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Research Article

Development of A Multimetric Index Based on Benthic Macroinvertebrates for Rivers (BMIR) in Türkiye

Türkiye'deki Nehirler İçin Bentik Makroomurgasızlara Dayalı Bir Multimetrik İndeks (BMIR) Geliştirilmesi

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Abstract

Stream types determined according to altitude, slope and alkalinity in six different hydrobiogeographic regions of Türkiye were taken as the basis of the study. In line with the European Water Framework Directive, a macroinvertebrate-based multimetric method was tested for Turkish rivers as a potential assessment. In this study, benthic macroinvertebrate data (1875 taxa obtained from 1925 stations with reference points) were used to create a multimetric index for all river types in the hydrobiogeographic regions of Türkiye. Nine biological metrics were evaluated and index development criteria were chosen to capture meaningful results at the ecosystem, community, and individual levels. The metric combinations were chosen to show the best distinction between areas with no or only very minor anthropogenic disturbances and stressed areas (with discrimination efficiency values). The multimetric index including three different metrics from three different metric categories distinguishes reference or slightly distorted areas from stressed areas with an efficiency close to 100%. Index values were divided at a five-scale system between one (High) and zero (Bad) for biological evaluation. Further testing and research can be done so that the index will provide a more useful result as a bioassessment tool for decision-makers in hydrobiogeographic regions. Also, the index can provide a basis for methods by which river status is assessed based on stress factors.
Keywords: *Türkiye, EU Water Framework Directive, benthic macroinvertebrates, multimetric index, streams*

Öz

Türkiye'nin altı farklı hidrobiyocoğrafik bölgesinde rakım, eğim ve alkaliniteye göre belirlenen akarsu tipleri çalışmada temel alınmıştır. Avrupa Su Çerçeve Direktifi ile uyumlu potansiyel bir değerlendirme olarak Türkiye nehirleri için makroomurgasız tabanlı bir multimetrik yöntem test edilmiştir. Bu çalışmada, Türkiye'nin hidrobiyocoğrafik bölgelerindeki tüm nehir tipleri için bir multimetrik indeks oluşturmak amacıyla 1925 istasyondan, referans noktaları dahil, 1875 takson içeren bentik makroomurgasız verileri kullanılmıştır. Ekosistem, komunite ve bireysel düzeylerde anlamlı sonuçlar elde etmek için dokuz biyolojik metrik değerlendirilmiş ve indeks geliştirme kriterleri seçilmiştir. Metrik kombinasyonları, antropojenik etkilerin hiç olmadığı veya çok küçük

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olduğu alanlar ile stresli alanlar arasındaki en iyi ayrımı (ayrışma değerleriyle) gösterecek şekilde belirlenmiştir. Üç farklı metrik kategorisinden üç farklı metriği içeren multimetrik indeks, %100'e yakın bir verimlilikle referans veya hafif stresli alanları stresli alanlardan ayırır. İndeks değerleri biyolojik değerlendirme için bir (Çok iyi) ve sıfır (Kötü) arasında beş ölçekli bir sisteme bölündü. İndeksin hidrobiyocoğrafik bölgelerdeki karar vericiler için bir biyo-değerlendirme aracı olarak daha faydalı bir sonuç sağlaması için daha fazla test ve araştırma yapılabilir. Ayrıca indeks, stres faktörlerine dayalı olarak nehir durumunun değerlendirildiği yöntemler için bir temel sağlayabilir.

Anahtar sözcükler: *Türkiye, su çerçeve direktifi, bentik makroomurgasızlar, multimetrik indeks, akarsular*

Introduction

The EU Water Framework Directive (WFD) (The EU Water Framework Directive [WFD], 2000/60/EC) demands member states and other participating countries to prevent further degradation, conserve and advance the condition of surface waters and recover all categories of water bodies that are not in good ecological status. For sustaining the aquatic ecosystems which harbour biodiversity and provide the services and products that humans rely on, good ecological status is essential (Munné et al., 2015; Everard, 2012). Introducing reference conditions as a unifying concept for not heavily modified water bodies enables the determination of ecological status. In the WFD assessment, the relationships between the biota and the hydromorphological and chemical components are used to determine the ecological status of water bodies. The WFD requires that bioassessments to be stated as a proportion (Ecological Quality Ratio, EQR) at a five-grade framework ranging between 0 (Bad) and 1 (High). The EQR is the ratio of the observed value for a given water body type to the expected value for the same types under reference conditions. Benthic macroinvertebrates, macrophytes, diatoms, phytoplankton, and fish are used in the biological assessment to determine the ecological quality status of surface water bodies according to the WFD. Benthic invertebrates have long been employed to evaluate the impacts of human-based activities in coastal, transitional and freshwater habitats and are known to be susceptible to varying degrees of local disturbance (Zeybek, 2017; Birk et al., 2012; Hellawell, 2012; Medeiros et al., 2012; Borja et al., 2011; Chainho et al., 2008; Chaves et al., 2005). In the implementation of the WFD the parameters (i) taxonomic composition and abundance, (ii) diversity, and (iii) ratio of disturbance sensitive to insensitive species for benthic macroinvertebrate quality element should be addressed.

Biological indices, which are aimed to be developed based on three basic approaches, are used to evaluate biological integrity: the first step is regionalization (Omernik, 1987, 1995), the second step is a multimetric approach (Barbour et al., 1996; Davis & Simon, 1995; Karr et al., 1986; Karr & Dudley, 1981) and third, the determination of reference conditions (Hughes, 1995; Hughes et al., 1986).

Regionalization is the categorization of ecologically separate units based on physiography, soil type, climate, vegetation, geology, and land use. The presupposition that geophysical settings together with biogeographic processes are ecologically beneficial classification, is one of the pillars of regionalization (Karr & Chu, 1999). The geographical distinction of homogeneity within region and heterogeneity between regions has become a fundamental aspect of bioassessment (Hawkins et al., 2010; Hawkins & Norris, 2000). To establish a similar basis in ecological assessment, the final classification level must meet sufficient classes and provide a means of demonstrating the biological status of an area. Measurements must incorporate a variety of factors due to complex biological systems and major anthropogenic impacts on aquatic populations. The individual, community, and landscape-scale metrics are some of these numerous aspects. Individual measurements, or metrics, may be generated from functional traits like feeding patterns and life histories, structural components of communities like species composition and abundance, and measures of condition (e.g. presence or absence of tolerant organisms and individual health). Multimetric indices are made up of ecologically based measurements with recognized reactions to disturbances brought on by human (Sorrano et al., 2011; Butcher et al., 2003). The ratio of the observed assessment value to the expected value is utilized as the reference condition for determining the degree of anthropogenic effect. Reference conditions are defined as basic measurements of ecological variables that represent an ecosystem where there is no anthropogenic impact or at a level of concern (Stoddard et al., 2006; Miller et al., 1988). Land use, the physicochemical features of water bodies, habitat quality, monitoring data on water quality, and expert opinion can be used to quantify reference conditions in determining ecological status (Pardo et al., 2012; Herlihy et al., 2008; Whittier et al., 2007).

There is a need for the establishment of stream typology and the creation of an evaluation system based on a multimetric index emerges with the implementation of the WFD. As a EU candidate country, Türkiye requires an assessment method that reveals the quality status of aquatic ecosystems concerning benthic macroinvertebrates. In light of the WFD's implementation, the creation of a new multimetric index has been planned. When determining the state of an ecosystem, a multimetric index uses more than one variable (metric). These metrics, which evaluate ecosystem quality from different aspects, are combined into a single index value. The advantages of multimetric indices are that they are adaptable, convenient to add and eliminate metrics, and that the metric scoring system can be easily changed (Gabriels et al., 2010). Many countries have established multimetric indices that use different organisms, including macroinvertebrates, to assess natural and unnatural effects on water quality, and there are some studies in this direction in

Türkiye as well (Odabaşı et al., 2022; Akay & Dalkıran, 2020; Dügel, 2016; Allan, 2004; Barbour et al. 1996). Therefore, the development of a type-specific multimetric index based on macroinvertebrates for Turkish rivers is a potential mean to meet WFD requirements. The new index, known as the Benthic Macroinvertebrate Multimetric Index for River (BMIR), enables the score criteria to be modified for each river type in all hydrobiogeographic regions to reflect the relative distance to the reference conditions. This document provides an overview of the BMIR and its development process for all river types in Türkiye.

The objectives of this study include: (1) to determine reference conditions for the river types in hydrobiogeographic regions based on the benthic macroinvertebrate community and (2) to develop a multimetric index for benthic macroinvertebrate communities using metrics.

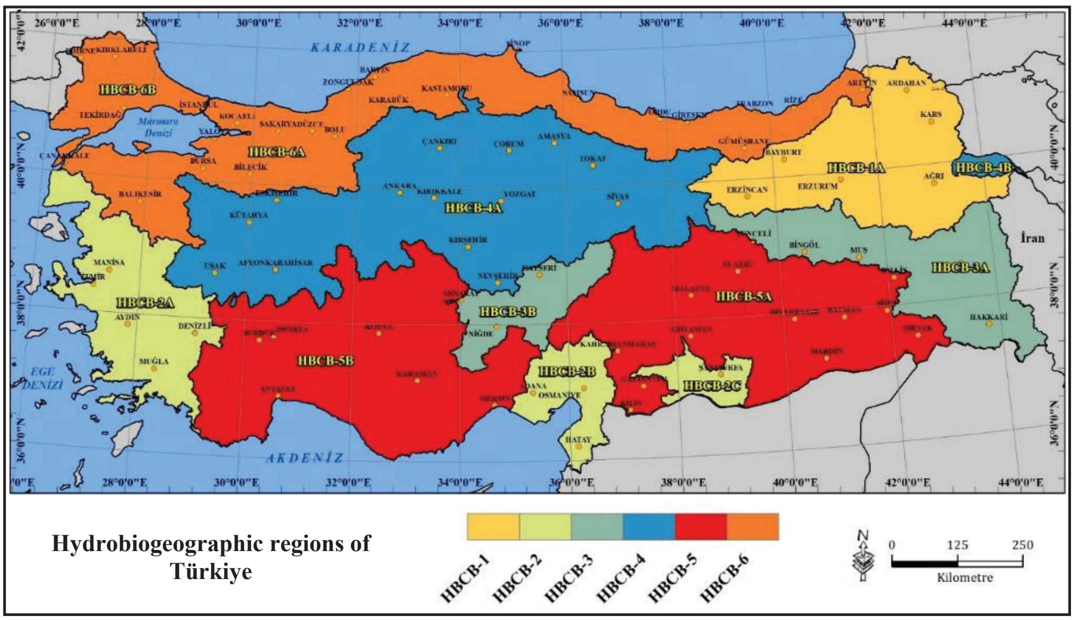
Methods

Hydrobiogeographic Regions and Typology

The hydrobiogeographic regions and typologies of streams of Türkiye were determined with the project named Digitizing Water Resources, Preparation of Monitoring Programs by Performing Typology, Water Body, and Risk Assessment (Digitizing Project, 2022). This project was carried out by the General Directorate of Water Management between 2017-2021. Within the scope of the project, water bodies and water body typologies were determined using the water resources base created in the project, and the basin monitoring programs were updated by determining the risk situation based on pressure for each water body. According to the Digitizing Project (2022), in the regionalization study carried out in Türkiye, meaningful abiotic factors determining the habitat conditions of aquatic organisms were determined and used to reflect the structure and functioning of the aquatic ecosystems more accurately. As a result of the regionalization studies carried out with the determined five significant abiotic factors (average temperature, relative humidity, sunshine intensity, closure, and altitude), six hydrobiogeographic regions were obtained (Fig. 1). In this study, these six hydrobiogeographic regions determined for Türkiye were used.

Figure 1

Map of Türkiye

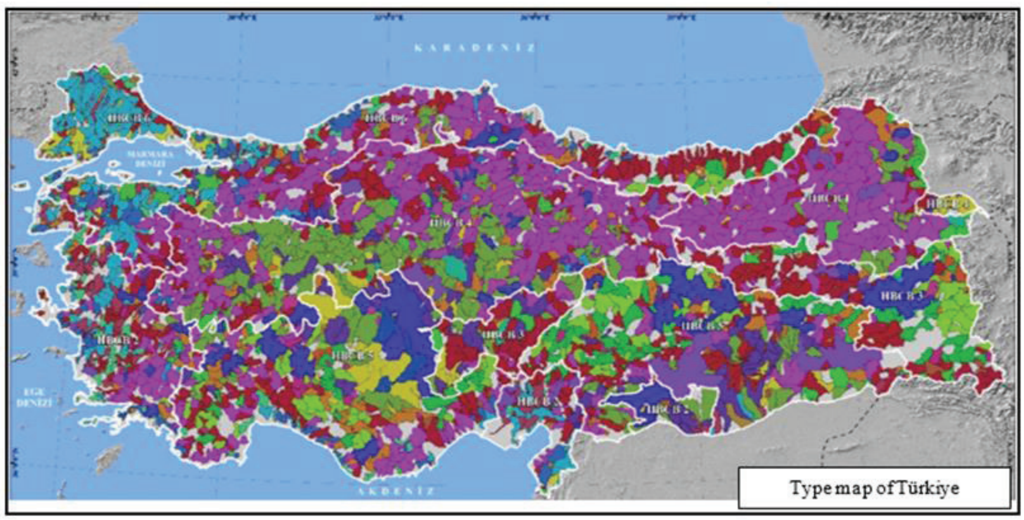


Note. Adapted from "Digitizing Project, 2022."

Type criteria (altitude, slope, and alkalinity) by selecting benthic macroinvertebrates distributed in the rivers of each hydrobiogeographic region and their associated, significant abiotic environmental parameters, were determined in the Digitizing Project (2022). Class boundary values of the types were determined for each hydrobiogeographic region, taking into account the environmental parameter ranges preferred by benthic macroinvertebrates, as well as the groupings (aggregations) that occur while dispersing within these ranges and the breaking points of these aggregations (Digitizing Project, 2022). The BMIR is a hydrobiogeographic region-based type-specific index, which means that index calculation depends on the type of river a sampling site belongs to. The river typology system in Türkiye (Fig. 2) developed by the project named Digitizing Project (2022) was used in this study.

Figure 2.

Map of River Types of Türkiye's Hydrobiogeographic Regions



Note. Adapted from "Digitizing Project, (2022)".

An overview of the types used in BMIR, class limits, features and abbreviations are presented in Table 1.

Table 1

The Types of Rivers in The Hydrobiogeographic Regions as Used Within The BMIR, and Class Boundaries

	Hydrobiogeographic Region-1			Hydrobiogeographic Region-2			Hydrobiogeographic Region-3		
Types	ABX, BAB, BAX, BBA, BBB, BBX, CBA, CBB, CBX			AAA, AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX, CBA, CBB, CBX			BAA, BAB, BAX, BBA, BBB, BBX, CAB, CAX, CBA, CBB, CBX		
Class boundaries	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
altitude (m)	<800	800-2500	>2500	<400	400-1300	>1300	<800	800-2000	>2000
slope (%)	<6	>6		<9	>9		<6	>6	
alkalinity (mg $CaCO^3$/L)	<60	>60		<200	>200		<170	>170	

Table 1

(Continued)

	Hydrobiogeographic Region-4			Hydrobiogeographic Region-5			Hydrobiogeographic Region-6		
Types	AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX			AAA, AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX, CAA, CAB, CAX, CBA, CBB, CBX			AAA, AAB, AAX, ABA, ABB, ABX, BAA, BAB, BAX, BBA, BBB, BBX, CBA, CBB, CBX		
Class boundaries	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
altitude (m)	<600	600-2500	>2500	<500	500-1300	>1300	<400	400-1500	>1500
slope (%)	<8	>8		<8	>8		<10	>10	
alkalinity (mg $CaCO^3$/L)	<130	>130		<150	>150		<120	>120	

Note. Adapted from "Digitizing Project, (2022)".

In triple-type notation, the first letter represents altitude, the second is slope, and the last is alkalinity parameter. X was used for the parameters whose class values could not be determined.

Sampling, Sorting, Identification and Counting

Data were handed from the Türkiye National Monitoring Program of surface water quality, supplied by the General Directorate of Water Management, Republic of Türkiye the Ministry of Agriculture and Forestry. The data on benthic macroinvertebrates between the years 2014-2020 for analyses were used. The collected data are at family, genus and species level. Altogether, 1875 taxa from 1925 monitoring sites were analyzed.

Sampling is done in spring and late summer or early autumn. To provide a reliable water quality assessment, it is recommended to avoid macroinvertebrate sampling during the winter months to avoid extreme conditions such as both the hydrological regime and temperature. Per-site samples are taken in different seasons using a multi-habitat approach (Biological Monitoring Communiqué, 2019; Hering et al., 2004). A multihabitat method is used as the sampling method, in which the main habitats covering more than 5% area in the sampling area are proportionally sampled. Benthic macroinvertebrates are systematically gathered from all in-river habitats in the sample area. A total of 20 samples are taken from the microhabitats detected in the sampling area and an area of approximately 1.25 m^2 is sampled. For example, if 50% of the in-river microhabitats are gravel, 10 sampling samples are taken from that microhabitat. It is ensured that all living individuals obtained are identified at the species level as much as possible. A list of all taxa taken into consideration for the BMIR is consisting of 1875 taxa. For each identified taxon, the number of individuals sampled and the number of individuals per square meter in that sample are recorded. The database contained taxa lists of the macroinvertebrate fauna with the number of individuals per square meter and data on hydrobiogeographic region and river types of each site. The measurements in the database are divided by hydrobiogeographic regions and river types in hydrobiogeographic regions respectively.

Metric Selection and Calculation of Metrics

ASTERICS (AQEM/STAR Ecological River Classification System) program with a large number of metrics such as richness/diversity metrics, composition/abundance metrics, and sensitivity/tolerance metrics (Furse et al. 2006; The Development and Testing of an Integrated Assessment System for the Ecological Quality of Streams and Rivers throughout Europe using Benthic Macroinvertebrates [AQEM], 2002) were reviewed.

Various monitoring studies have been carring out in accordance with the EU Water Framework Directive in order to determine both reference and degraded areas (e.g Project on Establishment of Reference Monitoring Network in Türkiye [Reference Project], 2020) and appropriate metrics in Türkiye, and multimetric indices containing different metrics have been developed for eight of twenty five river basins (Dügel 2016; Akay & Dalkıran, 2020). In the multimetric index development process, metrics in ASTERICS, which were assigned by Dügel (2016) for the eight basins were used. These evaluated and analyzed candidate metrics were given in Table 2. The requirements for these metrics to be able to make calculations (e.g. ecological trait scores of taxon, tolerance scores, etc.) were examined.

Table 2

The List of the Metrics Evaluated and Analyzed Firstly

Candidate metrics	Metric type
Biological Monitoring Working Party, BMWP (1978) Spanish version (BMWP-S)	Tolerance / intolerance measures
Shannon-Wiener (H') (1949)	Diversity measures
Margalef (1951)	Diversity measures
%EPT	Composition measures
%Type Aka Lit Psa	Substratum type measures
%Epirithral	Zonation measures
%Littoral	Zonation measures
%Hyporithral	Zonation measures
%Grazers-scrapers	Functional/Trophic measures

Using the biological data (taxa lists, abundance) nine candidate biological metrics were calculated in all hydrobiogeographic regions. The software package Excel Data Analysis ToolPak was used for metric calculation, statistical analysis, and graphical visualization. For metrics operating at the species level, taxa identified at the genus level in the calculations were entered as genus sp.

Removal of Redundant Metrics

Some metrics were eliminated due to lack of data, such as having not available (NA) or operating within a very narrow range of values. For the metrics to be potentially useful, their ability to make a clear distinction between quality classes was taken into account (Barbour, 1999). Descriptive statistics such as central tendency, range, distribution, and outliers were used to reveal the metric performances in determining the quality of observed areas versus reference areas.

Those with highly correlated and linear gradients between metrics generally provide the same information (Barbour et al., 1996; Karr, 1991; Karr et al., 1986). Among the candidate metrics, pairwise correlation analysis (Pearson product-moment correlation) was used in order not to increase the effect in the same direction and to eliminate them. The upper limit of the correlation coefficient was defined as $r = 0.75$. As stated earlier, highly correlated metrics were eliminated because they contributed in the same direction.

The nine metrics (Table 2) were tested to determine the degree to which they discriminate between reference points and disturbing points in stream types located in hydrobiogeographic regions. By visualizing the distribution of the metrics within the quality classes, the discrimination capacities of the metrics were assessed. We used box plots to visualize the distinct values of the metrics between the reference points and the degraded points. The metrics with the highest degree of divergence were evaluated as the most appropriate metrics. Metrics with insufficient separation degrees between the reference and disturbed areas were eliminated.

To aggregate the final metrics into the multimetric index, special attention was paid to selecting metrics to include at least three primary metric types and to show the ability to distinguish between degraded fields and undisturbed or slightly degraded fields (Karr & Chu, 1999).

Standardization of Final Metrics and Calculation of BMIR Index

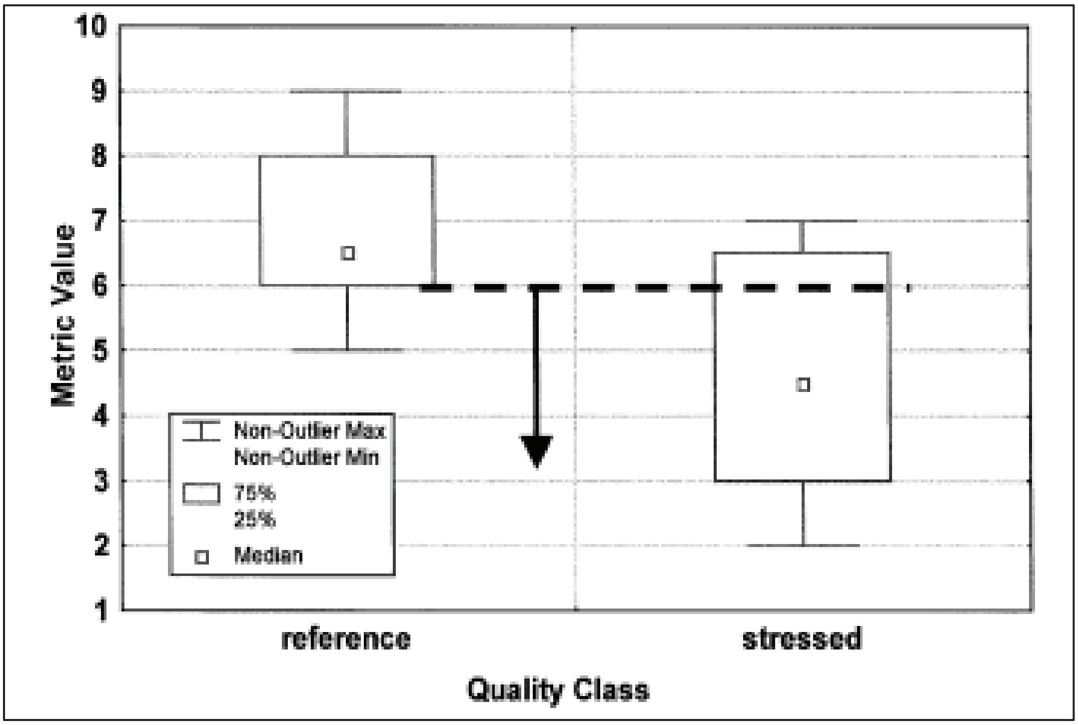
Multimetric indices are used in order to obtain an integrated and common meaning from the information obtained through biological metrics. To integrate, scores from the final metrics need to be normalized by converting them to scores in the same range of values. It is ensured through standardization that each metric has the same value and importance. The method followed in this study United States - Environmental Protection Agency's Rapid Bioassessment Protocols (Barbour, 1999): The score obtained at all sampling points (including reference points) of each metric is based on the distribution of values. The 95^{th} percentile of the distribution of score values for each metric was used to eliminate discrete values. Standardization was performed by calculating the metric scores as a percentage of the 95^{th} percentile. As a result, metric scores near the 95^{th} percentile were valued higher, while metric scores deviating from this percentile by a greater percentage were lower. Metric scores exceeding the 95^{th} percentile were scored as 1. The resulting index value is calculated using the average of the metric values obtained.

The Discrimination Efficiency of Index

Discrimination efficiency (DE) (Karr & Chu, 1999) values were estimated to see the strength of the index.

Figure 3

Discrimination Efficiency



The DE was calculated as the percentage of stressed samples with metric values lower than the 25^{th} percentile of reference values for decreasing metrics, and higher than the 75^{th} percentile for increasing metrics, respectively (Fig. 3).

As part of the WFD, data from reference areas according to the index were combined and tested against degraded areas, as this would help us decide whether action is needed to improve the quality of a river area (Directive, 2000/60/EC). Due to insufficient data on interactions between quality changes and hydromorphological features, final reference conditions based on macroinvertebrate data were used to develop a multimetric index (Buffagni et al., 2004).

Class Boundary Values

Class boundary values have been created based on index ranges, thus allowing for differentiation between different stress conditions. Many different methods have been developed in the literature to determine class limit values

(Barbour, 1999). In this study, a four-class boundaries of five quality grades was used to meet the requirements of the WFD;

- 95^{th} percentile High and Good quality class,
- 60^{th} percentile Good and Moderate quality class,
- 30^{th} percentile Moderate and Poor quality class,
- 5^{th} percentile Poor and Bad quality class.

Class boundary values suggested in the BMIR index were defined using unequal intervals. The fit of the thresholds was verified using index performance (DE) and precision estimates.

Results

Benthic Macroinvertebrate Fauna

Of the 1875 taxa analyzed, 1373 were at the species level, 410 at the genus level, and 92 at the family level. For metrics operating at the species level, taxa identified at the genus level in the calculations were entered as genus sp.

Elimination and Selection of Metrics

By visualizing the distribution of the metrics within the quality classes, the discrimination capacities of the metrics were assessed (Fig. 4). Metrics with insufficient separation degrees between the reference and disturbed areas were eliminated.

The metrics with the highest degree of discrimination are %Epirithral, BMWP-S, Shannon-Wiener, %EPT and Margalef. Among the candidate metrics, pairwise correlation analysis (Pearson product-moment correlation) was used (Table 3) in order not to increase the effect in the same direction and to eliminate them. Highly correlated metrics were eliminated because they contributed in the same direction.

Figure 4

The Discrimination Efficiency Degrees of the Metrics Between the Reference and Stressed Areas

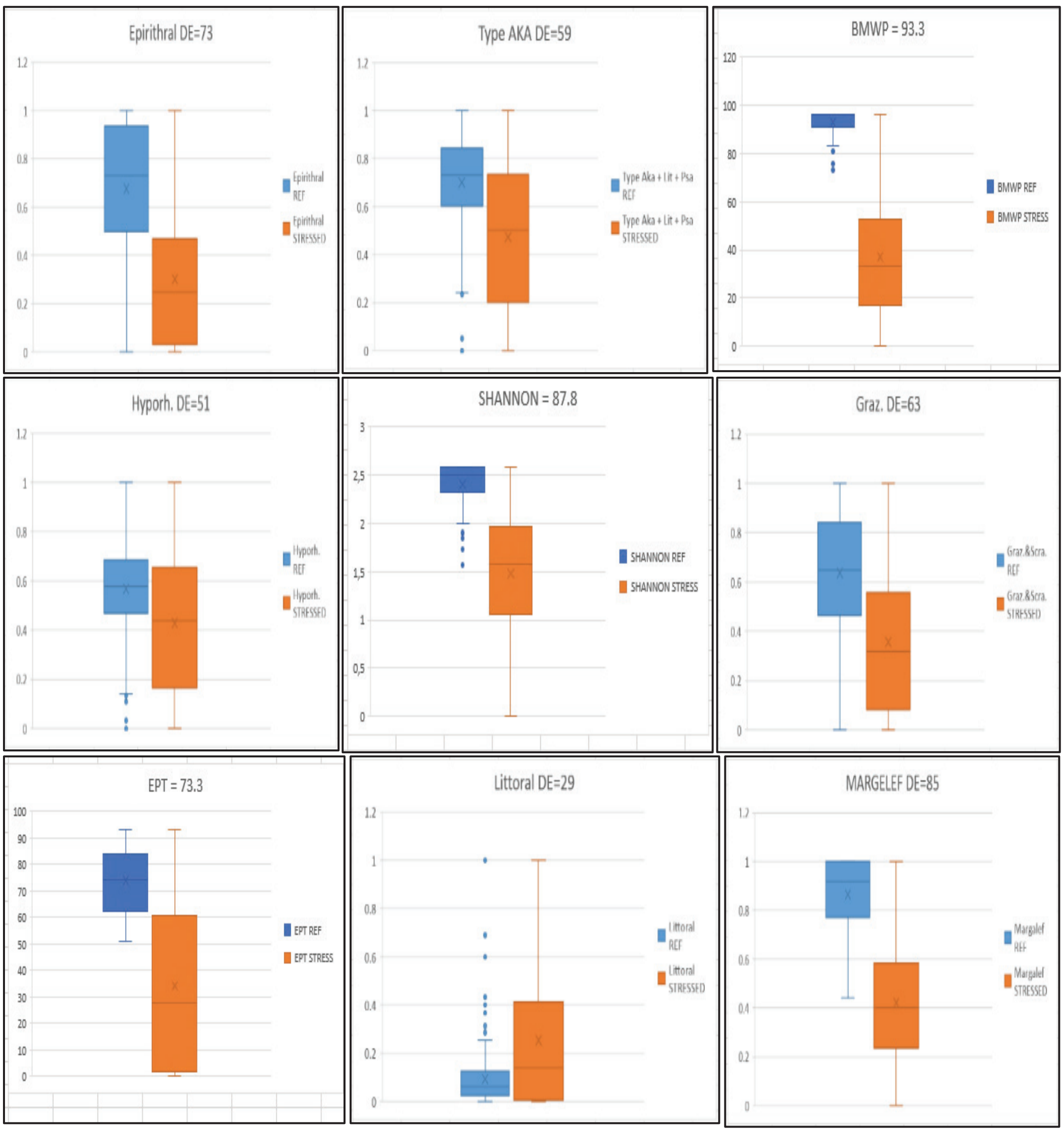


Table 3

The Correlation Degrees of the Metrics

Metrics	*BMWP-S*	*Shannon-Wiener*	*Margalef*	*%EPT*	*%Epirithral*	*%Littoral*	*%Hyporithral*	*%Grazers-scrapers*	*%Type Aka Lit Psa*
BMWP-S	1								
Shannon-Wiener	0,6679	1							
Margalef	0,7936	0,8675	1						
%EPT	0,3993	0,2585	0,2522	1					
%Epirithral	0,4088	0,2164	0,2368	0,5032	1				
%Littoral	-0,288	-0,1182	-0,1628	-0,4003	-0,4751	1			
%Hyporithral	0,1559	0,0458	0,0547	0,3346	0,2850	-0,3809	1		
%Grazers-scrapers	0,2122	0,1365	0,1458	0,3803	0,4268	-0,1871	0,2829	1	
%Type Aka Lit Psa	0,3106	0,1652	0,1681	0,4603	0,6070	-0,4335	0,5192	0,2054	1

The Margalef metric was eliminated as it showed high correlation with both BMWP-S and Shannon-Wiener. Lastly, among these metrics, the %Epirithral metric was eliminated on the assumption that the %Epirithral score values of the species in Türkiye were insufficient.

Final Metrics

Finally, the metrics that can reach the score values of species in Türkiye, that is, enable the calculations, and the metrics with the highest discriminant values were selected. The metrics that could be used in the final index after the metric eliminations were called final metrics. The discrimination efficiency values of the final metrics are shown in Fig. 5.

For the composition measures %EPT taxa were selected, which have high discriminatory power in all hydrobiogeographic regions. Within tolerance/intolerance measures the BMWP-S showed very useful results in all hydrobiogeographic regions. Among the diversity indices tested, the Shannon-Wiener diversity index gave the best results in all hydrobiogeographic region types.This resulted in a final list of three metrics. The final metrics comprised in the BMIR are, the Percentage of Ephemeroptera, Plecoptera and Trichoptera Taxa (%EPT), the Shannon-Wiener Diversity Index and the BMWP-S (Table 4).

Table 4

The List of Final Metrics Comprised in the BMIR

Metrics		Metric type
BMWP-S	Biological monitoring working party-Spanish version	Tolerance / intolerance measures
Shannon-Wiener	Shannon-Wiener diversity index	Diversity measures
%EPT	Percentage of Ephemeroptera, Plecoptera and Trichoptera taxa	Composition measures

Figure 5

The Discrimination Efficiency Values of Final Metrics in All Hydrobiogeographic Regions

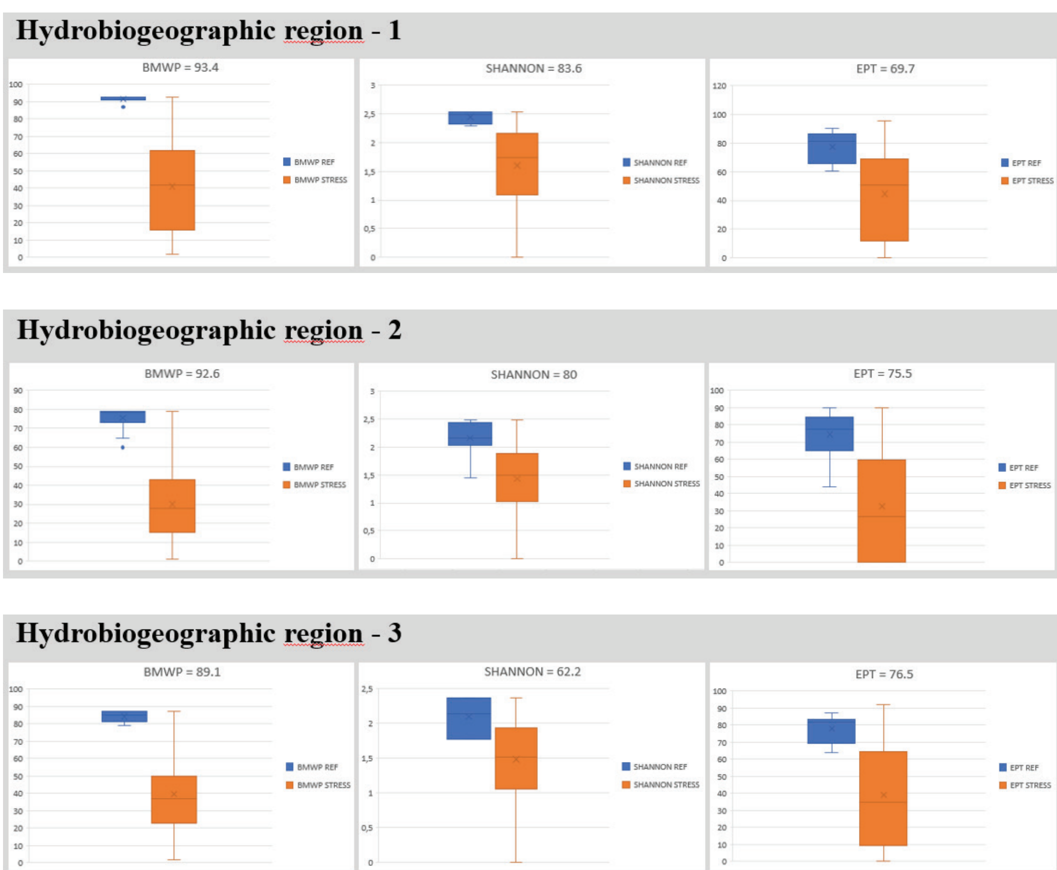


Figure 5

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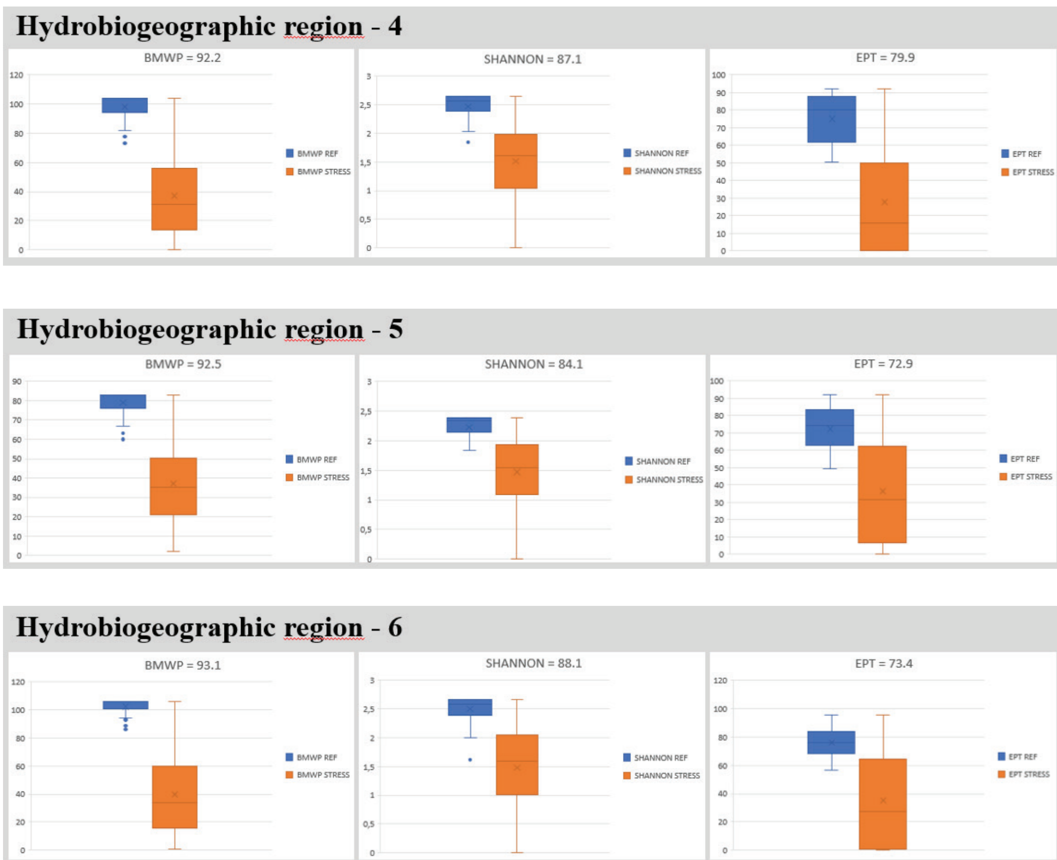


Reference Values of BMIR and Index Calculation

Reference values of three metrics were created for all types in each hydrobiogeographic region. These values were derived from the 95th percentile of the metric scores at the sampling points belonging to each type of hydrobiogeographic region. However, there was insufficient data on some types within hydrobiogeographic regions. For these types, a single reference value was produced from the data set created by combining the data of all types in the hydrobiogeographic regions they belong to. The reference values of three metrics for all types are summarized in Table 5.

Table 5

Metric Reference Values of Types in Hydrobiogeographic Regions

	Reference Values of Hydrobiogeographic Region-1 Types		
Metrics	*BBA*	*BBB*	*BAB, BBX, ABX, BAX, CBA, CBB, CBX*
BMWP-S	98,95	98,49	98
Shannon-Wiener	2,69	2,52	2,62
%EPT	90,72	97,75	95,39

	Reference Values of Hydrobiogeographic Region-2 Types						
Metrics	*AAA*	*AAB*	*ABA*	*ABB*	*BBA*	*BBB*	*BAA, AAX, BAB, BBX, ABX, CBA, BAX, CBB, CBX*
BMWP-S	61,01	55,30	75,76	98	85	76,03	78,41
Shannon-Wiener	2,47	2,19	2,53	2,27	2,62	2,45	2,48
%EPT	85,24	81,01	81,10	86,92	94,83	94,45	90,08

	Reference Values of Hydrobiogeographic Region-3 Types		
Metrics	*BBA*	*BBB*	*CBB, CBA, BAB, BAA, BAX, BBX, CAB, CAX, CBX*
BMWP-S	85	88,81	87
Shannon-Wiener	2,37	2,44	2,37
%EPT	93,16	72,15	92,39

	Reference Values of Hydrobiogeographic Region-4 Types				
Metrics	*BBA*	*BBB*	*BAB*	*BAA*	*ABB, BBX, BAX, AAB, AAX, ABA, ABX*
BMWP-S	115,69	104,41	76,5	61	104
Shannon-Wiener	2,67	2,67	2,31	2,28	2,65
%EPT	92,12	93,49	66,16	41,84	92,31

Table 5

(Continued)

Reference Values of Hydrobiogeographic Region-5 Types									
Metrics	*CBA*	*BBB*	*BBA*	*CBB*	*BAA*	*BAB*	*ABA*	*ABB*	*AAB, AAA, BAX, CBX, CAB, ABX, CAX, BBX, CAA, AAX*
BMWP-S	93,71	67,81	91	83	67,52	47,88	67,94	79,38	83
Shannon-Wiener	2,52	2,31	2,39	2,41	2,29	2,05	2,25	2,31	2,39
%EPT	96,68	94,69	85,96	95,76	59,99	80,37	77,81	100	91,86

Reference Values of Hydrobiogeographic Region-6 Types									
Metrics	*BBA*	*AAB*	*BBB*	*CBA*	*ABB*	*ABA*	*AAA*	*BAB*	*AAX, ABX, CBB, BBX, BAA, BAX, CBX*
BMWP-S	116,64	63,42	123,09	108,02	71,12	95,72	85	80,05	105,56
Shannon-Wiener	2,62	2,43	2,77	2,73	2,25	2,62	2,20	2,20	2,66
%EPT	100	72,58	97,36	100	85,12	93,43	86,40	84,27	95,73

The multimetric index calculation of a sampling point is explained below:

- Three metrics (BMWP-S, Shannon-Wiener, %EPT) are calculated separately.
- The metric scores obtained are divided by the reference value of those metrics determined for that type.
- The score values (between 0 and 1) obtained from each metric are summed up and averaged.
- The result of the multimetric index is obtained (BMIR value).

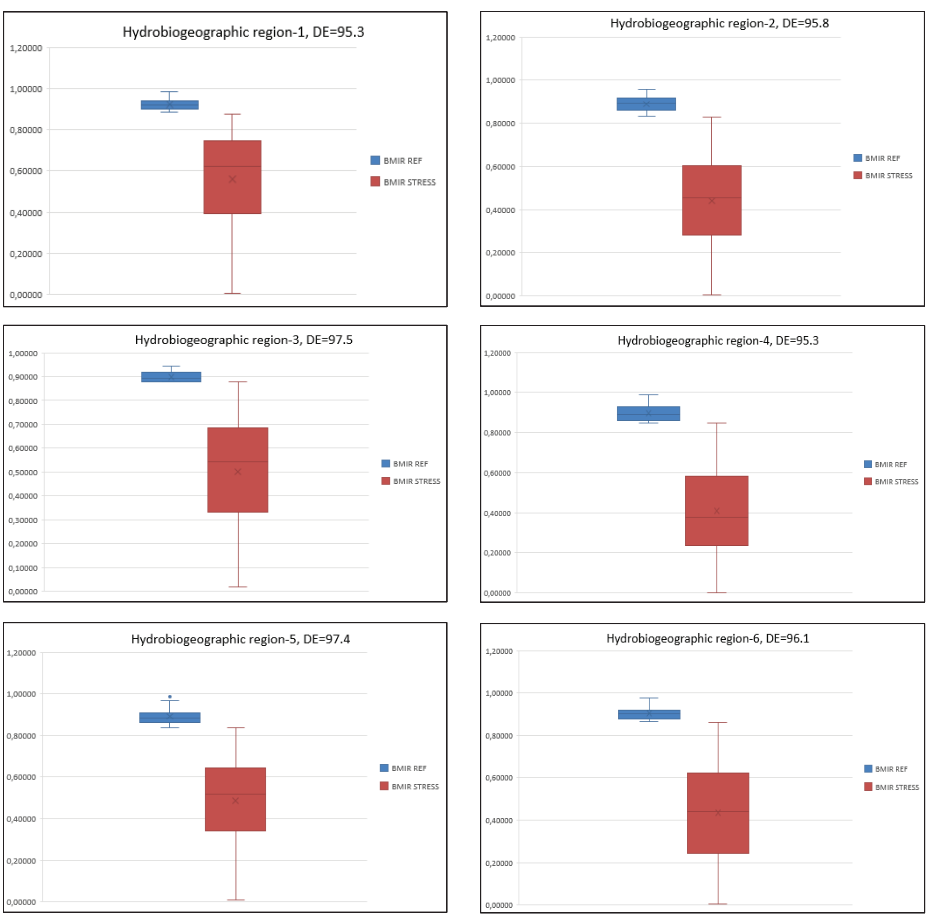
DE Values of BMIR

The final index that discriminated best between the different stages of disturbance is summarized in Figure 6 including calculated DE’s.

The resulting index comprises three metrics from three metric categories (composition, tolerance/intolerance, and diversity measures) and distinguishes reference/slightly disturbed sites from stressed sites with probabilities between 95.3% and 97.5%.

Figure 6

Discrimination Efficiency Values of BMIR (final index) in Hydrobiogeographic Regions



Quality Class Boundary Values of BMIR

BMIR, as mentioned above, produces a score ranging from 0 to 1 by averaging the three metric scores. This means that for the BMIR value to be 1, all metric values must be close to the type-specific reference values for these metrics. Therefore, the BMIR index result can be used as an EQR.

The quality class boundaries were derived from the percentile of index scores in the sampling sites belonging to each type in all hydrobiogeographic regions. Variable class ranges were defined for proposed class boundary values in the BMIR indices. Quality class thresholds were obtained by dividing BMIR index scores into five classes based on percentiles. These percentiles are 95th (High-Good), 60th (Good-Moderate), 30th (Moderate-Poor) and 5th (Poor-Bad) percentile. Proposed class boundary values are summarized in Table 6.

As mentioned in the methodology section, there was insufficient data on some types in hydrobiogeographic regions. For these types, common class boundary ranges were produced from the data set created by combining the data of all types in the hydrobiogeographic regions they belong to.

Table 6

BMIR's Class Boundary Values for the Types in All Hydrobiogeographic Regions

	Class Boundaries of Hydrobiogeographic Region-1 Types		
Quality classes	*BBA*	*BBB*	*BAB, BBX, ABX, BAX, CBA, CBB, CBX*
High	0,89-1,00	0,91-1,00	0,88-1,00
Good	0,72-0,89	0,67-0,91	0,68-0,88
Moderate	0,53-0,72	0,50-0,67	0,50-0,68
Poor	0,19-0,53	0,15-0,50	0,15-0,50
Bad	0,00-0,19	0,00-0,15	0,00-0,15

Table 6

(Continued)

Class Boundaries of Hydrobiogeographic Region-2 Types							
Quality classes	*AAA*	*AAB*	*ABA*	*ABB*	*BBA*	*BBB*	*BAA, AAX, BAB, BBX, ABX, CBA, BAX, CBB, CBX*
High	0,79-1,00	0,86-1,00	0,78-1,00	0,74-1,00	0,83-1,00	0,86-1,00	0,83-1,00
Good	0,46-0,79	0,41-0,86	0,46-0,78	0,50-0,74	0,54-0,83	0,63-0,86	0,53-0,83
Moderate	0,28-0,46	0,21-0,41	0,29-0,46	0,30-0,50	0,36-0,54	0,46-0,63	0,33-0,53
Poor	0,12-0,28	0,05-0,21	0,03-0,29	0,05-0,30	0,07-0,36	0,19-0,46	0,08-0,33
Bad	0,00-,012	0,00-0,05	0,00-0,03	0,00-0,05	0,00-0,07	0,00-0,19	0,00-0,08

Class Boundaries of Hydrobiogeographic Region-3 Types			
Quality classes	*BBA*	*BBB*	*CBB, CBA, BAB, BAA, BAX, BBX, CAB, CAX, CBX*
High	0,88-1,00	0,81-1,00	0,88-1,00
Good	0,64-0,88	0,56-0,81	0,62-0,88
Moderate	0,42-0,64	0,29-0,56	0,39-0,62
Poor	0,14-0,42	0,14-0,29	0,13-0,39
Bad	0,00-0,14	0,00-0,14	0,00-0,13

Class Boundaries of Hydrobiogeographic Region-4 Types					
Quality classes	*BBA*	*BBB*	*BAB*	*BAA*	*ABB, BBX, BAX, AAB, AAX, ABA, ABX*
High	0,88-1,00	0,85-1,00	0,82-1,00	0,77-1,00	0,85-1,00
Good	0,63-0,88	0,54-0,85	0,39-0,82	0,44-0,77	0,49-0,85
Moderate	0,36-0,63	0,35-0,54	0,21-0,39	0,24-0,44	0,27-0,49
Poor	0,16-0,36	0,13-0,35	0,04-0,21	0,09-0,24	0,08-0,27
Bad	0,00-0,16	0,00-0,13	0,00-0,04	0,00-0,09	0,00-0,08

Table 6

(Continued)

Class Boundaries of Hydrobiogeographic Region-5 Types									
Quality classes	*CBA*	*BBB*	*BBA*	*CBB*	*BAA*	*BAB*	*ABA*	*ABB*	*AAB, AAA, BAX, CBX, CAB, ABX, CAX, BBX, CAA, AAX*
High	0,85-1,00	0,84-1,00	0,82-1,00	0,86-1,00	0,91-1,00	0,79-1,00	0,88-1,00	0,79-1,00	0,84-1,00
Good	0,62-0,85	0,59-0,84	0,52-0,82	0,66-0,86	0,48-0,91	0,48-0,79	0,60-0,88	0,61-0,79	0,59-0,84
Moderate	0,44-0,62	0,45-0,59	0,33-0,52	0,55-0,66	0,31-0,48	0,24-0,48	0,35-0,60	0,48-0,61	0,39-0,59
Poor	0,21-0,44	0,09-0,45	0,12-0,33	0,29-0,55	0,13-0,31	0,06-0,24	0,16-0,35	0,29-0,48	0,12-0,39
Bad	0,00-0,21	0,00-0,09	0,00-0,12	0,00-0,29	0,00-0,13	0,00-0,06	0,00-0,16	0,00-0,29	0,00-0,12

Class Boundaries of Hydrobiogeographic Region-6 Types									
Quality classes	*BBA*	*AAB*	*BBB*	*CBA*	*ABB*	*ABA*	*AAA*	*BAB*	*AAX, ABX, CBB, BBX, BAA, BAX, CBX*
High	0,87-1,00	0,76-1,00	0,85-1,00	0,90-1,00	0,76-1,00	0,79-1,00	0,77-1,00	0,88-1,00	0,86-1,00
Good	0,59-0,87	0,42-0,76	0,62-0,85	0,77-0,90	0,44-0,76	0,63-0,79	0,50-0,77	0,46-0,88	0,53-0,86
Moderate	0,40-0,59	0,18-0,42	0,41-0,62	0,68-0,77	0,27-0,44	0,47-0,63	0,30-0,50	0,25-0,46	0,30-0,53
Poor	0,11-0,40	0,01-0,18	0,12-0,41	0,42-0,68	0,05-0,27	0,20-0,47	0,07-0,30	0,13-0,25	0,06-0,30
Bad	0,00-0,11	0,00-0,01	0,00-0,12	0,00-0,42	0,00-0,05	0,00-0,20	0,00-0,07	0,00-0,13	0,00-0,06

Discussion and Conclusion

In the assessment of the ecological status of a water body under the EU Water Framework Directive, biological quality element indices, which show changes such as the composition and abundance of type-specific taxa, are of central importance and imply that biota rather than abiotic conditions are prioritized. When there is no alteration in quality over the sampling period, an efficient index should not vary much and show only minor differences between comparable sites of the same type (Karr et al., 1987). The choice of final metrics depended on several factors; it should be suitable for use for all water body types, contain metrics from more than one metric category, be effective in evaluating water quality, and meet WFD criteria. The fact that the metrics to be selected are also data that can be used effectively and that are easy to select and measure can provide convenience in practice. In order to shed light on future studies, it is necessary to produce the ecological traits score values of the species (specific to Türkiye), so that aquatic ecosystem assessments can be made more soundly.

All hydrobiogeographic region types utilized the same set of metrics, however scoring thresholds varied by type-specific. This allowed for typological differences to be considered in an index's calculation while maintaining clarity and simplicity. Butcher et al. (2003) took a similar technique by altering the threshold values of some measures linearly with the natural logarithm of stream width to differentiate the Benthic Community Index.

In this study, nine metrics representing diversity, composition, and tolerance, including functional metrics, were included in the evaluation of benthic macroinvertebrate based ecological status (Odabaşı et al., 2022; Dügel, 2016) for the Türkiye's hydrobiogeographic regions. The BMIR was developed with three key metrics selected from metric groups. According to the Dügel (2016), for eight river basins of Türkiye, several metrics such as BMWP-S, EPT [%], Margalef, Shannon-Wiener, Gra+Scr [%], epirhithral [%], littoral [%], hyporhithral [%], and Type Akal+Lithal+Psammal were found as appropriate. Among these metrics, BMWP-S, Shannon-Wiener and EPT [%] took part in the metric development process for Türkiye. Multimetric indices integrate different metrics into a single evaluation. In this manner, multiple dimensions of ecosystem functioning or diverse measures of ecological integrity are expected to be integrated into a more comprehensive assessment. At least one metric related to the metric group (composition/abundance, richness/diversity, sensitivity/tolerance, and functions) should be utilised for estimating the functionality of the freshwater groups (Hering et al., 2004). In addition, it is commonly assumed that combining several metrics improves the reliability and efficiency of an index because accidental outliers of one metric can be smoothed out by the other metrics (Gabriels et al., 2010). Compared to the individual metrics, the multimetric index provides more reliable and consistent findings, showing higher discrimination efficiency. There are three different metric types in three different metric categories in the multimetric index, thus increasing the capacity of the index to discriminate against different stress intensities. The calculation of the chosen metrics was based on the number of taxa and the number of taxa per square meter within taxonomic groups.

Richness or diversity metrics are generally implemented as indicators of ecological integrity. Diversity metrics are based on the assumption that disruption of the aquatic ecosystem or stress on communities reduces biodiversity (Gabriels et al., 2010). Moreover, richness metrics indicate the diversity of an aquatic community and are recognized as the most useful indicator of deterioration (Resh et al., 1995). Detection of the elimination of taxa from a naturally diversified system can be done easily (Barbour et al., 1996). In particular, species belonging to the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) are widely considered to be susceptible to perturbation, and the loss of taxonomic richness within this group implies impairment (Wallace et al., 1996). According to Guerold (2000), Shannon-Wiener index, one of the diversity indexes, can be used to illustrate the changes of the ecosystem condition. In this study, we used the Shannon-Wiener index as a measure of diversity and provided accurate results in all stream types. This metric contributes to the index of all stream types. The use of sensitivity metrics in macroinvertebrate-based water quality studies is widespread. Metrics based on sensitivity have the benefit over richness and diversity metrics, in that taxon-specific features can be included. The principle that varied taxa respond to disturbance in different ways, is base for these metrics (Gabriels et al., 2010). The majority of macroinvertebrate-based assessment systems incorporate this principle (Gabriels et al., 2010; Armitage et al., 1983). Measurements of composition give information on the relative contribution of taxonomic groups to the total fauna. A healthy and stable assemblage will have reasonably consistent proportional representation, according to the premise (Barbour et al., 1996). According to Ode et al. (2005), %EPT is sensitive to anthropogenic stress in aquatic ecosystems, measures the response of Ephemeroptera, Plecoptera, and Trichoptera taxa to pressures. This study, %EPT taxa composition measures promoted to the index: High discriminatory power was found for %EPT taxonomic composition measurements across all stream types and hydrobiogeographic regions. Pollution-tolerant and intolerant taxa or percent composition are included in the content of Tolerance/Intolerance measures (Barbour, 1999). In this study, BMWP-S was used for that measure. In many countries around the globe, the BMWP metric or a modification thereof has been widely used, and in many published reports, its efficiency for water quality studies has been demonstrated (Arslan et al., 2016; Wyżga et al., 2013; Yu et al., 2004; Mustow, 2002; Junqueira & Campos, 1998). Also, Dügel (2016) suggested that the BMWP-S index is one of the most appropriate tolerance metric for Türkiye. This was confirmed by our results, where the BMWP-S results were responsive in all hydrobiogeographic regions.

On benthic macroinvertebrates of Turkish rivers, many metric-based studies are done for some river basins to date (Arslan & Mercan, 2020; Akay & Dalkıran, 2020; Zeybek, 2017; Arslan et al., 2016; Dügel, 2016; Kalyoncu & Zeybek, 2011; Kazancı & Türkmen, 2010; Kazancı et al., 2010; Duran, 2006). However, most of them assess biological quality on the basis of a single metric rather than a multimetric approach. To our knowledge, this article is the first in the literature to evaluate multimetric-based benthic macroinvertebrates covering the whole of Türkiye. For this reason, the BMIR index is expected to be valuable for international researchers as well as helping in the ecological status assessment of Turkish rivers.

In conclusion, the tested multimetric approach was found to be useful and effective for assessing the ecological status of Türkiye's running rivers. The index developed in this study was quite specialized, for a unique combination of hydrobiogeographic regions and stream types; furthermore, the data size of some stream types in each hydrobiogeographic region was necessarily smaller than the data size of hydrobiogeographic regions. Index development for full implementation in Türkiye, it will be necessary to build stressor-specific indices or to generalize to multiple stressor types. Combining measurements considered suitable for individual stressors or developing hydrobiogeographic-specific indices can facilitate generalization. For nationwide index use, it is not necessary to develop a separate index for each river water body type. Separate indices or separate class boundaries may only be used for regions with great faunal variation, such as ecoregions. This study aimed to create a general index for all hydrobiogeographic regions based on a certain metric group, as well as to derive the reference and class boundary ranges of the index specific to the types within the regions. Here, a general index was developed containing the same metrics for all ecoregions, in addition, changes were made to the reference values of the metrics and class boundary ranges for each ecoregion. For each stream type, the final threshold values and reference values can be calibrated. It is thought that the developed BMIR index will help decision makers in determining the ecological quality of Turkish rivers.

References

Akay, E., & Dalkıran, N. (2020). Assessing biological water quality of Yalakdere stream (Yalova, Turkey) with benthic macroinvertebrate-based metrics. *Biologia*, *75*(9), 1347-1363. **https://doi.org/10.2478/s11756-019-00387-9**

Allan, J. D. (2004). Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual review of ecology, evolution, and systematics*, 257-284.

AQEM. (2002). Manual for the application of the AQEM system. *A comprehensive method to assess European streams using benthic macroinvertebrates, developed for the purpose of the Water Framework Directive. Version*, *1*(02), 2002.

Armitage, P. D., Moss, D., Wright, J. F., & Furse, M. T. (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*(3), 333-347. **https://doi.org/10.1016/0043-1354(83)90188-4**

Arslan, N., Salur, A., Kalyoncu, H., Mercan, D., Barişik, B., & Odabaşi, D. A. (2016). The use of BMWP and ASPT indices for evaluation of water quality according to macroinvertebrates in Küçük Menderes River (Turkey). *Biologia*, *71*(1), 49-57. **https://doi.org/10.1515/biolog-2016-0005**

Arslan, N., & Mercan, D. (2020). Long-term macrobenthic community structure changes in the Upper Sakarya River System (1995–2015). *Zoosymposia*, *17*, 89-101. **http://dx.doi.org/10.11646/zoosymposia.17.1.10**

Barbour, M. T., Gerritsen, J., Griffith, 3., Frydenborg, R., McCarron, E., White, J. S., & Bastian, M. L. (1996). A framework for biological criteria for Florida streams using benthic macroinvertebrates. *Journal of the North American Benthological Society*, *15*(2), 185-211. **https://doi.org/10.2307/1467948**

Barbour, M. T. (1999). *Rapid bioassessment protocols for use in wadeable streams and rivers: periphyton, benthic macroinvertebrates and fish*. US Environmental Protection Agency, Office of Water. **http://www.epa.gov/OWOW/monitoring/techmon.html**

Birk, S., Bonne, W., Borja, A., Brucet, S., Courrat, A., Poikane, S., Solimini, A., van de Bund, W., Zampoukas, N., & Hering, D. (2012). Three hundred ways to assess Europe's surface waters: An almost complete overview of biological methods to implement the Water Framework Directive. *Ecological Indicators*, *18*(1), 31-41. **https://doi.org/10.1016/j.ecolind.2011.10.009**

Biological Monitoring Communiqué. (2019). Biological Monitoring Communiqué, Official Newspaper, Date:21.06.2019, No:30808.

Biological Monitoring Working Party. (1978). *Final report of the Biological Monitoring Working Party: Assessment and presentation of the biological quality of rivers in Great Britain*. Department of the Environmental Water Data Unit, London.

Borja, A., Barbone, E., Basset, A., Borgersen, G., Brkljacic, M., Elliott, M., Garmendia, J.M., Marques, J.C., Mazik, K., Muxika, I., Neto, J.M., Norling, K., Rodríguez, J.G., Rosati, I., Rygg, B., Teixeira, H., & Trayanova, A. (2011). Response of single benthic metrics and multi-metric methods to anthropogenic pressure gradients, infive distinct European coastal and transitional ecosystems. *Marine Pollution Bulletin, 62*, 499–513. **http:// dx.doi.org/10.1016/j.marpolbul.2010.12.009**

Buffagni, A., Erba, S., Cazzola, M., & Kemp, J. L. (2004). The AQEM multimetric system for the southern Italian Apennines: assessing the impact of water quality and habitat degradation on pool macroinvertebrates in Mediterranean rivers. *Hydrobiologia; Dordrecht*, *516*(1-3), 313-329. **http://doi.org/10.1023/B:HYDR.0000025273.15958.6a**

Butcher, J. T., Stewart, P. M., & Simon, T. P. (2003). A benthic community index for streams in the northern lakes and forests ecoregion. *Ecological Indicators*, *3*(3), 181-193. **https://doi.org/10.1016/S1470-160X(03)00042-6**

Chainho, P., Chaves, M. L., Costa, J. L., Costa, M. J., & Dauer, D. M. (2008). Use of multimetric indices to classify estuaries with different hydromorphological characteristics and different levels of human pressure. *Marine Pollution Bulletin, 56*(6), 1128-1137. **https://doi.org/10.1016/j.marpolbul.2008.03.018**

Chaves, M.L., Chainho, P., Costa, J.L., Prat, N., & Costa, M.J. (2005). Regional and local environmental factors structuring undisturbed benthic macroinvertebrate communities in the Mondego River basin, Portugal. *Archiv für Hydrobiologie, 163* (4), 497–523. **http://dx.doi.org/10.1127/0003-9136/2005/0163-0497**

Davis, W. S., & Simon, T. P. (Eds.). (1995). *Biological assessment and criteria: tools for water resource planning and decision making*. CRC Press.

Digitizing Project, (2022). *The Project on Digitizing Water Resources, Preparation of Monitoring Programs by Performing Typology, Water Body and Risk Assessment.* The Republic of Türkiye Ministry of Agriculture and Forestry General Directorate of Water Management, 2017-2021.

Directive 2000/60/EC, 2000. European Parliament and the Council (EC) 2000/60/EC of 23 October 2000 on establishing a framework for Community action in the field of water policy. Off. J. Eur. Commun. L327, 1–72. **http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0060:en:NOT**

Duran, M. (2006). Monitoring water quality using benthic macroinvertebrates and physicochemical parameters of Behzat Stream in Türkiye. *Polish Journal of Environmental Studies*, *15*(5), 709-717. **http://www.pjoes.com/pdf-87923-21782?filename=Monitoring%20Water%20Quality.pdf**

Dügel, M. (2016). *Ülkemize özgü su kalitesi ekolojik değerlendirme sisteminin kurulması projesi*. The Ministry of Agriculture & Forestry General Directorate of Water Management, Ankara.

Everard, M. (2012). Why does ‘good ecological status’ matter? *Water and Environment Journal, 26*(2), 165-174. **https://doi.org/10.1111/j.1747-6593.2011.00273.x**

Furse, M., Hering, D., Moog, O., Verdonschot, P., Johnson, R. K., Brabec, K., Gritzalis, K., Buffagni, A., Pinto, P., Friberg, N., Murray-Bligh, J., Kokes, J., Alber, R., UsseglioPolatera, P., Haase, P., Sweeting, R., Bis, B., Szoszkiewicz, K., Soszka, H., Springe, G., Sporka, F., & Krno, I. J. (2006). The STAR project: context, objectives and approaches. In M. T. Furse1, D. Hering, K. Brabec, A. Buffagni, L. Sandin & P. F. M. Verdonschot (Eds.), *The ecological status of European Rivers: Evaluation and intercalibration of assessment methods* (pp. 3-29). Springer, Dordrecht. **http://www.jlakes.org/ch/book/978-1-4020-5493-8.pdf**

Gabriels, W., Lock, K., De Pauw, N., & Goethals, P. L. (2010). Multimetric Macroinvertebrate Index Flanders (MMIF) for biological assessment of rivers and lakes in Flanders (Belgium). *Limnologica-Ecology and Management of Inland Waters*, *40*(3), 199-207. **https://doi.org/10.1016/j.limno.2009.10.001**

Guerold, F. (2000). Influence of taxonomic determination level on several community indices. *Water research, 34*(2), 487-492. **https://doi.org/10.1016/S0043-1354(99)00165-7**

Hawkins, C. P., Olson, J. R., & Hill, R. A. (2010). The reference condition: predicting benchmarks for ecological and water-quality assessments. *Journal of the North American Benthological Society*, *29*(1), 312-343. **https://doi.org/10.1899/09-092.1**

Hawkins, C. P., & Norris, R. H. (2000). Performance of different landscape classifications for aquatic bioassessments: introduction to the series. *Journal of the North American Benthological Society*, *19*(3), 367-369.

Hellawell, J. M. (Ed.). (2012). *Biological indicators of freshwater pollution and environmental management*. Springer Science & Business Media.

Herlihy, A. T., Paulsen, S. G., Sickle, J. V., Stoddard, J. L., Hawkins, C. P., & Yuan, L. L. (2008). Striving for consistency in a national assessment: the challenges of applying a reference-condition approach at a continental scale. *Journal of the North American Benthological Society*, *27*(4), 860-877.

Hering, D., Moog, O., Sandin, L., & Verdonschot, P. F. (2004). Overview and application of the AQEM assessment system. *Hydrobiologia*, *516*(1), 1-20. **http://dx.doi.org/10.1023/B:HYDR.0000025255.70009.a5**

Hughes, R. M. (1995). Defining acceptable biological status by comparing with reference conditions. In *Biological assessment and criteria: Tools for water resource planning and decision making* (pp. 31-48). Boca Raton (FL), USA: Lewis.

Hughes, R. M., Larsen, D. P., & Omernik, J. M. (1986). Regional reference sites: a method for assessing stream potentials. *Environmental management*, *10*(5), 629-635.

Junqueira, V. M., & Campos, S. C. M. (1998). Adaptation of the “BMWP” method for water quality evaluation to Rio das Velhas watershed (Minas Gerais, Brazil). *Acta Limnologica Brasiliensia*, *10*(2), 125-135.

Kalyoncu, H. and Zeybek, M. (2011). An application of different biotic and diversity indices for assessing water quality: A case study in the Rivers Çukurca and Isparta (Türkiye). *African Journal of Agricultural Research*, *6*(1), 19-27.

Karr, J. R., Fausch, K. D., Angermeier, P. L., Yant, P. R., & Schlosser, I. J. (1986). Assessing biological integrity in running waters. *A method and its rationale. Illinois Natural History Survey, Champaign, Special Publication*, *5*, 1-28.

Karr, J. R., Yant, P. R., Fausch, K. D., & Schlosser, I. J. (1987). Spatial and temporal variability of the index of biotic integrity in three midwestern streams. *Transactions of the American Fisheries Society*, *116*(1), 1-11.

Karr, J. R. (1991). Biological integrity: a long- neglected aspect of water resource management. *Ecological applications*, *1*(1), 66-84. **https://vtechworks.lib.vt.edu/bitstream/handle/10919/46860/1941848.pdf?sequence=1**

Karr, J. R., & Chu, E. W. (1999). *Restoring life in running waters*. Island Press.

Karr, J. R., & Dudley, D. R. (1981). Ecological perspective on water quality goals. *Environmental Management*, *5*(1), 55-68.

Kazancı, N., & Türkmen, G. (2010). *Proceeding of Balwois: Assessment of water quality of Kelkit Stream (Türkiye) with application of various macro invertebrate-based metrics*. **https://www.academia.edu/705867/Assessment_of_water_quality_of_Kelkit_Stream_Turkey_with_application_of_various_macro_invertebrate_based_metrics**

Kazancı, N., Türkmen, G., Ertunç, Ö. , Ekingen, P., Öz, B., & Gültutan, Y. (2010). Assessment of ecological quality of Yeşilırmak River (Türkiye) by using macroinvertebrate-based methods in the content of Water Framework Directive. *Review of Hydrobiology*, *3*(2), 89-110. **https://www.academia.edu/1877972/Assessment_of_ecological_quality_of_Ye%C5%9Fil%C4%B1rmak_River_Turkey_by_using_macroinvertebrate_based_methods_in_the_content_of_Water_Framework_Directive**

Margalef, R. (1951). Diversidad de especies en les communideades natural. *Public Institutte of Biologic, Barcelonia, 9,* 5– 27. **https://digital.csic.es/handle/10261/165981**

Medeiros, J.P., Chaves, M.L., Silva, G., Azeda, C., Costa, J.L., Marques, J.C., Costa, J.C., & Chainho, P. (2012). Benthic condition in low salinity areas of the Mira estuary (Portugal): lessons learnt from freshwater and marine assessment tools. *Ecological Indicators, 19*, 79–88. **http://dx.doi.org/10.1016/j.ecolind.2011.09.008**

Miller, D. L., Hughes, R. M., Karr, J. R., Leonard, P. M., Moyle, P. B., Schrader, L. H., Thompson, B.A., Daniels, R.A., Fausch, K., Fitzhugh, G. A., & Gammon, J.R. (1988). Regional applications of an index of biotic integrity for use in water resource management. *Fisheries*, *13*(5), 12-20. **http://dx.doi.org/10.1577/1548-8446(1988)013%3C0012:RAOAIO%3E2.0.CO;2**

Munné, A., Ginebreda, A., & Prat, N. (2015). *Experiences from surface water quality monitoring: The EU Water Framework Directive implementation in the Catalan River Basin District (Part I)*. Springer.

Mustow, S.E. (2002). Biological monitoring of rivers in Thailand: use and adaptation of the BMWP score. *Hydrobiologia*, *479*(1), 191-229. **https://doi.org/10.1023/A:1021055926316**

Odabaşı, D. A., Odabaşı, S., Ergül, H. A., Özkan, N., Boyacı, Y. Ö., Bayköse, A., Kayal, M., Ekmekci, F., Dagdeviren, M., Güzel, B., Canli, O., & Dügel, M. (2022). Development of a macroinvertebrate-based multimetric index for biological assessment of streams in the Sakarya River Basin, Turkey. *Biologia*, *77*(5), 1317-1326. **http://dx.doi.org/10.1007/s11756-022-01041-7**

Ode, P. R., Rehn, A. C., & May, J. T. (2005). A quantitative tool for assessing the integrity of southern coastal California streams. *Environmental Management*, *35*(4), 493-504. **https://doi.org/10.1007/s00267-004-0035-8**

Omernik, J. M. (1987). Ecoregions of the conterminous United States. *Annals of the Association of American Geographers*, *77*(1), 118-125. **https://doi.org/10.1111/j.1467-8306.1987.tb00149.x**

Omernik, J. M. (1995). Ecoregions: a framework for managing ecosystems. In The George Wright Forum (Vol. 12, No. 1, pp. 35-50). George Wright Society.

Pardo, I., Gómez-Rodríguez, C., Wasson, J. G., Owen, R., van de Bund, W., Kelly, M., Bennett, C., Birk, S., Buffagni, A., Erba, S., Mengin, N., Murray-Bligh, J., & Ofenböeck, G. (2012). The European reference condition concept: a scientific and technical approach to identify minimally-impacted river ecosystems. *Science of the Total Environment*, *420*, 33-42. **https://doi.org/10.1016/j.scitotenv.2012.01.026**

Reference Project, (2020). *Project on Establishment of Reference Monitoring Network in Türkiye*. The Republic of Türkiye Ministry of Agriculture & Forestry General Directorate of Water Management, 2016-2020.

Resh, V. H., Norris, R. H., & Barbour, M. T. (1995). Design and implementation of rapid assessment approaches for water resource monitoring using benthic macroinvertebrates. *Australian Journal of Ecology*, *20*(1), 108-121. **https://doi.org/10.1111/j.1442-9993.1995.tb00525.x**

Shannon, C.E., & Wiener, W. (1949). *The mathematical theory of communication*. The University of Illinois Press.

Soranno, P. A., Wagner, T., Martin, S. L., McLean, C., Novitski, L. N., Provence, C. D., & Rober, A. R. (2011). Quantifying regional reference conditions for freshwater ecosystem management: A comparison of approaches and future research needs. *Lake and Reservoir Management*, *27*(2), 138-148. **http://dx.doi.org/10.1080/07438141.2011.573614**

Stoddard, J. L., Larsen, D. P., Hawkins, C. P., Johnson, R. K., & Norris, R. H. (2006). Setting expectations for the ecological condition of streams: the concept of reference condition. *Ecological applications*, *16*(4), 1267-1276. **http://dx.doi.org/10.1890/1051-0761(2006)016[1267:SEFTEC]2.0.CO;2**

Wallace, J. B., Grubaugh, J. W., & Whiles, M. R. (1996). Biotic indices and stream ecosystem processes: results from an experimental study. *Ecological Applications*, *6*(1), 140-151. **http://dx.doi.org/10.2307/2269560**

Whittier, T. R., Stoddard, J. L., Larsen, D. P., & Herlihy, A. T. (2007). Selecting reference sites for stream biological assessments: Best professional judgment or objective criteria. *Journal of the North American Benthological Society*, *26*(2), 349-360.**http://dx.doi.org/10.1899/0887-3593(2007)26[349:SRSFSB]2.0.CO;2**

Wyżga, B., Oglęcki, P., Hajdukiewicz, H., Zawiejska, J., Radecki-Pawlik, A., Skalski, T., & Mikuś, P. (2013). Interpretation of the invertebrate-based BMWP-PL index in a gravel-bed river: insight from the Polish Carpathians. *Hydrobiologia*, *712*(1), 71-88. **http://dx.doi.org/10.1007/s10750-012-1280-0**

Yu, L., Vermaat, J. E., de Ruyter, E. D., & de Kruijf, H. A. M. (2004). Modification and application of biomonitoring ISO-BMWP method of macrofauna in river pollution evaluation in China. *Zhongshan da xue xue bao. Zi ran ke xue ban= Acta Scientiarum Naturalium Universitatis Sunyatseni*, *43*(4), 102-105.

Zeybek, M. (2017). Macroinvertebrate-based biotic indices for evaluating the water quality of Kargı Stream (Antalya, Türkiye). *Turkish Journal of Zoology*, *41*(3), 476-486. **https://aj.tubitak.gov.tr/zoology/issues/zoo-17-41-3/zoo-41-3-11-1602-10.pdf**

Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Türkiye'deki Nehirler İçin Bentik Makroomurgasızlara Dayalı Bir Multimetrik İndeks Geliştirilmesi (BMIR)

AB Su Çerçeve Direktifi (SÇD) (Directive, 2000/60/EC), üye devletlerden ve diğer katılımcı ülkelerden yüzey sularının daha fazla bozulmasını önlemelerini, mevcut durumlarını korumalarını ve iyi durumda olmayan tüm su kütlelerini iyileştirmelerini talep etmektedir. SÇD, su kütlelerinin ekolojik durumunu belirlemek için biyota ile hidromorfolojik ve kimyasal bileşenler arasındaki ilişkileri kullanmakta ve biyolojik değerlendirmenin 0 (Kötü) ile 1 (Çok İyi) arasında değişen beş sınıflı bir gösterimle oransal (Ekolojik Kalite Oranı, EKO) olarak belirtilmesini istemektedir. EKO, bir su kütlesi tipi için gözlemlenen değerin, referans koşullar altında aynı tip için beklenen değere oranıdır. SÇD'de yüzey suyu kütlelerinin ekolojik kalite durumunu belirlemek için biyolojik değerlendirmede bentik makroomurgasızlar, makrofitler, diatomlar, fitoplanktonlar ve balıklar kullanılmaktadır. Bentik makroomurgasızlar, kıyı, geçiş ve tatlı su habitatlarında insan temelli faaliyetlerin etkilerini değerlendirmek için uzun süredir kullanılmakta ve çeşitli derecelerdeki bozulmalara duyarlı oldukları bilinmektedir (Zeybek, 2017; Birk ve diğerleri, 2012; Hellawell, 2012; Medeiros ve diğerleri, 2012; Borja ve diğerleri, 2011; Chainho ve diğerleri, 2008; Chaves ve diğerleri, 2005).

SÇD'nin uygulanmasıyla birlikte nehir tipolojisinin belirlenmesi ve multimetrik indekse dayalı bir değerlendirme sisteminin oluşturulması ihtiyacı ortaya çıkmaktadır. Türkiye nehirleri için makroomurgasızlara dayalı tipe özgü bir multimetrik indeksin geliştirilmesinin, SÇD gerekliliklerini karşılamak için potansiyel bir araç olacağı düşünülmektedir. Nehir Bentik Makroomurgasız Multimetrik İndeksi (BMIR) olarak bilinen bu yeni indeks, tüm hidrobiyocoğrafik bölgelerdeki her nehir tipi için belirlenen sınıf sınır aralıklarını referans koşullara göreli mesafeyi yansıtacak şekilde değiştirilmesine olanak sağlamaktadır.

Biyolojik değerlendirmede kullanılmak için geliştirilen biyolojik indeksler üç temel yaklaşıma dayanmaktadır. (i)Bölgeselleşme (Omernik, 1987, 1995), (ii)multimetrik yaklaşım (Barbour ve diğerleri, 1996; Davis ve Simon, 1995; Karr ve diğerleri, 1986; Karr ve Dudley, 1981) ve (iii)referans koşullarının belirlenmesidir (Hughes, 1995; Hughes ve diğerleri, 1986). Çalışma bu üç temel üzerine kurulmuştur.

Bu çalışmada kullanılan veriler, Su Yönetimi Genel Müdürlüğü tarafından yürütülen Su Kalitesi İzleme Programı'ndan elde edilmiştir. Ayrıca, Su Kaynaklarının Sayısallaştırılması, Tipoloji, Su Kütlesi ve Risk Değerlendirmesi Yapılarak İzleme Programlarının Hazırlanması Projesi (Digitizing Project, 2022) kapsamında Türkiye için belirlenen 6 hidrobiyocoğrafik bölge ve nehir tipoloji sistemi kullanılmıştır. Elde edilen veritabanı, metrekare başına düşen birey sayısı ile birlikte makroomurgasız faunanın takson listelerini ve hidrobiyocoğrafik bölge ve her bölgenin nehir tipleri hakkındaki verileri içermektedir.

Metrik seçimlerinde çeşitlilik, bolluk, tolerans gibi çok sayıda metrik içeren ASTERICS programı gözden geçirilmiştir. İlk olarak dokuz aday metrik değerlendirilmiş ve analiz edilmiştir. Bu metriklerin hesaplama yapabilmesi için gereksinimler (örn. türlerin ekolojik özellik skorları, tolerans değerleri vb.) incelenmiştir. Biyolojik veriler kullanılarak tüm hidrobiyocoğrafik bölgelerde dokuz aday metrik hesaplanmıştır. Metrik hesaplama, istatistiksel analiz ve grafik görselleştirme için Excel Data Analysis ToolPak kullanılmıştır.

Gözlemlenen alanların kalitesini referans alanlara göre belirlemede metrik performanslarını ortaya koymak için merkezi eğilim, aralık, dağılım ve aykırı değerler gibi tanımlayıcı istatistikler kullanılmıştır. Aday metriklerden etkiyi aynı yönde artırmamak ve ortadan kaldırmak için ikili korelasyon analizi (Pearson çarpım-moment korelasyonu) kullanılmıştır. Korelasyon katsayısının üst sınırı r = 0.75 olarak tanımlanmıştır. Referans noktaları ve bozulmuş noktalar arasındaki metriklerin ayrım değerlerini görselleştirmek için kutu grafikleri (box-plot) kullanılmıştır.

Türlerin ekolojik isterleri açısından değeri belirlenememiş veya çok dar bir değer aralığında çalışan bazı metrikler elenmiştir. Aynı yönde katkı sağladıkları için yüksek korelasyonlu metrikler ve referans ve bozulmuş alanlar arasında yetersiz ayrışma derecesine sahip metrikler elimine edilmiştir. Yüksek ayrışma derecesine sahip metrikler, uygun metrikler olarak değerlendirilmiştir. Son olarak, Türkiye'deki türlerin ekolojik skor değerlerine ulaşabilen yani hesaplamaları mümkün kılan metrikler ve ayrışma değerleri en yüksek olan metrikler nihai metrikler olarak seçilmiştir. Nihai metriklerin seçiminde ayrıca farklı metrik kategorilerinden metrik seçimine de özen gösterilmiştir (Karr ve Chu, 1999).

Her bir metrik tüm örnekleme noktalarında (referans noktaları dahil) hesaplanmıştır. Elde edilen skor değerler yüzdelik dilimlere bölünmüştür. Ayrık değerleri elimine etmek için her bir metrik için skor değerleri dağılımının 95. yüzdelik dilimi kullanılmıştır. Standardizasyon, metrik skorlarının 95. yüzdelik diliminin yüzdesi olarak hesaplanmasıyla gerçekleştirilmiştir. 95. yüzdelik dilimi aşan metrik skorları 1 olarak hesaplanmıştır. Nihai metrik (3) değerlerin ortalaması alınarak indeks değeri hesaplanmıştır.

İndeks aralıklarına dayalı olarak sınıf sınır değerleri oluşturulmuştur, böylece farklı stres koşulları arasında ayrım yapılmasına olanak sağlanmıştır. Literatürde sınıf sınır değerlerini belirlemek için birçok farklı yöntem geliştirilmiştir (Barbour, 1999). Bu çalışmada, SÇD'nin gereksinimlerini karşılamak için beş sınıflı bir kalite sınıfı aralığı kullanılmıştır;

- 95. persentil Çok İyi ve İyi kalite sınıf sınırı,
- 60. persentil İyi ve Orta kalite sınıf sınırı,
- 30. persentil Orta ve Zayıf kalite sınıf sınırı,
- 5. persentil Zayıf ve Kötü kalite sınıf sınırı.

İndeksi oluşturan metriklerden, kompozisyon metriği için yüksek ayrım gücüne sahip %EPT metriği seçilmiştir. Tolerans/hassas metrikleri için seçilen BMWP-S tüm hidrobiyocoğrafik bölgelerde çok faydalı sonuçlar göstermiştir. Test edilen çeşitlilik indeksleri arasında Shannon-Wiener çeşitlilik indeksi tüm hidrobiyocoğrafik bölge tiplerinde en iyi sonuçları vermiştir. BMIR'de nihai olarak 3 metrik seçilmiştir, bunlar, Ephemeroptera, Plecoptera ve Trichoptera Takson Yüzdesi (%EPT), Shannon-Wiener Çeşitlilik İndeksi ve BMWP-S'dir.

Her bir hidrobiyocoğrafik bölgede tüm tipler için 3 metriğin referans değerleri, her bir hidrobiyocoğrafik bölge tipine ait örnekleme noktalarındaki metrik skorlarının 95. yüzdelik diliminden türetilmiştir. Ancak, hidrobiyocoğrafik bölgelerdeki bazı tipler hakkında yeterli veri bulunmamaktadır. Bu tipler için ait oldukları hidrobiyocoğrafik bölgelerdeki tüm tiplerin verilerinin birleştirilmesiyle oluşturulan veri setinden tek bir referans değer üretilmiştir.

Bir örnekleme noktasının BMIR indeks hesaplaması aşağıda açıklanmıştır:

- 3 metrik (BMWP-S, Shannon-Wiener, %EPT) ayrı ayrı hesaplanır.
- Elde edilen metrik skorlar, o tip için belirlenen metriklerin referans değerine bölünür.
- Her bir metrikten elde edilen skor değerleri (0 ile 1 arasında) toplanır ve ortalaması alınır.
- Multimetrik indeksin sonucu elde edilir (BMIR değeri).

BMIR, yukarıda bahsedildiği gibi, 3 metrik skorunun ortalamasını alarak 0 ile 1 arasında bir değer üretir. Bu nedenle, BMIR indeks sonucu EKO olarak kullanılmaya uygundur.

Sonuç olarak, test edilen multimetrik yaklaşımın Türkiye'nin akarsularının ekolojik durumunu değerlendirmede faydalı ve etkili olacağı tahmin edilmektedir. Geliştirilen indeks, hidrobiyocoğrafik bölgelerin ve akarsu tiplerinin bentik makroomurgasızlar açısından kalite durumunu ortaya koymada hassastır. Türkiye'de ileri seviye bir uygulama için, stres faktörüne özel indeksler oluşturmak veya birden fazla stres faktörünü genelleyerek indeks geliştirmek bir sonraki çalışma olabileceği düşünülmektedir. Bu çalışmanın amacı, belirli bir metrik grup bazında tüm hidrobiyocoğrafik bölgeler için genel bir indeks oluşturmak ve ayrıca bölgeler içindeki tiplere özel indeksin referans ve sınıf sınır aralıklarını türetmektir. Burada, tüm hidrobiyocoğrafik bölgeler için aynı metrikleri içeren genel bir indeks geliştirilmiş, hidrobiyocoğrafik bölgelerdeki nehir tiplerine ait farklı referans değerler ve sınıf sınır aralıkları üretilmiştir. Her nehir tipi için nihai sınıf sınır değerleri ve referans değerleri kalibre edilebilir özelliktedir. Geliştirilen BMIR indeksinin Türkiye nehirlerinin ekolojik kalitesinin belirlenmesinde karar vericilere yardımcı olacağı düşünülmektedir.