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Abundance-Biomass Comparison approach to assess the environmental stressors in Diyawannawa wetland in monsoonal and non-monsoonal seasons

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Abstract Abundance-Biomass Comparison (ABC) approach is a graphical approach that compares the abundance and biomass of organisms in order to predict the environmental stress level of an ecosystem. The present study was conducted in selected sites located at non-rehabilitated and rehabilitated areas of the Diyawannawa wetland in Sri Lanka in the monsoonal and non-monsoonal seasons. The ABC was performed on the macrobenthic mollusk species collected from the study sites. Eight species of macrobenthic mollusks, namely, *Bithynia tentaculata, Melanoides turbeculata, Melanoides turriculus, Thiara scabra, Lamellidens marginalis, Pila globosa, Gyraulus saigonensis* and *Lymnaea stagnalis* were recorded during the study period. Based on Principal Component Analysis, *B. tentaculata,* and, *P. globosa* were identified as characteristic gastropod species that could be used to classify study sites in the rehabilitated and non-rehabilitated areas of this tropical wetland system. In the monsoonal season, overlapping cumulative percentage dominance of abundance and cumulative percentage dominance of biomass curves in sites A, B, and F indicated partially disturbed environmental conditions. The site C of the non-rehabilitated area, showed a typical undisturbed condition and the sites D and E of the rehabilitated area the cumulative percentage dominance of biomass curve was located above the abundance curve, indicating disturbed environmental conditions in these sites during monsoonal season. During the non-monsoonal season in all the sites except site F of the rehabilitated area, the cumulative percentage dominance of abundance curve was located above the biomass curve, indicating undisturbed environmental conditions in these sites. In the site F, the cumulative percentage dominance of abundance and the cumulative percentage dominance of biomass curves were crossing each other, indicating partially disturbed environmental conditions at this site. The values of the W statistic, which ranged from 0.004 to 0.374 in the non-monsoonal season and ranged from 0.1 to 0.2 in the monsoonal season, and pollution and water quality categorization by modified biotic index (MBI) were in agreement with the results of the ABC approach.

Keywords: Gastropods; Wetland health; W statistic; Modified biotic index; Sri Lanka

INTRODUCTION

Wetlands are unique ecosystems that share characteristics of terrestrial and aquatic ecosystems. Being transitional ecosystems, wetland structure and associated functions are always influenced by the adjacent terrestrial and aquatic ecosystems. Therefore, the wetlands are continuously adjusting and changing their structure and function to successfully withstand the environmental influences of adjacent ecosystems.

Any relatively discrete event in time that disrupts the ecosystem, community, or population structure and changes of resources, substrate availability, or the physical environment is defined as a disturbance or a stress on an ecosystem (White and Pickett 1985). Disturbances can be natural or human-induced based on how the disturbance is created. Flooding, erosion, landslides, biomass removal, introduction of the alien invasive species, temperature and salinity fluctuations, accumulation of heavy metals and domestic solid wastes are some of natural and anthropogenic stresses/disturbances occurring in wetland ecosystems (Keddy 2010; Zhang and Ma 2011; Means et al. 2017). Most wetland ecosystems are often exposed to a variety of natural and anthropogenic disturbances, and the effects of these perturbations are non-quantifiable and vary from place to place (Kashian et al. 2007). These disturbances impact on the species composition of wetland communities by increasing or decreasing the diversity of species depending on the stress tolerance and stress avoidance ability of them (Zhang and Ma 2011; Means et al. 2017).

Mollusks are a group of organisms that are commonly present in wetlands and associated ecosystems and they significantly contribute to the macrobenthic community in wetlands. The wide range of habitat preferences and presence of the slow- moving or sedentary adult stage of macrobenthic mollusks have made them ideal indicators for predicting the effects of disturbances on wetland communities (Oehlmann and Schulte-Oehlmann 2003). Many researchers have conducted studies to assess the suitability of using macrobenthic mollusk species to quantify the disturbances associated with aquatic ecosystems (Clarke 1990; Gamlath and Wijeyaratne 1997; Borja et al. 2003; Borja and Muxika 2005; Dahanayaka and Wijeyaratne 2006; Dehghan-Madiseh et al. 2012; Idroos and Manage 2012; Wijeyaratne and Bellanthudawa 2017). Most of such studies are based on the use of univariate assessment approaches such as the use of abundance data and use of diversity indices. Some studies have relied on multivariate assessment methods to determine the relationships among the distribution of macrobenthos with the environmental parameters (Dahanayaka and Wijeyaratne 2006; Wijeyaratne and Bellanthudawa 2017). However, it is considered that multivariate techniques are more sensitive and accurate compared to univariate methods in studying environmental disturbance associated community changes in ecosystems (Warwick and Clarke 1993).

In the recent years, assessments of disturbances in wetland ecosystems have conducted using graphical representations such as Abundance-Biomass Comparison (ABC) approach. This method has been used to assess the disturbances on macrobenthic communities (Beukema 1988; Rahman and Bharkati 2004; Dehghan-Madiseh et al. 2012) as well as bird populations in coastal wetland ecosystems (Meire and Dereu 1990). The abundance biomass comparison is illustrated in a graphical model that assesses the changes in three components; the number of species, the abundance of species and biomass of species in response to environmental parameters. The changes in the pattern of abundance and biomass of species are used as an indicator of the level of disturbance (Warwick 1986). In the graphical presentation, depending on the level of disturbance, the biomass curve may lie above or below the abundance curve or may cross each other once or several times (Warwick 1986). Therefore, predictions on the level of disturbance at a particular ecosystem can be made based on the graphical representations of changes in the community (Beukema 1988; Rahman and Bharkati 2004; Dehghan-Madiseh et al. 2012). Abundance biomass comparison approach for assessing environmental stress is useful over the univariate disturbance assessment methodologies, as this does not require sampling of a reference site to compare the level of disturbance (Beukema 1988; Rahman and Bharkati 2004; Dehghan-Madiseh et al. 2012). Therefore, this approach considerably reduces time and costs associated with the sampling of a reference site. In addition, the abundance biomass comparison approach is less complex and easily applicable compared to multivariate environmental stress assessment methods (Warwick 1986).

In spite of the advantages of this approach, this method is not widely used in many parts of the world. Most of the environmental stress assessments are focused on heavy metal (Zhang and Ma 2011; Esmaeilzadeh et al. 2016), nutrient or organic pollutants (Zhang et al. 2015; Mukherjee 2011), and identification of biomonitoring organisms or biomarkers (Zhang and Ma 2011; Bonanno et al. 2017; Alonso et al. 2018) from the stressed ecosystems. The present study was conducted with a view to applying the abundance biomass comparison approach, to predict the environmental stress levels in rehabilitated and non-rehabilitated areas in a tropical wetland system and to identifying the benthic macroinvertebrate species that would be able to reflect the disturbances in this wetland ecosystem.

MATERIALS AND METHODS

Study area

Among the wetlands in Sri Lanka, Diyawannawa wetland is one of the most popular urban wetlands located in the commercial capital of the country. This is primarily a low lying freshwater marsh at 0 m of mean sea level. Some parts of the wetland are dredged, banks are restored and the aquatic vegetation is removed using mechanical removal methods in order to improve the water retention capacity of the wetland. In the non–rehabilitated area of the wetland, the human interventions on the wetland ecosystem are minimal and are maintained in pristine conditions. This area is rich in biodiversity and provides habitats for several threatened and endemic species in Sri Lanka (Wijeyaratne and Bellanthudawa 2017).

The present study was carried out from April to December 2016 to cover the monsoonal and non-monsoonal seasons. Six sampling sites were selected from the study area to represent rehabilitated and non-rehabilitated areas. The locations of the sampling sites in the Diyawannawa wetland is shown in Fig 1. Site A (6° 54'.585"N, 79° 54'.722" E), Site B (6° 54'.664" N, 79° 54'.633" E) and site C (6° 54'.609" N, 79° 54'.604" E) were located in the non–rehabilitated area of the wetland. Site D (6° 54'.68" N, 79° 54'.610" E), Site E (6° 54'.751" N, 79° 54'.735" E) and Site E (6° 54'.741" N, 79° 54'.525" E) were located in the rehabilitated area of the wetland.

The sites in the non-rehabilitated area (Sites A, B and C) were characterized by having a thick vegetation cover in the wetland banks. In the rehabilitated area, Site D was characterized by the dominance of aquatic macrophytes, Site E was receiving runoff from small scale poultry farms located within 100 m of the wetland and Site F was located in a highly-urbanized area and was prone to human settlement associated disturbances including domestic waste water and storm water input.

Shallow sediment quality parameters

From each site shallow sediments samples (0 - 0.4 m depth) were collected for sediment quality analysis and benthic mollusk diversity determination. Sampling was carried out once in 6 weeks for a period of 7 months from April to December in 2016.

At each sampling site, sediment pH and conductivity were measured *in-situ* using the calibrated digital multiparameter (YSI Environmental Model-556 MPS) as described in USEPA (1997). Sediment organic matter content was measured in the laboratory using the loss upon ignition method and the percentage sand, silt and clay content of the sediments were measured using the sedimentation jar.

Sediment quality parameters were measured in triplicate within a 1 m^2 area and averaged for each sampling site.

Sampling of macrobenthic mollusks and determination of biomass

At each site, five replicate sediment samples from an approximate sediment depth of 0 - 0.4 m were collected using the Peterson grab. The collected samples were preserved in 5 percent Rose Bengal Solution on site and were transported to the laboratory. In the laboratory, the samples were wet sieved through 4 mm, 2 mm and 1 mm mesh sieves to separate benthic mollusks. The organisms retained in each sieve were collected and preserved in 10% formalin and after a week they were transferred into 10% ethyl alcohol to prevent dehydration as described by Dahanayaka and Wijeyaratne (2006). Mollusks were identified to family level using keys given by Fernando and Weerawardhena (2002). The number of individuals of each taxon and the number of families at each sampling site were counted. Ash-free dry weight (AFDW) analysis as described by Meire and Dereu (1990) was determined for biomass measurement. The collected macrobenthic mollusks were dried for 24h at 70°C in the oven **(**Model: BRIT.PAT.NO: 882942**)** and incinerated for 2h at 550°C using the muffle furnace (Model no: DMF/03 and LENTON FURNANCE ECF 12/6) (Meire and Dereu 1990).

Data analysis

After confirming the normality using Anderson-Darling test, the spatial variation of physical and chemical parameters of sediments at each sampling site in monsoonal and non-monsoonal seasons was analyzed using one way ANOVA followed by Tukey’s pair-wise comparison. The percentage sand, silt, clay and TOC were arcsine transformed before analysis. The modified biotic index was calculated for each study site and the water quality and the level of organic pollution of the study sites were predicted as described by Mandaville (2002).

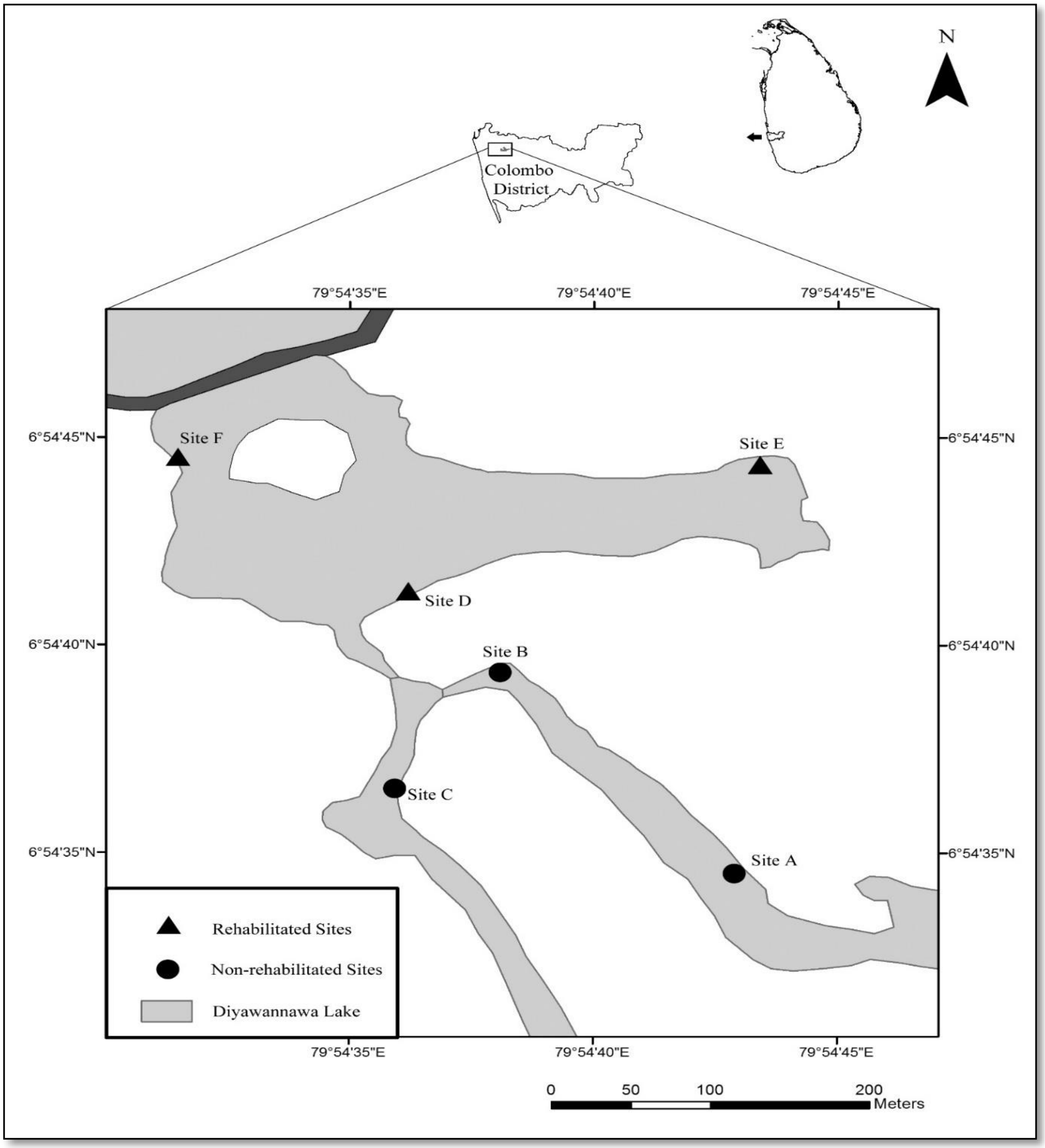

Fig. 1 The map of the study area indicating the locations of the sampling sites at the non-rehabilitated and rehabilitated areas of the Diyawannawa wetland.

The changes in the dominance pattern of macrobenthic assemblages based on the abundance and biomass were assessed using the Abundance-Biomass Comparison (ABC) method (Warwick 1986). The abundance of freshwater macrobenthic mollusks (number of the individual per m^2) and the biomass of freshwater macrobenthic mollusks (g per m^2) for each species were calculated. These parameters were arranged according to the dominance order in covering both aspects of abundance dominance and biomass dominance for each sampling site. Thereby species in each sampling site were ranked according to the importance based on percent dominance of abundance or biomass as described by Warwick (1986). The abundance and biomass comparison graphs were developed and the shapes of the graphs were compared with the typical comparisons described by Warwick (1986).

Clarke's W statistic (Clarke 1990) describing the degree and direction of separation of the abundance biomass curves was calculated using the following formula:

$$W = \sum_{i=1}^{S} \frac{(B_i - A_i)}{[50(S-1)]}$$

where S is the number of species, A_i is abundance value of the each of species rank i, and B_i is biomass value of each species rank, i. A_i and B_i need not to be the same species, as species are ranked separately for each abundance measure.

RESULTS

Shallow sediment quality parameters

The spatial variation of mean ± SD of shallow sediment quality parameters in the monsoonal season is given in Table 1. There was a significant spatial variation of percentage sand, clay and silt contents and the conductivity during the monsoonal season ($p<0.005$; ANOVA, Tukey's pairwise comparison; Table 1). Significantly high percentage clay content was recorded from sites E and F of the rehabilitated area and the highest conductivity was recorded from site F. Significantly highest percentage sand content and significantly lowest conductivity were recorded from site B.

Table 1 Spatial variation of mean ± standard deviation of sediment quality parameters at each sampling station in the monsoonal season. For each parameter, mean values indicated by different superscript letters at each row are significantly different from each other (ANOVA, Tukey's pairwise comparison; n = 7).

Parameter	Site A	Site B	Site C	Site D	Site E	Site F
% sand	74.32 ± 1.15^a	90.47 ± 1.89^b	81.18 ± 0.48^a	71.17 ± 2.27^a	12.15 ± 0.07^c	9.09 ± 0.38^c
% silt	16.62 ± 0.18^a	6.51 ± 1.60^b	13.51 ± 0.15^a	22.69 ± 1.56^c	19.96 ± 0.37^c	21.80 ± 0.29^c
% clay	9.11 ± 1.05^a	3.03 ± 1.36^b	5.45 ± 1.37^b	6.26 ± 0.72^b	67.94 ± 0.32^c	69.16 ± 0.17^c
% Organic matter	12.41±0.02	12.33±0.03	12.43±0.03	12.37±0.01	12.49±0.06	12.45±0.06
conductivity (µS/cm)	47.54 ± 0.84^a	43.3 ± 0.96^a	67.81 ± 1.23^b	79.00 ± 0.30^c	79.60 ± 0.48^c	92.43 ± 0.96^d
pH	6.00 ± 0.09^b	5.21 ± 0.28^b	5.96 ± 0.13^b	6.07 ± 0.18^a	6.00 ± 0.18^b	6.17 ± 0.12^a

The spatial variation of mean ± SD of shallow sediment quality parameters in non- monsoonal season is given in Table 2. Only sediment conductivity and percentage sand content showed a significant spatial variation in the non-monsoonal season ($p < 0.05$; ANOVA, Tukey's pairwise comparison, Table 2). The highest sediment conductivity was recorded from site F of the rehabilitated area and significantly lower percentage sand content was recorded at Site C of the non-rehabilitated area (Table 2).

At each site, the percentage sand, clay and silt contents during the non-monsoonal season were different than those during the monsoonal season. In the non-monsoonal season, each site showed high percentage clay contents and very low percentages of sand and silt contents (Table 2). However, in the monsoonal season, sites A, B, C and D showed high percentage sand content and sites E and F showed high percentage clay contents than other particles (Table 1).

Percentage dominance of abundance and biomass of macrobenthic mollusks

Eight species of macrobenthic mollusks, namely, *Bithynia tentaculata, Melanoides turbeculata, Melanoides turriculus, Thiara scabra*, *Lamellidens marginalis, Pila globosa, Gyraulus saigonensis* and *Lymnaea stagnalis* were recorded from the study sites. The percentage abundance of macrobenthic mollusk species among sampling sites in non-rehabilitated and rehabilitated areas during the monsoonal and non-monsoonal seasons is given in Fig. 2. *Bithnia tentaculata* was the dominant species in all the study sites except site D of the rehabilitated area in both monsoonal and non-monsoonal seasons. However, in both seasons, *Melanoides turriculus* showed significantly higher abundance in the site D than in other sites. *Pila globosa* was recorded only from sites E and F of the rehabilitated area both during monsoonal and non-monsoonal seasons (Fig. 2). *Tharia scraba* showed higher abundance in sites E and F of the rehabilitated area compared to other sites (Fig. 2).

The percentage dominance of biomass of macrobenthic mollusk species among sampling sites in non-rehabilitated and rehabilitated areas during the monsoonal and non-monsoonal seasons is given in Fig. 3. *Bithnia tentaculata* showed the highest percentage biomass in all the study sites in the non-monsoonal season. In the monsoonal season, *Bithnia tentaculata* showed the highest biomass in all study sites, except in Site F. *Lamellidens marginalis* showed the highest biomass (43.9%) in site F in the monsoonal season (Fig. 3). In the monsoonal season, the highest percentage biomass of *Bithnia tentaculata* was recorded at Site C (91.9%) while in the non-monsoonal season it was at site B (81.5%). *Tharia scraba* showed higher percentage biomass in site F than in site E in both seasons (Fig. 3).

Correlation of abundance and biomass with sediment quality parameters

The correlation between the abundance of macrobenthic mollusks and sediment quality parameters (Table 3) indicated that the abundance of *Bithynia tentaculata* (r = 0.645), *Pila globosa* (r = 0.668), *Lamellidens marginalis* (r = 0.697) and *Melanoides turbeculata* (r = 0.611) showed significant positive correlations with sediment conductivity. In addition, the abundance of *Bithynia tentaculata* (r = 0 .865) and *Pila globosa* (r = 0.885) also showed significant positive correlations with percentage clay content of the sediments. Further, the abundance of *Bithynia tentaculata* was positively correlated (r = 0.627) with total organic matter content of the sediments (Table 3). The other macrobenthic mollusk species did not show significant correlations of their abundance with the sediment quality parameters (Table 3).

The modified biotic index (MBI) values for monsoonal and non-monsoonal seasons in each site, and water quality characterization based on MBI as described by Mandaville (2002) are given in Table 4. The MBI values of the study sites ranged from 6.873 to 7.654 and indicated similar variations in monsoonal and non-monsoonal seasons. Sites E and F showed comparatively higher MBI values during both seasons and the lowest MBI was recorded at site D during the study period. However, the spatial variation of MBI during both seasons was not statistically significant (ANOVA; $p > 0.05$, Table 4). As classified by Mandaville (2002), the predicted water quality of the study sites based on MBI ranged from moderately poor to poor and degree of organic pollution ranged from significant to very significant (Table 4).

Table 2 Spatial variation of mean values ± standard deviation of sediment quality parameters at each sampling station in the non-monsoonal season. For each parameter, mean values indicated by different superscript letters at each row are significantly different from each other (ANOVA, Tukey's pairwise comparison; n=7).

Parameter	Site A	Site B	Site C	Site D	Site E	Site F
% sand	2.00 ± 0.01^a	1.98 ± 0.01^a	1.13 ± 0.01^b	1.68 ± 0.01^a	1.56 ± 0.04^a	1.76 ± 0.02^a
% silt	1.20±0.01	1.16±0.00	1.12±0.01	1.24±0.02	1.32±0.02	1.43±0.02
% clay	96.8±0.03	96.9±0.04	97.8±0.04	97.1±0.03	97.1±0.06	96.8±0.04
% Organic matter	12.44±0.02	12.34±0.01	12.26±0.02	12.33±0.06	12.47±0.02	12.54±0.03
conductivity (µS/cm)	48.63 ± 1.18^a	44.55 ± 1.10^a	75.45 ± 5.65^b	67.72 ± 5.06^b	73.23 ± 3.39^b	89.95 ± 2.60^c
pH	6.45±0.07	6.58±0.01	6.47±0.12	6.20±0.13	6.56±0.08	6.50±0.16

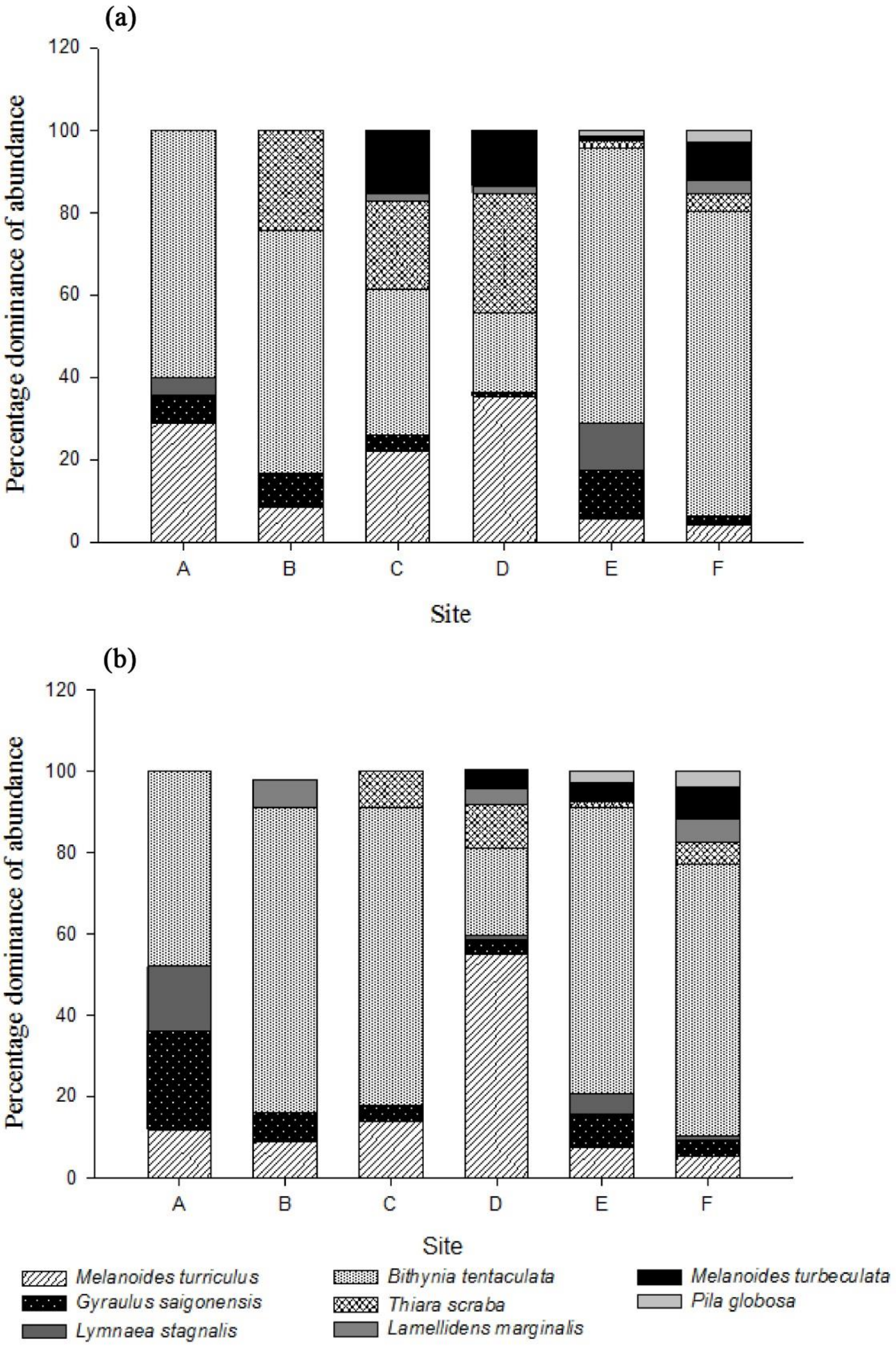

Fig. 2 The percentage dominance of abundance of freshwater mollusk species among sampling sites during the study period (a: Non - Monsoonal season; b: Monsoonal season). Sites A, B, and C; non-rehabilitated area and sites D, E, and F; rehabilitated area.

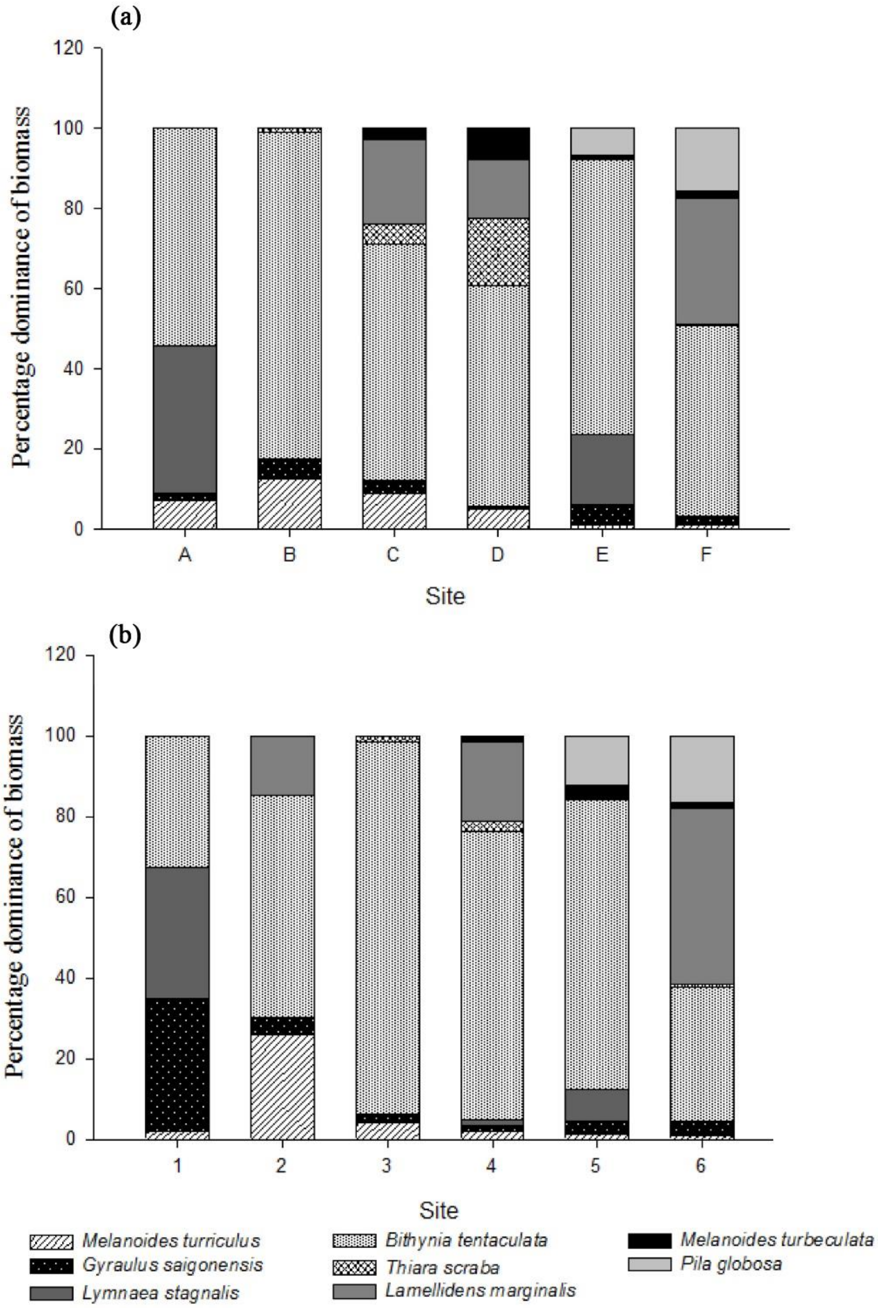

Fig. 3 The percentage dominance of biomass of freshwater mollusk species among sampling sites during the study period (a: Non-monsoonal season; b: Monsoonal season). Sites A, B, and C; non-rehabilitated area and sites D, E, and F; rehabilitated area.

Table 3 Pearson's correlation coefficients (r) between the abundance of freshwater mollusks species and sediment quality parameters of the study sites during the study period.

Species	Shallow sediment TOM	Shallow sediment pH	Shallow sediment conductivity	Sand %	Clay %	Silt %
Bithynia tentaculata	0.627**	0.134	0.645**	-.0445**	0.865**	0.133
Gyraulus saigonensis	0.120	0.282**	0.310**	-0.341	0.314**	-0.050
Lamellidens marginalis	0.216*	0.126	0.697**	-0.267*	0.231*	0.023
Lymnaea stagnalis	0.065	0.154	0.109	-0.226*	0.189	0.048
Melanoides turbeculata	0.195	0.063	0.611**	0.005	-0.092	0.392**
Melanoides turriculus	-0.062	0.057	0.148	0.156	-0.187	0.221*
Pila globosa	0.265*	0.144	0.668**	-0.332**	0.885**	0.042
Thiara scabra	-0.028	0.140	0.166	0.122	-0.178	0.310**

** significant at 99% level
* significant at 95% level

Table 4 The modified biotic index ±SEM values for monsoonal and non-monsoonal seasons for each site, and water quality characterization based on MBI as described by Mandaville (2002). In each site, mean MBI values during monsoonal and non-monsoonal seasons were not significantly different (ANOVA, p>0.05).

Site	MBI value		Water quality	Degree of pollution
	Monsoonal	Non monsoonal		
A	7.371±0.10	7.297±0.10	Moderately poor	Significant organic pollution
B	7.160±0.10	7.154±0.10	Moderately poor	Significant organic pollution
C	7.093±0.10	7.124±0.08	Moderately poor	Significant organic pollution
D	6.873±0.10	6.987±0.10	Moderately poor	Significant organic pollution
E	7.619±0.09	7.654±0.10	poor	very significant organic pollution
F	7.548±0.10	7.589±0.08	poor	very significant organic pollution

Modified biotic index values

Abundance biomass comparison curves

The cumulative percentage abundance and biomass was used to create the abundance biomass curves (ABC curves). These curves were used to evaluate the disturbance status at each sampling site. The ABC curves for the study sites in the rehabilitated and non-rehabilitated areas of the Diyawannawa wetland during the non-monsoonal season are given in Fig. 4. In all the sites, except Site F of the rehabilitated area, the cumulative percentage dominance of abundance curve was located above the biomass curve, indicating undisturbed environmental conditions in these sites (Fig. 4). In the site F of the rehabilitated area, the cumulative percentage dominance of abundance and the cumulative percentage dominance of biomass curves were crossing each other, indicating partially disturbed environmental conditions at this site (Fig. 4).

The ABC curves for the study sites in the rehabilitated and non-rehabilitated areas of the Diyawannawa wetland during the monsoonal season are given in Fig. 5. The sites A, B, and F the showed overlapping cumulative percentage dominance of abundance and cumulative percentage dominance of biomass curves indicating partially disturbed environmental conditions at these sites. The site C of the non-rehabilitated area, showed a typical undisturbed condition. In the sites D and E of the rehabilitated area, the cumulative percentage dominance of biomass curve was located above the abundance curve, indicating disturbed environmental conditions in these sites during monsoonal season (Fig. 5).

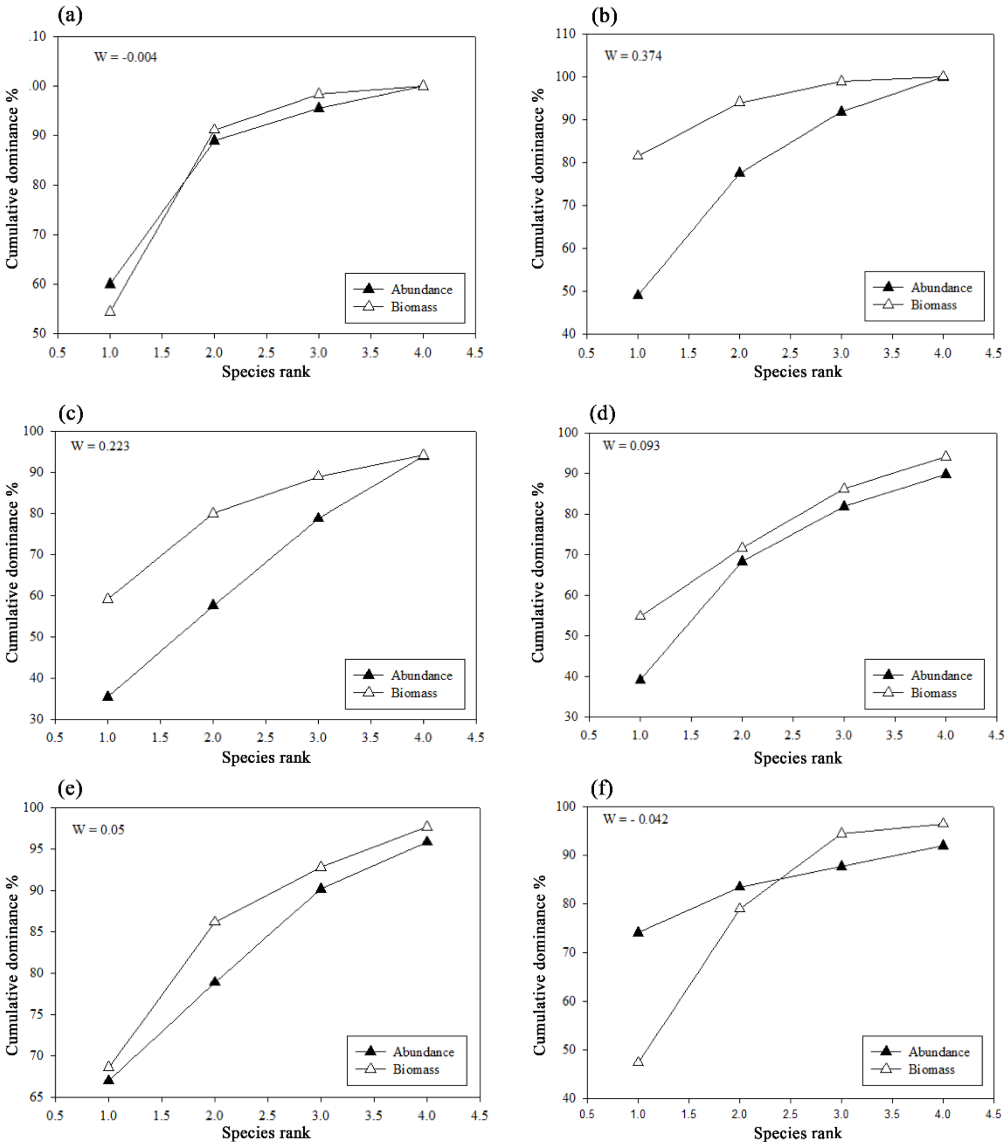

Fig. 4 The abundance biomass comparison curves for the study sites at the rehabilitated and non-rehabilitated areas of the Diyawannawa wetland during the Non-monsoonal season (a: Site A; b: Site B; c: Site C; d: Site D; e: Site E; f: Site F). Sites A, B and C; non-rehabilitated area and sites D, E, and F; rehabilitated area.

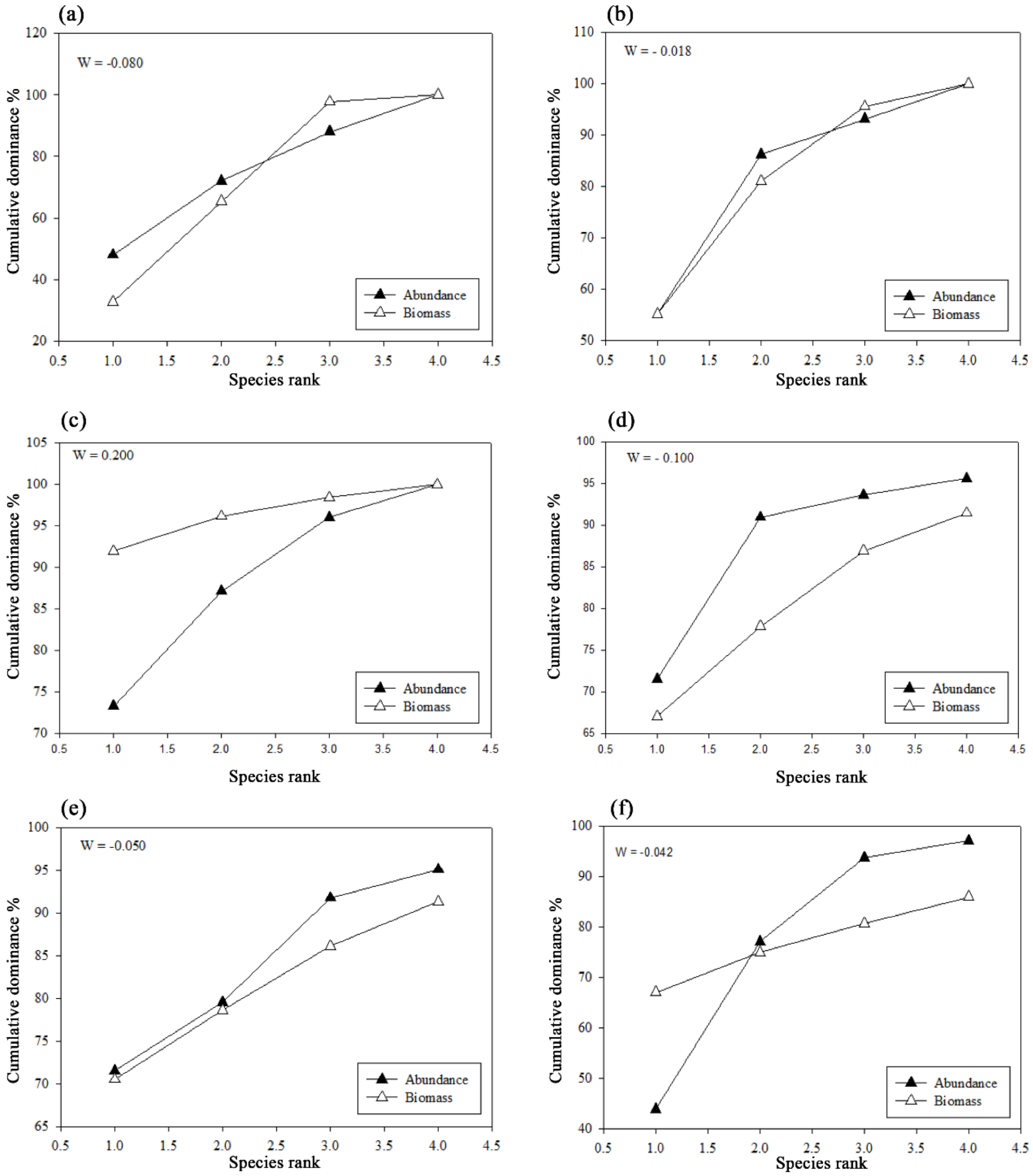

Fig. 5 The abundance biomass comparison curves for the study sites at the rehabilitated and non-rehabilitated areas of the Diyawannawa wetland during the Monsoonal season (a: Site A; b: Site B; c: Site C; d: Site D; e: Site E; f: Site F). Sites A, B and C; non-rehabilitated area and sites D, E, and F; rehabilitated area.

DISCUSSION

Many freshwater mollusks are known as key species for the functioning of bottom habitats in freshwater wetlands (Barbour et al. 1999). They can respond to the stressor or disturbance regimes by changing their population and community structure (Smitha and Mustak 2017). As they live a sedentary or slow-moving life style in the adult stage, these mollusk communities are readily exposed to changes in the aquatic environment. The responses to changing environmental conditions can be expressed by changes in their community or population structure and composition through changes in abundance and biomass. Therefore, freshwater mollusk communities and populations are considered as important ecosystem health indicators (Ali and Fishar 2005; Idroos and Manage 2012).

Sediment quality parameters can affect the distribution and abundance in macrobenthic mollusks in the aquatic ecosystems. The present study indicated significant spatial variations of silt and clay contents and sediment conductivity in the monsoonal season in Diyawannawa wetland. In tropical countries, heavy intermittent rain events are common in the monsoonal season, thereby increasing surface runoff and sediment deposition in the aquatic systems were recorded (Rahman and Barkati 2004). The sites E and F of the rehabilitated area of this wetland system, were receiving runoff from animal feedlots, urban and domestic runoff, indicating that there is a high possibility of increased sedimentation during the rainy season. However, the sites in the non-rehabilitated area and the site D of the rehabilitated area contained a thick vegetation cover, which may have helped in sediment retention and controlling input of clay and silt into these sites. However, in the non-monsoonal season the absence of significant variations in silt and clay content of the sediments in the study sites could be due to less runoff and sedimentation during the non-rainy period.

The abundance and biomass of the macrbenthic mollusks were dominated by *B. tentaculata* in almost all the sites (Fig. 3) where *Pila globosa* showed a significant contribution to abundance, and biomass in sites E and F of the rehabilitated area. *Pila globosa* is a common gastropod abundantly found in many tropical freshwater wetlands (Sousa et al. 2005). However, the distribution of *P. globosa* Diyawannawa wetland was restricted to sites E and F of the rehabilitated area and their abundance showed significant positive correlations to sediment conductivity and percentage clay content (Fig. 2, Table 3). Similar results have been recorded in Indian wetlands and it has been indicated that sediment quality parameters such as conductivity and particle size distribution can play a significant role in determining the abundance and distribution of gastropods including apple snails (Mannino and Montagna 1997, Sousa et al. 2005; Sousa et al. 2006; Smitha and Mustak 2017).

The abundance-biomass comparison (ABC) approach integrates species richness, species abundance and biomass into a visual model, which can be used to predict the level of disturbance to each community (Rakocinski et al. 2000). Clarke's W statistic is also an important indicator of the level of disturbance in the ecosystems. The W statistic value can range between -1 and +1, where W is +1 for even abundances across species but biomass is dominated by a single species (undisturbed), and W is -1 indicating severely disturbed situation (Clarke 1990, Clarke and Warwick 2001). There can be many intermediate situations in between these two extreme environment conditions as well.

In the present study, during the non-monsoonal season, W statistic of the sites ranged from -0.004 to 0.374. In the monsoonal season, W statistic of the sites ranged from -0.1 to 0.2. According to the W statistic all the sites except site C of the non-rehabilitated area were minus values indicating moderate to a severe disturbance at these sites in the monsoonal season. The ABC curves confirmed the results of the W statistic. According to the ABC curves, sites A, B, and F indicated partially disturbed environmental conditions and site C showed a typical undisturbed condition in the monsoonal season (Fig. 5). Further, Sites D and E showed disturbed environmental conditions in this season (Figure 5).

However, in the non-monsoonal season, only site F of the rehabilitated area showed partially disturbed environmental conditions and other sites were at typical undisturbed state (Fig. 4). During the field visits of the present study, it was observed that the sites in the rehabilitated area were continuously affected due to removal of riparian vegetation, cattle encroachments, the input of domestic and storm water runoff and eutrophication. In contrast, the sites in the non-rehabilitated area had less frequency of disturbances. The results of ABC analysis agreed with the variations of the sediment quality parameters in the study sites during monsoonal and non-monsoonal seasons. During the monsoonal season the disturbances on study sites were higher compared to the non-monsoonal season due to intermittent heavy rain events and storm water runoff might bring allochthounous nutrients to the wetland which could have effects on the wetland community structure, These effects were reflected in differences indicated by ABC curves in the two seasons (Figs 4 and 5).

P. globosa that was dominated in disturbed sites during both monsoonal and non-monsoonal seasons, was also a very common species recorded in disturbed environmental conditions in other regions of the world (Rahman and Barkati 2004; Sousa et al., 2005, Sousa et al. 2006; Smitha and Mustak 2017). Also, the findings of the present study were comparable with similar studies that used ABC approach to represent the ecosystem stresses in various types of ecosystems including wetlands (Bilkovic et al. 2006, Cardoso et al. 2012). In a study conducted in estuarine environments of the Chesapeake Bay, U.S.A., the ABC approach was successfully used to reflect the effects of land use patterns at near and far proximities to shore on macrobenthic community (Bilkovic et al. 2006). The study suggested that the significant temporal variations of increased precipitation can affect the macrobenthic abundance and biomass thereby, reflecting these changes in ABC curves (Bilkovic et al. 2006). A similar study conducted in Cuiabá River in Brazil using phytoplankton abundance biomass distributions suggested that surrounding land uses and distances between the lakes and the river affected biomass and abundance of phytoplankton in the wetland (Cardoso et al. 2012). A study assessing the community composition of polychaetes in a riverine wetland near Shenzhen River, Hong Kong indicated that input of polluted sediments can have significant effects on changes in abundance, biomass as well as changes in community structure (Chen et al. 2012).

A similar trend was observed in the results of the water quality and pollution classification using MBI (Table 5). The MBI of the study sites, during the project period, ranged from 6.873 to 7.654. During both monsoonal and non-monsoonal seasons, water quality of the study sites based on MBI ranged from moderately poor to poor and degree of organic pollution ranged from significant to very significant (Table 5). The results of the MBI were in agreement with the interpretations of the ABC approach indicating higher level of pollution and poor water quality in site F in both monsoonal and non-monsoonal seasons. However, although the MBI showed similar trend in site E, the ABC approach classified site E as disturbed site only during the monsoonal season. This may be due to the variations in abundance and biomass of macrobenthic mollusks in this site, during both seasons. In both seasons the highest contribution to abundance and biomass of the site E was *B. tentaculata*. However, during the monsoonal season the abundance contributions of the other species were comparatively higher compared to those during non-monsoonal season. According to Warwick (1993), during disturbed conditions, the number of opportunistic species tend to increase which makes them numerically dominant. Therefore, in this site other species can be considered as opportunistic species, whereas *B. tentaculata* was the conservative species.

Disturbances regimes are also important in wetland health evaluation. The abundance-biomass comparison curves are assessment tools that can evaluate pollution or disturbance level in relation to the species composition of the wetland (Warwick 1986).

CONCLUSION

Bithynia tentaculata and *Pila globosa* were identified as characteristic gastropod species that could be used to classify study sites in the rehabilitated and non-rehabilitated areas of the Diyawannawa wetland system. Further, the abundance, biomass comparison curves, W statistic and the water quality and pollution status classification based on MBI can be considered as very important interrelated parameters in assessing and comparing the level of disturbance to the macrobenthic mollusk community. The results of the present study can be extrapolated to other tropical wetland systems to predict the levels of disturbance and to identify characteristic organisms to predict the environmental conditions in the wetland health assessment programmes.

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