Acta Oceanol. Sin., 2023, Vol. 42, No. 10, P. 108–116
https://doi.org/10.1007/s13131-022-2094-1
http://www.aosocean.com
E-mail: ocean2@hyxb.org.cn

Seasonal implications for taxonomic sufficiency to simplify M-AMBI methodology in the coastal area adjacent to a eutrophic estuary

Chenman Yang[1], Hongjun Song[2], Yi Sun[1], Pengfei Xie[1], Yuan Liu[1], Hongjun Li[1, 2]*

[1] State Environmental Protection Key Laboratory of Coastal Ecosystem, National Marine Environmental Monitoring Center, Dalian 116023, China

[2] Observation and Research Station of Bohai Strait Eco-Corridor, First Institute of Oceanography, Ministry of Natural Resources, Qingdao 266061, China

Received 24 May 2022; accepted 12 August 2022

Abstract

Taxonomic sufficiency (TS) refers to identifying taxa to a taxonomic level sufficient to detect community changes in stressed environments and may provide a cost-effective approach in routine monitoring programs. However, there is still limited information regarding the seasonal impact of applying TS and its implications for the ecological quality evaluation in the estuarine ecosystem. This study investigated the relationship between the multivariate-AZTI's Marine Biotic Index (M-AMBI) and environmental variables in three seasons (i.e., spring, summer, and autumn) in the Liaohe River Estuary. We tested the reliability of TS for simplifying the M-AMBI methodology. The results showed that family and genus level data could reproduce the spatial-temporal patterns of community structure at the species level. The M-AMBI values showed a consistent spatial distribution pattern in all sampling seasons, with a decreasing trend with the increasing distance from the estuary mouth. Both genus and family level data performed nearly as well as species level in detecting the seasonal variations of pollutants (i.e., nutrients and total organic content). The family level M-AMBI was feasible to discern stress in the Liaohe River Estuary because of the high aggregation ratios at different taxonomic levels in all sampling seasons. These findings suggest that applying taxonomic sufficiency based on the M-AMBI provides an efficient approach for evaluating ecological quality in the Liaohe River Estuary.

Key words: M-AMBI, ecological quality, macrofauna, taxonomic sufficiency, eutrophication, Liaohe River Estuary

Citation: Yang Chenman, Song Hongjun, Sun Yi, Xie Pengfei, Liu Yuan, Li Hongjun. 2023. Seasonal implications for taxonomic sufficiency to simplify M-AMBI methodology in the coastal area adjacent to a eutrophic estuary. Acta Oceanologica Sinica, 42(10): 108–116, doi: 10.1007/s13131-022-2094-1

1 Introduction

Globally, estuaries are among the most valuable and productive ecosystems, support various essential ecological functions, and provide social benefits to human beings (Costanza et al., 1997). In recent years, estuarine ecosystems have been experiencing habitat degradation caused by intensive anthropogenic activities (e.g., urbanization, industrial development, shipping, fishing, and aquaculture) (Elliott and Whitfield, 2011; Lotze, 2010; Korpinen and Andersen, 2016). Accordingly, legislations worldwide implement routine monitoring programs to evaluate the estuarine ecological quality (EcoQ) (Borja et al., 2008; Borja and Elliott, 2013). Most governments make great efforts to define EcoQ at the ecosystem level using several biological and environmental elements (Borja et al., 2016).

Macrofaunal communities are reliable biological elements for evaluating the ecological status of coastal ecosystems due to their specific physiological characteristics of wide distribution, limited mobility, and sensitivity to environmental disturbance. However, traditional monitoring programs rely on expensive and time-consuming identification of macrofaunal organisms to species level (Sun et al., 2021). The easier way to simplify this process is using coarser taxonomic resolutions (e.g., family and genus instead of species). Ellis (1985) introduced the concept of taxonomic sufficiency, which involves the analysis of higher taxa, rather than species, without significant loss of information in detecting community changes exposed to environmental stresses. Previous studies showed that even the family-level data are sufficient to discern community variations (Gesteira et al., 2003; Lampadariou et al., 2005; Thompson et al., 2003). However, it is still challenging to make generalizations, and the taxonomic sufficiency remains largely unexplored along natural gradients in coastal areas (Wlodarska-Kowalczuk and Kedra, 2007). The coastal ecosystems are highly susceptible to seasonal freshwater and saltwater input variations. Thus, within these ecosystems, the biological communities are expected to fluctuate with seasons, making the ecological quality evaluation challenging.

Benthic indices are especially relevant in environmental management because they can integrate complex scientific data and provide information that policymakers easily understand (Chainho et al., 2007b). Hence, Borja et al. (2000) developed the AZTI's Marine Biotic Index (AMBI) based on the proportion of species assigned to five ecological groups according to specific

---

Foundation item: The National Marine Public Welfare Research Project of China under contract No. 201305030; the Open Fund from Observation and Research Station of Bohai Strait Eco-Corridor under contract No. BH202201.

*Corresponding author, E-mail: hjli@nmemc.org.cn tolerances to human pressures (Borja et al., 2000). In its further development, Muxika et al. (2007) combined AMBI scores with species richness and diversity to produce multivariate-AMBI (M-AMBI). However, since AMBI and M-AMBI were initially developed in European coastal waters, they should be tested or calibrated for new geographic regions before implementation (Pelletier et al., 2018).

This study investigated the benthic EcoQ using M-AMBI in three seasons (i.e., summer, autumn, and spring) in the Liaohe River adjacent coastal area. The aims of this study were: (1) to describe the spatial-temporal variation of EcoQ by the M-AMBI; (2) to test the effects using higher taxonomic data on the performance of M-AMBI; and (3) to relate the EcoQ based on M-AMBI with environmental variables.

2 Materials and methods

2.1 *Field sampling*

The Liaohe River Estuary (40°20′–41°00′N, 121°20′–122°00′E) locates in the Liaodong Bay, a part of the Bohai Sea, northeastern China (Fig. 1). With the rapid industrialization and urbanization of upstream cities, the Liaohe River Estuary is exposed to considerable anthropogenic pressures, including industrial and agricultural effluent, domestic sewage discharge, oil mining, and physical disturbance by trawling and dredging. The surrounding seagoing rivers (i.e., Liaohe River, Shuangtaizi River, Daling River, and Xiaoling River) carry large amounts of terrigenous pollutants, which significantly deteriorate the habitat quality of Liaohe River Estuary. With the massive expansion of high-density aquaculture practice in the Liaohe River delta wetland, crab aquaculture pollution has also caused severe environmental problems. Liaohe River Oilfield, the third-largest oilfield in China, also poses high pollution pressures on the surrounding environment. Furthermore, Liaohe River Estuary serves as a vital fishery ground, and commercial bottom trawling may alter the structure and function of ecosystems. According to the official environmental bulletin, the Liaohe River Estuary is one of the most contaminated areas in China (State Oceanic Administration of China, 2012). The primary pollutants are inorganic nitrogen and labile phosphate.

We selected 25 coastal sampling stations in the Liaohe River Estuary in the present study. We divided them into six categories based on the distance from the station to the river mouth (A: Nos S1–S2; B: Nos S3–S6; C: Nos S7–S10; D: Nos S11–S15; E: Nos S16–S20; and F: Nos S21–S25; A to F meant closest to farthest from the river inlet) for further analysis. We collected samples for three seasons, including spring (May 2014), summer (August 2013), and autumn (November 2013). It was unappeasable to collect the fieldwork sediment samples for S1 and S3 in summer, S2 and S4 in spring, and S23 in autumn, probably due to the nearby sand dredging project. We collected sediment samples using a 0.05 m^2 Van Veen grab. Four replicates were collected for each station and pooled together before further treatments. The samples were sieved over 0.5 mm mesh to separate the macrofaunal specimens and fixed in 5% formaldehyde. Meanwhile, 100 g of sediment was taken to measure sediment texture, total organic content (TOC), and petroleum hydrocarbons (PHc). Bottom seawater samples in each station were collected simultaneously with 5 L Niskin bottles. The salinity and pH were measured *in situ* with a multiparameter sensor (YSI 6600).

2.2 *Laboratory analysis*

In the laboratory, specimens in each sediment were isolated, counted, and identified to the lowest possible taxonomic level using a dissecting microscope and an optical microscope. We checked the validity and synonyms of taxa names with the database of the World Register of Marine Species (http://www.marinespecies.org/). Aggregation ratio (ϕ) (Bevilacqua et al., 2012) higher rank taxon count to species count) was also calculated for three seasons to understand the congruency between species and higher taxonomic levels.

We determined the grain size for sediment samples using a Mastersizer 2000 laser particle size analyzer (Malvern, UK). Approximately 0.2 g of powdered samples were digested in a Teflon vessel with a mixed solution of HNO_3 + HCl + HF (5:4:1) on a heating plate and heated (<150°C) to dryness. Afterward, the residue was extracted with HNO_3 and diluted to a specific volume. We measured the TOC values with an elemental analyzer. The Winkler titration method determined dissolved oxygen (DO) for seawater samples. We filtered each seawater sample with a 0.45 μmol/L microporous filter membrane, and the concentrations of chlorophyll *a* (Chl-*a*), chemical oxygen demand

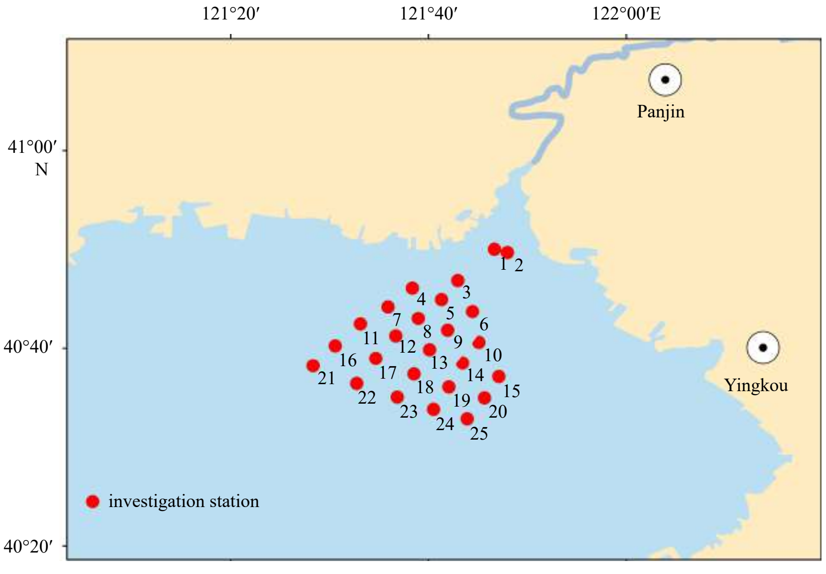

Fig. 1. The sampling stations of Liaohe River Estuary. S1 in the text is the abbreviation of Station 1, and so on.

(COD), NO_2^--N, NO_3^--N, NH_4^+-N, and PO_4^{3-}-P in seawater were determined colorimetrically according to the methods described by Grasshoff et al. (1983).

2.3 *Data analysis*

We respectively tested the environmental variables among the three seasons and the six different distances from the inlet, using a one-way ANOVA with Turkey's HSD analysis. Before the ANOVAs, Hellinger transformation was applied to the environmental variables making them suitable for parametric tests.

The AMBI was calculated using the software provided at the AZTI's website (http://ambi.azti.es) with the updated species list (December 2020). Calculation of M-AMBI includes a factor analysis (FA) of AMBI score, species richness, and Shannon-Wiener diversity. At "high" status, the M-AMBI value reaches one, and at "bad" status, the M-AMBI reaches zero. In the present study, reference conditions for M-AMBI calculation were set using the highest and lowest values in the datasets for each metric (Borja et al., 2009). The M-AMBI scale was divided into five EcoQ categories (i.e., High, Good, Moderate, Poor, and Bad) by assigning a numerical value to each class boundary.

The M-AMBI EcoQ of each station was determined and compared with species-genus- and family-level databases. At the species level, taxa were ascribed to an ecological group (EG) based on the AMBI library. When species were not assigned in the database, they were assigned to the most common group found for the genus. If absent hitting, species were classified as "not assigned" (Checon et al., 2018). At the genus and family level, taxa not included in the AMBI library were assigned to EGs based on median values of all AMBI entries in the parental taxa, as described by Forde et al. (2013). We used a Kappa analysis (Cohen, 1960; Landis and Koch, 1977) to test the agreement between the number assigned to each of the five EcoQ categories based on the species-, genus-, and family-level data. To inter-calibrate EcoQ outputs to maximize the agreement across different taxonomic levels, legendary boundaries (i.e., for status, High, $\geqslant 0.77$; Good, $[0.53, 0.77)$; Moderate, $[0.39, 0.53)$; Poor, $[0.20, 0.39)$; and Bad, <0.20) were modified using the approach suggested by Borja et al. (2007).

The Spearman's Rank correlation coefficient (r) was estimated between abiotic variables and M-AMBI values obtained from different taxonomic levels to test if this index performed better with coarse taxonomy using SPSS 18.0. To relate M-AMBI values with eutrophication, the eutrophication index (EI) was calculated using the following formula: EI = $(\mathrm{COD} \times \mathrm{DIN} \times PO_4^{3-} \times 10^6)/4\,500$, where DIN = NO_3^--N + NO_2^--N + NH_4^+-N, and COD, DIN and PO_4^{3-} are in mg/L.

3 Results

3.1 *Environmental variables*

The spatial-temporal variability of abiotic parameters in the studied estuary is presented in Fig. 2. Significantly higher Chl-*a*, NO_2^--N, and COD concentrations were recorded in summer compared to spring and autumn (ANOVA, $p < 0.05$). In contrast, the water salinity increased in spring and decreased in summer compared to autumn (ANOVA, $p < 0.05$). The NO_3^--N and NH_4^+ contents in the water were higher in summer and lower in autumn compared to spring (ANOVA, $p < 0.05$). Moreover, the TOC concentrations in summer and autumn were significantly higher than in spring. However, the PO_4^{3-}-P in spring and summer was significantly lower than autumn (ANOVA, $p < 0.05$). In addition, no significant differences were observed in the sediment compositions and PHc content among the different seasons (ANOVA, $p > 0.05$).

Changes in environmental quality indicators at different distances within the same season were also analyzed. Salinity rose in all three seasons as the distance from the inlet increased. In summer, Chl-*a* concentrations in water samples from the A, D, E, and F regions were significantly higher than in the other samples (ANOVA, $p < 0.05$). In summer and spring, the NO_2^--N, NO_3^--N, NH_4^+-N, PO_4^{3-}-P, and COD concentrations significantly decreased as the distance from the inlet increased (ANOVA, $p < 0.05$). In contrast, the values of these indicators showed no significant spatial variance in autumn (ANOVA, $p > 0.05$). As the distance from the estuary increased, the proportion of sand and clay in sediments decreased at first and then increased. No noticeable change in the pattern of PHc content was found in the sediments at different distances within the same season (ANOVA, $p > 0.05$).

3.2 *Macrofaunal community structure and seasonal variation*

We sampled 15 455 individuals from 100 species during three seasons, representing 87 genera and 71 families. Annelida was the dominant taxa with the most significant number of species. Arthropoda and Mollusca were also common; in addition, Bryozoa, Nemertea, Sipuncula, and Platyhelminthes were far less common. Mollusca (57.1%) was the dominant taxa in terms of abundance, followed by Annelida (23.7%), Arthropoda (13.6%), and others (5.5%). The number of each taxonomic unit and the dominant species in each season with ϕ are shown in Table 1. Species number slightly decreased from summer to spring and autumn, with 59, 56, and 53, respectively. Only 22 species (22.2%) were shared among all three seasons, while 52 species (52.5%) were season-specific. Moreover, 30 species were common in both spring and summer, 33 in both summer and autumn, whereas 28 in spring and autumn (Fig. 3).

All the identified taxa of different sensitivities were assigned to 5 EGs based on the AZTI's classification (Table S1), 33 taxa (31.4%) were classified as EG I, 36 taxa (34.3%) assigned to EG II, 16 taxa (15.2%) were assigned to EG III, 7 taxa (6.7%) assigned to EG IV, 2 taxa (1.9%) assigned to EG V, and 11 species (10.5%) were unassigned. In terms of abundance, EG VI and EG I dominated, due to the densities of *Potamocorbula laevis* and *Amphioplus* sp., respectively. Aggregating the species data to genus and family taxonomic levels produced 93 and 74 taxa, respectively (Table S1).

3.3 *Calculation and inter-calibration of M-AMBI across taxonomic levels*

Among all 66 M-AMBI values for sampling stations in all three seasons, the ecological status derived from species-level data indicated that most of the stations were categorized as Good, Poor, and Moderate status (47%, 19.7%, and 15.2%, respectively). A minority of 10.6% of stations were classified as High, and 7.6% were ranked as Bad. In terms of seasonal variability, 21 of 25 (84%) showed variations in their ecological status over the sampling periods, and most of the variations occurred among the adjacent categories (Fig. 4). The stations with consistent ecological classification belonged to the Good (S13, S15, S17, and S19) categories. Overall, the summer showed the highest M-AMBI values among the three seasons, indicating decreased ecological status. Moreover, M-AMBI values showed consistent spatial distribution during all three seasons, with a clear distribution pattern related to the distance from the estuary and coast. The nearshore sites were more disturbed than the offshore sites. It is noted that the nearshore sites (e.g., S1 to S6) generally had the highest temporal variations in the ecological status. Conversely,

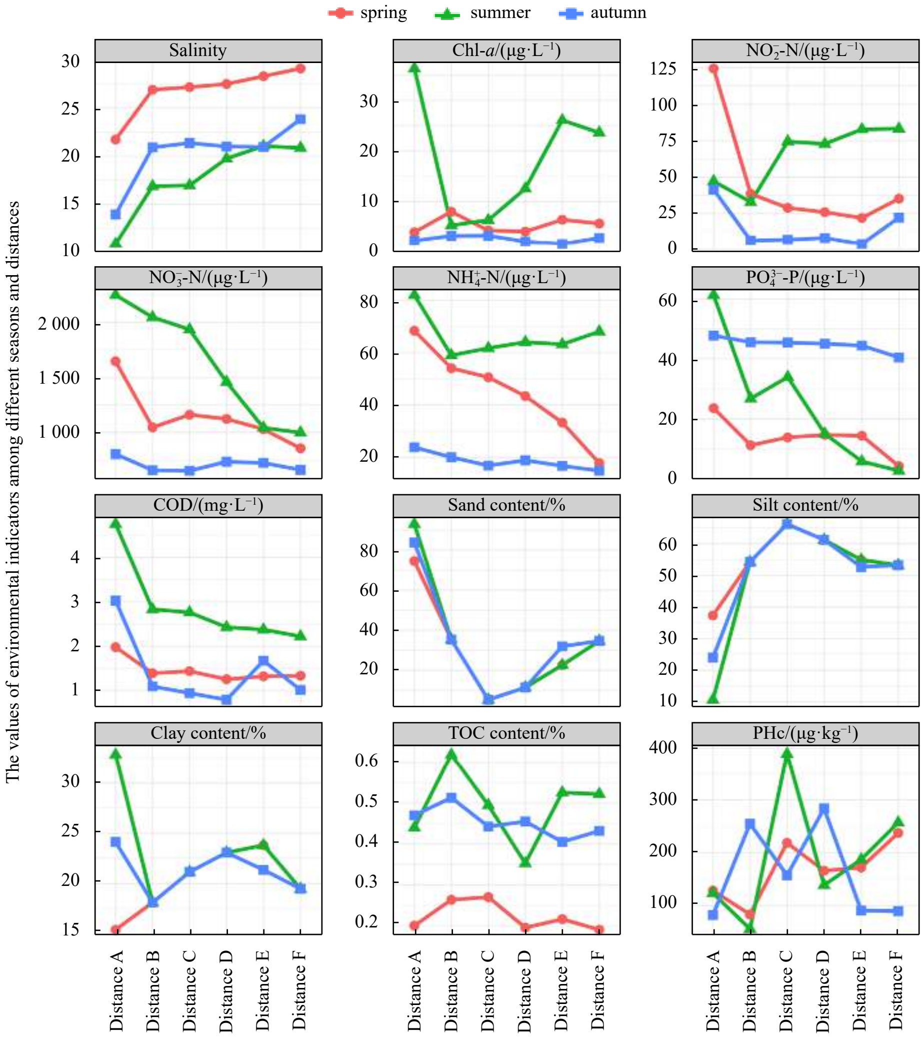

Fig. 2. Spatial-temporal distribution of environmental variables (Chl-*a*: Chlorophyll *a* concentration; COD: chemical oxygen demand concentration; TOC: total organic carbon content; PHc: petroleum hydrocarbons content) in the Liaohe River Estuary. The stations were divided into six categories based on the distance from the station to the river inlet (A: Nos S1–S2; B: Nos S3–S6; C: Nos S7–S10; D: Nos S11–S15; E: Nos S16–S20; F: Nos S21–S25).

Table 1. Summary of family, genus, species counts, aggregation ratio (ϕ) for higher taxonomic resolutions, and dominant species in three seasons. Ecological groups assigned to dominant species are presented in the parenthesis

Season	Family (ϕ)	Genus (ϕ)	Species	Dominant species (Ecological Group)
Spring	45 (0.80)	48 (0.86)	56	*Potamocorbula ustulata* (V) *Ampelisca* sp. (I)
Summer	47 (0.80)	58 (0.98)	59	*Potamocorbula laevis* (V) *Capitella capitata* (V)
Autumn	45 (0.85)	47 (0.89)	53	*Corophium acherusicum* (III) *Grandidierella* sp. (I) *Amphioplus* sp. (I) *Capitella capitata* (V) *Potamocorbula laevis* (V) *Glossaulax didyma* (I)

offshore sites showed a relatively consistent increased ecological status. Most conclusions applied to genus and family levels, and only the S25 changed from Good status to Moderate at the genus level. However, at the family level, some station's status were modified to higher levels (S5, S12, S18, and S19) .

Kappa analysis indicated an "almost perfect" agreement existing between species- and genus-level M-AMBI EcoQ classifications using the standard class boundaries (Table 2) (Kappa value = 0.975, Asymp. Std. Error = 0.03%). However, similar analysis for species- and family-level outputs resulted in "substantial" agreement (Kappa value = 0.893%, Asymp. Std. Error = 0.045%) between EcoQ classifications.

3.4 *Relationships between M-AMBI, macrofaunal structures, and environmental variables*

We used the db-RDA analysis to determine the similarity of

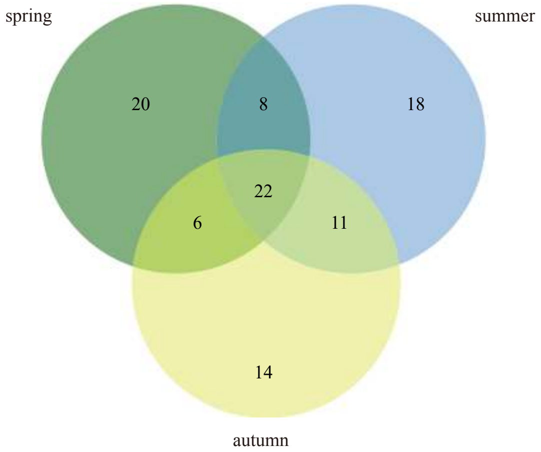

Fig. 3. Venn diagram for the seasonal distribution of taxa numbers in the Liaohe River Estuary.

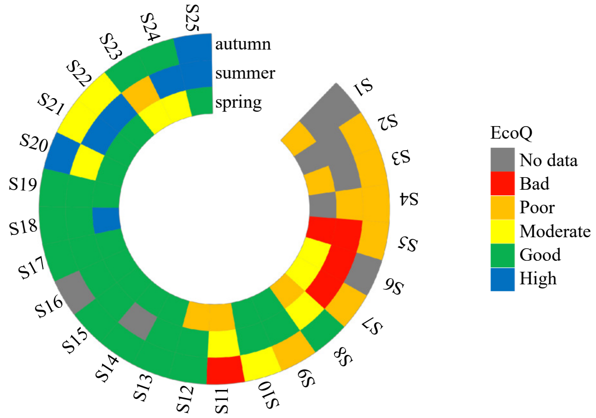

Fig. 4. M-AMBI ecological classification across stations and seasons. S1–S25: sampling stations 1 to 25 indicate the increased distance from the river inlet.

community compositions at different taxonomic levels among three seasons (Fig. 5). The three taxonomic levels all showed a significant difference among the three seasons, with different explanation variations. What is interesting is that the increased prediction power (adjusted R^2) was observed as taxonomic levels increased, with the family level showing the best predictive power, followed by the genus and species levels. The relationships between Ecological Groups and the environmental variables were also revealed. The most sensitive species and indifferent species (EG I and EG II) were positively correlated with salinity, and negatively correlated with Chl-*a*, NO_2^--N, NO_3^--N, NH_4^+-N, PO_4^{3-}-P, TOC and PHc, while EG III species showed negative cor-

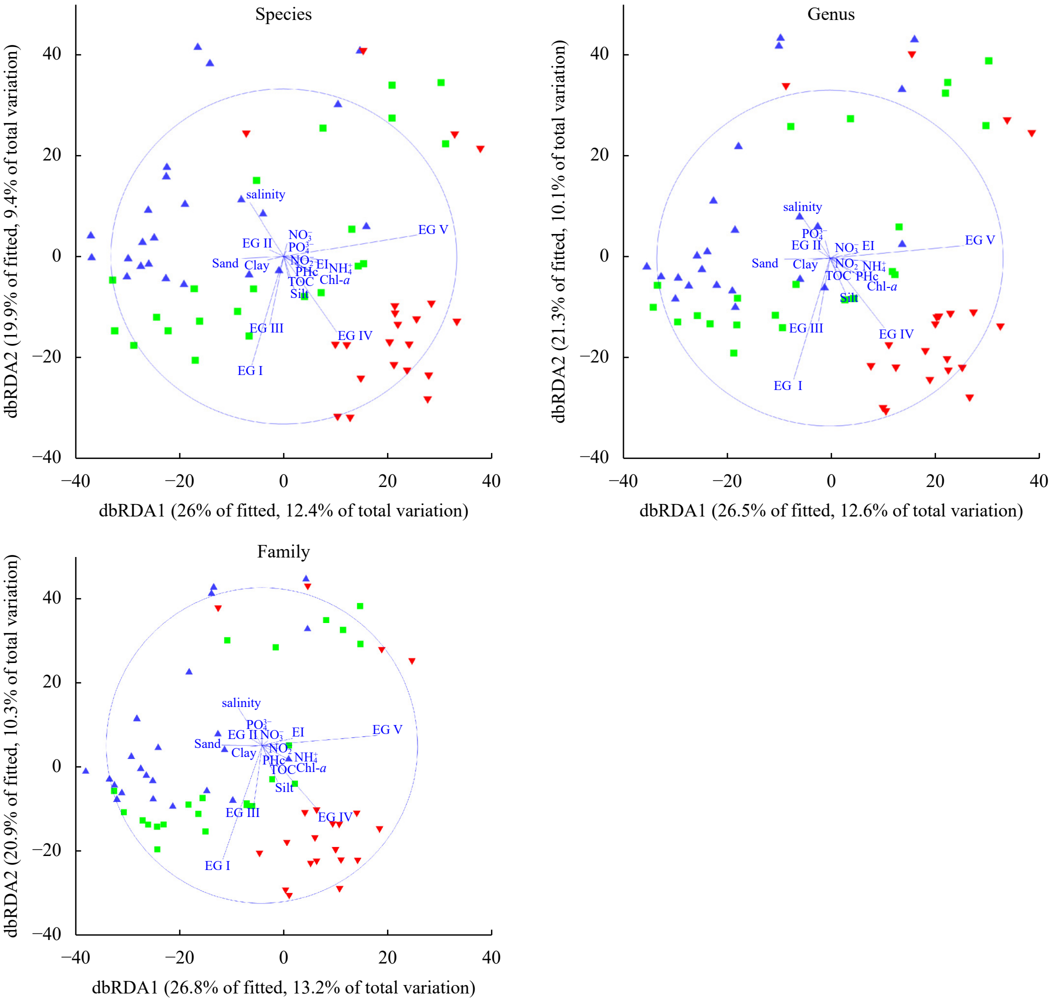

Fig. 5. Ordination plots of distance-based Redundancy Analysis (db-RDA) of species-, genus- and family-level assemblages between environmental variables, EG (Ecological Groups I–V), and sampling stations in three seasons (▲, spring; ▼, summer; ■, autumn).

Table 2. Number of stations for each ecological quality (EcoQ) classification using the M-AMBI calculated with aggregated datasets

EcoQ classification	Aggregation level		
	Species	Genus	Family
High	7	7	9
Good	31	30	29
Moderate	10	10	12
Poor	13	14	12
Bad	5	5	4
Total	66	66	66

Note: Standard EcoQ classification boundaries used; for status, High, ⩾0.77; Good, [0.53, 0.77); Moderate, [0.39, 0.53); Poor, [0.20, 0.39); Bad, <0.20.

relation with NO_3^--N and PO_4^{3-}-P. All the contamination variables (NO_2^--N, NO_3^--N, NH_4^+-N, PO_4^{3-}-P, TOC and PHc) were in positive correlation with second-order and first-order opportunistic group (EG IV and EG V). M-AMBI scores obtained from three taxonomic-level datasets (i.e., species, genus, and family) indicated a significant relationship with environmental variables. M-AMBI scores showed strong correlation with salinity, EI, and TOC (Fig. 6). M-AMBI values based on different taxonomic levels were similarly correlated with the abiotics. The highest correlations with salinity, EI, and TOC were all obtained from the family-level data (Fig. 6).

4 Discussion

Legislations implement environmental monitoring programs that determine the ecosystem status in the global coastal area. There has been a concerted effort to develop methods to maximize information with minimal expense because large-scale geographical areas need to be routinely monitored in countries with long coastlines. TS is one of the practical solutions in comprehensive monitoring programs. While the TS approach could work in routine programs to survey vast areas, it can lead to the loss of information on species diversity, functional groups, dominant species, and species loss when investigating biodiversity status (Bertasi et al., 2009). This study aimed to select appropriate data analytical methods of different taxonomic levels to weigh the input costs against the information loss.

In this study, the family-level M-AMBI for EcoQ assessment effectively reproduced the spatial-temporal patterns at species-level communities in the Liaohe River Estuary (Fig. 5). Previous studies suggested that a high aggregation ratio (ϕ>0.4) might produce similar results among different taxonomic resolutions and in turn, support the robust application of taxonomic sufficiency (Bevilacqua et al., 2018). In this study, the aggregation ratios for genus (0.86) and family (0.80) were high, so little information was lost when higher taxonomic levels were applied. Taxonomic sufficiency was also suitable in the case containing an increased number of monotypic taxa (Ferraro and Cole, 1995). In the present study, 87% of the genera and 71% of families were monotypic. Genus and family levels were proved effective when there were significant monotypic genera and families (Soares-Gomes et al., 2012).

The present study observed the highest predicted power in the family-level model for studying the community-environment relationships. This result indicates that most congeneric species responded to the environmental gradient in the same way. A concern regarding the application of taxonomic sufficiency is the loss of ecologically important information provided by the species-level data that may help reflect particular disturbances (De-La-Ossa-Carretero et al., 2012; Maurer, 2000). That is troublesome in

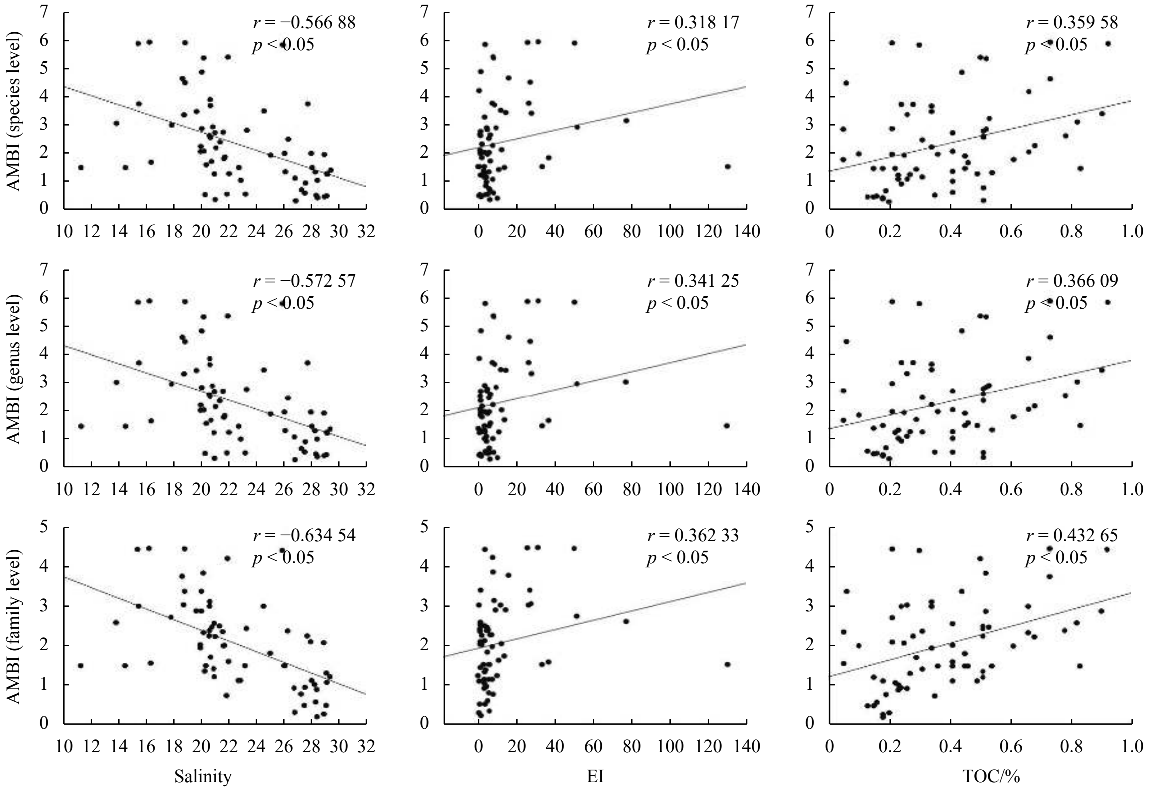

Fig. 6. Spearman's correlations between AMBI scores derived from species-, genus- and family-level datasets and environmental variables. EI: eutrophication index; TOC: total organic carbon content.

freshwater ecosystems where congeners give diversified responses to various disturbances. However, it is suggested that marine macrofaunal congeners exhibit a similar response to pollution (Forde et al., 2013; Tweedley et al., 2014). On the other hand, the diversity of high taxon may influence the consistency of responses to environmental gradients since a species-rich high taxon may be more likely to show internal ecological heterogeneity (Bertasi et al., 2009). In areas characterized by a low degree of radiation, coarser taxonomies (e.g., family or ever order) are suitable for studying community-environment relationships (Heino and Soininen, 2007).

The current study found temporal variations in the ecological status of some sampling stations in three seasons, especially in areas with poor environmental conditions (i.e., sampling stations near the mouth of the river). Several studies have shown that M-AMBI is more impervious than AMBI to natural abiotic fluctuations (Reiss and Kröncke, 2005; Salas et al., 2004; Yan et al., 2020). However, other studies have suggested the temporal variations of AMBI in an area subject to anthropogenic activities (Dias et al., 2018; Feebarani et al., 2016; Mulik et al., 2020). In the present study, the area at the mouth of the river is the closest to land-based pollution sources. Therefore, this region may receive more constant and direct human disturbances, partly explaining the energetic temporal variation patterns. In the Liaohe River Estuary, the summer presents the most stressed scenario due to the accumulation of contaminants, whereas better environmental conditions prevail during the autumn and spring due to the flushing out of contaminants after summer. For the macrofaunal community, the mortality and recruitment of organisms during different seasons result in seasonal variations in composition and abundance. We recommend that determining the ecological quality of marine benthic environments should not be based on only one sampling event. A seasonal sampling strategy would give a comprehensive view of temporal variations in EcoQ.

Large scale monitoring programs require tremendous resources such as project funding, sampling efforts and experimental analysis to generate the species-level data that is traditionally needed. However, discrepancies in the literature or changes in personnel collecting data could contribute to significant inaccuracies. For example, apparent changes in biological community structure arose from changes in the expert staff or in the laboratory responsible for data collection in time-series monitoring programs (Peperzak, 2010; Wiltshire and Dürselen, 2004). Therefore, formulating quick and efficient monitoring strategies like taxonomic sufficiency is necessary. Taxonomic sufficiency tended to increase the accuracy and trustworthiness of the results obtained, especially for large-scale and long-term programs (Bevilacqua et al., 2012). A big challenge for monitoring programs is the lack of taxonomists who provide information on biodiversity, provides species names for communication, and are at the forefront of documenting biological community structure. Coarser taxonomic resolution may be a more efficient way to ensure temporal and geographical comparability, especially for countries with a heterogeneous coastal line with high biodiversity.

In China, researchers have argued that the feasibility of M-AMBI might depend on the extent of sediment pollution in the studied area. Wu et al. (2018) suggested that AMBI would not be suitable for the EcoQ assessment in Fujian Province since the TOC content of sediment is low in that area. M-AMBI could be an appropriate biotic index to assess the environmental status of the coastal area adjacent to the Changjiang River (Liu et al., 2014). The present study corroborates that M-AMBI is suitable as an indicator of organic and nutrient enrichment since it responds predictably to those pressures (Liu et al., 2014). Considering the effects of monitoring periods and stations on the performance of benthic indices, as shown in this study, it is crucial to take consistent program design in large-scale estuary monitoring programs.

5 Conclusions

This study tested the seasonal reliability of high taxonomic levels to simplify benthic index M-AMBI operations in a heavily polluted estuary. The results indicated that family level data provides sufficient confidence for application with M-AMBI since it produced an excellent classification of sampling stations affected by riverine freshwater input with seasonal variability. The ability of M-AMBI to classify EcoQ consistently at increasingly higher taxonomic levels supports the idea of TS approach in coastal monitoring programs. The high temporal variability of both the biological and environmental variables suggested the importance of different seasonal sampling strategies in estuarine ecosystems. Considering that the AMBI database does not assign some local species, the application of M-AMBI requires further expertise to recognize species tolerance and improve ecological group classifications in China. Test the efficacy of TS and its applicability in other areas is recommended for the management of the coastal environment in China.

References

Bertasi F, Colangelo M A, Colosio F, et al. 2009. Comparing efficacy of different taxonomic resolutions and surrogates in detecting changes in soft bottom assemblages due to coastal defence structures. Marine Pollution Bulletin, 58(5): 686–694, doi: 10.1016/j.marpolbul.2009.01.003

Bevilacqua S, Mistri M, Terlizzi A, et al. 2018. Assessing the effectiveness of surrogates for species over time: Evidence from decadal monitoring of a Mediterranean transitional water ecosystem. Marine Pollution Bulletin, 131: 507–514, doi: 10.1016/j.marpolbul.2018.04.047

Bevilacqua S, Terlizzi A, Claudet J, et al. 2012. Taxonomic relatedness does not matter for species surrogacy in the assessment of community responses to environmental drivers. Journal of Applied Ecology, 49(2): 357–366, doi: 10.1111/j.1365-2664.2011.02096.x

Borja A, Bricker S B, Dauer D M, et al. 2008. Overview of integrative tools and methods in assessing ecological integrity in estuarine and coastal systems worldwide. Marine Pollution Bulletin, 56(9): 1519–1537, doi: 10.1016/j.marpolbul.2008.07.005

Borja Á, Elliott M. 2013. Marine monitoring during an economic crisis: the cure is worse than the disease. Marine Pollution Bulletin, 68(1–2): 1–3, doi: 10.1016/j.marpolbul.2013.01.041

Borja A, Elliott M, Andersen J H, et al. 2016. Overview of integrative assessment of marine systems: the ecosystem approach in practice. Frontiers in Marine Science, 3: 20, doi: 10.3389/fmars.2016.00020

Borja A, Franco J, Pérez V. 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Marine Pollution Bulletin, 40(12): 1100–1114, doi: 10.1016/S0025-326X(00)00061-8

Borja A, Josefson A B, Miles A, et al. 2007. An approach to the intercalibration of benthic ecological status assessment in the North Atlantic ecoregion, according to the European Water Framework Directive. Marine Pollution Bulletin, 55(1–6): 42–52, doi: 10.1016/j.marpolbul.2006.08.018

Borja A, Miles A, Occhipinti-Ambrogi A, et al. 2009. Current status of macroinvertebrate methods used for assessing the quality of European marine waters: implementing the Water Framework Directive. Hydrobiologia, 633(1): 181–196, doi: 10.1007/s10750-009-9881-y

Chainho P, Lane M F, Chaves M L, et al. 2007b. Taxonomic sufficiency as a useful tool for typology in a poikilohaline estuary.

Hydrobiologia, 587(1): 63–78, doi: 10.1007/s10750-007-0694-6

Checon H H, Corte G N, Muniz P, et al. 2018. Unraveling the performance of the benthic index AMBI in a subtropical bay: The effects of data transformations and exclusion of low-reliability sites. Marine Pollution Bulletin, 126: 438–448, doi: 10.1016/j.marpolbul.2017.11.059

Cohen J. 1960. A coefficient of agreement for nominal scales. Educational and Psychological Measurement, 20(1): 37–46, doi: 10.1177/001316446002000104

Costanza R, d'Arge R, De Groot R, et al. 1997. The value of the world's ecosystem services and natural capital. Nature, 387(6630): 253–260, doi: 10.1038/387253a0

De-La-Ossa-Carretero J A, Simboura N, Del-Pilar-Ruso Y, et al. 2012. A methodology for applying taxonomic sufficiency and benthic biotic indices in two Mediterranean areas. Ecological Indicators, 23: 232–241, doi: 10.1016/j.ecolind.2012.03.029

Dias H Q, Sukumaran S, Srinivas T, et al. 2018. Ecological quality status evaluation of a monsoonal tropical estuary using benthic indices: comparison via a seasonal approach. Environmental Science and Pollution Research, 25(23): 22672–22688, doi: 10.1007/s11356-018-2344-0

Elliott M, Whitfield A K. 2011. Challenging paradigms in estuarine ecology and management. Estuarine, Coastal and Shelf Science, 94(4): 306–314, doi: 10.1016/j.ecss.2011.06.016

Ellis D. 1985. Taxonomic sufficiency in pollution assessment. Marine Pollution Bulletin, 16(12): 459, doi: 10.1016/0025-326X(85)90362-5

Feebarani J, Joydas T V, Damodaran R, et al. 2016. Benthic quality assessment in a naturally- and human-stressed tropical estuary. Ecological Indicators, 67: 380–390, doi: 10.1016/j.ecolind.2016.03.005

Ferraro S P, Cole F A. 1995. Taxonomic level sufficient for assessing pollution impacts on the Southern California Bight macrobenthos—revisited. Environmental Toxicology and Chemistry, 14(6): 1031–1040, doi: 10.1002/etc.5620140614

Forde J, Shin P K, Somerfield P J, et al. 2013. M-AMBI derived from taxonomic levels higher than species allows Ecological Status assessments of benthic habitats in new geographical areas. Ecological Indicators, 34: 411–419, doi: 10.1016/j.ecolind.2013.05.014

Gesteira J L G, Dauvin J C, Fraga M S. 2003. Taxonomic level for assessing oil spill effects on soft-bottom sublittoral benthic communities. Marine Pollution Bulletin, 46(5): 562–572, doi: 10.1016/S0025-326X(03)00034-1

Grasshoff K, Ehrhardt M, Kremling K. 1983. Methods of Seawater Analysis. 2nd Revised and Extended edition. Weiheim: Verlag Chemie

Heino J, Soininen J. 2007. Are higher taxa adequate surrogates for species-level assemblage patterns and species richness in stream organisms?. Biological Conservation, 137(1): 78–89, doi: 10.1016/j.biocon.2007.01.017

Korpinen S, Andersen J H. 2016. A global review of cumulative pressure and impact assessments in marine environments. Frontiers in Marine Science, 3: 153, doi: 10.3389/fmars.2016.00153

Lampadariou N, Karakassis I, Pearson T H. 2005. Cost/benefit analysis of a benthic monitoring programme of organic benthic enrichment using different sampling and analysis methods. Marine Pollution Bulletin, 50(12): 1606–1618, doi: 10.1016/j.marpolbul.2005.06.030

Landis J R, Koch G G. 1977. The measurement of observer agreement for categorical data. Biometrics, 33(1): 159–174, doi: 10.2307/2529310

Liu Lusan, Li Baoquan, Lin Kuixuan, et al. 2014. Assessing benthic ecological status in coastal area near Changjiang River Estuary using AMBI and M-AMBI. Chinese Journal of Oceanology and Limnology, 32(2): 290–305, doi: 10.1007/s00343-014-3125-3

Lotze H K. 2010. Historical reconstruction of human-induced changes in U. S. estuaries. In: Gibson R N, Atkinson R J A, Gordon J D M, eds. Oceanography and Marine Biology: An Annual Review. New York: Chapman and Hall/CRC, 48: 267–338

Maurer D. 2000. The dark side of taxonomic sufficiency (TS). Marine Pollution Bulletin, 40(2): 98–101, doi: 10.1016/S0025-326X(99)00235-0

Mulik J, Sukumaran S, Dias H Q. 2020. Is the benthic index AMBI impervious to seasonality and data transformations while evaluating the ecological status of an anthropized monsoonal estuary?. Ocean & Coastal Management, 186: 105080, doi: 10.1016/j.ocecoaman.2019.105080

Muxika I, Borja Á, Bald J. 2007. Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive. Marine Pollution Bulletin, 55(1–6): 16–29, doi: 10.1016/j.marpolbul.2006.05.025

Pelletier M C, Gillett D J, Hamilton A, et al. 2018. Adaptation and application of multivariate AMBI (M-AMBI) in US coastal waters. Ecological Indicators, 89: 818–827, doi: 10.1016/j.ecolind.2017.08.067

Peperzak L. 2010. An objective procedure to remove observer-bias from phytoplankton time-series. Journal of Sea Research, 63(2): 152–156, doi: 10.1016/j.seares.2009.11.004

Reiss H, Kröncke I. 2005. Seasonal variability of benthic indices: an approach to test the applicability of different indices for ecosystem quality assessment. Marine Pollution Bulletin, 50(12): 1490–1499, doi: 10.1016/j.marpolbul.2005.06.017

Salas F, Neto J M, Borja A, et al. 2004. Evaluation of the applicability of a marine biotic index to characterize the status of estuarine ecosystems: the case of Mondego Estuary (Portugal). Ecological Indicators, 4(3): 215–225, doi: 10.1016/j.ecolind.2004.04.003

Soares-Gomes A, Mendes C L T, Tavares M, et al. 2012. Taxonomic sufficiency of polychaete taxocenes for estuary monitoring. Ecological Indicators, 15(1): 149–156, doi: 10.1016/j.ecolind.2011.09.030

State Oceanic Administration of China. 2012. Bulletin of Marine Environmental Status of China. Beijing: State Oceanic Administration of China

Sun Yi, Li Hongjun, Gu Yanwu, et al. 2021. Optimization of Macrobenthos monitoring strategy using taxonomic sufficiency in the Liaohe Estuary. Acta Ecologica Sinica (in Chinese), 41(4): 1645–1655, doi: 10.5846/stxb202001230169

Thompson B W, Riddle M J, Stark J S. 2003. Cost-efficient methods for marine pollution monitoring at Casey Station, East Antarctica: the choice of sieve mesh-size and taxonomic resolution. Marine Pollution Bulletin, 46(2): 232–243, doi: 10.1016/S0025-326X(02)00366-1

Tweedley J R, Warwick R M, Clarke K R, et al. 2014. Family-level AMBI is valid for use in the north-eastern Atlantic but not for assessing the health of microtidal Australian estuaries. Estuarine, Coastal and Shelf Science, 141: 85–96, doi: 10.1016/j.ecss.2014.03.002

Wiltshire K H, Dürselen C D. 2004. Revision and quality analyses of the Helgoland Reede long-term phytoplankton data archive. Helgoland Marine Research, 58(4): 252–268, doi: 10.1007/s10152-004-0192-4

Wlodarska-Kowalczuk M, Kedra M. 2007. Surrogacy in natural patterns of benthic distribution and diversity: selected taxa versus lower taxonomic resolution. Marine Ecology Progress Series, 351: 53–63, doi: 10.3354/meps07127

Wu Haiyan, Fu Shifeng, Cai Xiaoqiong, et al. 2018. Suitability of various benthic biotic indices in assessing the coastal ecological quality in Fujian Province, China. Chinese Journal of Applied Ecology (in Chinese), 29(6): 2051–2058, doi: 10.13287/j.1001-9332.201806.032

Yan Jia, Sui Jixing, Xu Yong, et al. 2020. Assessment of the benthic ecological status in adjacent areas of the Yangtze River Estuary, China, using AMBI, M-AMBI and BOPA biotic indices. Marine Pollution Bulletin, 153: 111020, doi: 10.1016/j.marpolbul.2020.111020

Supplementary information:

Table S1. The Ecological Group (EG) assignment of macrofaunal species collected at the 25 sites in the Liaohe River Estuary.

The supplementary information is available online at https://doi.org/10.1007/s13131-022-2094-1 and http://www.aosocean.com/. The supplementary information is published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.