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Redundancy in the ecological assessment of lakes: Are phytoplankton, macrophytes and phytobenthos all necessary?

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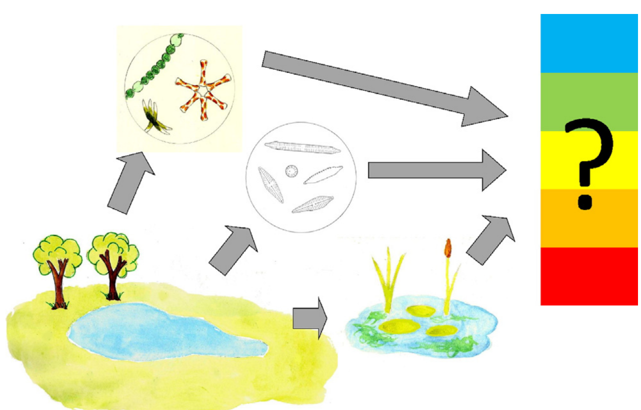
HIGHLIGHTS

- High costs of data mean that the value of different types is evaluated carefully.
- The benefits of phytobenthos to lake classification was examined.
- The added value of phytobenthos as a third indicator was assessed.
- Most impacted lakes were detected using phytoplankton and macrophytes.
- Few additional lakes were detected using phytobenthos in addition to these.
- There are some specific situations where phytobenthos has relevance for lake assessment.

GRAPHICAL ABSTRACT



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ABSTRACT

Although the Water Framework Directive specifies that macrophytes and phytobenthos should be used for the ecological assessment of lakes and rivers, practice varies widely throughout the EU. Most countries have separate methods for macrophytes and phytobenthos in rivers; however, the situation is very different for lakes. Here, 16 countries do not have dedicated phytobenthos methods, some include filamentous algae within macrophyte survey methods whilst others use diatoms as proxies for phytobenthos. The most widely-cited justification for not having a dedicated phytobenthos method is redundancy, i.e. that macrophyte and phytoplankton assessments alone are sufficient to detect nutrient impacts. Evidence from those European Union Member States that have dedicated phytobenthos methods supports this for high level overviews of lake condition and classification;

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however, there are a number of situations where phytobenthos may contribute valuable information for the management of lakes.

1. Introduction

The Water Framework Directive (WFD: European Union, 2000) is based on the principle that healthy ecosystems are the basis for sustainable water resources. The various components that comprise a healthy ecosystem are interconnected (e.g. via food webs) and will, in turn, provide ecosystem services as well as having sufficient intrinsic resilience to counteract short-term impacts. The overall condition of these components for any water body is the "ecological status", a term with a very similar meaning to "ecological health" or "ecological integrity". The definition, as given in the WFD, breaks ecological status down into components reflecting the physical, chemical and biological state of the water body, and each of these is further divided. In the case of biological quality elements (BQEs), particular characteristics ("species composition", "abundance") of named groups of organisms ("phytoplankton", "benthic invertebrates" etc.) that should be assessed are prescribed in Annex V and it is easy to lose sight of the holistic principles behind the legislation amidst all the detail. As the objective of the WFD is to raise all water bodies to at least "good ecological status" (GES), assessment serves not just to determine the condition of the biota with respect to this objective, but also to diagnose reasons for failure to achieve GES. In practice, the widespread nature of common problems in lakes (e.g. eutrophication) means that the role of assessing status and diagnosing causes can overlap, and this in turn suggests a potential for redundancy: if BQE 1 indicates that the lake is eutrophic, then why measure BQE 2, if that, too, is responsive to nutrients? As ecological assessment is an expensive activity, savings made could free up resources for more efficient use elsewhere (Lovett et al., 2007). Yet, at the same time, such savings come at a cost to the holistic insights that should arise from having information from several interconnected components of the ecosystem and may affect confidence in ecological assessments and hence the willingness to take action (Moss, 2008).

The WFD and subsequent European Commission documentation gives countries leeway in deciding national approaches to ecological assessment, representing the guiding principle of "subsidiarity", which underlies all European law (European Union, 2002, Article 5). For example, it is not necessary to use a BQE (or, by inference, part of a BQE) if "… it is not possible to establish reliable type-specific reference conditions … due to high degrees of natural variability in that element, not just as a result of seasonal variations" (WFD: Annex II, 1.3.). Moreover, a key principle of the EU's intercalibration exercise (see Poikane et al., 2015) is that where a BQE consists of two components, "… it may be sufficient to use only one of the two components" (European Commission, 2010). European Commission (2010) go on to say that "It is up to the Member State to decide how it develops its methods. If only one component is used then it must be demonstrated that the impacts of the existing pressures are being sufficiently detected by that component."

The assessment of "macrophytes and phytobenthos" in lakes and rivers represents one particular instance where the issue of a potentially redundant metric occurs. These two very different components of the benthic freshwater flora are generally assessed separately (Kelly et al., 2015; Poikane et al., 2015) but are included as a single BQE in Annex V of the WFD which, in turn, has led some countries to argue that assessment of phytobenthos (i.e. benthic algae, or "periphyton") is "redundant" because their national assessment system for macrophytes is adequate to detect the pressures to which phytobenthos are sensitive (e.g., Pall and Moser, 2009). This is despite a widespread understanding that macrophytes and phytobenthos react at different time and spatial scales, e.g. macrophytes generally react over yearly time scales to changes in pollution whereas phytobenthos can react within days or even hours (Schaumburg et al., 2004; European Commission, 2010). However, in lakes, unlike most rivers, phytoplankton are also assessed and some countries have argued that these provide an adequate proxy for the rapidly-reacting component. Such arguments, however, bypass functional ecology and focus on a superficial value of different biological components as "indicators" (Moss, 2008). It could equally be argued that phytobenthos and macrophytes provide complementary roles in the structure and carbon-flow within river and lake littoral ecosystems, thus rendering phytoplankton redundant, whilst Trobajo et al. (2002); Jones and Sayer (2003); Moss (2010) and others demonstrate how all three components interact with each other and with invertebrates and fish to maintain ecological integrity in shallow lakes. This broadens the debate from simply considering how including or excluding a component influences the high-level classification of water bodies, to thinking about the types of information that a lake manager might need in order to restore a water body to GES.

The current paper, therefore, aims to gather together data from those countries within the EU that have separate macrophyte and phytobenthos assessment systems (the latter based on diatoms as proxies for the whole benthic algal community), in order to test whether redundancy exists. A further source of confusion lies in the inclusion of filamentous macroalgae in some macrophyte-based assessment systems (most of which already include charophytes). A purely legal interpretation of the WFD would suggest that countries which adopt this practice have fulfilled their obligations. Therefore, a further set of analyses looks at the unique contribution that filamentous macroalgae make to one macrophyte assessment system (UK; Willby et al., 2009). Finally, we consider situations where a separate phytobenthos method may provide additional insights over and above a statistically-driven approach to classification of ecological status.

2. Methods

2.1. Theoretical consideration of redundancy

Several countries claim that phytobenthos analysis in lakes is redundant because it offers no additional information over and above that provided by macrophytes and/or phytoplankton (Pall and Moser, 2009). However, to be objective, this concept needs to be translated into terms relevant to the WFD. If we argue that the purpose of ecological assessment is to detect change due to anthropogenic pressures, then the null hypothesis for these assessments is that such pressures have no more than a slight impact on the biota of a particular water body (i.e. corresponding to the definition of GES). Consequently, "redundancy" can be defined as omission of a BQE (or sub-element) that will have a low risk of a Type 2 error (erroneous retention of null hypothesis); in other words, we are unlikely to wrongly classify an impacted lake as being at GES or High Ecological Status (HES) when following the classification guidance given in the WFD. This stipulates that the final status of a water body is defined by the lowest of the measured BQEs (i.e. the "one out, all out" principle). In practice, "macrophytes and phytobenthos" form a single BQE. The analyses that follow assume that Member States use the most stringent of the two sub-elements to determine the classification; however, a few Member States (e.g. Germany: Schaumburg et al., 2004) prefer to average these sub-elements.