Original Article

Assessing Changes in Ecological Quality Status of Sediment in Tri An Reservoir (Southeast Vietnam) by using Indicator of Nematode Communities

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Abstract: Nematode communities in Tri An Reservoir (Dong Nai Province, Southeast Vietnam) were explored in the dry season (March) and pre-rainy season (July) of 2019 and analyzed to evaluate their usage as bioindicators for ecological quality status of sediment. Nematode communities consisted of 23 genera belonging to 19 families, 8 orders for the dry and 24 genera, 17 families, 8 orders for the pre-rainy season. Several genera dominated in Tri An Reservoir such as Daptonema, Rhabdolaimus, Udonchus, and Neotobrilus indicated for organic enrichment conditions. The percentage of cp3&4 and MI (Maturity Index) value in the dry season was higher than that in the pre-rainy season expressed the ecological quality status of sediment in the dry season were better than those in the pre-rainy season. Furthermore, the result revealed that MI and c-p% composition can be used to evaluate the ecological quality status of sediment efficiently.

Keywords: Bioindicator, ecological quality status of sediment, freshwater habitats, maturity index, nematodes, reservoir.

1. Introduction

Contrasting to natural processes of lake formation, reservoirs are artificial or man-made lakes formed by building a dam across flowing rivers [1]. Artificial freshwater reservoirs are important water sources in many countries around the world [2]. Water in the reservoir has made a substantial contribution to human socioeconomic development in many ways, such

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as hydroelectricity generation, irrigation, fisheries, and recreation or as water sources for domestic or industrial use [3,4]. Nowadays, new reservoirs are being built mainly for the purpose of power generation [5]. Thus, there have been more than 96,000 of dams and their reservoirs constructed since the 1950s [6]. As a result, ecological impacts of reservoir dams have been reported from diverse aspects such as i) barrier for seasonal migration paths of migratory fishes like anadromous fish [7], ii) eutrophication of reservoirs by plankton blooming [8], iii) causing negative impacts on biodiversity by losses of forests and changes in the river environment [9], iv) decreasing flow volumes in downstream and increase in substrate grain size by sediment trapping, etc. [10].

Vietnam is a Southeast Asian country, which is directly influenced by the subtropical humid monsoon climate with its annual rainfall is high [11]. Most of the territory is mountainous or hilly; therefore, it has good potential for water reserves and hydropower generation. Furthermore, rainfall, almost the only source of surface flow, concentrates in a few months in a year during the rainy season. Thus, there is an urgent need to be regulated by reservoirs. Vietnam has 800 medium and large dams and reservoirs, and 1,967 reservoirs with a storage capacity of at least 0.2 km^3. Seven reservoirs have a capacity of at least 1 km^3 such as Hoa Binh (9.5 km^3), Thac Ba (2.9 km^3), Tri An (2.7 km^3), Tuyen Quang (2.2 km^3), Dau Tieng (1.6 km^3), Thac Mo (1.4 km^3), and Yaly (1.0 km^3) [12].

Tri An Reservoir (TAR) was built in 1986, which is a multi-purpose reservoir for hydropower generation (mainly), flood-control, domestic and industrial water use, irrigation, and fisheries [13]. Water from the reservoir directly and indirectly supplies domestic activities for millions of people in Southeast Vietnam mainly in Dong Nai, Binh Duong Provinces, and Ho Chi Minh City [14]. While studies and reviews on Tri An reservoir's geography are increasingly common [15,16], to date, few studies have assessed the presence, fate, and biodiversities of aquatic fauna communities, especially for

benthic fauna. Even fewer studies have been completed in ichthyology and phytoplankton communities. The fish fauna of Tri An reservoir reflects the fauna of the impounded Dong Nai and La Nga rivers, which is consisted of 109 species, belonging to 28 families and 9 orders [17]. Moreover, the phytoplankton community in TAR is known to constitute 197 species belonging to seven classes, Cyanophyceae (cyanobacteria), Chlorophyceae (green algae), Bacillariophyceae (diatoms), Chrysophyceae (golden algae), Xanthophyceae (yellow algae), Euglenophyceae (euglenoids) and Dinophyceae (dinoflagellates). Among them, cyanobacteria were abundant and dominant in the reservoir [18].

Inflowing rivers bring organic matter (especially for nitrogen and phosphorus compounds) and anthropogenic pollutants from upstream, loading them into reservoirs [3]. This leads to increased eutrophication, which often causes a mass proliferation of cyanobacteria [8]. In TAR, toxic cyanobacteria, cyanobacterial blooms and their toxins have been observed and reported in previous studies [14,18]. As cyanobacteria in a bloom die, its toxins were deposited in sediment; thus, sediment in reservoirs is also known as a sink or source of nutrients and toxins [3]. Because TAR is a domestic water supply for millions of people in Southern Vietnam, the ecological quality status of surface water, as well as sediment, should be given more concern.

The nematode communities (NC) or roundworms constitute the phylum Nematoda. They are small sediment-dwelling organisms and are among the most diverse phyla on earth [19]. They play a crucial role in component processes of most ecosystem services, such as nutrients, materials cycling, and energy flow in aquatic ecosystems [20,21]. In benthic food webs, nematodes are also known as trophic link between the microfauna and larger fauna [22]. On the other hand, because nematodes are i) the most abundant, and diversified in ecosystems, further are ii) sensitive and able to respond rapidly to natural and anthropogenic disturbance, they serve as elegant indicators of

environmental disturbance [21,23,24]. Therefore, nematodes have pivotal roles in benthic ecosystems, as well as they are a meaningful tool for bioindicators in their environment.

Given the above-identified knowledge gaps and challenges, the current study aimed to i) describes the composition of NC in TAR, ii) to evaluate the ecological quality status of sediment (EcoQ) in TAR based on Maturity Index (MI) of NC. These findings can provide useful information to water resource management and monitoring as well.

2. Materials and methods

2.1. Study area and sample collection

Tri An Reservoir situated in Dinh Quan District, Dong Nai Province, Southeast Vietnam, about 70 km Northeast from Ho Chi Minh City (lies between latitudes 10^0 00' to 12^0 20' North and longitudes 107^0 00' to 108^0 30' East). The reservoir is mainly used for hydroelectricity generation [25]. TAR is the biggest reservoir of Vietnam, with a catchment area of approximately 14,800 km², an average annual outflow of 15,100 million m³ and a total volume of 2,765 km³. The reservoir has a water surface area of around 324 km², with an average depth of 8.5 m, about 44 km in length and has a maximum width of 10 km [26]. The reservoir belongs to a tropical climate region, with annual rainfall and average temperature are 2,400 mm and 25.4^0 C, respectively (Vietnam Ministry of Science Technology & Environment, 2001). Furthermore, TAR contains about 50 coves of various sizes and connects to many tributaries of the Dong Nai and La Nga rivers [27].

Sampling was carried out in dry season (D, March) and pre-rainy season (PR, July) in 2019. A total of eight stations was sampled: DQ and LN (situated in upstream), TA1-5 (inside the reservoir), DN (downstream) (Fig. 1). Three sample replicates per station were taken by using a plastic core of 3.5 cm diameter and 30 cm high. The cores were pushed down into the sediment up to 10 cm depth and collected 10 cm² surface area. The samples were all fixed in a 7% formaldehyde solution (heated to 60°C) and gently stirred before transportation to the laboratory of the Department of Environmental Management and Technology, Institute of Tropical Biology.
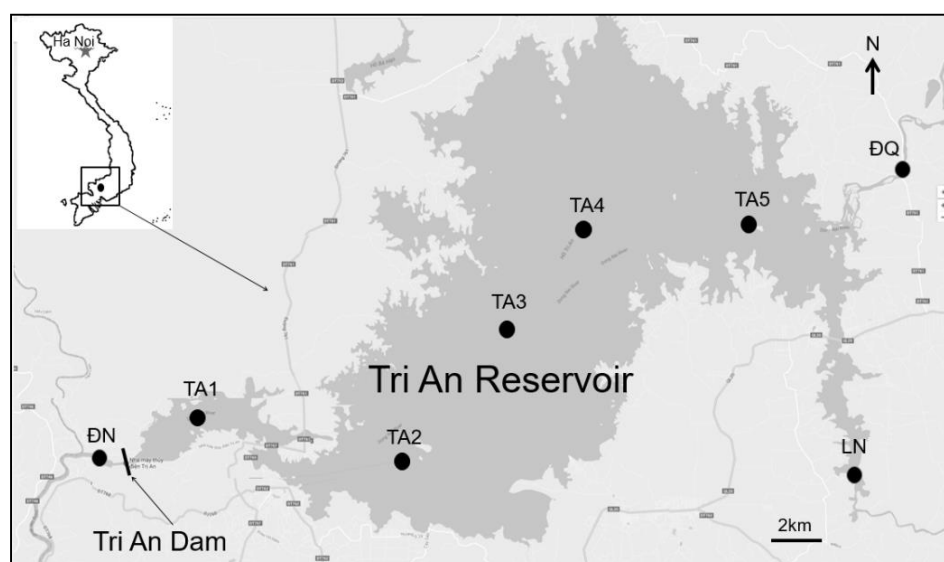

Fig. 1. Map of sampling stations in Tri An Reservoir, Dong Nai Province.

2.2. Sample handling and analyzing procedure

In the laboratory, nematode samples were sieved through a 38 µm mesh and extracted by a flotation technique with Ludox-TM50 solution (specific gravity of 1.18) [28]. Samples were stained with 3–5 mL Rose Bengal solution (1 %). All individual numbers were counted under a stereomicroscope, two hundred nematodes were used for making slides according to the guide of De Grisse (1969) for identification [29]. Nematodes were identified to genus level by using taxonomy literature, such as Abebe et al. (2006) [30] and Zullini (2010) [31].

2.3. Data process and analysis

2.3.1. Assessing the ecological quality status of sediment in Tri An Reservoir based on Maturity index of nematode communities

The maturity index (MI, [23,32]) was calculated as the weighted average of the individual colonisers persister (c-p) values:

$$MI = \sum_{i=0}^{n} v(i) * f(i)$$

where v is the cp value of genus i and f(i) is the frequency of that genus. This index has been proposed as a semiquantitative value giving an indication of ecosystem conditions according to the nematode assemblage composition.

The maturity index values are between 1 and 5 and can be converted in the EcoQ using the fixed scale provided by Moreno et al. (2011): High EcoQ, MI>2.8; Good EcoQ, 2.6<MI≤2.8; Moderate EcoQ, 2.4<MI≤2.6; Poor EcoQ, 2.2<MI≤2.4, and Bad EcoQ, MI≤2.2 [33].

2.3.3. Multivariate analyses

Multivariate techniques like the Bray-Curtis multidimensional scaling ordination (MDS) were performed to present several dominant nematode genera from the different stations. Those analyses were carried out by the software PRIMER v.6.

3. Results and Discussion

3.1. Describing nematode compositions and its changed throughout seasons

In the dry season, NC in TAR, Dong Nai Province consisted of 23 genera belonging to 19 families, 8 orders (Chromadorida, Dorylaimida, Enoplida, Monhysterida, Mononchida, Plectida, Rhabditida, and Triplonchida), and 2 class (Enoplia-62.02%, Chromadorea-37.98%). In the dry season, most individuals belong to three dominant families: Xyalidae (31.57% of total abundance), Rhabdolaimidae (25.07%), and Mononchidae (14.61%). The percentage of the remaining families ranged from 0.09% to 9.52%. The dominant genera were *Daptonema* (30.63%), *Rhabdolaimus* (24.22%), and *Mononchus* (14.33%) (Fig. 2). In total, 24 genera belonging to 17 families, 8 orders (Chromadorida, Dorylaimida, Enoplida, Monhysterida, Mononchida, Plectida, Rhabditida, and Triplonchida), and 2 class (Enoplia-48.70%, Chromadorea-51.30%) were found in the pre-rainy season in which Xyalidae had the highest abundance 41.45%. The subdominant families were Rhabdolaimidae (19.52%), Tobrilidae (16.23%). The percentage of the remaining families ranged from 0.17 % to 4.84 %. Furthermore, the dominant genera were *Daptonema*, *Udonchus*, and *Neotobrilus* with 40.76%, 17.79%, and 16.23% of total abundance, respectively (Fig. 2, Appendix 1).

From dry to the pre-rainy season, genus *Daptonema* still dominated which was lead to the family Xyalidae further dominated in both seasons; however, in pre-rainy season, genus *Daptonema* dominated with a higher percentage rather than its in the dry season. The subdominant genera in dry season were *Rhabdolaimus* and *Mononchus*, whereas, *Udonchus* and *Neotobrilus* were the subdominant ones in the pre-rainy season; nevertheless, genera *Rhabdolaimus* and *Udonchus* belonged to the same family (Rhabdolaimidae). In the dry season, genus *Daptonema* was found more abundant in the upstream station (DN), while genera *Rhabdolaimus* and *Mononchus* were mostly occurred in the downstream station (DN). Regarding the pre-rainy season, genera *Daptonema*, *Udonchus*, and *Neotobrilus* were also found mainly inside the reservoir (TA1-5) (Fig. 3).
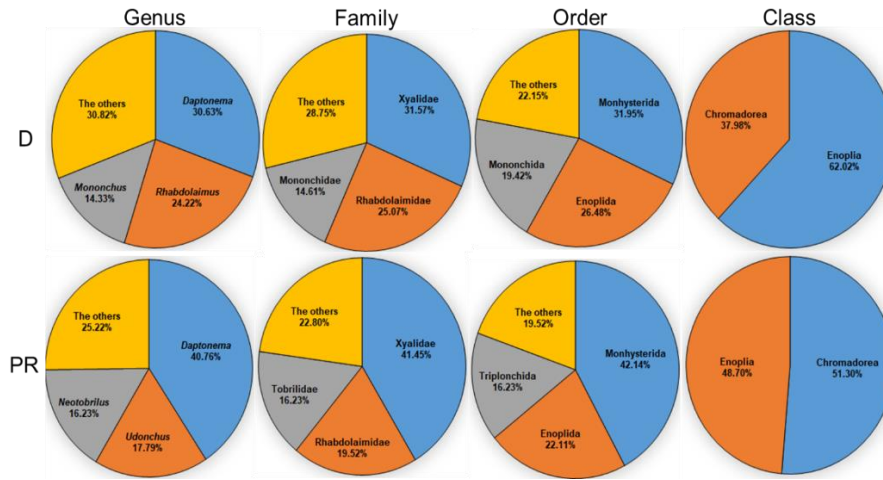
Fig. 2. Structure of nematode communities in TAR. (D) Dry season, (PR) Pre-rainy season.
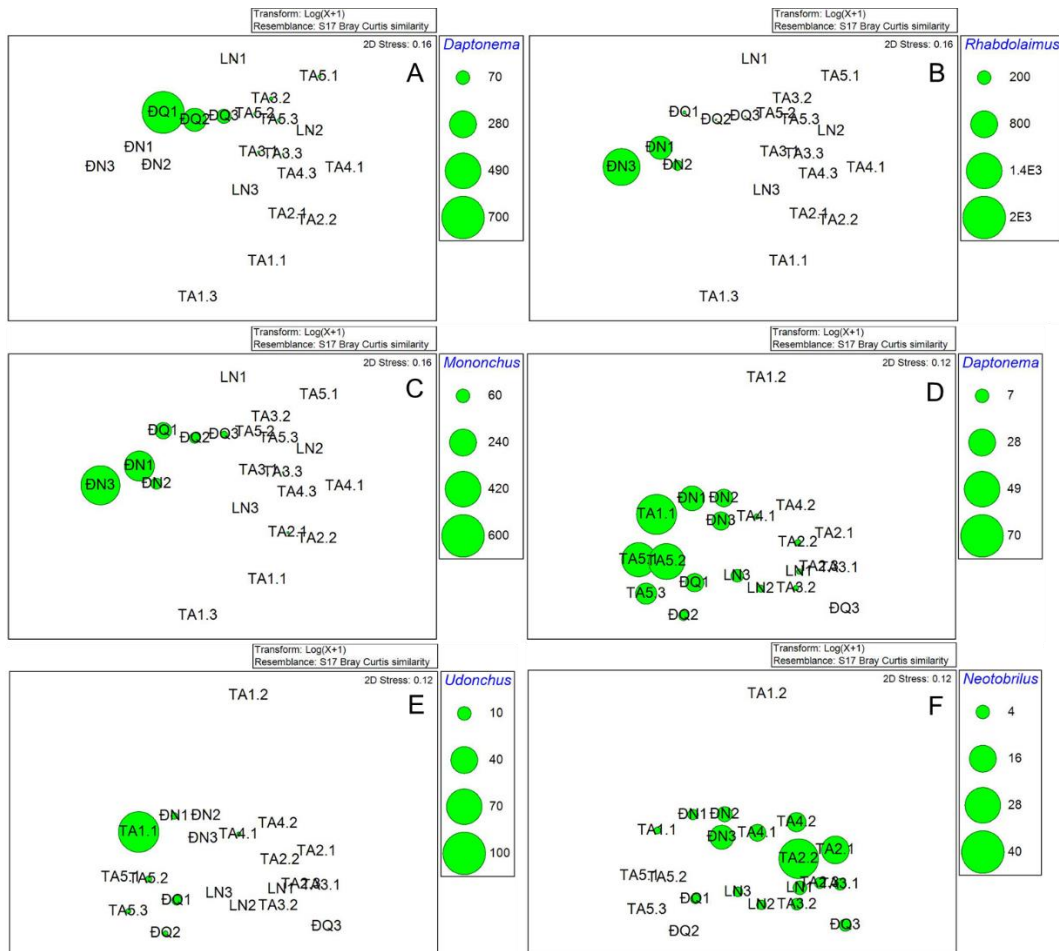

Fig. 3. MDS bubble plots for several dominant genera. In the dry season: (A) *Daptonema*, (B) *Rhabolaimus*, (C) *Mononchus*; In the pre-rainy season: (D) *Daptonema*, (E) *Udonchus*, (F) *Neotobrilus*.

In general, these dominated genera in TAR might tolerate a wide range of environmental conditions. Nevertheless, several studies reported that they indicated for organic enrichment conditions such as genus *Daptonema*, *Rhabdolaimus*, *Udonchus*, especially for genus *Neotobrilus* (be found in seriously polluted habitats). By contrast, genus *Mononchus* appeared to be an indicator of un- and sightly polluted conditions (Table 1).

Table 1. Several dominant genera in Tri An reservoir and their indicated characteristics.
FT (Feeding type): B: bacterial feeder, S: substrate feeder, O: omnivore

Genus	c-p	FT	Characteristics
Daptonema	2	S	Known as an opportunistic genus in relation to heavy metals [34-36] and hydrocarbons [37]. Indicators of pollution and organic enrichment conditions [38]
Rhabdolaimus	3	B	It is occurred widely from slightly to seriously polluted habitats, especially for heavily polluted conditions [39]
Mononchus	4	O	Appearances on medium to high contaminated conditions [30]. Most abundant in organically enriched sediments [40].
Udonchus	3	B	It is found in seriously polluted habitats [39]
Neotobrilus	2	O, B	Tolerating a wide range of environmental conditions but it is found more abundant in sites with medium to high contamination [30]. Several species also occurred in polluted waters [41]

3.2. The ecological quality status of sediment in Tri An reservoir indicated by nematode communities

The MI based on a priori classification of nematode genera in one of five colonisers–persisters groups (c-p) ranging from extreme r – strategists (colonisers) to extreme k - strategists (persisters). More specifically, five cp groups based upon different sensitivity levels (from very sensitive to opportunistic): cp5, 4, 3, 2, 1 which means decreasing levels of environmental disturbances [23,32].

3.2.1. Colonizers persister (c-p) index

Most of the sampling stations in the dry season had a high percentage of cp4, except for station TA4 and DQ with a high percentage of cp1&2. However, when compared to the dry season, the percentage of each cp group did vary so much in pre-rainy season where most of the stations had an extremely high percentage of cp1&2, especially for station TA2, TA5, and LN. Contrastly, only station TA4 had a slight high percentage of cp4 (Table 2). This fluctuation might indicate that the EcoQ of TAR in the pre-rainy season more disturbing rather than its in the dry season.

Table 2. The percentage (%) of each cp groups in nematode communities at the eight sampling station

cp groups	Dry season							
	TA1	TA2	TA3	TA4	TA5	LN	DQ	DN
cp4	85.71	63.64	53.49	12.50	48.00	52.00	15.35	35.96
cp3	0.00	0.00	0.00	4.17	0.00	20.00	2.63	61.70
cp1&2	14.29	36.36	46.51	83.33	52.00	28.00	82.02	2.34
	Pre-rainy season							
cp4	8.84	2.13	0.00	53.85	4.39	22.73	30.61	33.33
cp3	54.14	0.00	14.29	7.69	4.39	0.00	18.37	14.17
cp1&2	37.02	97.87	85.71	38.46	91.23	77.27	51.02	52.50

The ecological triangle of NC was created based on the percentage of cp value in 3 groups such as cp4, cp3, and cp1&2 (Table 2). In the dry season, because of the high percentage of cp1&2 in station DQ and TA4 brought these stations to the right-bottom side of the triangle. This indicated that these stations migh be heavily impacted by environmental disturbances. In contrast, the station such as TA1, 2, 3, and LN had the high percentage of cp3&4; thus, these

stations located in the up-side of the triangle. This could also indicate that the EcoQ was fine or less impacted by disturbances. In the pre-rainy season, the number of stations with the high percentage of cp1&2 increased when compared its in the dry season. Therefore, from dry to pre-rainy season, a tendency of these stations to move down the ecological triangle which was increasing levels of environmental disturbances (Fig. 4).
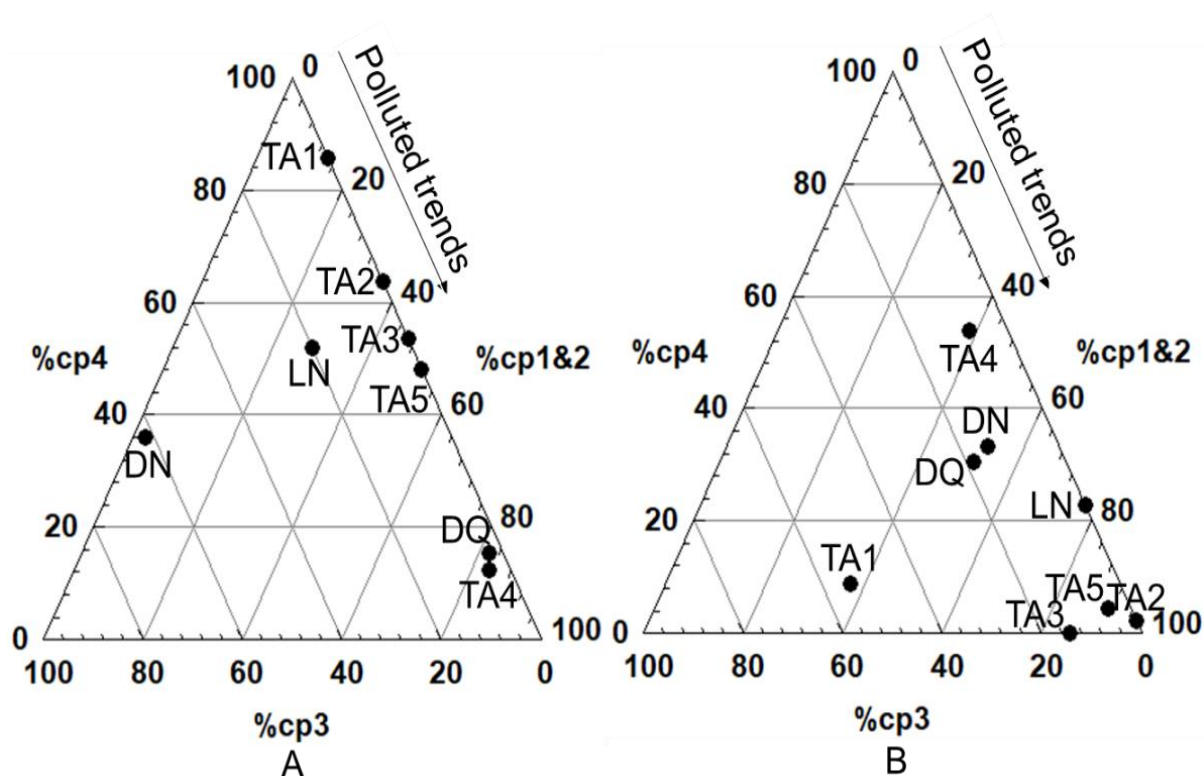

Fig. 4. The cp triangle with unweighted proportional representation of cp1, cp2, cp3, and cp4 group of the nematode communities. (A) Dry season, (B) Pre-Rainy season.

3.2.2. Maturity index (MI)

Overall, the MI ranged from 2.35±0.10 to 3.50±0.70 in dry and measured from 2.10±0.14 to 3.35±0.92 in pre-rainy season. The station TA1, 2, 3, 5, LN, and DN had the high MI value and could be classified as high EcoQ conditions. In turn, the station TA4 and DQ assigned to poor EcoQ status because of its low MI value. For the

pre-rainy season, the high MI value observed in TA1, 4, DQ, and DN and its stations assigned to high, and good EcoQ status. Station TA2 and LN classified as poor EcoQ status whereas the bad EcoQ status observed in TA2, and TA5 because of its low MI value. Obviously, the EcoQ status in TAR in dry season expressed better conditions than its in the pre-rainy season (Fig 5).
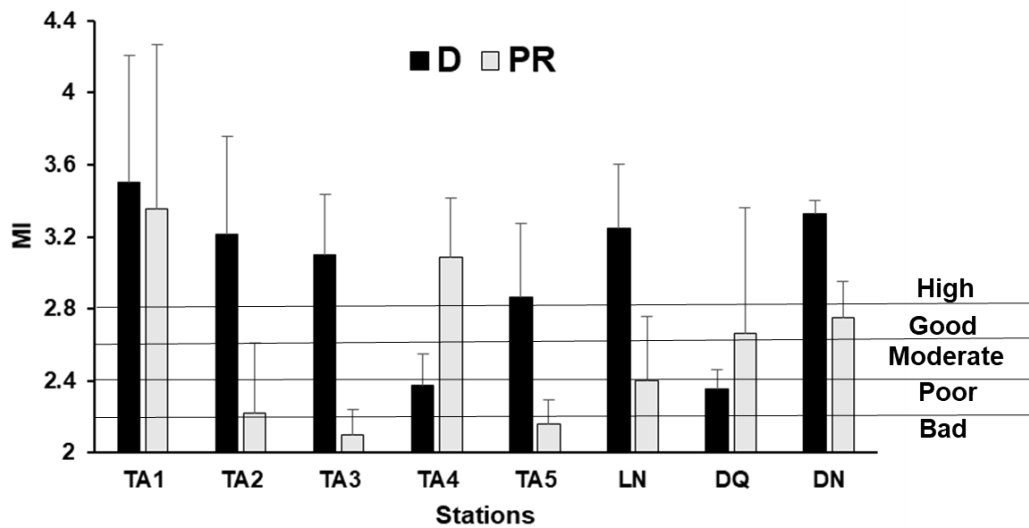
Fig. 5. MI value in each sampling station and changed in the ecological quality status
of sediment throughout season.

There was increasing in the percentage of cp1&2 group from dry to pre-rainy season. This indicated that the EcoQ in TAR was enriched by organic matter, particularly in the pre-rainy season. In fact, several nutrients (nitrite, ammonium, total nitrogen, and total phosphorus) and BOD5 parameter in surface water in TAR were analyzed, and their results showed that nutrient concentrations were the highest from June to August (pre-rainy season) and lowest in March (dry season). It demonstrated a richness of organic compounds for heterotrophic bacterial development [18]. This also explains why NC in TAR dominated by omnivore, bacterial, and substrate feeder nematodes, especially for the pre-rainy season. The main cause for this was during the rainy season in southern Vietnam (May–November), two rivers (La Nga and Dong Nai) have been bringing more organic and inorganic matter into the reservoir. In addition, fish caging activities and wastewater from a sugar factory located at the inflow of La Nga River have also been contributing to the nutrient enrichment [18].

The result of the present study was further supported by Ferris and Bongers (2006) [42], who reported that nematode assemblages had

more responsive than others to resource enrichment. Nowadays, NC has been widely using in bioindicator studies [43]. The MI value has already been used for the assessment of the EcoQ in various environmental habitats such as Mediterranean coastal ecosystems [33], Black Sea [44], Beigang River Basin [39]. In Vietnam, using of the MI of NC for monitoring environmental qualities have emphasized in recent papers: Can Gio mangroves [45], Sai Gon River [46], Ba Lai River [47]. In this study, MI has been used for the first time in the assessment of EcoQ conditions in Tri An Reservoir, Dong Nai Province.

4. Conclusion

This is the first comprehensive study investigating NC and their ability to assess the EcoQ in TAR, Dong Nai Province. NC in TAR consisted of 24 genera belonging to 19 families, 8 orders in both sampling seasons. Several genera indicated for organic enrichment conditions such as genus *Daptonema*, *Rhabdolaimus*, *Udonchus*, *Neotobrilus* founded in TAR, especially for the pre-rainy season. The percentage of cp1&2 increased from the dry to

the pre-rainy season. Moreover, the MI value in the dry was higher rather than that in the pre-rainy season. This indicated that the EcoQ conditions in the dry were better than those in the pre-rainy season. Moreover, the EcoQ in TAR was enriched by organic matter, particularly in the pre-rainy season. The result also suggested that nematodes might be useful indicators for biomonitoring studies in freshwater habitats. However, the future study should pay more experience from field studies and laboratory experiments in order to better interpret changes in the composition of NC, and thus to be able to use sophisticated indices, such as the MI, for ecological quality status assessment of sediment.

Acknowledgment

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Appendix

Appendix 1. Structure of nematode communities in Tri An Reservoir

Genus	Family	Order	Class	Dry	P-Rainy
Achromadora	Achromadoridae	Chromadorida	Chromadorea	+	+
Aphanonchus	Aphanolaimidae	Plectida	Chromadorea		+
Aphelenchoides	Aphelenchoididae	Rhabditida	Chromadorea	+	
Cephalobus	Cephalobidae	Rhabditida	Chromadorea	+	
Chromadorita	Chromadoridae	Chromadorida	Chromadorea	+	+
Cobbonchus	Mononchidae	Mononchida	Enoplia	+	+
Cryptonchus	Cryptonchidae	Mononchida	Enoplia	+	+
Daptonema	Xyalidae	Monhysterida	Chromadorea	+	+
Dichromadora	Chromadoridae	Chromadorida	Chromadorea		+
Goffartia	Diplogastridae	Rhabditida	Chromadorea		+
Ironus	Ironidae	Enoplida	Enoplia	+	+
Mesodorylaimus	Dorylaimidae	Dorylaimida	Enoplia	+	+
Mononchulus	Mononchulidae	Mononchida	Enoplia	+	+
Mononchus	Mononchidae	Mononchida	Enoplia	+	+
Monshystera	Monhysteridae	Monhysterida	Chromadorea	+	+
Monshystrella	Monhysteridae	Monhysterida	Chromadorea	+	+
Mylonchulus	Mylonchulidae	Mononchida	Enoplia	+	+
Neotobrilus	Tobrilidae	Triplonchida	Enoplia	+	+
Paractinolaimus	Actinolaimidae	Dorylaimida	Enoplia	+	
Paracyatholaimus	Cyatholaimidae	Chromadorida	Chromadorea		+
Paraplectonema	Leptolaimidae	Plectida	Chromadorea	+	+
Plectus	Plectidae	Plectida	Chromadorea	+	
Ptycholaimelus	Chromadoridae	Chromadorida	Chromadorea		+
Prismatolaimus	Prismatolaimidae	Triplonchida	Enoplia	+	
Rhabditidoides	Diplogastridae	Rhabditida	Chromadorea	+	+
Rhabdolaimus	Rhabdolaimidae	Enoplida	Enoplia	+	+
Theristus	Xyalidae	Monhysterida	Chromadorea	+	+
Terschellinia	Linhomoeidae	Monhysterida	Chromadorea		+
Udonchus	Rhabdolaimidae	Enoplida	Enoplia	+	+