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Application of the new multimetric MMI_PL index for biological water quality assessment in reference and human-impacted streams (Poland, the Slovak Republic)

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ABSTRACT

A new multimetric MMI_PL index, which is based on the macroinvertebrate composition and combines six single key metrics, has already been implemented in Poland according to the requirements of the EU Water Framework Directive. The objectives of our survey were to assess the biological water quality using the new multimetric MMI_PL index in both reference and human-impacted streams, to analyze whether the values of the new multimetric index properly reflect the ecological status of the water in upland and mountain streams as well as to determine which environmental factors influence the distribution of benthic macroinvertebrates and the values of the metrics. The study was carried out from 2007 to 2010 in three Ecoregions that were established by the EU WFD. A total of 60 sampling sites: 36 reference sites that were situated in the headwaters of mountain streams at mid- and high-altitudes and 24, human-impacted sampling sites were selected. The benthic macroinvertebrate surveys were supported by both a hydromorphological and macrophyte assessment according to the River Habitat Survey (RHS) and to the Macrophyte Methods for Rivers. Canonical correspondence analysis (CCA) showed that the values of the Habitat Quality Assessment (HQA) index, conductivity, pH and altitude were the parameters most associated (statistically significant) with the distribution of benthic macroinvertebrate taxa and the values of the metrics in both the reference and human-impacted (impaired) sections of the streams in Ecoregions 9, 10 and 14. The new MMI_PL index was useful for biological water quality assessment and was also important for separating both the reference and impaired sections of streams. The MMI_PL index and some key metrics performed contrary to what was expected in relation to the reference high-altitude siliceous streams (the High Tatra Mts., Ecoregion 10). Low values of multimetric index and key metrics did not properly reflect their high ecological status and pristine character as reflected by the hydromorphological (RHS) and macrophyte surveys or the physical and chemical parameters of the water.

Introduction

Habitat loss and degradation such as modification of running water environments, deforestation of pristine wildernesses, habitat alternation including channel straightening and a reduction in near-stream vegetation, pollution are major factors that threaten to destroy riverine ecosystems. Streams and rivers with natural channel morphologies are subjected to erosion to a lesser degree and export fewer sediments than those that have been transformed. What is more, shading by a riparian forest ameliorates temperature extremes, which results in lower maximum values in summer and higher values in winter (Allan and Flecker, 1993). In freshwater lotic ecosystems, macroinvertebrates contribute significantly to the cycling of nutrients and carbon, the turnover of organic material as a crucial intermediate link between primary producers, detritus pools or primary consumers and as suspension feeders, they also increase the retention of carbon. In addition, predators including fish depend on macroinvertebrates (Malmqvist, 2002).

The human impact on freshwater ecosystems, e.g., riparian clearing, nutrient enrichment, changes in the morphology of

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streams or the introduction of alien species cause changes in the composition of macroinvertebrate communities and therefore modify the food web. Benthic macroinvertebrates are capable of reflecting different anthropogenic perturbations, thus they enable a holistic assessment of streams. Besides organic pollution, which can be assessed using a large number of indices, benthic macroinvertebrates can also be used to detect acidification, habitat degeneration and overall stream degradation. Thus, the use of benthic macroinvertebrates as indicators of the ecological status of rivers has been made mandatory in European countries according to the implementation and requirements of the European Union Water Framework Directive (EU WFD) (Nicola et al., 2010).

Multimetric indices combine single-component metrics that reflect different aspects of the transformations of a water ecosystem. Therefore, they are well-suited for assessing the impact of organic pollution, degradation in stream morphology, acidification or general degradation (AQEM Consortium, 2002; Hering et al., 2006). Thus, multimetric indices, which integrate multiple attributes of stream communities (metrics) in order to describe and evaluate the ecological condition of rivers, are regarded as more reliable than water quality assessment methods that are based on single metrics (AQEM Consortium, 2002; Klemm et al., 2003; Hering et al., 2006). Therefore, multimetric indices are recognized as essential tools that can be applied in assessing the ecological quality of streams with benthic macroinvertebrates using a system that fulfills the demands of the EU WFD (Directive, 2000/60/EC). The multimetric index is widely applied in the assessment of the biological water quality in both freshwater and brackish water ecosystems (Vlek et al., 2004; Gabriels et al., 2010; Navarro-Llácer et al., 2010; Mondy et al., 2012; Basset et al., 2013). In Poland, a new multimetric MMI_PL index, which is based on the macroinvertebrate composition as well as on the abiotic types of streams and combines six single key metrics, has already been implemented in accordance with the EU WFD requirements (Bis, 2012). At present, the multimetric MMI_PL index has been accepted by the Chief Inspectorate of Environmental Protection as the official, compulsory tool for biological water quality assessment and it is used by the State Environmental Monitoring.

The objectives of our survey were to assess the biological water quality using the new multimetric MMI_PL index based on macroinvertebrates according to the EU Water Framework Directive requirements in both reference and human-impacted streams, to analyze whether the values of the new multimetric MMI_PL index can reliably distinguish between the reference and impaired sections in three biocenotic upland and mountain types of streams, to analyze whether the values of the new multimetric index properly reflect the ecological status of the water and to determine which environmental factors influence the distribution of benthic macroinvertebrates and the values of some metrics in the reference and impaired sections of streams.

Materials and methods

Study area

The study was carried out from 2007 to 2010 (June, July) in three Ecoregions established by the EU WFD (2000/60/EC), i.e., in the Carpathians (Ecoregion no. 10), the Central Highlands (Ecoregion no. 9), and in the Central Plains (Ecoregion no. 14) (Table 1). A total of 60 sampling sites were selected: 36 reference sampling sites that were likely to be of a high ecological status situated in the headwaters of mountain streams at mid- and high-altitudes and 24 human-impacted (impaired) sampling sites (morphological transformation, pollution of water). Most of the reference sampling sites were situated within national parks or reserves, i.e., the Babia Góra National Park (one of the first Biosphere Reserves in the world), the Gorce National Park, the Tatra National Park, the Tatranský Národný Park in the Slovak Republic, and the nature reserve "Wisła" (the Silesian Beskids). The reference sites in the Tatra Mts. were situated on the territory of the Tatra UNESCO Biosphere Reserve, which covers two national parks, i.e., the Tatra National Park (Poland) and the Tatranský Národný Park (the Slovak Republic) (Fig. 1).

Selection of reference and human-impacted sites

The initial field recognition (site visits) and choice of sampling sites took place prior to the fundamental field survey. The reference sites were chosen according to the EU WFD criteria: the geology; the catchment area with respect to its physical, chemical, and biological attributes; altitude (mid-altitude 200–800 m a.s.l.), high altitude (>800 m a.s.l.); the pristine nature of the headwater streams as was proven by physical and chemical analyses and the absence of any obvious sources of pollution or alien species as well as little or no commercial forestry operations (Directive, 2000/60/EC; Nijboer et al., 2004; Baattrup-Pedersen et al., 2009). Reference conditions were defined using the following criteria (Furse et al., 2006; Sánchez-Montoya et al., 2009): (1) hydromorphological elements: values of the HMS < 8 and the HQA > 47 (Walker et al., 2002; Szoszkiewicz et al., 2010a); (2) biological elements: values of the MIR index that were established by the Polish legislation that reflects the high status of the water (Dziennik Ustaw, 2011) in stream types; (3) physical and chemical elements (parameters), the values of which reflect the high status of the water: ammonium $\leq 0.95\ mg\ NH_4^+\ L^{-1}$, phosphates $\leq 0.20\ mg\ PO_4^{3-}\ L^{-1}$, nitrites $\leq 0.09\ mg\ NO_2^-\ L^{-1}$, nitrates $\leq 10.0\ mg\ NO_3^-\ L^{-1}$ and conductivity $\leq 1000\ \mu S\ cm^{-1}$. Human-impacted sites were defined using similar criteria, i.e., (1) hydromorphological elements (values of the HMS > 8 and the HQA < 47), (2) biological elements (values of the MIR index reflecting other than the high status of the water) and (3) physical and chemical elements: ammonium $> 0.95\ mg\ NH_4^+\ L^{-1}$, phosphates $> 0.20\ mg\ PO_4^{3-}\ L^{-1}$, nitrites $> 0.09\ mg\ NO_2^-\ L^{-1}$, nitrates $> 10.0\ mg\ NO_3^-\ L^{-1}$ and conductivity $> 1000\ \mu S\ cm^{-1}$.

Three out of six biocenotic types of streams were selected within the study area. Type 1: the Tatra Mts. streams (Ecoregion 10), type 2: the Sudety Mts. streams and siliceous western upland rivers (Ecoregion 9), and type 3: eastern calcareous and siliceous upland rivers (Ecoregions 10 and 14) (Table 1). Reference (R1, R2, R3) and human-impacted (impaired) (Hi1, Hi2, Hi3) sections of the streams were selected within these biocenotic types of streams, i.e., types 1, 2 and 3.

Water samples, benthic macroinvertebrates, hydromorphological and macrophyte surveys

Water samples were collected from each sampling site immediately before the sampling of macroinvertebrates. Analyses of the physical and chemical parameters of the water, i.e., conductivity, temperature, and pH were measured in the field using a portable HI 9811-5 pH/EC/TDS/°C meter (Hanna Instruments) and dissolved oxygen with a CO-401 oxygen meter (Elmetron). Analysis of ammonium, nitrite, nitrate, and phosphate concentrations in the water and alkalinity were carried out using colorimetric and titrimetric methods using meters and reagents from Hanna Instruments or Merck. The samples of benthic macroinvertebrates were collected using a hand net with a square frame (25 cm × 25 cm = sampling surface of 625 cm^2) and a mesh size below 500 μm according to the methodology of AQEM Consortium (2002), Bis (2006), and Bis and Wenikajtys (2006). A total of 20 replicates (subsamples) was taken from all major habitat types in the reach (sampling surface of 1.25 m^2) using a hand net at each sampling site. In addition, benthic macroinvertebrates were collected from the