Development of a Macroinvertebrate–based Index of Biotic Integrity (MIBI) for Colombo-Sri Jayewardenepura Canal System

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Abstract

Macroinvertebrates have been identified as excellent indicators of stream/ wetland health as they respond rapidly to environmental changes and provide short to medium term pollution history records. Current study was aimed to develop a Macroinvertebrate-based Index of Biotic Integrity (M-IBI) which is a new approach to monitor stream/wetland health of Colombo-Sri Jayewardenepura canal system. Sixty eight macroinvertebrate samples were obtained using a D-framed kick net from ten stations namely Kotte, Nawala, OUSL, Kirimandala Mw., Wellawatta, Orugodawatta, St. Sebastian, Beira Lake, Buthgamuwa and Royal Park representing main branches of the system and marshes covering dissimilar environmental conditions of the canal system during the period of Nov. 2008 to June 2009 on monthly basis. Habitat characteristics and some water quality parameters also recorded. For the index development, those ten stations were grouped into two as 'Reference' and 'Degraded' based on their environmental conditions. Then ten candidate metrics were selected out of 41 for M-IBI development after evaluating their sensitivity and appropriateness. Validity of the index was tested with a new independent data set. Scores acquired were positively correlated with DO values ($r = 0.578$). That concluded the potential of using M-IBI developed for biological monitoring and improving biotic integrity of streams/ wetlands.

Keywords: *Macroinvertebrates, stream health, biotic integrity, Multimetric index, Colombo-Sri Jayewardenepura canal system*

1. Introduction

The canal system which is in and around Colombo-Sri Jayewardenepura area is currently in such an environmentally deteriorated condition due to rapid development and urbanization of the area. The quality of water and habitat in most of the areas are influenced by industrial and public effluent discharge to the canal system. According to the Beira Lake Restoration Study (1993) cited by Fernando (1994), the data collected by the Central Environmental Authority during a period of 23 months (from March 1991 to February 1993) has shown that St. Sebastian canal, which is a branch of the Colombo canal system, had recorded high turbidity, BOD and COD values, richer in nutrients; reduction of nitrate into nitrite and ammonia (due to eutrophication), high concentrations of metals and faecal coliform.

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These records have already shown an unhealthy condition of the canal system for living beings. Also it has been severely affected on well being of the community live around the canal system. Aquatic macroinvertebrates are organisms that are large enough to be seen with the naked eye, lack of a backbone and inhibit all types of waters including lentic, lotic and muddy habitats (Viklund, 2011). They are capable of indicating any change in the environment through their responses at different levels of organization, ranging from the individual animal to the total invertebrate community (Hodkinson and Jackson, 2005). Since they live in the water for all or most of their life cycle, are exposed directly to the stress of pollution and the prevailing conditions of the aquatic environment, are easy to collect, differ in their tolerance to amount and types of pollution, are easy to identify, often live for more than one year thus well suited to long-term observation of stresses. Their high species diversity which means many potentially different reactions to many different environmental effects can be used as bioindicators for assessing and monitoring the state of health of aquatic environments (Invertebrates as indicators, 2008). The biological integrity of a stream or an aquatic ecosystem means how well the habitat can support biological communities, including algae, invertebrates, fish, aquatic mammals and birds. For a given habitat, to have high biological integrity, it should be unimpaired or minimally disturbed by human or other activities and must contain a diverse assemblage of naturally occurring plants and animals (Jensen, 2007).

Multimetric indices are commonly used for evaluating the biological condition of water bodies. Most multimetric indices consist of a number of measures or metrics (attributes), describing a specific assemblage like fish or macroinvertebrates, which are combined into a single 'multimetric' value representing the condition of a water body (Blocksom, 2003). These metrics can represent a wide range of ecological characteristics, including taxa richness, taxonomic composition, pollution tolerance, functional feeding groups, and behavioural habits. The Indices of Biotic/Biological Integrity (IBI) are one form of Multimetric index that focuses on Fish, Periphyton, or Benthic communities. These IBIs are region-specific due to the variations in communities across a wide range of ecological habitats. Therefore it is only applicable only for regions that show same environmental conditions (Wittman and Mundahl, 2002).

This study was aimed to develop a macroinvertebrate-based multimetric index of biological integrity as an alternative for other conventional methods like chemical and instrumental which are much expensive and need advance laboratory facilities.

2. Methodology

2.1. Study Area

Colombo-Sri Jayewardenepura (Diyawanna Oya) canal net work is a man made canal system which is located on the left bank of the lower valley of Kelani Ganga. It is situated in the Western province, Colombo district of Sri Lanka, latitudes 6 52' 55" - 6 55' 45" N and longitudes 79 52' 35" - 79 55' 15" E. Main catchment areas of the canal system are the low-lying marshlands known as Kolonnawa, Heen Ela and Kotte marsh (Figure 1). These are also important as major flood detention zones in the city of Colombo (Colombo Flood Detention Areas, 1995). Total area of the marsh is around 400ha. The canal system has 3 outfalls to the sea namely Mutwal (underground tunnel system), Wellawatta and Dehiwala (last two are open drains). The average depth of these canals is about 1.5 meters. It may vary seasonally due to heavy sedimentation of silts and bank erosion in the rainy season and it was frequently clogged with floating weeds & dumps (polythene, plastics & domestic wastes). It has been found that 43.5% of the families in the study area dump their household garbage into the marsh (Colombo Flood Detention Areas, 1995). Present study was carried out covering an extensive area of the canal network. Ten sites were selected considering human factors (such as density of settlements, industries, etc.), habitat characteristics (such as availability of marshlands and riparian vegetation) and representing significant canals and streams.

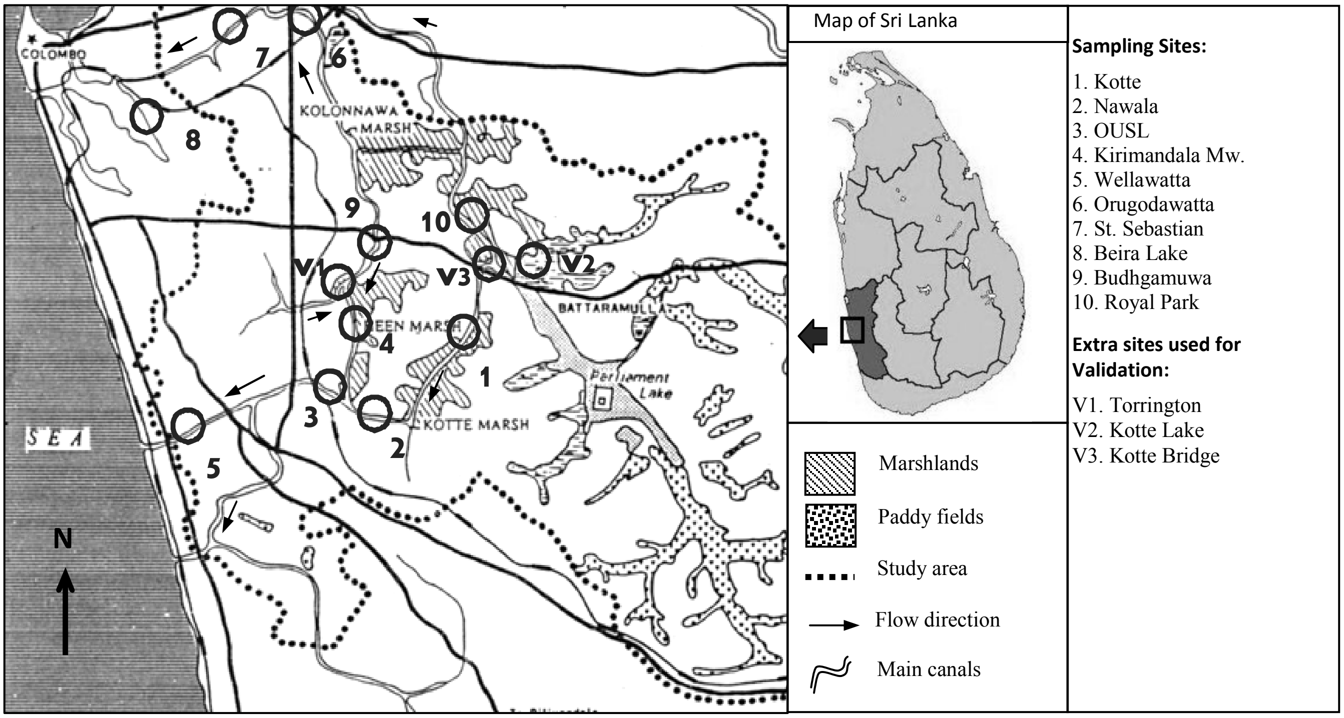

Figure 1: Study area map: Colombo - Sri Jayewardenepura canal system

2.2. Data Collection

Biological sampling and habitat assessments were made in ten sampling sites on monthly basis during the period of November 2008 to June 2009. After developing the index a new set of samples was obtained for validation test during the period of May to June 2011. It was included with 3 new sites. Macroinvertebrates were sampled using a D-framed kick net with a 400 µm mesh bag. It was dragged along both river banks within a known distance (10 meters). Collected macroinvertebrate samples were sorted and identified at least up to family level by using naked eye, a hand lens or microscope and according to both locally and internationally reputed keys and guides such as Mendis and Fernando (1962), Fernando, (1963, 1964, and 1969), The Waterwatch Australia Steering Committee (2004) and Bartlett (2009), then enumerated and computerized. Some of the physical and-chemical parameters like Temperature, pH value, Conductivity and Total Dissolved Solids (TDS) of the water were measured at the field using potable measuring instrument [Electrical Conductivity Metre (340-set1, WTW Co., Weilheim, Germany)]. For further water quality analysis, additional water samples were collected and brought into the laboratory. Then, other physical and chemical parameters were analyzed in the laboratory as mentioned below; dissolved oxygen (DO): Winkler Method, Biochemical Oxygen Demand (BOD): standard5-day BOD testing method, Alkalinity and Cl^- concentration: Titrimetric.

2.3. Data Analysis

Following steps were used to analyse data collected to develop the Macroinvertebrate-based Index of Biotic Integrity (M-IBI).

Step 1. Identification of Reference and Degraded sites (sampling stations): Reference and Degraded sites were identified and designated based on selection criteria (Table 1) that comprise both laboratory and field survey records (DO value, BOD value, urban land and Forested land use practices of the area).

Table 1: Criteria used for designating reference and degraded sampling sites

Reference site	Degraded site	Reference
DO value >= 2.5	DO value < 2.5	(Stribling et al., 1998)
Urban land use <= 50%	Urban land use > 50%	(Stribling et al., 1998)
Forested/Marshy land use > 25%	Forested/ Marshy land use < 25%	(Stribling et al., 1998)
BOD value < 5mg/L	BOD value >= 5mg/L	(Chauhan et al., 2011)

Step 2. Compiling and calculating candidate metrics: Candidate metrics for testing and potential inclusion in the M-IBI were nominated primarily by assessing the previous work done, parallel studies or documents/ protocols/ guidelines published by varies authors or institutes such as Stribling (1998), Chirhart (2003), Macroinvertebrates as bio-indicators (2008), Jensen (2007), Calculating and Interpreting the Genus-Level B-IBI (2001), Bennett and Rysavy (2003), Wittman and Mundahl (2002), Weigel et al. (2002), Mandaville (2002) and Karr et al. (2002). These Macroinvertebrate based 41 candidate metrics were grouped in to five and listed out with their possible response to environmental stresses (stream impairment) in Table 2.

Table 2: Candidate metrics and their predicted response to increasing stressors

Candidate Metric	Predicted response
1. Taxonomic Richness	
(i). Overall Species Richness	Decrease
(ii). Tot no of individuals of the sample (Average)	Decrease
(iii). Tot EPT (Ephemeroptera+Plecoptera+Tricoptera)	Decrease
(iv). No of Diptera Taxa	Decrease
(v). No of Molluscs Taxa	Decrease
(vi). No of Odonata Taxa	Decrease
(vii). No of Hemiptera Taxa	Decrease
(viii). No of Coleoptera Taxa	Decrease
(ix). No of Annelida/Policheata Taxa	Decrease
(x). No of Crustacea Taxa	Decrease
(xi). No of Chironomidae Taxa	Decrease
2. Taxonomic composition & Abundance	
(xii). % of Diptera	Increase
(xiii). % of EPT	Decrease
(xiv). % of Molluscs	Decrease
(xv). % of Odonata	Decrease
(xvi). % of Hemiptera	Decrease
(xvii). % of Coleoptera	Decrease
(xviii). % of Annelid/ Polycheats	Decrease
(xix). % of Crustacen	Decrease
(xx). % of Chironomids	Increase
(xxi). Most abundant species and %	Decrease

Table 2 continues …

3. Pollution Tolerance / Intolerance	
(xxii) Hilsenhoff family biotic index (FBI)	Increase
(xxiii) No of Intolerant Taxa	Decrease
(xxiv) No of Intolerant Individuals	Decrease
(xxv) % Intolerant Ind of the sample	Decrease
(xxvi) No of Tolerant Taxa	Increase
(xxvii) No of Tolerant Individuals	Increase
(xxviii) % Tolerant Ind of the sample	Increase
4. Trophic Structure (Functional Feeding Groups)	
(xxix) No of Predator Taxa	Decrease
(xxx) No of Collector - Gatherer Taxa	Variable
(xxxi) No of Collector - Filter Taxa	Variable
(xxxii) No of Scraper Taxa	Decrease
(xxxiii) No of Shredder Taxa	Decrease
(xxxiv) % Predator Individuals	Decrease
(xxxv) % Collector - Gatherer Individuals	Decrease
(xxxvi) % Collector - Filter Individuals	Decrease
(xxxvii) % Scraper Individuals	Decrease
(xxxviii) % Shredder Individuals	Decrease
5. Incorporated Diversity	
(xxxix) Shannon-Wiener diversity index (H)	Decrease
(xxxl) Simpson's Diversity Index (1-D)	Decrease
6. Proportional Metrics	
(xxxli) Heterogeneity	Decrease

Step 3. Selecting Candidate Metrics: The criterion used for the selection of Candidate Metrics was based on;

1. *Their sensitivity to stream impairment/ human influences:* Each candidate metrics was tested to determine its correlation with environmental parameters such as DO, Cl^-, TDS and Conductivity by using Pearson's Product-Moment Correlation method. Metrics showed significant correlation ($r >= 0.5$ / -0.5) with those environment parameters were considered further.

2. *Their ability to distinguish between Reference and Degraded sites*: The distributions of metric values of Reference and Degraded sites were compared using a non parametric statistical test (t test). Metrics whose values differed between reference and degraded sites ($p < 0.05$) were retained for further analysis, whereas those metrics having similar medians and distributions in reference and degraded sites were eliminated.

3. *Their contribution of non-redundant information to the M-IBI:* Many metrics are sensitive to the same change in conditions of stream habitat. These metrics that are highly correlated with one another do not contribute much new information to the M-IBI score (Stribling, 1998). Hence the redundancies among these metrics were calculated using Pearson's product-movement correlation method. Redundant metrics ($r >= 0.75$) were used in index combinations only if inclusion increased the index classification efficiency.

Step 4. Index development and scoring: Finalized metrics for the index development were further taken into consideration and the calculated metric values were converted to metric scores. Quartile statistics for each of the final metrics were calculated for both reference and degraded data sets. Metric values that are equal or above 25th percentile of reference sites were scored as 5 while metric values equal or lower than 25th percentile of degraded sites were scored as 0 and those were in between these two boundaries were scored as 3. To obtain the final M-IBI for a given site, scores obtained for all metrics simply added together. Metrics those expectations were reversed were scored conversely. Finally the qualitative ratings and the stream condition that describe the status of the canal assessed were developed for five rating categories as excellent, good, fair, poor and very poor by dividing the total index score into five equal classes.

Step 5. M-IBI testing and validation**:** Once the M-IBI was developed it was tested using a new independent data set of macroinvertebrates collected from ten sites of Colombo-Sri Jayawardhanpura Canal system during the period of April-May, 2011. Apart from seven sampling stations used for index development there were three (3) new sampling sites namely, Torrington, Kotte Lake (near renovation site) and Kotte Bridge (near Lion's club). Also to test the validity and to check if any relationship existed between the M-IBI and habitat parameters used in conventional monitoring, M-IBI scores were plotted against habitat parameters (DO value) for all ten sites.

3. Results and Discussion

3.1. Habitat assessment and designation of sampling stations

Based on the criteria developed for designating reference and degraded sites; Kotte, Nawala, OUSL, Buthgamuawa and Royal Park sites were declared as reference sites whereas the others were as degraded sites. Evaluation criteria and the scores obtained for sites are given in Table 3.

Table 3: Evaluation and designation of sampling stations base on their DO, BOD values, urban land use and Forested land use practices of the surrounding area

Sampling Station	DO value > 2.5	BOD value < 5mg/L	Urban Land Use < 50%	Forested Land Use > 25%	Total Score	Category (Reference>=3/ Degraded <3)
Kotte	1	1	1	1	4	Reference
Nawala	1	1	0	1	3	Reference
OUSL	1	1	0	1	3	Reference
Kirimandala MW	0	1	0	1	2	Degraded
Wellawatta	0	1	0	0	1	Degraded
Orugodawatta	0	1	0	0	1	Degraded
St. Sebastian	0	1	0	0	1	Degraded
Beira Lake	0	0	0	0	0	Degraded
Buthgamuwa	1	1	1	1	4	Reference
Royal Park	1	1	1	1	4	Reference

3.2. Metric selection and evaluation

Results for the first step of metrics evaluation was obtained by finding the correlation between 41 candidate metrics and DO, Cl-, TDS and Conductivity values, also between reference and degraded sites. Thirty one candidate metrics resulted Pearson's correlation coefficient value as (r) >=0.50 or -0.50 and got the conclusion as 'Positive'. As for the second step, again a t- test was done for all candidate metrics and out of them 11 metrics resulted as 'Positive'. Collectively, fifteen candidate metrics representing five main categories (ecological characteristics) were qualified for the next step which was for the redundancy. After considering the redundancy test results, ten metrics that had less occurrence of obtaining redundancy value (r) >= 0.75 were considered for the index development. However candidate metrics like; (i) overall species richness, (x) no of crustacean taxa, (xxx) Shannon-wiener index and (xxxli) Heterogeneity were included to the final list as to increase the classification efficiency.

3.3. Index development and scoring

As the final outcome, ten (10) out of forty one (41) candidate metrics were designated for the M-IBI development. Then their values were converted to unitless M-IBI scores as in Table 4.

Table 4: Scoring Criteria for the ten metrics used in Macroinvertebrates based Index of Biological Integrity (M-IBI)

Metrics	Predicted response to increasing stressors	M-IBI Score		
		5	3	1
Overall Species Richness	Decrease	>14.67	14.67 - 6.67	<6.67
No of Hemiptera Taxa	Decrease	>1.75	1.75 - 0.00	<0.00
No of Coleoptera Taxa	Decrease	>2.67	2.67 - 0.00	<0.00
No of Crustacea Taxa	Decrease	>2.25	2.25 - 0.25	<0.25
% of Diptera	Increase	<2.33%	2.33 - 51.79%	>51.79%
% of Odonata	Decrease	>2.04%	2.04 - 0.52%	<0.52%
No of Intolerant Taxa	Decrease	>1.25	1.25 - 0.50	<0.50
No of Collector - Gatherer Taxa	Decrease	>5.50	5.50 - 2.67	<2.67
Shannon-Wiener diversity index (H)	Decrease	>1.95	1.95 - 1.59	<1.59
Heterogeneity	Increase	<67.44%	67.44 - 87.77%	> 87.77%

Finally, the status or the narrative ratings of the M-IBI and their score were classed into five ranges (rating categories) as excellent, good, fair, poor and very poor as given in Table 05.

Table 5: M-IBI score ranges and corresponding narrative ratings

M-IBI Score	Stream condition (Narrative rating)
50 – 46	Excellent
38 – 45	Good
28 – 37	Fair
18 – 27	Poor
10 – 17	Very Poor

3.4. M-IBI testing and validation

M-IMI scores and stream conditions obtained from the validation test done with the independent data set (ten sites) are shown in Table 06. The M-IBI scores ranged from 17 to 40 for the tested sites. According to the test results, none of the sites were ranked as ‘Excellent’. Site named as Royal Park was ranked as ‘Good’ while others were ‘Fair’ for 6 sites (Nawala, OUSL bridge, Kirimandala Mw., Torrington, Kotte Lake & Buthdamuwa), ‘Poor’ for the sites called Senanayake Ground (Kotte) and Kotte bridge, and “Very Poor” for Wellawatta. These M-IBI scores were positively correlated (r = 0.578) with habitat parameter (DO values) recorded from same tested sites. Additional tests are needed to be conducted with more sites for further improvements.

Table 06: M-IBI scores and narrative rating (stream condition) of ten tested sites

Tag No	Site location	Canal name	M-IBI score	Stream condition (Narrative rating)
1	Senanayake lane	Kotte canal	20	Poor
2	Nawala Road	Kotte canal	30	Fair
3	Narahenpita Rd - OUSL bridge	Kotte canal	36	Fair
4	Kirimandala Mawatha	Heen ela (canal)	32	Fair
5	Near St Peter's College	Wellawatta canal	17	Very Poor
6	Heen Marsh	Torington canal	28	Fair
7	Wetland restoration site	Kotte lake	28	Fair
8	Kotte bridge - near Lion's club	Kotte canal	18	Poor
9	Buthgamuwa - Kolonnawa Marsh	Kolonnawa canal	36	Fair
10	Heen Marsh - near Royal Park	Heen ela (canal)	40	Good

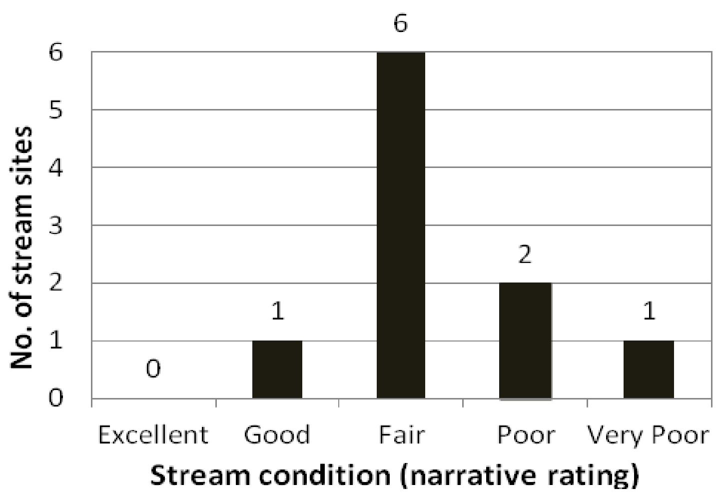

Figure 2: Overview of the stream condition from the scores obtained for ten sites tested

4. Conclusion

The M-IBI has shown the potential of using it for biomonitoring and improving biotic integrity of streams/ wetlands. Excluding monitoring the health of a natural freshwater ecosystem, M-IBI can be used for monitoring the progress of restored or constructed ecosystems particularly for a renovated wetland like Diyawannawa Oya. It is ready to be introduced to any government authorities institutes, neighbouring schools, universities, etc. who engaged in stream health monitoring.

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