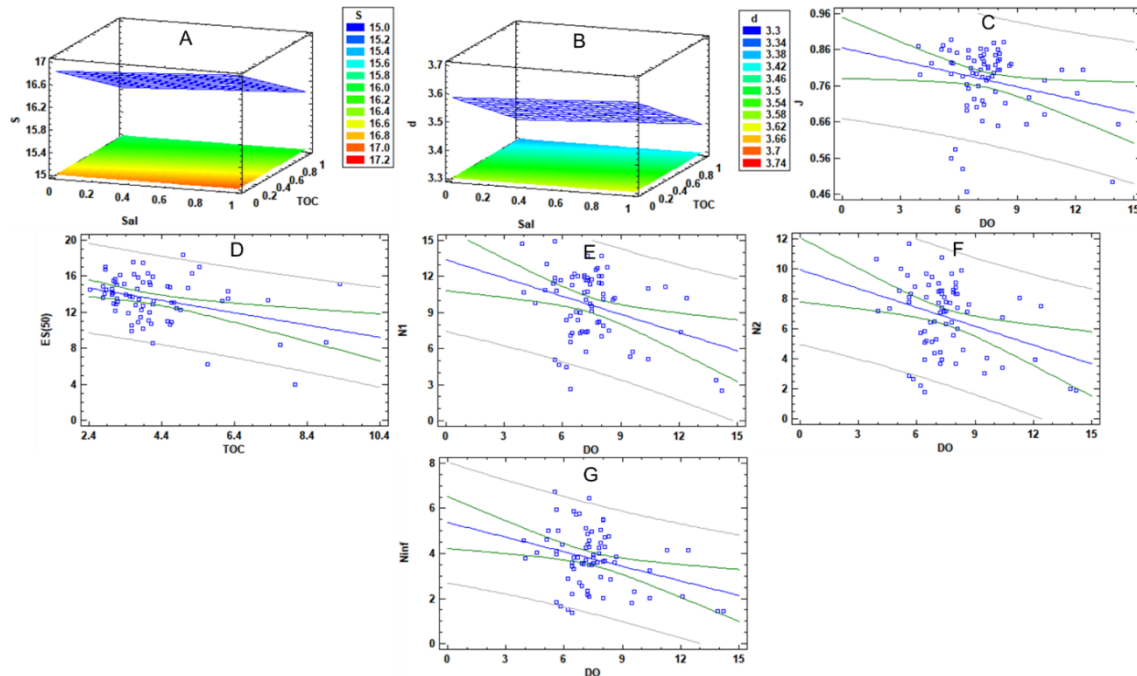


Figure 5. A plot of fitted (A) Multi-regression model between S and Sal/TOC, (B) Multi-regression model between d and Sal/TOC, (C-G) Simple regression model between J' and DO, ES(50)-TOC, Hill indices-DO, respectively

DISCUSSION

Comparison of nematode bio-indices in Ca Mau mangrove-shrimp farming ponds with other similar habitats and its impact

The recent study by Tran et al. (2018c) is one of the first investigations on nematode biodiversities in the CMMSFP. Therefore, we used their biodiversity data (Tran et al. 2018c) in combination with results of the present study to better understand the diversity of nematode communities in the CMMSFP and to compare them with similar studies on MSFPs around the world. The composition and densities of nematode communities in some ponds were different leading to differences in bio-indices. However, seasonal factors do not often significantly affect bio-indices of nematode communities because the tropical climate allows for continuous cycle of reproduction of nematodes (Ngo et al., 2013c).

Among biodiversity indices, H' index has been widely used for quantifying species diversity, especially for nematode diversities (Semprucci & Balsamo, 2012). The present study estimated the nematode diversities in CMMSFP not only based on the H' index but also on other indices such as S, d, J', and Hill indices. A first attempt is made to compare our results with other data on nematode biodiversities in mangroves and mudflats (Table 4). Although the primary objectives of other studies were quite different and not completely similar methods or techniques were applied, it gives an indication of nematode diversity in our farming ponds. In general, the biodiversity of nematode communities in the CMMSFP was higher than those in a temperate intertidal mudflat in France or in the intertidal tropical mangrove mudflats in Brazil and Australia. This supports the point that Ca Mau's mangrove forest is characterized by high nematode diversities.

Table 4. Global data on nematode diversities from mangroves

Location	Habitat	Diversities	References
Ca Mau mangrove, Vietnam	Mangrove-shrimp farming ponds (38-104 cm in depth)	H': 2.14±1.07–3.61±0.24	H' from Tran et al. (2018c)
Can Gio mangrove, Vietnam	Mangrove mudflat	H': 3.6–4.2	Ngo et al. (2007)
Hunter river and Fullerton, Australia	Mangrove	H': 1.28–2.76	Hodda & Nicholas (1985)
Cape York peninsula, Australia	Mangrove estuarine	H': 2.02–2.91	Alongi (1987)
Merbok, Malaysia	<i>Rhizophora</i> , <i>Brugiera</i>	H': 2.0–3.2	Gee & Somerfield (1997)
Victoria, SE Australia	Only <i>Avicennia</i>	H': 0.558 ± 0.084	Gwyther (2003)
Marennes-Oléron, France	Temperate intertidal mudflat	H': 2.7–3.5	Rzeznik–Orignac et al. (2003)
Santa Catarina, South Brazil	Mangrove	H': 2.5–3.5	Netto & Gallucci (2003)

Globally, mangrove forests have been destroyed by coastal aquaculture, mainly shrimp farming (Hamilton, 2013; Richards &

Friess, 2016). Integrated mangrove-shrimp farming has emerged as a part of the potential solution to protect mangrove-forest

faced by shrimp aquaculture (Primavera et al., 2000). In 1978, integrated mangrove-shrimp farming was first used in Vietnam (Hai, 2005). Nowadays, this model has been widely practiced in the country (especially in Ca Mau Province), considered as the best method for providing farming households with a sustainable livelihood through mangrove conservation (Ha et al., 2012). In recent years, the model has been faced with many challenges, mainly due to poor technical knowledge (Bosma et al., 2016). In CMMSFP, farmers do not apply feeds and chemicals but depend on natural recruitment of shrimp (Primavera et al., 2000). Therefore, abundances of natural food play a pivotal role in the success of the model. Presently, *Penaeus monodon*, commonly known as the giant tiger prawn or Asian tiger shrimp has been broadly farmed in the CMMSFP (Tho et al., 2011). The productivity of shrimp is affected by several variables including farm management, pond size, availability of natural food (zoobenthos, periphyton, phytoplankton and zooplankton), water quality (dissolved oxygen, pH), and weather conditions (sunlight, rainfall) (Fitzgerald, 2000; Takashima, 2000). While El Hag (1984) reported that *Penaeus monodon* adults are omnivores, being able to feed on both small organisms and organic matter, nematodes and small organism are still considered to be a main food source of *Penaeus monodon* (Chong & Sasekumar, 1981). The high density and biodiversity of

the nematode communities in the CMMSFP have been providing a very suitable natural food source for shrimps. This is an advantage of ecological solution of the CMMSFP model in Vietnam.

Comparison between single vs multi-correlations and interpretation of their effects on nematode bio-indices

Regarding the single correlations, S index significantly correlated with three variables (Sal, TOC, and TN), d with two variables (Sal, TOC), and ES(50) with one (Sal), whereas other indices did not correlate with any variables. Thus, the question was whether these correlations were still true in multi-correlation analysis. In fact, there was only the d index that still correlated with two variables (its model: $d = 3.58 + 0.03 \cdot \text{Sal} - 0.21 \cdot \text{TOC}$). The multi-correlation of others was completely different from the single-correlations. More specifically, S index was affected by two variables (its model: $S = 16.82 + 0.17 \cdot \text{Sal} - 0.97 \cdot \text{TOC}$), J' and Hill indices were affected by one variable (DO), also ES(50) by one (TOC) (Fig. 6). This study suggested that it is necessary to pay attention to the complex interactions between the environmental variables and the impacted nematode communities. Answers to the question could help explain the differences between single-and multi-correlation as well as its effect on nematodes in particular and aquatic organisms in general.

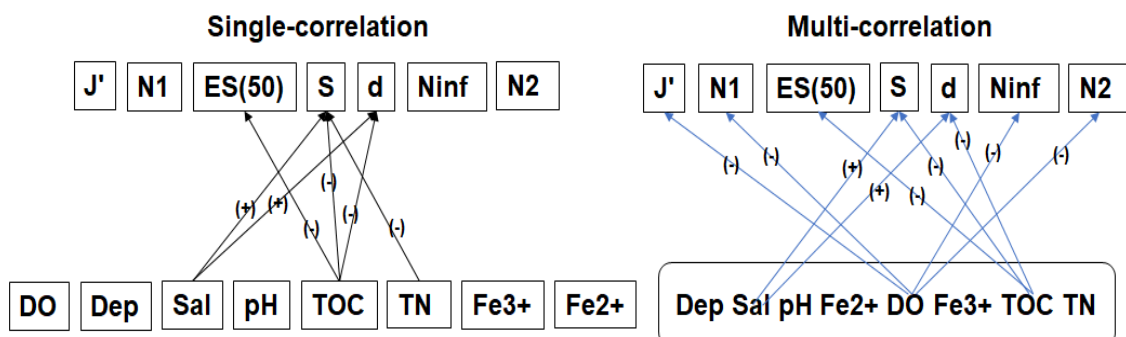


Figure 6. Single and multi-correlation between the nematode bio-indices and the environmental variables

What variables need to be considered to raise biodiversity of nematode communities (shrimp's food source)?

Using the multi-correlation results from this study in combination with other studies (Table 5), high salinity could help promoting nematode diversities, whereas a high value of depth, DO, pH, and organic concentration (TOC, TN) could decrease the diversity. Although nematode diversities can be affected by a number of abiotic variables such as salinity, temperature, hydrodynamics, sediment grain size, oxygenation level and food availability (Ingels et al., 2011; Cai et al., 2012; Ngo et al., 2013a; Zeppilli et al., 2013; Górska et al., 2014), salinity is the most important variable. Several studies showed

that salinity is one of the most common ancillary measures used in coastal and marine ecological studies to monitor drivers of benthic assemblages (Alber, 2002; Ysebaert & Herman, 2002; Kimmel & Roman, 2004). Moreover, salinity gradients could be more important in explaining diversity across multiple estuarine systems (Van Diggel, 2016). Therefore, salinity concentration should be considered and regularly monitored in CMMSFP. The optimal salinity for shrimp culture is about 15–25 ppt (Boyd, 1995) which is vital for pond dynamics, although shrimps can be grown in salinities varying from 4 ppt to 26 ppt. Likewise, in an earlier study, *P. monodon* favored salinity ranging from of 6.5 ppt to 25.5 ppt favored the growth (Das et al., 2001).

Table 5. Single-correlation between the nematode bio-indices and the environmental variables from others studies

	Dep	Sal	DO	pH	TN
S	-[1]	+[2, 7]	-[3]	-[4]	-[7]
d	-[5]	+[7]	N.A	-[4]	-[7]
H'	-[5, 6]	+[2]	-[3]	-[4]	-[3]
ES(50)	N.A	N.A	-[3]	N.A	-[7]
N ₁	-[5]	+[2]	-[3]	-[3]	-[3]
N ₂	-[5]	N.A	-[3]	-[3]	-[3]
N _{inf}	-[5]	N.A	N.A	-[3]	-[3]

Notes: “+”: Positive correlations; “-”: Negative correlations; N.A: Not available; [1]: Gambi et al. (2003); [2]: Tran et al. (2018b); [3]: Ngo et al. (2016); [4]: Ngo et al. (2013b); [5]: Tran et al. (2017a); [6]: Liu et al. (2015); [7]: This contribution.

CONCLUSION

This study found significant multi-interaction between nematode communities' bioindices with environmental variables in the CMMSFPs. The biodiversity of nematode communities have been considered to be high which provided more natural food for shrimps. Furthermore, the multi-correlation between the nematode bio-indices and the environmental variables produced completely different results from those of single-correlation analyses. Although the present study has been able to show the advantage of the multi-correlation, there are still some

points we would like to address in future work, especially the complex interactions between the environmental variables and nematode communities.

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