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Assessing Sediment Ecological Quality in Organic Shrimp Farming Ponds by Comparing the Shannon-Wiener, AMBI, and M-AMBI Indices

Tran Thanh Thai[1], Le Hai Dang[1], Ngo Xuan Quang[1,2,*]

[1]*Institute of Tropical Biology, Vietnam Academy of Science and Technology, 85 Tran Quoc Toan, District 3, Ho Chi Minh City, Vietnam*

[2]*Graduate University of Science and Technology, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, Cau Giay, Hanoi, Vietnam*

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Abstract: The Shannon-Wiener Index (H′), AZTI's Marine Biotic Index (AMBI) and multivariate AMBI (M-AMBI) of macrofauna communities were applied for comparing their applicability in assessing the status of sediment ecological quality (EcoQ) in eight organic shrimp farming ponds (OSFP) in Ca Mau province. There were obvious differences between the evaluation results of the three indices in the eight OSFP. The EcoQ given by the AMBI and M-AMBI was higher than that given by the H' index. This indicates that H' index may also be more sensitive to environmental disturbances than the AMBI and M-AMBI. Furthermore, the EcoQ given by the M-AMBI was a neutralization between those given by the H' and AMBI indices. As there were no environmental data available in this study, that the H′ index was more sensitive to environmental disturbances than the AMBI and M-AMBI has yet to be further elucidated. Further investigation of these three indices with environmental data is also needed to get a comprehensive answer to this matter.

Keywords: AMBI, benthic indices, H′, indicator, M-AMBI, macrofauna communities, organic shrimp farming ponds.

1. Introduction

Macrofauna communities (MC) are responding rapidly to disturbances taking place in the ecosystems [1] and serving as a crucial role in cycling materials and nutrients in benthic habitats [2]. It could be one of the major reasons why the MC are commonly utilized to monitor the environmental health in the natural ecosystems. On the other hand, they are used for assessing the status of the ecosystems and biogeographic perturbation taking place in benthic habitats [3]. Benthic indices, based on the MC, can be a helpful tool in the health

* Corresponding author. Tel.: 84-28-39326296.
Email: ngoxuanq@gmail.com

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assessment of ecosystems as well as the determination of relevant decision for natural or anthropogenic impacts [4, 5]. Traditional benthic indices include species richness, diversity and dominance indices [6], and modern benthic indices are AZTI's marine biotic index (AMBI, [7]) and multivariate-AMBI (M-AMBI, [8]). The Shannon-Wiener (H′, [9]), AMBI, and M-AMBI indices, in particular, have been widely applied in coastal and marine habitats [10]. Firstly, the Shannon-Wiener index is the most frequently used for assessing the environmental health in Asia, especially in the coastal and marine regions of China [9]. Secondly, AMBI index was first developed in European by Borja et al. (2000) [7]. AMBI index has been the most commonly used benthic index along European estuarine and coastal waters and has had successful application to others areas (already described in detail in Tran and Ngo, 2018 [11]). Tran and Ngo (2018) successfully applied this index to analyze perturbation in benthic communities in order to estimate the EcoQ in OSFP, Ca Mau province [11]. Finally, M-AMBI is the benthic index newly developed by Muxika et al. (2007) [8] and has been successfully utilized to assessing the EcoQ in worldwide [12], especially in China [13-15]. Detailed information about M-AMBI index will be described later in the data analysis section of our research paper.

Although the Shannon-Wiener, AMBI, and M-AMBI indices have been successfully applied in the evaluation of EcoQ in worldwide, no single index is likely to produce stress classifications without unacceptable misclassifications. Therefore, their applicability to needs further investigation, due to these indices governed by specific biological communities, regions, and environmental pressures [5, 16]. Suitable benthic indices will be selected depending on the influence of various ecosystem factors and environmental pressure [17]. Prior the indices are used in new regions, their applicability should be analyzed by using a gradient data of ecosystem pressure and then compared to verify their ecological relevance [18].

The present study aims to utilize the Shannon-Wiener, AMBI, and M-AMBI indices of MC to assess EcoQ in OSFP, Ca Mau province (detailed information about study area already described in Tran and Ngo, 2018 [11]) and then compared to verify the ecological relevance of three indices.

2. Materials and methods

2.1. Study area, sampling and laboratory procedures

The sampling area is located in eight OSFP, Tam Giang commune of Nam Can district, Ca Mau province in the Mekong Delta region of Vietnam (Fig. 1). Details about the study site, sampling method, and laboratory activities can be found in Tran and Ngo (2018) [11].

2.2. Data analysis

In the present study, three benthic indices (H′, AMBI, and M-AMBI) were used to assess the EcoQ in OSFP. The H′ was calculated according to the method of Shannon [19]. The threshold of EcoQ classes for H' was defined by Cai et al. (2002): High EcoQ, $H' \geq 3.0$; Good EcoQ, $2 \leq H' < 3$; Moderate EcoQ, $1 \leq H' < 2$; Poor EcoQ, $H' < 1$ and if a region was azoic, the benthic communities was extremely disturbed and the EcoQ was bad [9].

The AMBI and M-AMBI indices were calculated using AMBI 5.0 software (freely available at http://ambi.azti.es) with the updated species list of November 2014 and following the guideline is given in Borja and Muxika (2005) [20]. Details about determination and threshold of EcoQ classes for AMBI can be found in Tran and Ngo (2018) [11]. The M-AMBI index was calculated by factorial analysis of AMBI, richness, and values of Shannon–Wiener index (for details, see Muxika et al., 2007 [8]). M-AMBI values are between 0 and 1 (At 'high' status, the M-AMBI value reaches one, whereas, at 'bad' status, the M-AMBI reaches zero) and can be converted in EcoQ using the fixed scale provided by Borja et al. (2007): High EcoQ, M-AMBI ≥ 0.77; Good EcoQ, 0.53 ≤ M-AMBI < 0.77; Moderate EcoQ, 0.38 ≤ M-AMBI < 0.53; Poor EcoQ, 0.20 ≤ M-AMBI <0.38 and Bad EcoQ, M-AMBI < 0.20 [21]. In general, high values of the H′, M-AMBI and low AMBI values were related to healthy benthic ecosystems, whereas low values of the H′, M-AMBI and high AMBI values were related to poor benthic ecosystems.

Two-way ANOVA analysis was used to test the significant differences among benthic indices (between ponds, seasons as well as the interaction factors). All statistical analyses were performed using a software STATISTICA 7.0.

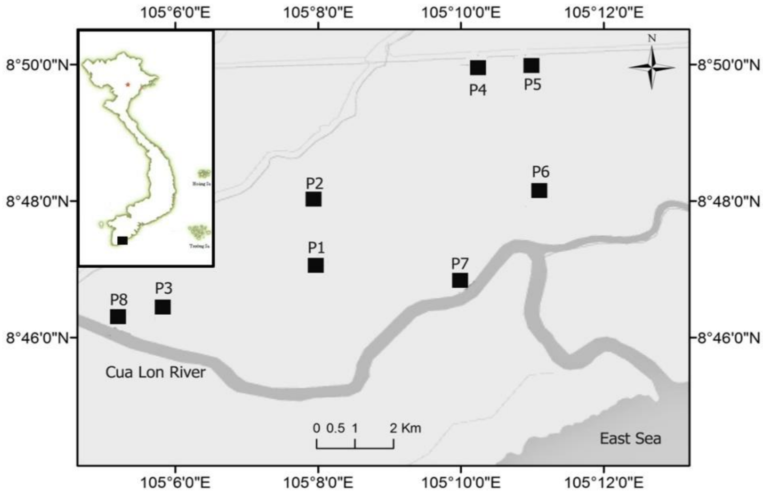

Figure 1. Sampling sites in organic shrimp farming ponds, Ca Mau province.

3. Results and discussion

3.1. Macrofauna composition and characteristics

The MC of the eight OSFP in Nam Can district, Ca Mau province are composed of 28 species (per $0.1m^2$). They belonged to five class such as Polychaeta, Oligochaeta, Crustacea, Gastropoda, and Bivalvia. Furthermore, MC in the eight OSFP, are mainly consisted of three phylum: Mollusca, Annelida, and Arthropoda.

Over the eight OSFP, average densities (inds/$0.1m^2$) ranged from 107.3 ± 32.9 to 535 ± 204.9 in dry season, from134.7 ± 46.2 to 1,012 ± 424.4 in transitional season and from 163 ± 80.7 to 845.7 ± 465.5 in rainy seasons.
Diversity of MC was measured by the Shannon - Wiener (H') and species richness (S). The H' ranged from 1.53 ± 0.49 to 2.5 ± 0.17 for dry, between 0.63 ± 0.22 - 2.3 ± 0.5 for transitional and between 0.6 ± 0.32 - 2.74 ± 0.09 for rainy season. The diversity of MC expressed in species richness (S) varied from 5 and 12 species in dry and transitional season, respectively, while ranged between 8 to 12 species in rainy season. Details about composition and characteristics of MC in 8 OSFP already described in detail in Tran and Ngo (2018) [11].

3.2. Ecological quality status evaluated by the H', AMBI, and M-AMBI indices

Shannon-Wiener index H'

The mean H' values in eight OSFP varied from 1.53 ± 0.49 to 2.5 ± 0.17 in dry, between 0.63 ± 0.22 - 2.3 ± 0.5 for transitional, and between 0.6 ± 0.32 - 2.74 ± 0.09 for rainy season, as shown in Fig. 2B. In the total (24 samples - three seasons), the H′ values of 15.67% of samples (4/24) were between zero and one with a "Poor" EcoQ, however, no values were equal to zero (classified to "Bad" EcoQ). The H′ values of 54.17% of samples (13/24) were between one and two with a "Moderate" EcoQ and the H' values of 29.17 % of samples (7/24) were between two and three with a "Good" EcoQ. No H′ values were higher than or equal to three (classified to "High" EcoQ). In general, according to the H' index, a "Moderate" EcoQ in the OSFP was observed mostly in transitional, particularly in rainy seasons (Fig. 3).

A two-way ANOVA indicated that there were significant differences of the H′ values between ponds ($p = 0.00006$), seasons ($p = 0.006$) and the interaction terms ($p = 0.002$).

AZTI's Marine Biotic Index (AMBI)

The mean AMBI values ranged from 0.57 ± 0.51 to 2.85 ± 1.50 for dry, between 0.18 ± 0.10 - 1.73 ± 0.60 for transitional and between 0.29 ± 0.19 - 1.80 ± 0.37 for rainy season (Fig. 2A). In the 24 samples, no AMBI values were higher than 3.3 (classified to "Bad", "Poor" and "Moderate" EcoQ). The AMBI values of 29.17% of samples (7/24) were ranged from 1.2 to 3.3 with a "Good" EcoQ, and 70.83% of samples (17/24) were classified to "High" EcoQ for which the AMBI values were lower than or equal to 1.2 (Figure. 3). Details about AMBI analyses can be found in Tran and Ngo (2018) [11].

A two-way ANOVA showed that the AMBI value has significant differences between ponds ($p = 0.000063$), seasons ($p = 0.001$) and the interaction terms ($p = 0.04$).

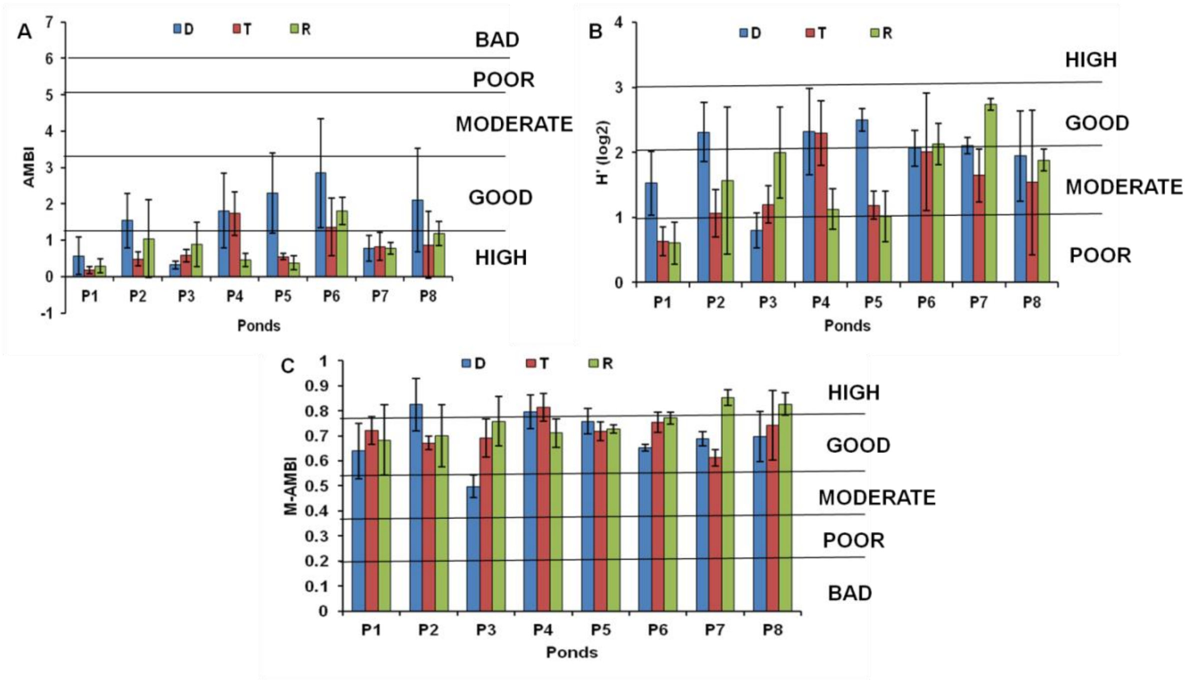

Figure 2. Temporal and spatial variation of the AMBI (A), Shannon–Wiener (B), M-AMBI (C), and EcoQ classes in eight OSFP (D-Dry, T-Transitional, R-Rainy season).

Multivariate AMBI (M-AMBI)

The M-AMBI values in eight OSFP varied from 0.50 ± 0.05 to 0.82 ± 0.10 for dry, between 0.61 ± 0.03 - 0.81 ± 0.06 for transitional and between 0.68 ± 0.14 - 0.85 ± 0.03 for rainy season (Fig. 2C). In the 24 samples, only the M-AMBI values of 1 sample (1/24 or 4.17%) were between 0.38 and 0.53 with a "Moderate" EcoQ. The M-AMBI values of 75% of samples (18/24) were ranged from 0.53 to 0.77 with a "Good" EcoQ and 20.83% of samples (5/24) were classified to "High" EcoQ for which the M-AMBI values were higher than or equal to 0.77. Furthermore, no M-AMBI values were lower than 0.38 (classified to "Poor" and "Bad" EcoQ). In general, a "Good" EcoQ in the OSFP was mostly observed in three seasons based on M-AMBI index (Fig. 3).

A two - way ANOVA analysis showed significant differences in the M-AMBI values between ponds (p = 0.01), seasons (p = 0.02) and the interaction terms (p = 0.003).

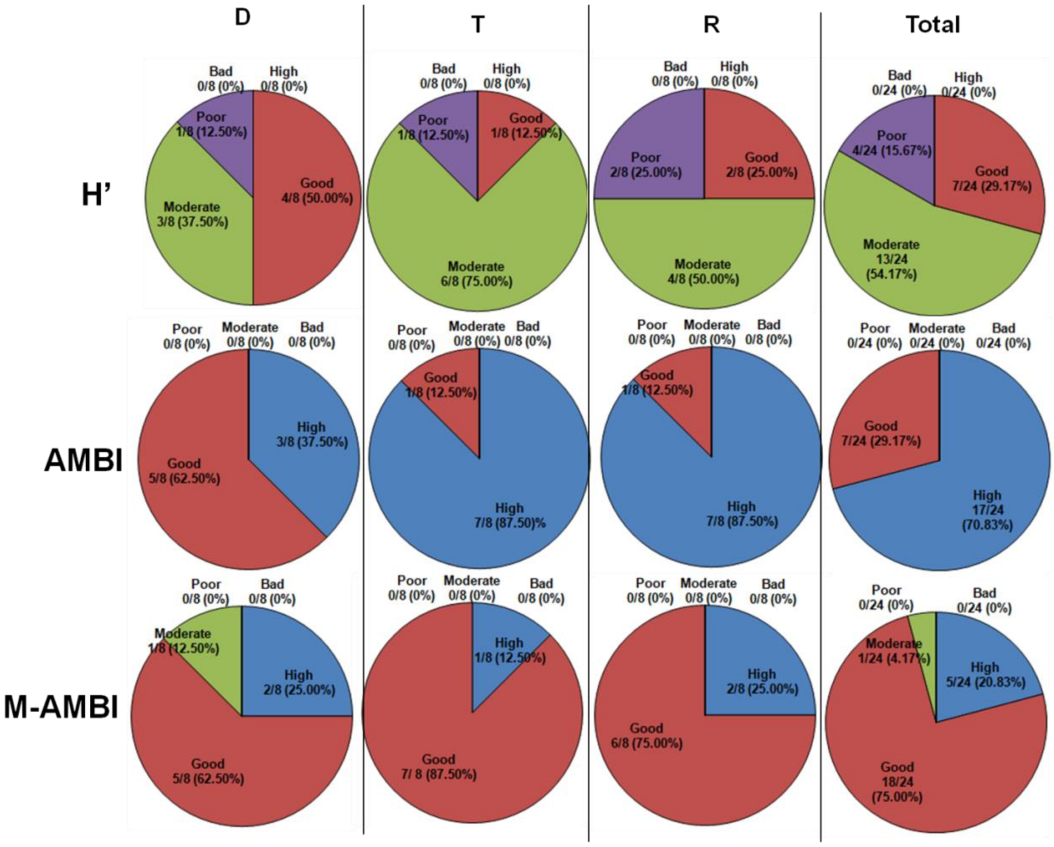

Figure 3. Percentage of each EcoQ for H', AMBI, and M-AMBI of 8 OSFP in dry (D), transitional (T), and rainy season (R).

3.3. A comparison of the applicability of three indices

In the present study, the results for EcoQ estimated by the H′, AMBI, and M-AMBI indices showed obvious differences in the eight OSFP through three seasons. The study by Borja et al. (2008) have grouped the EcoQ into those that are "undegraded", including "High" and "Good", and into those that are "degraded", including “Moderate”, “Poor”, and “Bad” [16]. Our results showed that the percentages of “undegraded” samples were 100% for the AMBI, and 95.83% for the M-AMBI, respectively. However, the percentage of “undegraded” samples reached 29.17% for the H′. By contrast, the percentages of “degraded” samples were 69.83% for the H’, 0% for the AMBI, and 4.17% for the M-AMBI, respectively. In general, the EcoQ given by the AMBI and M-AMBI was higher than that given by the H’ index of the study area. This is also explained by the MC of eight OSFP in three seasons with low species richness but the large abundance of single species and most of the species belonged to EGI, EGII, and EGIII. Indeed, species richness (S) of eight OSFP varied from 5 to 12 species in dry and transitional season, while it ranged between 8 and 12 species in rainy season. However, individuals from EGI was the dominant group at all seasons [11]. This indicates that the H′ was more sensitive to environment perturbation than the AMBI and M-AMBI. Furthermore, the EcoQ given by the M-AMBI was a neutralization between that given by the H’ and AMBI indices. Because there are no environmental variables data available in this study, the H′ index was really more sensitive to environmental disturbances than the AMBI and M-AMBI, that have yet to be fully elucidated. The future study should pay more attention to the applicability of three indices by comparing the results and the sensitivity of these indices to environmental gradient data. A stronger correlation between the benthic indices with environmental variables showed that the indices are more sensitive to environmental pollution and disturbances [10]. A correlation analysis between H’, AMBI, M-AMBI, and environmental parameters were reported by Luo et al. (2016) in the Huanghe (Yellow River) estuary, China. Results indicated that the three indices (especially the M-AMBI and H′) were mainly affected by physical variables in the Huanghe estuary, things like the water depth, DO, and sediment texture. However, Luo et al. (2016) noticed that the M-AMBI includes AMBI, species richness, and Shannon diversity could more comprehensively reflect environmental status. Clearly, the M-AMBI was more really effective in assessing the status of the ecosystems and biogeographic perturbation [10].

Differences in EcoQ assessment estimated by the H′, AMBI, and M-AMBI indices may be explained by several factors, like:

(i) The H’ just concerned in a number of species without regard to characteristics of each species. The high value of the H′ was related to healthy benthic community, whereas the low value of it was related to poor benthic communities. AMBI index totally depended on characteristics of each species and their abundance in samples (classified to an ecological group - EG). For instance, the Gastropoda species *Sermyla tornatella* was dominant with a large number of individuals during three seasons (50.29%, 75.26%, and 76.33% in dry, transitional, and rainy season, respectively) that might lead to a small number of species. Therefore, the values of H’ was low and related to poor benthic communities. According to AMBI, *Sermyla tornatella* was classified in EG1 (including species that are very sensitive to organic matter enrichment and disturbance). Therefore, the EcoQ was given by the AMBI index was high with “High and Good” conditions. While, the M-AMBI index was estimated by factorial analysis of AMBI, richness, and values of Shannon–Wiener index [8]. It could be one of the major reasons why the EcoQ given by the M-AMBI was a neutralization between that given by the H’ and AMBI indices.

(ii) The assignment of species to an EG is often arguably since based on local scientist experience rather than right knowledge of their autoecology [22] and may vary between expertise and geographical area [23]. Furthermore, because of the incompleteness of the EG species list, this difficulty could lead to the assignment to an EG is not fulfilled for taxa living in limited geographical regions (particularly in tropical area). It could impair the assessment of EcoQ of stations where the dominance of one or few species is commonly observed. Therefore, it would be necessary to incorporate local ecologist expertise in new EG assignments and re - assignments based on previous data from monitoring programs or the local expert experience with the ecological characteristics of the macrobenthic communities in the studied habitats.

(iii) The threshold of EcoQ has seen unfair classification between “Good” and “Moderate” class. In the present study, the distance of “Good” class of EcoQ can be as high or higher than the distance of “Moderate” class. The highest distance was obtained by AMBI, followed by M-AMBI and H’. In fact, AMBI set a wider “Good” class (1.2–3.3) compared to the “Moderate” class (3.3–4.4), M-AMBI was 0.53-0.77 and 0.38-0.53 for “Good” and “Moderate” class, respectively. However, H’ sets the same distances for the “Good” and “Moderate” classes (Table 1). Quite a different scaling in AMBI, M-AMBI, and H’ could affect the EcoQ assessment [24, 25]. Solving this problem, thresholds settled in the benthic index scale values need to be modified according to the monitoring programs or the local expert experience with the ecological characteristics of the MC in the studied habitats.

Table 1. Estimated distances in “Good” and “Moderate” classes

Indices	Status	Thresholds settled	Distances in each threshold
AMBI	Good	1.2 - 3.3	2.1
	Moderate	3.3 - 4.4	1
M-AMBI	Good	0.53 - 0.77	0.24
	Moderate	0.38 - 0.53	0.15
H’	Good	2 - 3	1
	Moderate	1 - 2	1

4. Conclusion

The OSFP’s EcoQ estimated by the H′, AMBI, and M-AMBI led to differences between their evaluation results. When the H’ index indicated degraded conditions, AMBI and M-AMBI indices indicated undegraded conditions. The H’ may also be more sensitive to environmental disturbances than the AMBI and M-AMBI. Further research should analyze three indices with environmental data to potentially increase the precise answer to this issue. Furthermore, the AMBI and M-AMBI indices totally depended on ecological groups (EG) of the MC and the relative abundance of each EG, therefore, prior to AMBI and M-AMBI application assignment of each of the sampled species to an EG must be done. AMBI and M-AMBI proved to be cheap, simple, highly sensitive, and in particular they require minimal local calibration databases. Thus, these indices should be paid special attention in the future aquatic environment research.

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So sánh các chỉ số sinh học Shannon-wiener, AMBI và M-AMBI trong đánh giá chất lượng sinh thái nền đáy ao nuôi tôm sinh thái, huyện Năm Căn, tỉnh Cà Mau

Trần Thành Thái[1], Lê Hải Đăng[1], Ngô Xuân Quảng[1,2]

[1]*Viện Sinh học Nhiệt đới, Viện Hàn lâm Khoa học và Công nghệ Việt Nam, 85 Trần Quốc Toản, Quận 3, Thành phố Hồ Chí Minh, Việt Nam*

[2]*Học viện Khoa học và Công nghệ, Viện Hàn lâm Khoa học và Công nghệ Việt Nam, 18 Hoàng Quốc Việt, Cầu Giấy, Hà Nội, Việt Nam*

Tóm tắt: Các chỉ số sinh học như: chỉ số Shannon-Wiener (H′), chỉ số sinh học biển AMBI (AZTI's Marine Biotic Index-AMBI) và chỉ số sinh học biển AMBI đa biến (M-AMBI-multivariate AMBI) của quần xã động vật đáy không xương sống cỡ lớn được áp dụng nhằm so sánh tính hiệu quả trong đánh giá chất lượng sinh thái nền đáy các ao nuôi tôm sinh thái, huyện Năm Căn, tỉnh Cà Mau. Chất lượng sinh thái nền đáy tại các ao tôm sinh thái được đánh giá bởi 3 chỉ số có khác nhau. Kết quả đánh giá chất lượng sinh thái nền đáy bởi chỉ số AMBI và M-AMBI luôn cao hơn khi so với chỉ số H'. Điều này một phần phản ánh chỉ số H' nhạy cảm với sự xáo trộn trong môi trường hơn khi so với chỉ số AMBI và M-AMBI. Ngoài ra, chỉ số M-AMBI đánh giá chất lượng nền đáy mức độ trung hòa giữa H' và AMBI. Tuy nhiên, nghiên cứu này chưa xét tới các phân tích tương quan giữa các chỉ số với điều kiện môi trường nên sẽ còn được tiếp tục nghiên cứu xa hơn, đặc biệt việc đánh giá thông qua chỉ số H' nhạy cảm hơn so với AMBI và M-AMBI.

Từ khóa: Ao tôm sinh thái, AMBI, chỉ số sinh học nền đáy, chỉ thị sinh học, Shannon-Wiener (H′), M-AMBI, quần xã động vật đáy không xương sống cỡ lớn.