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Water quality — Guidance on the design of Multimetric Indices

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Water quality - Guidance on the design of Multimetric Indices

Qualité de l'eau - Lignes directrices pour la conception des indices multimétriques

Wasserbeschaffenheit - Anleitung zur Planung und Erstellung Multimetrischer Indices

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Foreword

This document (CEN/TR 16151:2011) has been prepared by Technical Committee CEN/TC 230 “Water analysis”, the secretariat of which is held by DIN.

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Introduction

Multimetric Indices are among the commonly used tools for classification of the quality of fresh water and brackish water ecosystems (rivers, lakes, transitional waters, wetlands). A Multimetric Index combines several individual metrics, the results of which are finally combined into a Multimetric result. Thus Multimetric Indices integrate several attributes of a community (“metrics”) to describe and assess condition. Different categories of metrics (e.g. taxa richness, share of sensitive and tolerant species, trophic structure) reflecting different environmental conditions are combined into one Multimetric Index.

Multimetric Indices can be applied to different aquatic ecosystems (rivers, lakes, transitional waters, wetlands) and to different Biological Quality Elements (fish, benthic invertebrates, macrophytes, phytoplankton, phytobenthos). They are flexible in terms of the composition of metrics, since different metrics are suited for the assessment of different ecosystems or different stressors.

In recent years, a wide variety of Multimetric Indices has been developed and is now being applied, particularly for the purpose of implementing the Water Framework Directive. It can be expected that many existing Multimetric Indices will be adapted and many new ones will be developed within the next years. To enhance comparability between Multimetric assessment systems the procedure of developing and applying a Multimetric Index is described.

1 Scope

This document describes methods for developing and applying Multimetric Indices used for assessing rivers, lakes, transitional waters or wetlands. It is suitable for use with data on fish, benthic invertebrates, macrophytes, phytoplankton, and phytobenthos.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
Anchors (Upper and Lower Anchors)
values of a metric, which are empirically set and defined as “1” (Upper anchor) and “0” (Lower anchor), respectively, for transferring a metric’s result into a 0 to 1 score

NOTE The Upper Anchor relates to the reference value (i.e. the metric’s value under reference conditions). The Upper Anchor can be calculated from the median or mean of reference samples or by other appropriate statistical methods as described in 4.3.

The Lower Anchor is related to the lower limit of the metric’s value under the worst ecological quality conditions.

2.2
fresh water or brackish water type (river type, lake type, transitional water type)
division into an ecologically meaningful entity of sites with limited biotic and abiotic variation and a recognisable discontinuity with other types

NOTE Fresh water or brackish water types serve as “units“, to which an assessment system can be applied.

2.3
metric
measurable part or process of a biological system empirically shown to change in value along a gradient of human influence [2]

NOTE It reflects specific and predictable responses of the community to human activities, either to a single factor or to the cumulative effects of all events and activities within a watershed.

2.4
metric type
metrics addressing comparable aspects of a community, regardless of the stressor to which the metrics are responding

NOTE The following metric types can be distinguished (see Annex A):

- composition / abundance metrics: all metrics giving the share of a taxon or taxonomic group in relation to the total number of individuals counted; all metrics giving the abundance of a taxon or taxonomic group; metrics comparing reference and observed taxa (e.g. similarity indices);

- richness / diversity metrics: all metrics giving the number of taxa within a certain taxon (including the total number of taxa), all diversity indices;

- sensitivity / tolerance metrics: all metrics giving the ratio of taxa sensitive and insensitive to stress in general or to a certain stress-type, either using presence/absence or abundance information;

- functional metrics: all metrics addressing the characteristics of taxa other than their taxonomic definition (biological or ecological traits, ecological guilds): feeding types, habitat preferences, ecosystem type preferences, current preferences, life-history parameters, body-size parameters; they can be based on taxa abundance or richness.

2.5
Multimetric Index
combination of the results of three or more metrics

2.6
stressor
category of direct or indirect human impact to a fresh water, which potentially influences the composition and / or abundance of stream biota

NOTE The following stressors can be distinguished:

- organic pollution: organic matter input induced by human activities;
- eutrophication: nutrient input induced by human activities;
- acid stress: permanently or temporarily decreased pH value due to human activities;
- temperature stress;
- toxic stress: effects of toxic contaminants released by human activities;
- degradation in stream morphology: bed and bank alteration, habitat degradation, riparian land use, straightening, migration barriers, siltation;
- hydrological stress: alteration of flow regime, e.g. residual flow, pulse releases;
- general degradation: simultaneous and inseparable impacts of more than one stressor.

2.7
stressor gradient
set of sites of a fresh water ecosystem type with a varying intensity of a stressor

3 Principle

Two ways of calculating Multimetric Indices can be distinguished: the “general approach” and the “stressor-specific approach”.

In the “general approach”, various metrics are calculated from a taxa list. The metric results are individually compared to the respective metric values under reference conditions. From this comparison, a score for each metric is determined. These scores are finally combined into a Multimetric Index (Figure 1).

The “stressor-specific” approach sorts a suite of metrics according to their ability to detect a certain stressor. Thus, the scores of the metrics addressing a single stressor are first combined into a value reflecting the intensity of this stressor. The assessment results for all stressors are finally combined into the Multimetric Index (Figure 2).

Both ways of calculating Multimetric Indices may have advantages in certain situations: The “general approach”, carefully applied, provides an overview of a water body’s status and is, thus, mainly suited if the specific effects of individual stressors on the targeted organism group are not known in detail. It can, for example, be applied for the general ecological quality assessment and for intercalibration purposes. The “stressor specific approach” can only be applied if precise information on the effects of different stressors (e.g. acidification, organic pollution) on the targeted organism group are known and it is most suited for investigative monitoring purposes, tailored towards the identification of alteration causes.

The results of a Multimetric Index can be viewed at different levels: at the upper level there is the Ecological Quality Class, at the second level (in case of the stressor specific approach) are the results of the stressor specific modules (quality classes “organic pollution” and “stream morphology degradation” in Figure 2) and at the third level the results of the individual metrics are produced.

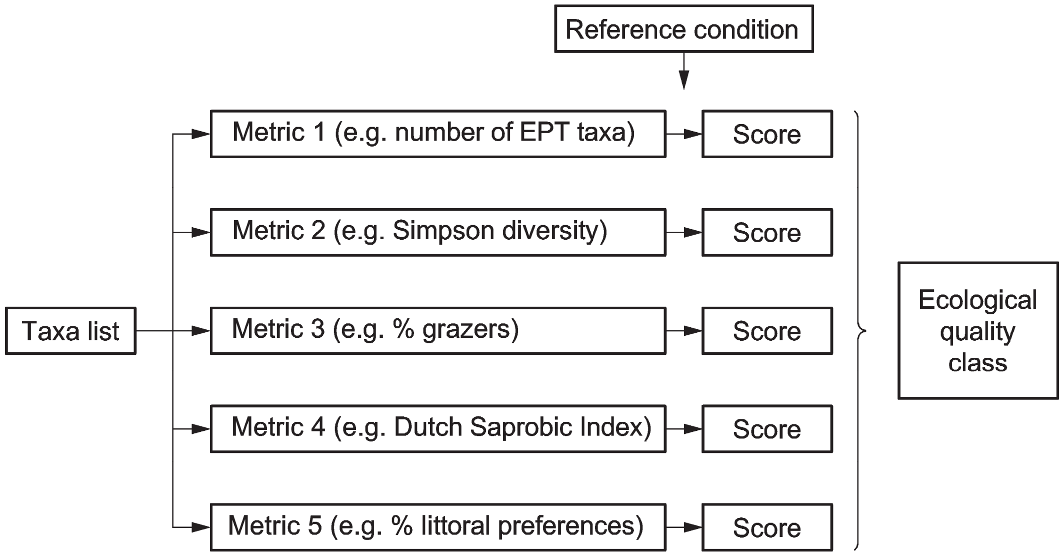

Figure 1 — The "general approach" of multimetric assessment

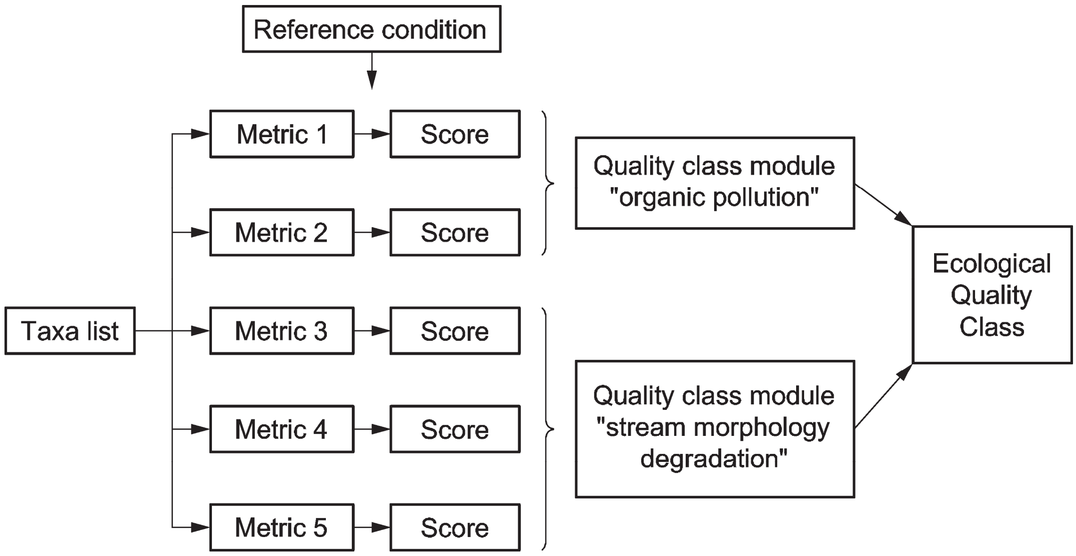

Figure 2 — "Stressor-specific approach" of multimetric assessment

4 Procedure

4.1 General

The procedure of developing a Multimetric Index is composed of the following steps:

— Selection of Candidate Metrics;

— Exclusion of Redundant Metrics;

— Definition of Upper and Lower Anchors;

— Transformation of Core Metrics into a 0 to 1 score;

— Selection of Core Metrics;

— Combination of Core Metrics to a Multimetric Index.

4.2 Selection of Candidate Metrics

Select only those metrics showing a quantitative dose-response change across a stressor gradient that is reliable, interpretable and not dispersed or obscured by natural variation. Selecting Candidate Metrics consists of the following steps:

a) Compilation of a data set of the freshwater type the Multimetric Index will apply to. This dataset shall include data on the Biological Quality Element that the Multimetric Index will use, for different sites covering the widest range of alteration.

b) If the required information is available, metrics of all metric types should be calculated (composition / abundance metrics, richness / diversity metrics; sensitivity / tolerance metrics; functional metrics).

c) Definition of a stressor gradient within the dataset by:

  1) using abiotic data on the individual sites, describing the impact of a single stressor (e.g. data on BOD_5 or on oxygen content for a Multimetric Index addressing organic pollution;

  2) using abiotic data on the individual sites, describing the impact of general degradation (e.g. data on catchment land use; hydromorphological modification and water pollution combined);

  3) defining a gradient within an ordination space of the taxonomic composition of the Biological Quality Element reflecting “general degradation” or the major single stressor.

The stressor gradient can either be defined covering the whole range from “high” to “bad” quality (preferred option), or by just defining a part of it. It can be defined either in five classes (“high”, “good”, “moderate”, “poor”, “bad”), or as “unstressed sites” and “stressed sites” or as a continuous gradient.

d) Correlating the results of a metric to the stressor gradient. If the stressor gradient has been defined in quality classes, t-Test, Mann-Whitney U test or rank correlation should be used. If the stressor gradient is defined as a continuous gradient, Pearson’s R or Spearman’s R should be used, or any appropriate statistical method. Using the appropriate test a Candidate Metric’s results must show a significant correlation to the stressor gradient. This correlation can be positive or negative, either across the whole stressor gradient measured or for a part of the stressor gradient measured (e.g. only moderate to high quality sites). Metrics fulfilling this criterion are in principle suitable for the assessment of degradation of the fresh water ecosystem type and can be selected as Candidate Metrics.

4.3 Exclusion of redundant metrics

Two Candidate Metrics belonging to the same Metric Type with a comparable ecological significance and delivering similar results within a data set, should not be simultaneously included into a Multimetric Index. To avoid this, a correlation matrix of all metrics selected as Candidate Metrics needs to be produced. If two analogous metrics have a Spearman’s R or Pearson’s R of > 0,8 one of those metrics should be excluded from the Multimetric Index, preferably the one with the poorest correlation with the stressor gradient.

4.4 Definition of Upper and Lower Anchors

The Upper Anchor is coherent to the reference value of the metric, i.e. a robust and predictable metric’s value under reference conditions. Reference conditions might be set site specifically (e.g. using a predictive system) or type specifically and relate to the site or type’s condition if they were undisturbed by stressors. If numerous data on reference sites are available, the Upper Anchor can be set as a percentile (25 % or 10 %) of all metric values of the reference sites. If few data are available for reference sites the most robust statistic, i.e. the median or the mean, should be used to avoid the high variability of the maximum value expected under natural conditions. If no data on reference sites exist but data on sites representing different degrees of stress are available, the reference value can be extrapolated, or derived from historical data, or set by expert judgment.

The Lower Anchor is coherent to the lower limit of the metric's value under the worst attainable conditions. If data on sites with bad ecological quality are available, the Lower Anchor is to be set as a percentile (e.g. 5 % or 10 %) of all metric values of the bad ecological quality sites, or at the lowest obtained or obtainable value. If no data on bad ecological quality sites exist but data on sites representing different degrees of stress are available, the Lower Anchor can be extrapolated or set by expert judgment.

4.5 Transformation into a 0 to 1 score

Before being used for the Multimetric Index, each metric result must be transferred into a value between 0 and 1, using Equation (1) for metrics decreasing with increasing impairment and Equation (2) for metrics increasing with increasing impairment:

$$m_i = \frac{m_{result} - a_{low}}{a_{up} - a_{low}} \quad (1)$$

$$m_i = 1 + \frac{m_{result} - a_{low}}{a_{up} - a_{low}} \quad (2)$$

where

m_i is the metric value between 0 and 1;

m_{result} is the result of the metric;

a_{low} is the lower anchor;

a_{up} is the upper anchor.

The Upper and Lower Anchors of a metric are coherent to the values 1 (reference condition) and 0 (worst attainable condition); results above 1 and below 0 are set as 1 and 0, respectively. Upper and Lower Anchors must be defined separately for each metric.

4.6 Selection of core metrics

While three metrics per Metric Type are considered ideal, a higher (i.e. more exhaustively describing the community attributes) or lower (i.e. when fewer suitable metrics can be identified) number of metrics can be included in a Multimetric Index. If there is at least one Candidate Metric of a Metric-Type, at least one metric of this Metric-Type must be selected as a Core Metric to ensure that each type is represented in the Multimetric Index.

The possible combinations of metrics resulting from the selection of Candidate Metrics must be correlated to the stressor-gradient used to select the Candidate Metrics. For this purpose, all metric results might first be transformed into a 0 to 1 score and the mean of the results of all Candidate Metrics must be calculated for each site.

The metrics, whose combination gives the strongest significant correlation to the stressor gradient and have an ecological significance, should be selected as Core Metrics.

4.7 Combination of Core Metrics to a Multimetric Index indicating a single stressor or indicating general degradation (general multimetric approach)

If the same number of metrics has been selected for each Metric Type, the Multimetric Index can be calculated as the mean of the 0 to 1 scores of all Core Metrics. This will attribute the same influence to each metric and Metric Type. If the number of Core Metrics belonging to the different Metric Types is different, weighting factors can be used so that e.g. each group of metrics (i.e. clustered within a type) has the same influence on the final Multimetric Index.

If, within a Metric Type, the various Core Metrics are based on information of different confidence (e.g. one is based on the whole invertebrate community, while the others on single Insect Orders) weighting factors can be allocated to metrics so that the more inclusive metrics contribute at a higher degree to the final score.

4.8 Combination of Core Metrics to a Multimetric Index separating the impact of different stressors

The scores or results of those Core Metrics, which have been selected using the gradient of a single stressor, should be combined to a Multimetric Index by calculating the mean of their 0 to 1 scores. This step results in, for example, a Quality Class for the stressor “organic pollution” or a Quality Class for the stressor “acidification”.

If the same degree of confidence is expected for the different stressor-specific indexes, the resulting stressor-specific Quality Classes are converted into the Ecological Quality Class using the worst result of all stressor-specific Quality Classes. Otherwise, priority can be given to the most robust metric, the results of the other metric(s) being used to confirm the obtained classification. Weighting factors also can be considered as explained above.

Annex A
(informative)

Examples for metrics used to assess individual Biological Quality Elements, assigned to metric types

Table A.1

Metric type	Fish	Benthic invertebrates	Macrophytes	Phytobenthos	Phytoplankton
Composition/ abundance metrics	Population age structure	[%] EPT	[%] Potamogeton pectinatus	[%] Centric diatoms	[%] Diatoms
	Population size	[%] Trichoptera			
Richness/ diversity metrics	Diversity (Shannon-Wiener, Margalef, Simpson)	Diversity (Shannon-Wiener, Margalef, Simpson)	Diversity (Shannon-Wiener, Margalef, Simpson)	Diversity (Shannon-Wiener, Margalef, Simpson)	Diversity (Shannon-Wiener, Margalef, Simpson)
	Number of river type specific species	Number of EPT taxa	Number of taxa	Number of taxa	Desmids: richness
		Number of taxa			Rare taxa and indicative taxa [3]
Sensitivity/ tolerance metrics	Tolerant species individuals	ASPT	Mean Trophic Ranking	Trophic diatom index [4]	[%] Eutrophication tolerant taxa
		Saprobic Indices (e.g. DIN 38410-1)		Trophic Index Austria [5]	
		Henrikson & Medin Index			
		French GFI			
Functional metrics	Number of rheophile species	[%] Sand-preferring taxa	Ellenberg numbers	[%] Planktonic taxa	[%] Planktonic taxa
	Number of lithophile species	[%] Shredders			
		RETI			
		[%] reproductive traits			

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