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Benthic macroinvertebrates in lake ecological assessment: A review of methods, intercalibration and practical recommendations

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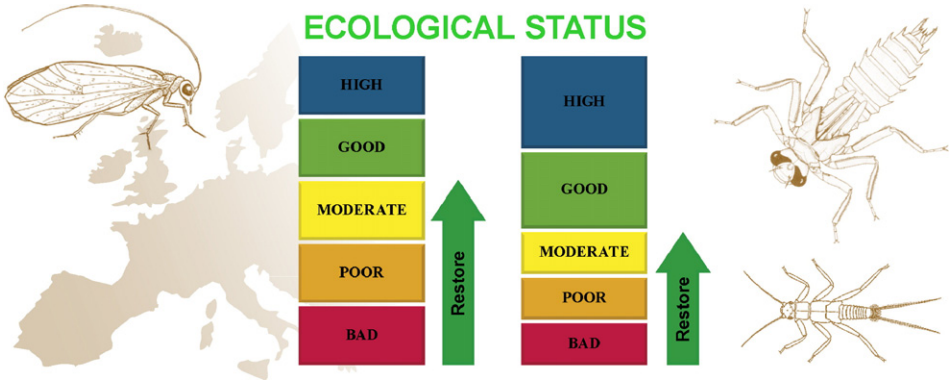
HIGHLIGHTS

- Ecological status of European surface waters is assessed using biological communities.
- We reviewed and intercalibrated 13 lake benthic invertebrate-based tools across Europe.
- These tools address acidification, eutrophication and morphological alterations.
- Two biological multimetric indices were developed for two large regions of Europe.
- We provide recommendations for the use of benthic invertebrates in lake assessment.

GRAPHICAL ABSTRACT



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ABSTRACT

Legislation in Europe has been adopted to determine and improve the ecological integrity of inland and coastal waters. Assessment is based on four biotic groups, including benthic macroinvertebrate communities. For lakes, benthic invertebrates have been recognized as one of the most difficult organism groups to use in ecological assessment, and hitherto their use in ecological assessment has been limited. In this study, we review and intercalibrate 13 benthic invertebrate-based tools across Europe. These assessment tools address different human impacts: acidification (3 methods), eutrophication (3 methods), morphological alterations (2 methods), and a combination of the last two (5 methods). For intercalibration, the methods were grouped into four

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intercalibration groups, according to the habitat sampled and putative pressure. Boundaries of the 'good ecological status' were compared and harmonized using direct or indirect comparison approaches. To enable indirect comparison of the methods, three common pressure indices and two common biological multimetric indices were developed for larger geographical areas. Additionally, we identified the best-performing methods based on their responsiveness to different human impacts. Based on these experiences, we provide practical recommendations for the development and harmonization of benthic invertebrate assessment methods in lakes and similar habitats.

1. Introduction

In recent years, much legislation has been developed in order to assess the ecological integrity of fresh waters worldwide (e.g. Clean Water Act in the USA, National Water Act in South-Africa, and Water Framework Directive in Europe). Furthermore, there is also growing interest in shifting the focus from assessment methods based on water chemistry and simple biotic metrics (e.g. saprobic index) towards more robust assessment methods based on indicators of degradation of ecological structure and function (Bonada et al., 2006; Karr, 1999; Stoddard et al., 2008). In Europe, since the adoption of the European Water Framework Directive (WFD) in 2000 (EC, 2000), much progress has been made regarding the ecological assessment of inland and coastal waters (Birk et al., 2012; Reyjol et al., 2014). A key concept of the European WFD is that a suite of biological assemblages is used to assess the ecological quality of surface waters. For lakes, assessment approaches based on phytoplankton, macrophytes and phytobenthos, benthic invertebrates, and fish fauna need to be implemented. Biological assessments, expressed as Ecological Quality Ratios (EQRs) – defined as the observed state/expected state – are divided into five status classes (high, good, moderate, poor and bad). For developing a programme of measures, the most important distinction is between good and moderate status (Birk et al., 2012) because, when the quality status is less than good, countries must take action to improve a water body until good status is achieved (Birk et al., 2013). Thus, the development of reliable assessment tools and the setting of ecological class boundaries have become two of the most critical and difficult tasks in implementing the WFD, with work still ongoing for several taxonomic groups (Birk et al., 2012; Brucet et al., 2013; Poikane et al., 2015).

Among the many taxonomic groups used in biomonitoring, from microbes to large metazoans such as fish and birds, macroinvertebrates are one of the most commonly used groups (Birk et al., 2012; Johnson et al., 1993; Resh and Jackson, 1993), fulfilling many of the criteria characterizing the ideal biomonitoring tool (Bonada et al., 2006). However, most studies advocating the use of macroinvertebrates in biomonitoring have focused on stream habitats (Hering et al., 2004; Resh and Jackson, 1993), with fewer studies addressing the efficacy of using lake macroinvertebrate assemblages (Brauns et al., 2007; Johnson et al., 2004, 2007). Indeed, a decade ago, the paucity of WFD-compliant macroinvertebrate assessment tools was identified as one of the major gaps impeding full assessment of the ecological quality of lakes (Solimini et al., 2006). Since then, stimulated by the WFD implementation, a multitude of biological metrics has been developed to assess the ecological quality of lakes (Brucet et al., 2013).

The main pressures affecting the integrity of lakes are eutrophication, acidification, and alterations of hydrology and geomorphology (cf. Young et al., 2005). Building on early assessment approaches (Wiederholm, 1980; Henrikson and Medin, 1986), several WFD compliant assessment metrics based on profundal (Jyväsjärvi et al., 2010, 2012) and littoral (Johnson et al., 2007; McFarland et al., 2010; Schartau et al., 2008) invertebrate communities have been developed to assess eutrophication and acidification. By contrast, quantifying the effects of hydromorphological alterations on littoral macroinvertebrates have only recently been developed (Brauns et al., 2007; Miler et al., 2015) and used for quantifying human-induced effects (Urbanič, 2014).

A basic requirement for successful river basin management is comparability of bioassessment approaches, as different data and indices can lead to inconsistent or conflicting assignment of ecological status (Birk et al., 2013; Cao and Hawkins, 2011). In Europe, legislation stipulates that values of the upper and lower "good" class boundaries must be harmonized (intercalibrated) to ensure that class boundaries are consistent with the normative definitions of the WFD and comparable between countries (Birk et al., 2013; Poikane et al., 2014b). For methods used in monitoring benthic invertebrate assemblages in lakes this task is particularly difficult. One reason is the diversity of methods currently used for addressing different pressures or combinations of pressures, often using different sampling methodologies and habitats (profundal, sublittoral or littoral). Another reason is that – compared to the use of phytoplankton in lakes and macroinvertebrates in streams – the use of benthic macroinvertebrates in lakes is relatively new, with the exception of profundal macroinvertebrates (Wiederholm, 1980). Furthermore, the large biogeographical range of EU countries results in high natural variability (lake/habitat types) and different types of impairment that need consideration. For example, densely populated central European countries, such as the Netherlands or Belgium, are comprised of mostly degraded water bodies (Gabriels et al., 2010), whereas lakes in the northern and eastern parts of the European Union, e.g. in Estonia, are often still in quite a natural state (Timm and Möls, 2012).

This paper describes the intercalibration exercise on benthic macroinvertebrate methods for assessing the ecological status of European lakes. The specific aims of this study are to:

- review the current status of macroinvertebrate methodologies proposed for European lakes, with particular attention to the metrics included and human impacts addressed;
- compare the lake assessment methods proposed by several countries and achieve a harmonization of class boundaries; and
- provide recommendations for the use of benthic invertebrates in the bioassessment of lakes.

2. Materials and methods

2.1. Assessment systems

Seventeen methods from 12 countries were considered as part of the intercalibration exercise: UK, Sweden and Germany each participated with several methods (addressing different pressures, different habitats or different lake types). From these methods, 13 methods from 10 countries were intercalibrated (see Table 1), while four methods — the German AESHNA sublittoral method (Miler et al., 2013b), the French macroinvertebrate index (Böhmer et al., 2014), the Italian BQI (Rossaro et al., 2007), and the Swedish ASPT (Johnson and Goedkoop, 2007) were excluded (see chapter on feasibility check).

Most of the methods (n = 9) were multimetric indices, while some (the Finnish and Swedish BQI, the UK CPET and LAMM) were single-metric methods. Metrics were grouped into four categories (sensitivity; richness/diversity; functional and taxonomic composition) based on classifications proposed by Hering et al. (2006); Stoddard et al. (2008) and Birk et al. (2012). Response of the methods to relevant pressures