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Zooplankton community in Thi Nai lagoon in the period of 2001–2020

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Abstract
This paper presents the results of the surveys on zooplankton in Thi Nai lagoon from 2001 to 2020. There were 179 species found in the lagoon, among which Copepod was the dominant group with 97 species (50.78% of total species), followed by Cladocera with 20 species (10.36%), Hydrozoa with 18 species (9.33%), Tunicata with 11 species (5.7%) and Siphonophora with 10 species (5.18%). Based on Bray-Curtis similarity analysis of zooplankton community and the station position, the sampling stations in the lagoon were grouped into three areas: The upper lagoon (UP), the middle (MI), and the mouth of the lagoon (MO). Among the surveyed years, there was a slight variation in the species number, while the density decreased by time and was especially low in 2020. Zooplankton density was much lower in the rainy season compared to that in the dry season, while the species number was less varied. Analysis of the differences between the areas in the lagoon demonstrated a clear distribution pattern of zooplankton with a decreasing density and an increasing number of species from upper lagoon to the mouth of the lagoon. Zooplankton diversity was less affected by time and only the Pielou index in the MI area between 2004 and 2009 was significantly different. Analysis of the various indices between seasons showed that the MO area was less volatile than the two other regions. The multi-dimensional scaling analysis demonstrated that zooplankton community was less variable by regions (50% similarity) compared to by the years (only 30% of similarity), except in 2009 and 2020 when differences among the areas were significant. Seasonal community change between the dry and rainy seasons was 30%.

Keywords: Zooplankton, Thi Nai lagoon, diversity indices.

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INTRODUCTION

Zooplankton are the organisms that drift in waters, are usually in microscopic size from micrometers to centimeters or larger, typically like some jellyfish [1]. Zooplankton mainly consume on phytoplankton, which are a primary producer, so they play a key role in energy transportation among nutrient levels in the marine food web. Besides, some of them are biological indicators of the aquatic environment [2, 3]. Consequently, study on zooplankton community can partly reflect the current status as well as the changes in the habitat in the study area.

Thi Nai lagoon is a saltwater region located in Quy Nhon city, Binh Dinh province. This lagoon is an enclosed area which is only connected to Quy Nhon bay by a narrow path (500–700 m length) and strongly influenced directly from Con and Tan An rivers from October to February [4]. The lagoon is also influenced by industrial waste, farming activities as well as fish farms in the lagoon. Due to the narrow sea gate, water exchange capacity is limited, coupled with the rapid increase in aquaculture, the risk of environmental pollution caused by full overload is probably happening. Therefore, study on zooplankton community may reflect the status of the lagoon.

Studies on zooplankton in Binh Dinh in general and Thi Nai lagoon in particular were very limited. Nguyen Cho and Nguyen Van Khoi, and his colleagues surveyed a few stations in offshore areas of Binh Dinh during a survey of Vietnam's waters in 1991. Nguyen Cho et al., recorded 134 zooplankton species in Thi Nai lagoon and Quy Nhon bay [5]. Nguyen Cho et al., (2011) published results of 124 zooplankton species in Thi Nai lagoon during the rainy and dry seasons of 2008 and 2009 [6].

Under these circumstances, this study aims to assess the changes of zooplankton community in Thi Nai lagoon from 2001 to 2020.

MATERIALS AND METHODS

Study area

Samples were collected in Thi Nai lagoon and the sampling map (figure 1) includes 21 stations in 2001, 2003, 2004, 2008, 2009, and 2020 (details in table 1).

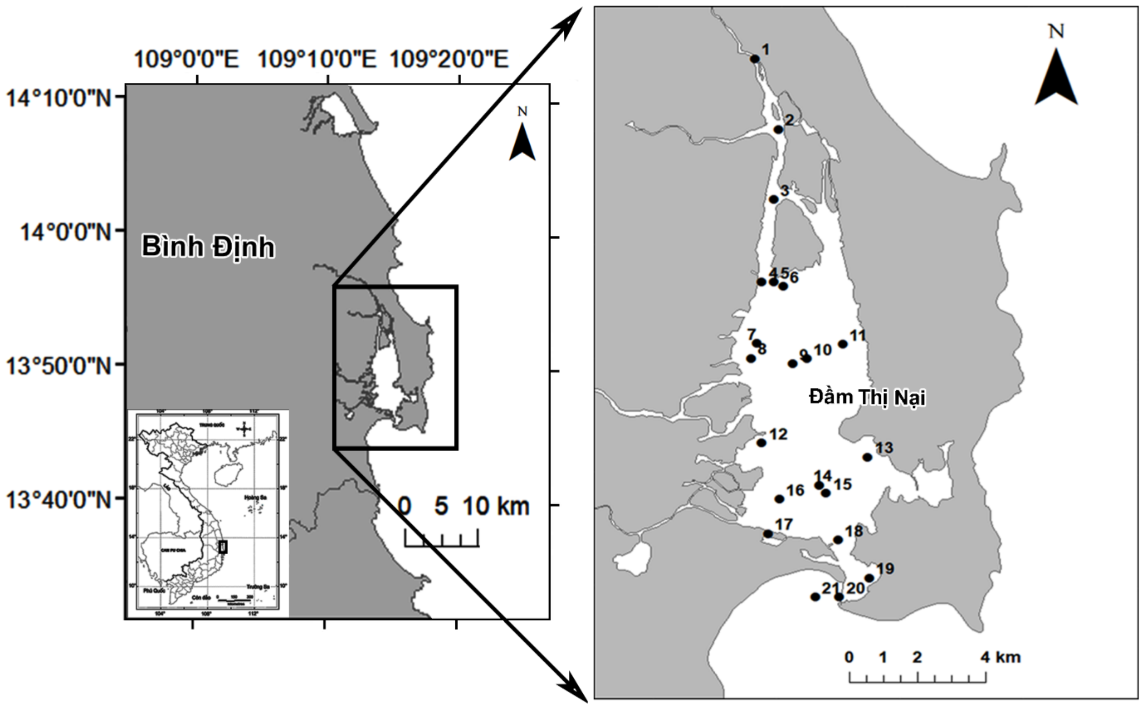

Figure 1. Sampling sites in Thi Nai lagoon in the period of 2001–2020

Table 1. Sampling information in Thi Nai lagoon in the period of 2001–2020

Areas	Station number	Month/Year (Season)	Number of samples
Upper lagoon (UP)	3–6	4/2003 (Dry)	7
		11/2003 (Rainy)	3
		6/2004 (Dry)	2
		11/2008 (Rainy)	3
		4/2009 (Dry)	3
		5/2020 (Dry)	2
MI	7–13	6/2004 (Dry)	3
		11/2008(Rainy)	4
		4/2009 (Dry)	4
		5/2020 (Dry)	3
MO	14–21	8/2001 (Dry)	9
		6/2004 (Dry)	12
		11/2008 (Rainy)	8
		4/2009 (Dry)	8
		5/2020 (Dry)	3

Most of the sampling times were in the dry season. Sampling in the rainy season was only in 2003 and 2008. The lagoon was divided into 3 areas based on station position and a Bray-Curtis similarity analysis of zooplankton community: The upper lagoon (UP: Stations 3 to 6); the middle lagoon (MI: Stations 7 to 13) and mouth of the lagoon (MO: The remaining stations).

Sampling method

The quantitative and qualitative samples were taken in vertical hauls using Juday net (nylon fiber) with 37 cm of diameter and 200 µm of mesh size. Samples were collected at 1 m above the bottom to the surface. The samples were stored in 0.5 l bottles and fixed with formaldehyde 5% and brought to the laboratory for later analysis.

Sample analysis

In the laboratory, the samples were first cleaned with fresh water; trashes and other large organisms such as fish, squid larvae, coelenterates,... which can be observed by bare eyes, were removed. After cleaning, the samples were divided into 2 size classes using 500 µm mesh size sieve: large (> 500 µm) and small zooplankton (< 500 µm). The large organisms (> 500 µm) were counted directly or further divided by using the Folsom plankton splitter (Longhurst and Seibert, 1967) depending on the density of the samples. The small-sized class (< 500 µm) was rinsed through a 25 µm sieve and the retained sample was diluted with distilled water to a convenient volume in a graduated cylinder (25, 50 or 100 ml) depending on sample density and then 1 ml was used for counting. Zooplankton samples were identified to species level by using stereoscopy and microscope following the technique of Goswami (2004) [7]. The abundance of zooplankton in each station was standardized to the individuals per cubic meter based on the depth of net tow and the mouth area of the net, assuming a 100% filtration efficiency.

Zooplankton species were mainly identified based on the literatures of Chen (1965) [8], Chen (1974) [9], Muyaldi (2002) [10], Shirota (1966) [11], Owre and Foyo (1967) [12], Nguyen Van Khoi (1994) [13], Nishida (1985) [14] and Bradford-Grieve et al., (1999) [15]. Taxonomy information was updated based on WoRMs (http://marinespecies.org).

The abundance of zooplankton was all recorded at species level except for Cnidaria and Ctenophora, wherein only occurrence/absence was listed due to the serious damage of the specimens during sampling period, and invertebrate larvae, wherein only higher taxa were enumerated due to deficient identification at the species level.

Data analysis

Density of zooplankton was calculated by the following equation:

$$\text{Total density (inds.m}^{-3}) = (A \times B) + (C \times D)/V$$

Where: A: Total individuals of the large-sized class (> 500 µm); *B*: Number of the splits by using Folsom splitter (of the large-sized class); *C*: Total individuals in 1 ml of the small-sized class (< 500 µm); *D*: Volume of the small-sized class (< 500 µm); *V*: Total water volume filtered through the net.

Primer software version 6 (Primer-E Ldt.) was used for calculating some community indices such as biodiversity, cumulative dominance and illustrating temporal and spatial differences among stations, and following equations were used:

Margalef's index: $d = (S - 1)/\log(N)$ [16].

Pielou index: $J' = H'/\ln(S)$ [17].

Wiener index:

$$H' = -\text{sum}(P_i * \log_2(P_i)) \text{ [18]}$$

Simpson index:

$$(D) = \frac{1}{\sum_{i=1}^{s} p_i^2} \text{ [19]}$$

Percentage of similarity was also calculated after [20] as an equation below:

$$BC_{ij} = 1 - \frac{2C_{ij}}{S_i + S_j}$$

Where: N_i: Individuals of species *i*; *N*: Total individuals in a sample; *S*: Total of number of species in a sample; P_i: Frequency of species *I* in a sample = present probability of species *i* in a sample; C_{ij}: Total of similar species between two samples *i* and *j*; S_i and S_j: Number of species in sample i and sample *j*.

Excel Microsoft Office 2013 was used for calculating and drawing graphs; R v3.6.0/RStudio was used for drawing graphs and basis statistic with package "plyrd" [21], "pgirmess" [22], ggplot2 [23] and vegan [24].

RESULTS AND DISCUSSION

Species composition and abundance of zooplankton community

A total of 179 species have been identified in Thi Nai lagoon from 2001 to 2020, wherein the Copepod was dominant with 97 species (50.78% in total species number), followed by Hydromedusa with 18 species (9.33%), Tunicata: 11 species (5.7%) and Siphonophora: 10 species (5.18%). Zooplankton community in Thi Nai lagoon had the highest species number in 2009 (81 species) and the lowest was in 2003 (55 species). In particular, many groups such as Isopoda, Polychaeta, Scyphozoa, and Tanaidacea were represented by only few species with low occurrence frequencies (table 2). Zooplankton species number in Thi Nai lagoon ranged from 55 to 81 in the period from 2001 to 2020. This species richness is similar to a nearby lagoon, Cu Mong lagoon, Phu Yen (70 species in 2000, unpublished data), but lower than in Quy Nhon bay (122 species) [5]. In 2008–2009, the species number in Thi Nai lagoon (table 2) was much higher than in Tam Giang - Cau Hai lagoon (48 species) [26].

In general, zooplankton density was decreasing from upper lagoon to the mouth of the lagoon while the number of species was increasing. The abundance of zooplankton was higher in the dry season than in the rainy season. The seasonal difference in zooplankton abundance could be due to eutrophic condition in the dry season [5, 25]. The results showed that both species richness and abundance of zooplankton communities decreased over time, especially during the dry season from 2003 to 2020. In the dry season, zooplankton density in the UP area in 2004 (178.000 ± 68.500 inds.m^{-3}) was much higher than that in the same area in 2020 (2.500 ± 1.900 inds.m^{-3}) (figure 2). Zooplankton abundance in the lagoon was much higher in the adjacent water, Quy Nhon bay (5.000–20.000 inds.m^{-3}) in 2004 [5].

Analysis of seasonal variation of zooplankton community was conducted in selected years including 2003 (at UP area), and 2008–2009 (the entire lagoon). Zooplankton density in the dry season was always higher than in the rainy season (figure 3). In 2003, the species number between the two seasons was not much different (figure 2), but the density was higher in dry season (127,500 inds.m^{-3}) compared to in the rainy season (4,500 inds.m^{-3}) (Permutation test, $p < 0.001$). In 2008–2009, zooplankton density between the two seasons was only significant in the MI area (Kruskal Wallis test, $p < 0.05$ with post hoc, $\alpha = 0.05$) (figure 3).

Table 2. Temporal variation of zooplankton community in the period of 2001–2020

Group/Year	2001	2003	2004	2008	2009	2020	Total
Amphipoda	1	1	1				2
Chaetognatha	2	2	3	4	1	2	5
Cladocera	2	5	1	6	3	1	11
Copepoda	46	35	48	51	52	37	97
Ctenophora			1		2	1	2
Cumacea		1	2		1		2
Hetero&Pteropoda	4			2	2	4	9
Hydromedusa	10	6	3	1	6	3	18
Isopoda					1		1
Mysidacea		1	1				2
Ostracoda	2	1					3
Polychaeta					1	1	1
Scyphozoa						1	1
Sergestidae	1	1	1	1	2	2	3
Siphonophora	6	0	3	4	3	5	10
Tanaidacea		1				1	1
Tunicata	2	1	6	7	7	5	11
Total	76	55	70	76	81	63	179

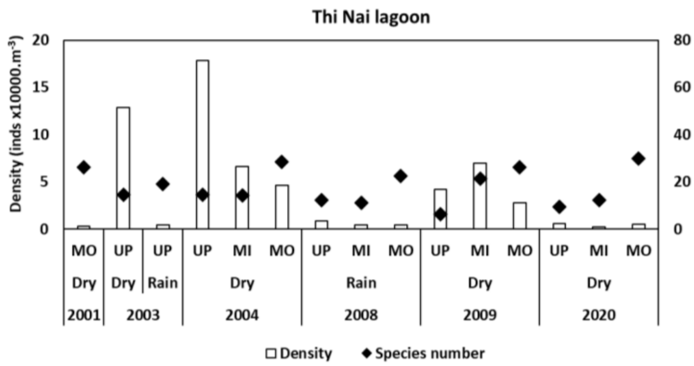

Figure 2. Variation in diversity and abundance of zooplankton community in Thi Nai lagoon (UP, MI and MO: Upper area, middle and mouth of the lagoon, respectively)

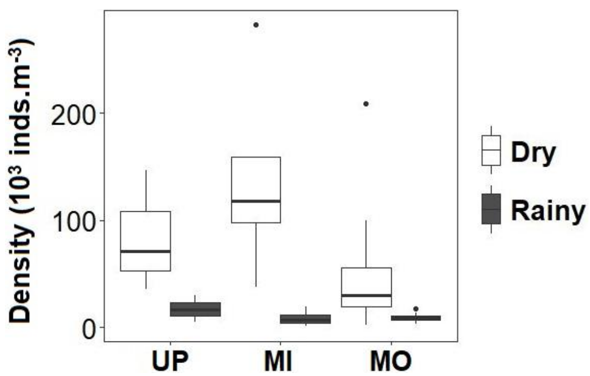

Figure 3. Seasonal variability of zooplankton density (UP, MI and MO: Upper area, middle and mouth of the lagoon, respectively)

Zooplankton diversity

Among the years, there was less variation in biodiversity indices of the MO area and only the Pielou index of the MI area in 2004 and 2009 was significantly different ($p < 0.05$). Obviously, there was the same trend of diversity indices among the surveyed areas in 2004, 2009 and 2020. In these years, the average values of Shannon and Simpson indices were increasing from upper lagoon to the mouth of the lagoon (figure 4).

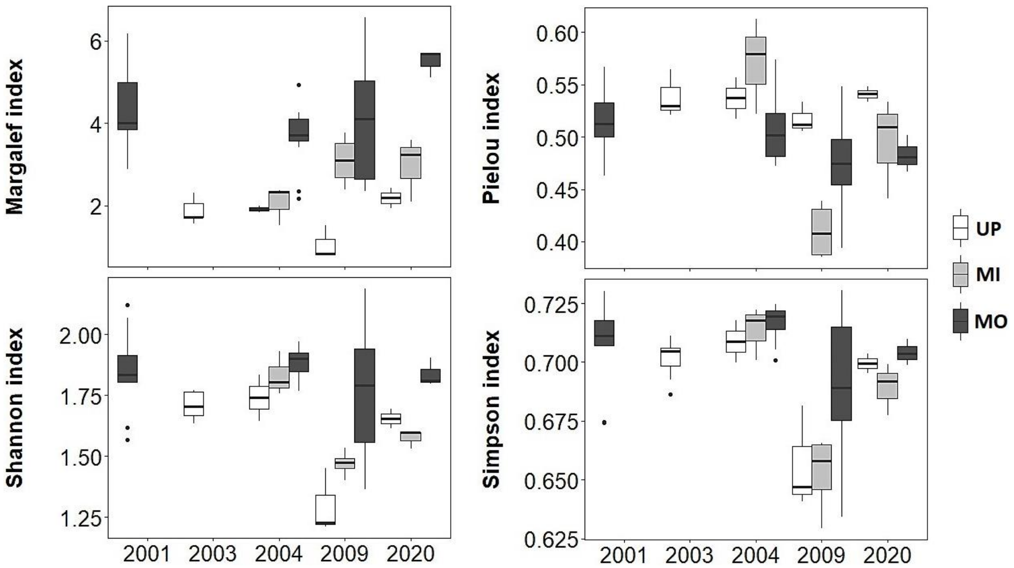

Figure 4. Spatial and temporal variability of zooplankton diversity indices in dry season (UP, MI and MO: Upper area, middle and mouth of the lagoon, respectively)

Table 3. Contribution of dominant zooplankton taxa (% abundance) in Thi Nai lagoon (UP, MI and MO: Upper area, middle and mouth of the lagoon, respectively)

Species/Area & Year	UP					MI				MO				
	2003	2004	2008	2009	2020	2004	2008	2009	2020	2001	2004	2008	2009	2020
Acartia (Juvenile)	8.9	7.7	11.8	26.2	12.1	7.2	10.7	5.4	11.7	6.0		10.7	6.2	7.1
Acartia (Acanthacartia) tsuensis			3.1	27.5	9.0			4.2				4.4		
Crustacean larvae	10.7	8.7			8.6	7.5		5.7	9.7	9.5	6.8		6.4	4.5
Polychaeta larvae		6.8				8.6					4.7			
Bivalvia larvae					5.5				7.5					5.2
Mollusc larvae		5.7			8.9	5.4		5.2	14.3		5.7			8.9
Naupli larvae					8.0			6.7	8.1			5.9	5.2	5.0
Phoronida larvae					6.0				3.1					
Bestiola similis					14.5				17.1					7.3
Diaphanosoma sarsi			5.6											
Euterpina acutifrons			5.4			5.2	6.5				6.0	5.1	6.3	
Microcyclops varicans							6.3							
Oithona (Juvenile)		5.0	8.6			6.4	6.9				5.1	7.7		
Oithona nana	10.3	12.7				10.1					6.1			
Oithona simplex	6.0	6.4				7.7					6.2			
Oithona attenuata	5.8													
Paracalanus parvus	10.2	8.9	15.9	23.5		9.7	16.4	15.1		9.5	8.3	15.9	6.4	4.0
Paracalanus (Juvenile)		11.5	15.6	3.5			12.9	9.3			8.0		6.9	
Parvocalanus crassirostris	8.9	9.3	10.1		10.1	6.9	8.9	7.2	11.7		5.7	4.5	4.6	5.7
Pseudodiaptomus (Juvenile)		5.0	9.3	3.9			11.3							

Dominant species in the study area showed the priority of small-sized groups. The density and frequency of the *Acartia* juvenile, *Paracalanus parvus*, and *Parvocalanus crassirostris* were high in almost all areas and years. In the UP area in 2009, the abundances of *Acartia* juvenile, *Paracalanus parvus* and *Acartia (Acanthacartia) tsuensis* were unusually high, with > 75% of the total density. Larval group was commonly found in each year but dominant in 2020, contributing > 90% of the total density in the UP and MI areas, and > 50% in the MO area. The two brackish water indicator species, *Diaphanosoma sarsi* [27, 28] and *Microcyclops varicans* [28], only appeared in the rainy season in 2008 in the UP and MI areas. Interestingly, *Bestiola similis* (often living in brackish waters) was dominant compared to other species in all areas in the dry season in 2020 (table 3).

These four biological indices revealed clear seasonal difference among the areas in the lagoon except for the MO area. Margalef's index of zooplankton communities at the UP and the MO areas was significantly different in the dry season (Kruskal Wallis test, $p < 0.01$). The UP and MI areas were in similar pattern for the Pielou, Shannon and Simpson indices with the values in the dry season consistently lower than in the rainy season. In particular, the Pielou index of zooplankton community at the MI area was significantly different between the two seasons (Kruskal Wallis, $p < 0.05$) (figure 5).

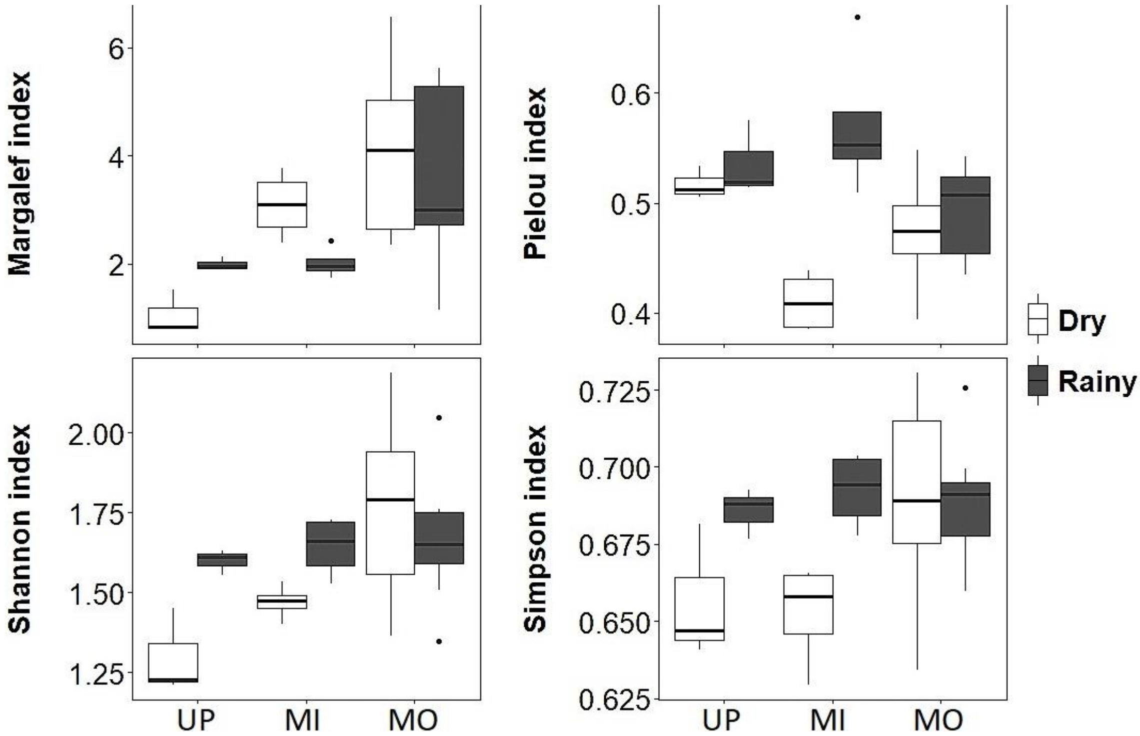

Figure 5. Spatial and seasonal variability of zooplankton diversity indices (UP, MI and MO: Upper area, middle and mouth of the lagoon, respectively)

Zooplankton community in Thi Nai lagoon generally varied by years with a similarity index of 30%. However, higher similarity (50%) of the zooplankton communities was found between the UP area in 2003 and the entire lagoon in 2004. A clear pattern of differences of species composition among the areas was found in 2009 and 2020. Whereas, in the other years, the whole lagoon was more homogeneous with similarity of zooplankton communities of 50% among the areas (figure 6).

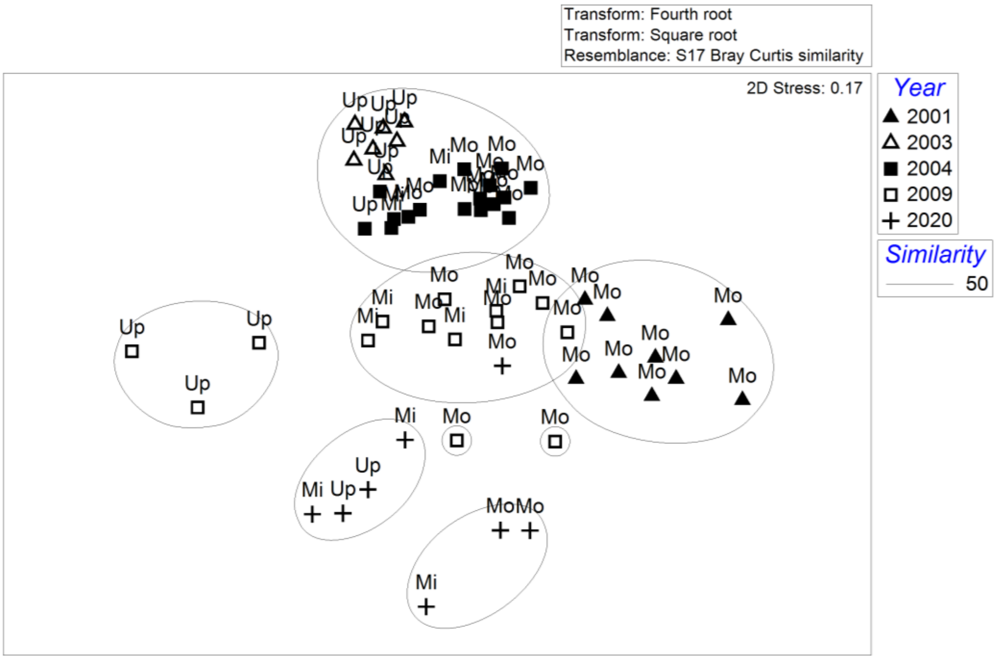

Figure 6. Spatial and temporal changes of zooplankton in Thi Nai lagoon in dry season

The MDS analysis (Multi-dimensional Scaling) showed a clear dissimilarity of the zooplankton community between the two seasons (figure 7). In the dry season 2009, the UP area was separated to the MI and MO areas (figure 7), indicating differences between the zooplankton communities at the upper lagoon and the other parts of the lagoon. In this season, the MI and MO areas shared ca. 50% similarity of the zooplankton community. A contrast pattern was found in the rainy season in 2008. The three outermost stations at the MO area were most differentiated in species composition compared to other areas in the lagoon (figure 7).

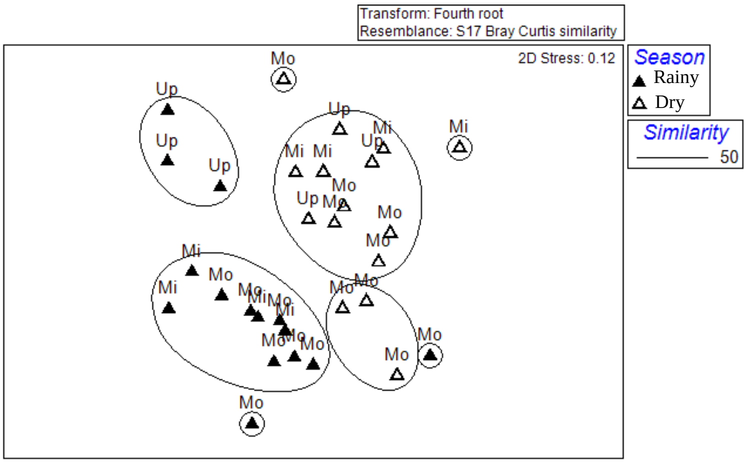

Figure 7. Spatial and seasonal changes of zooplankton in Thi Nai lagoon

CONCLUSION

There were 179 species found in the lagoon during surveys in 2001–2020, among which Copepod was the dominant group with 97 species (50.78% of total species), followed by Cladocera with 20 species (10.36%), Hydrozoa with 18 species (9.33%), Tunicata with 11 species (5.7%) and Siphonophora with 10 species (5.18%). Species richness and biodiversity indices of Thi Nai lagoon increased from the upper lagoon to the mouth of the lagoon. The analyzed data showed the temporal variability of zooplankton community in Thi Nai lagoon, wherein the density presented consistently decreasing pattern, but species number did not show any marked changes. The density of zooplankton in the dry season was always higher than that in the wet season and the species composition was quite dissimilar. Density data for the dry season of 2004, 2008, and 2009 showed a marked decrease in the abundance of zooplankton in the lagoon. The communities in each area also revealed the temporal and seasonal changes. Multi-dimensional Scaling analysis showed a clear dissimilarity of the zooplankton community between the two seasons, especially in 2008–2009. Besides, analysis of dominant species proved the presence of the brackish water species, *Bestiola similis,* in the entire lagoon.

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