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Application and development of invertebrate indices for water quality assessment in Indonesian streams

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Abstract

The invertebrate indices for assessing water quality have not been widely developed in tropical regions where invertebrate diversity is generally high and severe water quality degradation is ongoing. We compared the applicability of six existing invertebrate indices using the dataset from 23 Indonesian streams and developed a new index by modifying an existing one using Threshold Indicator Taxa Analysis (TITAN). Analyses using general linear models (GLMs) revealed that among the six existing indices, the biological monitoring working party (BMWP)-based scoring system for Thailand streams (BMWP THAI) exhibited the strongest negative relationship with phosphate (PO_4-P) concentration, a proxy for stream water quality. Based on the results of TITAN, five taxa were added to develop a modified invertebrate index, namely BMWP IDN, by assigning taxon scores in accordance with the responses to the water quality gradient. The relationship between the BMWP IDN and PO_4-P concentration was found to be stronger than any of the existing invertebrate indices, indicating the superiority of the new index. Therefore, the extraction of uncovered sensitive taxa was important for modifying the existing index, and this study can contribute to improving the invertebrate index for assessing water quality of Indonesian streams.

Introduction

Degradation in the water quality causes deterioration of stream ecosystems (Malmqvist & Rundle 2002, Allan & Castillo 2007). Water quality degradation in streams is caused by anthropogenic impacts in the catchment, such as urbanization, industrial activities, and agricultural land conversion (Uriarte *et al.* 2011, Miller and Hutchins 2017). For example, increased nutrient concentrations due to wastewater inflow from the catchment typically result in a loss of taxonomic diversity of stream-dwelling organisms through the disappearance of intolerant taxa (Lenat & Crawford 1994, Roy *et al.* 2003). Therefore, water quality management is of great importance for the conservation of biodiversity in stream ecosystems (Gasith & Resh 1999, Budi Prakoso *et al.* 2022).

Benthic macroinvertebrates are a highly diverse taxonomic group in stream ecosystems, including sensitive taxa with varying degrees of tolerance to water quality gradients (Lenat 1988, Strayer 2006, Verdonschot & Moog 2006, Schletterer *et al.* 2010). Therefore, the composition of the stream invertebrate community has been used as a comprehensive measure of water quality corresponding to the time scale of their life history (Karr 1991, Bonada *et al.* 2006). To date, a variety of biotic indices based on invertebrate composition have been developed to assess stream water quality worldwide (Hering *et al.* 2004, Morse *et al.* 2007, Eriksen *et al.* 2021). To calculate these invertebrate indices, scores are typically assigned to each indicator taxon according to its tolerance to poor water quality conditions, and then a community-level score is calculated to represent the water quality of a stream of interest (Hilsenhoff 1982, Ochieng *et al.* 2020).

Many invertebrate indices have been developed by improving and localizing the existing indices to suit the local environment and faunal composition of the target region that are often countries. For example, the classic biological monitoring working party (BMWP) scoring system was originally developed in the UK (Armitage et al 1983), and many localized versions have been derived in countries across Europe, North America, Latin America, Africa, and Asia (e.g. Czerniawska-Kusza 2005, Nguyen *et al.* 2014, Ochieng *et al.* 2020). Similarly, the family biotic index (FBI) is an invertebrate index developed in the USA (Hilsenhoff 1982) and has been adapted in Europe, Africa, and Asia (Sekiranda *et al.* 2004, Morse *et al.* 2007, Etemi *et al.* 2020). Although the development of invertebrate indices through localization and their validation has been undertaken worldwide, such an approach has not been widely implemented in developing countries, typically in tropical regions where invertebrate diversity is generally high and severe water quality degradation is ongoing (Dudgeon 2000).

Indonesia is the largest tropical country with regard to population (ca. 278 million), and severe water pollution, primarily due to urbanization, has been reported, particularly on Java Island, where more than half of the population is concentrated (Ardania *et al.* 2022, Brontowiyono *et al.* 2022). Some pilot studies have been conducted on the application and development of invertebrate indices in Indonesian streams. Dewi and Wardhana (2020) and Muntalif *et al.* (2023) applied current BMWP-related scoring systems to assess water quality. Furthermore, a new invertebrate index Biotilik has been developed for Indonesian streams based on FBI (Rini 2011) and applied in some studies (Nugrahaningrum *et al.* 2017, Sandi *et al.* 2017). However, to our knowledge, no study has compared the applicability of a wide range of indices or developed new indices based on solid empirical data, highlighting the need for studies that contribute to the development of reliable invertebrate indices for assessing water quality in Indonesian streams.

Herein, we compared the applicability of six existing invertebrate indices for assessing water quality in Indonesian streams. We used water quality and invertebrate data from a recent study conducted by Budi Prakoso *et al.* (2023), which demonstrated the strong relationship between water quality and invertebrate assemblages in an environmental gradient typically observed in Indonesia. Then, we conducted TITAN to extract indicator taxa using the dataset and utilized the results to improve an existing index. Our ultimate goal was to develop and propose a better invertebrate index for assessing water quality that can contribute to water quality assessment and ecosystem management of Indonesian streams.

Methods

Invertebrate and water quality data

We used the invertebrate and water quality data from Budi Prakoso *et al.* (2023). The data were collected at study sites established in 23 streams ranging from pristine forest streams to severely degraded urban streams in Yogyakarta Province, Java Island, Indonesia (Table S1 and Figure 1). The elevation of the study sites ranges from 53 m to 579 m. This area has typical Indonesian climatic characteristics, with temperatures ranging from 25 °C to 34 °C and annual rainfall of ca. 1,700 mm. We conducted the survey during the late rainy season (May 4–6, 2019; Lee 2015), when streamflow is relatively stable and suitable for collecting representative invertebrate fauna (Wakhid *et al.* 2021; Harahap *et al.* 2021). Benthic macroinvertebrates were collected by kick sampling using a D-frame net (0.5 mm mesh) at three locations (25×25 cm^2 area) along the thalweg of riffles (Miyake *et al.* 2021).

A surface water sample was concurrently taken at each site. In laboratory, invertebrates were sorted and identified to family level, if possible, using the taxonomic keys from previous local studies. Otherwise, they were identified to the lowest possible taxonomic level. The water samples were filtered and measured for nitrate (NO_3-N), nitrite (NO_2-N), ammonium (NH_4-N), and phosphate (PO_4-P) concentrations using an auto-analyzer (QuAAtro 2-HR) using a standard method (Budi Prakoso *et al.* 2022). Subsequent analyses showed that among the 10 habitat parameters, invertebrate metrics had the strongest relationship with the PO_4-P concentration in stream water (range: 2–166 μg l^{-1}), which was typically high in severely urbanized streams (see Budi Prakoso *et al.* 2023 for more details). These results indicated the importance of the data collected by Budi Prakoso *et al.* (2023) for evaluating the applicability of invertebrate indices for water quality assessment and the discriminative value of the PO_4-P concentration as a proxy of stream water quality that affects invertebrate assemblages.

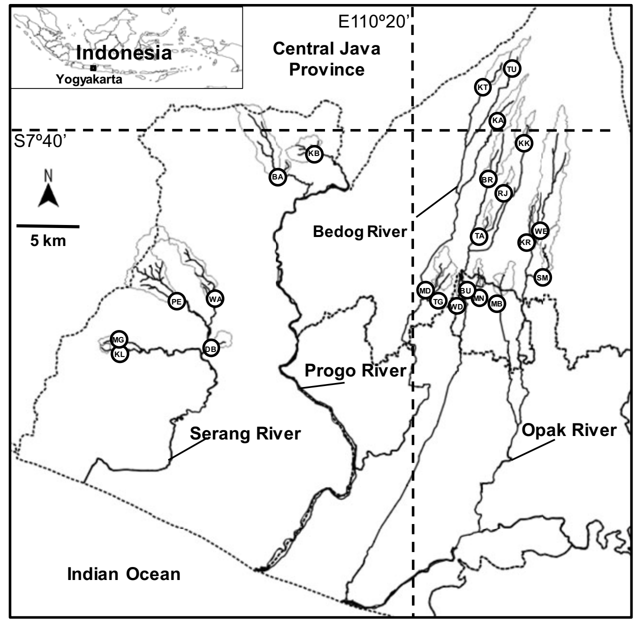

Figure 1. Location of study sites (white circles). See site codes for Table 1.

Existing invertebrate indices

We selected six existing invertebrate indices, BMWP UK (Armitage et al 1983), BMWP JPN (Nozaki 2012), BMWP THAI (Mustow 2002), BMWP MY (Wan Mohd Hafezul 2016), SingScore (Blakely *et al.* 2014), and Biotilik (Rini 2011), which could assess water quality in Indonesian streams. The selection criteria were as follows: the current dissemination of each index and the geographic proximity between the area where the index was developed and our target area (i.e. Yogyakarta Province, Indonesia).

The BMWP UK was developed in the UK; this index has a wide range of applications, and many BMWP-related procedures originated from the BMWP UK (Armitage et al 1983). The procedure assigns a score to the indicator taxa of water quality, ranging from 1 (most tolerant) to 10 (most sensitive). Then, the average score per taxon (ASPT, range: 1–10) was calculated as the average of the scores of each taxon found in the target stream to indicate water quality regardless of taxon richness. The BMWP JPN is an adaptation of the BMWP UK for Japanese rivers and streams, with the list of indicator taxa and the scores for each taxon modified to fit the Japanese invertebrate fauna. We selected the BMWP JPN because of its longest history of application among BMWP-related procedures in Asia, and this index has been modified since its utilization in the National Census on River Environment in 1993 (Nozaki 2012).

The BMWP THAI and BMWP MY are also adaptations of the BMWP UK for streams in Thailand and Malaysia, respectively, which are developing countries in Southeast Asia (Mustow 2002, Zakaria and Mohamed 2019). SingScore was developed for Singapore streams based on the macroinvertebrate community index (MCI), which was developed for New Zealand streams and is analogous to the BMWP (Blakely *et al.* 2014). A taxon score ranges from 1 to 10 similar to other BMWP-related indices, but the

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SingScore ranges from 20 to 200 multiplied by a constant of 20. Currently, Biotilik is the only invertebrate index developed for Indonesian streams. This index was a modification of the FBI, with indicator taxon scores ranging from 1 (most tolerant) to 4 (most sensitive) (Rini 2011). The Biotilik score is calculated as the average of the taxon scores weighted by the relative abundance of each taxon (range: 1–4).

We calculated the scores of the abovementioned six indices using the full list of invertebrate taxa from Budi Prakoso *et al.* (2023) for 23 study sites in Yogyakarta Province, Indonesia. We developed generalized linear models (GLMs) to examine the relationship between invertebrate indices and a water quality proxy, in order to assess the applicability of each invertebrate index as an indicator of water quality. The scores of each invertebrate index and the concentrations of PO_4-P were used as response and explanatory variables, respectively. The error distribution was assumed to be Gaussian for all invertebrate indices. Statistical significance was set at $P < 0.05$.

Development of a new invertebrate index

We developed a new invertebrate index for Indonesian streams by modifying an existing index. The existing index modified was selected for its applicability as an indicator of water quality in our study sites (i.e. the highest coefficient of determination, R^2, by GLMs). We added new taxa that were not included in the target existing index as indicator taxa. The new indicator taxa were extracted using TITAN, which has been used in previous invertebrate studies to extract indicator taxa (e.g. Sarremejane *et al.* 2019, Hu *et al.* 2022). The TITAN combines indicator species analysis with nonparametric change-point analysis and uses indicator species scores to integrate the occurrence, abundance, and directionality of taxa responses along an environmental gradient (Baker and King 2010). We targeted taxa that occurred at ≥5 stream sites (Baker and King 2010) and were examined within a range of 2–166 μg l^{-1} of PO_4-P concentration (Table S1). Bootstrapping (1000 replicates) was used to evaluate taxon-specific change points and distinguish negative (z−) and positive (z+) responses along the PO_4-P concentration gradient. Only taxa with high purity and reliability (≥0.95) were considered indicators (Nguyen *et al.* 2017). Then, we assigned a score to each extracted taxon based on the change point and its confidence interval along the PO_4-P concentration gradient, with reference to the scores of other taxa that were originally included in the existing index. We retained the original taxon scores for taxa that were already included in the existing index.

We calculated the value of the new invertebrate index for each study site based on the procedure used in the target existing index. Analysis using GLM was performed in the same way as for the existing indices to compare the applicability of the new index for assessing water quality. All statistical analyses were performed using the R environment for statistical computing (version 3.6.3, R Development Core Team, 2020), with the glm2 package for GLMs and the TITAN2 package for TITAN (Marschner 2011; Baker et al. 2015).

Results

Relationships between existing invertebrate indices and water quality

A total of 13,268 individuals and 60 taxa of stream invertebrates were found in 69 samples collected from 23 study sites by Budi Prakoso *et al.* (2023). The invertebrate abundance (N m^{-2}) was on average 2,910 across the study sites (range: 336–17,765 N m^{-2}) (Table S1). Each taxon was scored using the taxa list to calculate six existing invertebrate indices for each study site, if applicable (Table S2). Among the 60 taxa, 36 (60%) were used to calculate the BMWP THAI, SingScore, and Biotilik. The BMWP MY, BMWP JPN, and BMWP UK provided taxon scores for 33 (55%), 30 (50%), and 27 (45%) taxa, respectively. Six taxa (Acarina, Alpheidae, Gecarcinucidae, Podocopida, Psychidae, and Xiphocentridae) were found not to be included in the taxa list of any of the existing invertebrate indices.

The scores of six existing invertebrate indices varied among the 23 study sites. The BMWP index (possible range: 1–10) ranges were 3.00–6.38 for the UK, 5.00–7.57 for JPN, 3.00–6.36 for THAI, and 1.00–5.42 for MY (Table 1). The SingScore (possible range: 20–200) and Biotilik (possible range: 1–4) ranged from 32 to 133 and 1.00 to 2.50, respectively (Table 1). Analyses using GLMs revealed that all six existing invertebrate indices had a significant negative relationship with the PO_4-P concentration, although the strength of the relationship differed among the indices (Figure 2). The BMWP THAI exhibited the strongest negative relationship with PO_4-P concentration among six indices ($R^2 = 0.471$, $P < 0.001$), followed by the BMWP UK ($R^2 = 0.432$, $P < 0.001$). Contrarily, the relationship was relatively weaker for the SingScore ($R^2 = 0.342$, $P = 0.003$), BMWP MY ($R^2 = 0.232$, $P = 0.020$), BMWP JPN ($R^2 = 0.208$, $P = 0.029$), and Biotilik ($R^2 = 0.176$, $P = 0.046$), although the highest number of taxa (i.e. 36 taxa) was included to calculate the SingScore and Biotilik scores.

Development of a new Indonesian invertebrate index

TITAN revealed the community change along the PO_4-P concentration gradient (Figure S1). Twenty-six taxa were found in more than five stream sites and then included in the analysis (Table S3). A total of 11 indicator taxa were identified using the indices of purity and reliability (Figure 3; Table S3). Among them, eight taxa showed a threshold decline (*z*−) in response to the increasing PO_4-P concentration. The median of the change points in PO_4-P concentration of the declining taxa, Euphaeidae, Ceratopogonidae, Baetidae, Heptageniidae, Ecnomidae, Psychomyiidae, Leptophlebiidae, and Elmidae, ranged from 7.5 to 62.5 μg l^{-1}. By contrast, three taxa, namely, Podocopida, Oligochaeta, and Thiaridae, showed a positive response (*z*+) to the increasing PO_4-P concentration. The median of the change points in PO_4-P concentration of the increasing taxa ranged from 11.0 to 121.0 μg l^{-1}.

Of the 11 indicator taxa extracted by TITAN, five taxa did not appear to be included in the BMWP THAI scoring system. Then, we assigned taxon scores (possible range: 1–10) for five indicator taxa, namely, Euphaeidae, Ceratopogonidae, Ecnomidae, Elmidae, and Podocopida (Figure 3, Table S4). We assigned 10 to Euphaeidae and Ceratopogonidae because of their occurrence in a very low range of the PO_4-P concentration gradient. Elmidae was assigned 7 because its change point and confident interval were slightly higher than those of Psychomyiidae (BMWP THAI score: 8). Ecnomidae was assigned 4 because its change point was similar to that of Baetidae (BMWP THAI score: 4) and the confidence interval was fairly inclusive. We assigned 1 to Podocopida because of its occurrence in a very high range of the PO_4-P concentration gradient (Figure 3, Table S5).

The modified invertebrate index for assessing stream water quality in Indonesian streams (hereafter, BMWP IDN) was

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Table 1. Scores of the six existing indices and BMWP IDN for each study site. The location of the study sites is shown in Figure 1

Site Name	Code	BMWP UK	BMWP JPN	BMWP THAI	BMWP MY	SingScore	Biotilik	BMWP IDN
Kedung Logan	KL	6.18	6.31	6.00	5.08	120	2.08	6.64
Mrogo	MG	6.00	6.87	5.92	5.24	114	2.04	6.35
Danau Bandem	DB	4.80	6.64	5.30	5.09	105	1.82	5.06
Pengasih	PE	6.36	7.00	6.36	5.42	115	1.55	6.92
Wadas	WA	6.10	7.50	5.82	5.33	109	1.79	6.23
Banjarsari	BA	6.08	6.93	5.79	5.09	115	2.12	5.87
Kali Bawang	KB	5.78	7.30	5.50	5.22	108	2.50	5.07
Tunggularum	TU	5.70	6.45	5.45	5.31	106	2.47	5.33
Kretek	KT	5.82	7.45	5.77	5.17	129	2.40	5.77
Kali Aji	KA	5.77	6.87	5.73	5.31	126	1.54	5.71
Kedung Kuning	KK	6.38	7.17	6.00	5.00	112	1.83	5.87
Brayut	BR	4.75	6.86	4.90	4.67	88	1.23	5.09
Rejodani	RJ	5.71	7.57	6.00	4.75	133	2.01	6.11
Tirta Amartha	TA	5.36	6.70	5.18	5.00	86	1.35	5.19
Krakungan	KR	4.86	6.89	4.86	4.88	104	1.68	5.20
Wedo	WE	4.86	6.88	4.63	5.11	115	2.42	4.56
Modinan	MD	4.57	5.86	4.38	4.40	87	1.05	4.33
Tlogorejo	TG	3.25	6.00	3.17	2.50	60	1.36	3.17
Widuri	WD	3.83	5.75	3.63	3.67	69	1.55	3.63
Kali Buntung	BU	4.29	5.43	3.78	4.20	82	1.34	3.50
Mongisidi	MN	3.00	5.00	3.00	1.00	32	1.00	3.00
Mbelir	MB	3.75	5.33	3.50	3.33	71	1.00	3.50
Selokan Mataram	SM	4.00	5.67	3.71	3.67	73	1.28	3.44

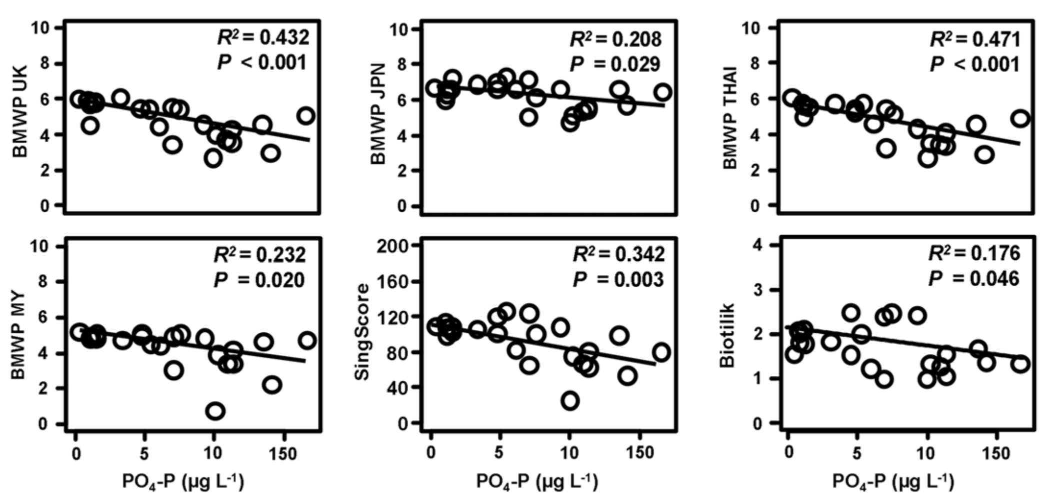

Figure 2. Relationship between existing invertebrate indices and PO_4-P concentration. The values inset into the graphs indicate the coefficients of determination (R^2) and P values obtained by generalized linear models (GLMs).

developed on the basis of the BMWP THAI by adding the five new indicator taxa. The BMWP IDN covered 41 taxa (68%) of the 60 taxa found by Budi Prakoso *et al.* (2023) (Table S2). The BMWP IDN ranged from 3.00 to 6.92, which was wider than that of BMWP THAI (3.00 to 6.36). Analysis using GLM revealed that the BMWP IDN was significantly and negatively related to PO_4-P concentration ($R^2 = 0.487$, $P < 0.001$; Figure 4). The relationship was stronger than any other existing invertebrate index examined in this study ($R^2 < 0.471$ for all; Figure 2).

Discussion

In this study, we compared the applicability of six existing invertebrate indices using the dataset from 23 various Indonesian

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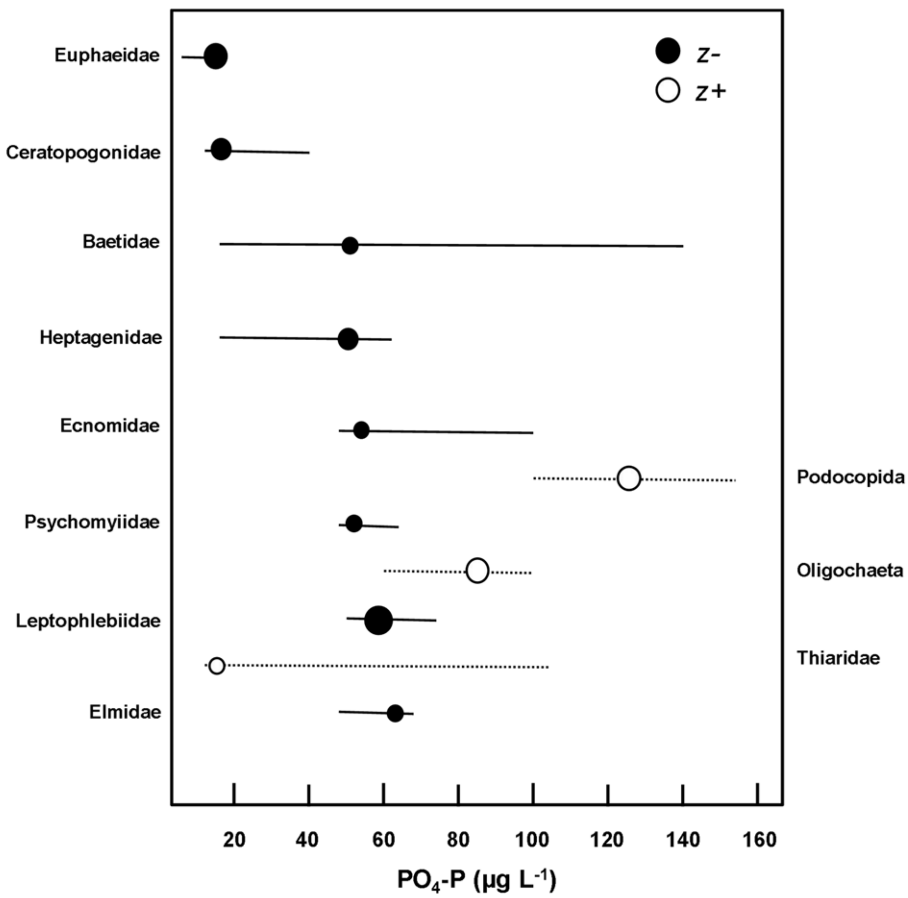

Figure 3. Threshold indicator taxa analysis (TITAN) of invertebrate community response to PO_4-P concentration. Horizontal lines represent 95% confidence intervals of observed change points (circles) for each taxon. Black circles and solid lines correspond to negative (z−) indicator taxa, whereas white circles and dashed lines correspond to positive (z+) indicator taxa. The size of change point symbol (circles) is proportional to the magnitude of the taxa response.

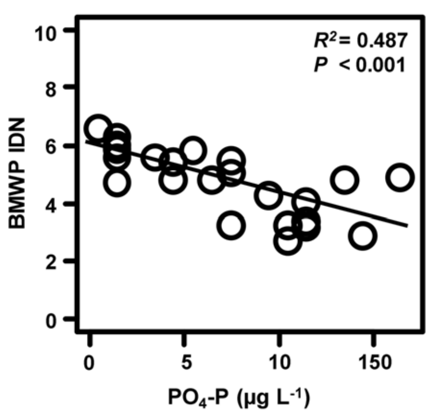

Figure 4. Relationship between BMWP IDN and PO_4-P concentration. The values inset into the graphs indicate the coefficients of determination (R^2) and P values obtained by generalized linear models (GLMs).

streams obtained by Budi Prakoso *et al.* (2023) and found that BMWP THAI was the best index for assessing water quality in the target streams. Then, we developed a modified invertebrate index, BMWP IDN, by adding five new taxa extracted by TITAN to BMWP THAI by assigning taxon scores. Consequently, BMWP IDN showed a stronger relationship with water quality (PO_4-P concentration) than any of the existing invertebrate indices. Some invertebrate indices such as BMWP UK and Biotilik have been applied to Indonesian streams in previous studies (Nugrahaningrum *et al.* 2017; Patang *et al.* 2018). Considering that these existing indices were fairly included in our analyses, our results implied the superiority of BMWP IDN at this stage. Therefore, this study can improve the invertebrate index to assess water quality and then promote the ecological conservation of Indonesian streams. We expect that our achievement would also facilitate the further development of invertebrate indices by incorporating the advanced methods, for example by incorporating multimetric indices (Hering *et al.* 2006; Magbanua *et al.* 2023), and by proposing a routine invertebrate monitoring in Indonesian streams that will enable long-term water quality assessment using invertebrate indices.

All of the six existing invertebrate indices showed significant negative relationships with PO_4-P concentration, a proxy for water quality in our study area. This finding indicated the utility of each index as an indicator of water quality, but the strength of the relationship differed among the six indices. BMWP THAI has the closest relationship with water quality and can be characterized by the highest number of taxa that were included in the calculation of index values, along with the other indices developed in Southeast Asian countries, such as SingScore and Biotilik. In previous studies, the high number of indicator taxa included contributed to the high applicability of the invertebrate index for assessing water quality, and the number increased when the index was developed in more geographically proximate areas (Czerniawska-Kusza 2005, Ochieng *et al.* 2020). Additionally, the relatively long trial history of BWMP THAI (Mustow 2002) compared with SingScore (Blakely *et al.* 2014) and Biotilik (Rini 2011) is likely to contribute to its high utility. This supposition may be supported by the relatively strong relationship of BMWP UK with PO_4-P

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concentration, which is the original of many BMWP-related procedures and has the longest history of application (Armitage et al 1983). Thus, our results suggest that the coverage of indicator taxa caused by geographical proximity and the historical persistence of indices determine the applicability of the invertebrate index when existing indices are applied to areas not yet well covered by those indices.

Herein, a new invertebrate index, BMWP IDN, was developed for assessing water quality in Indonesian stream. Using TITAN, we extracted 11 indicator taxa with negative and positive responses to the water quality proxy (PO_4-P concentration), and five taxa were newly added to BMWP THAI to create the BMWP IDN by assigning taxon scores. Consequently, BMWP IDN successfully showed a wider range of scores across the 23 study sites and stronger relationship with water quality than any other existing invertebrate index. This improvement is primarily due to the fact that highly tolerant and intolerant taxa have been added to BMWP IDN scoring system. The addition of sensitive taxa to the environmental gradient has been reported to improve the applicability of invertebrate indices in previous studies (Mustow 2002; Fishar and Williams 2008). Notably, probably due to their small body size, Podocopida was not included in any of the existing invertebrate indices examined in this study, despite having the lowest taxon score in this study (highly tolerant taxon). The inclusion of such neglected but diverse and sensitive taxa may improve invertebrate indices (Mori and Meisch 2012). The addition of highly intolerant taxa, Euphaeidae and Ceratopogonidae, also contributed to sensitizing BMWP IDN to water quality gradients across our study sites (Aziz and Mohamed 2019, Rahman et al 2022). The new list of indicator taxa provided in this study can promote the future development of water quality assessments in Indonesian streams.

In conclusion, we proposed a new invertebrate index for assessing water quality in Indonesian streams. The extraction of uncovered sensitive taxa by TITAN can improve the existing index to sensitize the new index, BMWP IDN. Moreover, the extraction of the indicator taxa may have been facilitated by the selection of study sites (Budi Prakoso *et al.* 2023), which included different land use conditions and water quality. The coverage of a wide range of environmental gradients can contribute to the creation of a new invertebrate index (Mustow 2002; Haase and Nolte 2008). In this context, our new index, together with other possible ones, is expected to be applied and validated in other areas of Indonesia, and efforts should continue in the long term to develop a better invertebrate index for assessing water quality.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S0266467424000257.

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Competing interests. The authors declare none.

References

Allan JD and Castillo MM (2007) *Stream ecology: Structure and function of running waters*. 2nd edition. Springer, The Netherlands.

Ardania CA, Widyati W, Rahmat SMR and Machdi I (2022) *Statistical yearbook of Indonesia 2022*. In *BPS-Statistics of Indonesia*, Jakarta, Indonesia. (In *Indonesia*).

Armitage PD, Moss D, Wright JF and Furse MT (1983) The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research* **17**, 333–347.

Aziz MAAA and Mohamed M (2019) Annotated checklist of odonates (Insecta: Odonata) in Sungai Bantang Recreational Forest, Bekok, Johor, Malaysia. *IOP Conference Series: Earth and Environmental Science* **269**, 012002.

Baker ME and King RS (2010) A new method for detecting and interpreting biodiversity and ecological community thresholds. *Methods in Ecology and Evolution* **1**, 25–37.

Baker ME, King RS and Kahle D (2015) TITAN2: Threshold indicator taxa analysis. URL: https://cran.r-project.org/web/packages/TITAN2/index.html.

Blakely TJ, Eikaas HS and Harding JS (2014) The Singscore: A macroinvertebrate biotic index for assessing the health of Singapore's streams and canals. *Raffles Bulletin of Zoology* **62**, 540–548.

Bonada N, Prat N, Resh VH and Statzner B (2006) Developments in aquatic insect biomonitoring: A comparative analysis of recent approaches. *Annual Review of Entomology* **51**, 495–523.

Brontowiyono W, Asmara AA, Jana R, Yulianto A and Rahmawati S (2022) Land-use impact on water quality of the Opak sub-watershed, Yogyakarta, Indonesia. *Sustainability* **14**, 4346.

Budi Prakoso S, Fukusaki K, Ueda W and Miyake Y (2022) Effect of sewerage development on water quality and invertebrate assemblages in a Japanese river over the long term. *Journal of Freshwater Ecology* **37**, 455–465.

Budi Prakoso S, Miyake Y, Ueda W and Suryatmojo H (2023) Impact of land use on water quality and invertebrate assemblages in Indonesian streams. *Limnologica* **101**, 126082.

Czerniawska-Kusza I (2005) Comparing modified biological monitoring working party score system and several biological indices based on macroinvertebrates for water-quality assessment. *Limnologica* **35**, 169–176.

Dewi SDK and Wardhana W (2020) Water quality assessment of Saluran Tarum Barat, West Java, based on biological monitoring working party-average score per taxon (BMWP-ASPT). *IOP Conference Series: Earth and Environmental Science* **481**, 012073.

Dudgeon D (2000) The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. *Annual Review of Ecology and Systematics* **31**, 239–263.

Eriksen TE, Brittain JE, Søli G, Jacobsen D, Goethals PL and Friberg N (2021) A global perspective on the application of riverine macroinvertebrates as biological indicators in Africa, South-Central America, Mexico and Southern Asia. *Ecological Indicators* **126**, 107609.

Etemi FZ, Bytyçi P, Ismaili M, Fetoshi O, Ymeri P, Shala-Abazi A, Muja-Bajraktari N and Czikkely M (2020) The use of macroinvertebrate based biotic indices and diversity indices to evaluate the water quality of Lepenci river basin in Kosovo. *Journal of Environmental Science and Health. Part A, Toxic/Hazardous Substances and Environmental Engineering* **55**, 748–758.

Fishar MR and Williams WP (2008) The development of a biotic pollution index for the River Nile in Egypt. *Hydrobiologia* **598**, 17–34.

Gasith A and Resh VH (1999) Streams in Mediterranean climate regions: Abiotic influences and biotic responses to predictable seasonal events. *Annual Review of Ecology and Systematics* **30**, 51–81.

Haase R and Nolte U (2008) The invertebrate species index (ISI) for streams in southeast Queensland, Australia. *Ecological Indicators* **8**, 599–613.

Harahap A, Mahadewi EP, Ahmadi D, Winoto H, Ganiem LM, Rafika1 M and Hartanto A (2021) Monitoring of macroinvertebrates along streams of Bilah River, North Sumatra, Indonesia. *International Journal of Conservation Science* **12**, 1.

Hering D, Feld CK, Moog O and Ofenboeck T (2006) Cookbook for the development of a Multimetric Index for the biological condition of aquatic ecosystems: Experiences from the European AQEM and STAR projects and related initiatives. *Hydrobiologia* **566**, 311–324.

Hering D, Moog O, Sandin L and Verdonschot PFM (2004) Overview and application of the AQEM assessment system. *Hydrobiologia* **516**, 1–20.

Hilsenhoff WL (1982) *Using a biotic index to evaluate water quality in streams.* Technical Bulletin No. 132. Department of Natural Resources, Madison, Wisconsin.

Hu X, Zuo D, Xu Z, Huang Z, Liu B, Han Y and Bi Y (2022) Response of macroinvertebrate community to water quality factors and aquatic ecosystem health assessment in a typical river in Beijing, China. *Environmental Research* **212**, 113474.

Karr JR (1991) Biological integrity: A long-neglected aspect of water resource management. *Ecological Applications* **1**, 66–84.

Lee HS (2015) General rainfall patterns in Indonesia and the potential impacts of local season rainfall intensity. *Water* **7**, 1751–1768.

Lenat DR (1988) Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. *Journal of the North American Benthological Society* **7**, 222–233.

Lenat DR and Crawford JK (1994) Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. *Hydrobiologia* **294**, 185–199.

Magbanua FS., Hilario JE, Salluta JCRB, Alpecho BC, Mendoza SS and Lit IL (2023) Freshwater biomonitoring with macroinvertebrates in the Philippines: Towards the development of the Philippine biotic index. *Limnologica* **102**, 126098.

Malmqvist B and Rundle S (2002) Threats to the running water ecosystems of the world. *Environmental Conservation* **29**, 134–153.

Marschner IC (2011) glm2: Fitting generalized linear models with convergence problems. URL: https://cran.r-project.org/web/packages/glm2/.

Miller JD and Hutchins M (2017) The impacts of urbanisation and climate change on urban flooding and urban water quality: A review of the evidence concerning the United Kingdom. *Journal of Hydrology: Regional Studies* **12**, 345–362.

Miyake Y, Makino H and Fukusaki K (2021) Assessing invertebrate response to an extreme flood event at a regional scale utilizing past survey data. *Limnology* **22**, 169–177.

Mori N and Meisch C (2012) Contribution to the knowledge on the distribution of recent free-living freshwater ostracods (Podocopida, Ostracoda, Crustacea) in Slovenia. *Natura Sloveniae* **14**, 5–22.

Morse JC, Bae YJ, Munkhjargal G, Sangpradub N, Tanida K, Vshivkova TS, Wang B, Yang L and Yule CM (2007) Freshwater biomonitoring with macroinvertebrates in East Asia. *Frontiers in Ecology and the Environment* **5**, 33–42.

Muntalif BS, Chazanah N, Ilmi F, Sari NE and Bagaskara SW (2023) Distribution of the riverine benthic macroinvertebrate community along the Citarum cascading dam system in west Java, Indonesia. *Global Ecology and Conservation* **46**, e02580.

Mustow SE (2002) Biological monitoring of rivers in Thailand: Use and adaptation of the BMWP score. *Hydrobiologia* **479**, 191–229.

Nguyen THT, Boets P, Lock K, Forio MAE, Van Echelpoel W, Van Butsel J, Utreras JAD, Everaert G, Granda LED, Hoang THT and Goethals PLM (2017) Water quality related macroinvertebrate community responses to environmental gradients in the Portoviejo River (Ecuador). *International Journal of Limnology* **53**, 203–219.

Nozaki T (2012) Biological assessment based on macroinvertebrate communities: Average score system for Japanese rivers. *Journal of Japan Society on Water Environment* **35**, 118–121. (in Japanese).

Nugrahaningrum A, Harianja MF, Nugroho H and Soesilohadi RCH (2017) Macroinvertebrate diversity role in water quality assessment of Winongo and Gajah Wong rivers, Yogyakarta, Indonesia. *Bonorowo Wetlands* **7**, 31–37.

Ochieng H, Odong R and Okot-Okumu J (2020) Comparison of temperate and tropical versions of biological monitoring working party (BMWP) index for assessing water quality of river Aturukuku in Eastern Uganda. *Global Ecology and Conservation* **23**, e01183.

Patang F, Soegianto A and Hariyanto S (2018) Benthic macroinvertebrates diversity as bioindicator of water quality of some rivers in east Kalimantan, Indonesia. *International Journal of Ecology* **2018**, 1–11.

Rahman MM, Burian A, Creedy TJ and Vogler AP (2022) DNA -based assessment of environmental degradation in an unknown fauna: The freshwater macroinvertebrates of the Indo-Burmese hotspot. *Journal of Applied Ecology* **59**, 1644–1658.

Rini DS (2011) Biotilik guide sheet for health monitoring of river flow. Ecological Observation and Wetlands Conservation, Gresik, *Indonesia*. (In *Indonesia*).

Roy AH, Rosemond AD, Paul MJ, Leigh DS and Wallace JB (2003) Stream macroinvertebrate response to catchment urbanisation (Georgia, U.S.A.). *Freshwater Biology* **48**, 329–346.

Sandi MA, Arthana IW and Sari AHW (2017) Bioassessment and river water quality of Legundi watershed Probolinggo, East Java. *Journal of Marine and Aquatic Sciences* **3**, 233–241. (In *Indonesia*).

Sarremejane R, Stubbington R, Dunbar MJ, Westwood CG and England J (2019) Biological indices to characterize community responses to drying in streams with contrasting flow permanence regimes. *Ecological Indicators* **107**, e105620.

Schletterer M, Füreder L, Kuzovlev VV and Beketov MA (2010) Testing the coherence of several macroinvertebrate indices and environmental factors in a large lowland river system (Volga River, Russia). *Ecological Indicators* **10**, 1083e1092.

Sekiranda SBK, Okot-Okumu J, Bugenyi FWB, Ndawula LM and Gandhi P (2004) Variation in composition of macro-benthic invertebrates as an indication of water quality status in three bays in Lake Victoria. *Uganda Journal of Agricultural Sciences* **9**, 396–411.

Strayer DL (2006) Challenges for freshwater invertebrate conservation. *Journal of the North American Benthological Society* **25**, 271–287.

Uriarte M, Yackulic CB, Lim Y and Arce-Nazario JA (2011) Influence of land use on water quality in a tropical landscape: A multi-scale analysis. *Landscape Ecology* **26**, 1151–1164.

Verdonschot PFM and Moog O (2006) Tools for assessing European streams with macroinvertebrates: Major results and conclusions from the STAR project. *Hydrobiologia* **566**, 299–309.

Wakhid, Rauf A, Krisanti M, Sumertajaya IM and Maryana N (2021) Aquatic insect communities in headwater streams of Ciliwung River watershed, West Java, Indonesia. *Biodiversitas* **22**, 1.

Wan Mohd Hafezul WAG (2016) *Development of Malaysian water quality indices using aquatic macroinvertebrates population of Pahang river basin, Pahang, Malaysia*. Doctoral dissertation. Universiti Sains Malaysia.

Zakaria MZ and Mohamed M (2019) Comparative analysis of biotic indices in water quality assessment: Case study at Sg. Bantang, Johor. *IOP Conference Series: Earth and Environmental Science* **269**, 012047.