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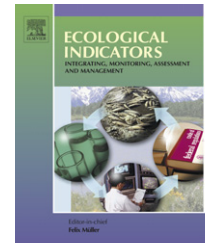


# Detection of ecological change in stream macroinvertebrate assemblages using single metric, multimetric or multivariate approaches

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The effects of nutrients on aquatic ecosystems are widespread and trying to understand the reaction of different response indicators is a complex issue. In this study, we used a data set of 21 stream site-samples situated in southern Sweden to assess the strength of single and multimetric indices and multivariate approaches for detecting the effects of nutrient enrichment on stream ecosystems using benthic macroinvertebrate communities. Our results showed both multimetric and multivariate approaches to be reliable tools for detecting the effects of nutrient enrichment on stream macroinvertebrate communities, superior to single metric approaches. In particular, the multimetric DJ index and the multivariate CA scores were sensitive (high coefficients of determination) to the stressor gradient and had high precision (low error). The Saprobic index was the 'best' of the six single metric approaches tested here. However, due to differences in the way taxa lists are managed in multimetric and multivariate approaches, we recommend that, if possible, both methods should be used in assessing the effects of nutrient enrichment of stream ecosystems.



## 1. Introduction

The landscape of much of Europe has been altered for centuries, resulting in substantial loss of habitat and biodiversity (e.g., Young et al., 2005). Although the type and severity of human-generated stressor(s) affecting freshwater ecosystems differ across Europe, the major drivers affecting the integrity of aquatic ecosystems can be summarized as overexploitation, nutrient enrichment, acidification, and alterations of hydrology and morphology. For example, despite decades of research and implementation of mitigation measures, such as water treatment and alternative land-use practices, nutrient enrichment of aquatic ecosystems is still considered a pan European problem 'of major concern' (Stanner and Bordeau, 1995; Johnson et al., 2003). This phenomenon is not unique to Europe, or as Carpenter (2005) recently emphasized "eutrophication is often a one-way trip", even after reduction of external nutrient input.

Because of the relatively long time scales of nutrient enrichment across Europe, as well elsewhere, the response of aquatic organisms is relatively well understood (Hynes, 1960; Hellawell, 1978, 1986; Mason, 1996; Hering et al., 2006b; Johnson et al., 2006a). For instance, many European countries have a long history of using benthic macroinvertebrates to monitor the ecological integrity of freshwater ecosystems (e.g., Hellawell, 1986); a tradition which began as early as the early 1900s (Kolkwitz and Marsson, 1902). Moreover, many countries have also developed biotic indices using

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macroinvertebrates for assessing nutrient effects (e.g., Johnson et al., 1993; Knoben et al., 1995), and, indeed, the use of benthic macroinvertebrates constitutes the basis for most biomonitoring programs currently in use in Europe (e.g., Whitton, 1979; Wiederholm, 1980; Sladecek et al., 1982; Metcalfe, 1989; Rosenberg and Resh, 1993). Methods used to assess stream integrity using benthic macroinvertebrates range from relatively simple algorithms or biotic indices, to combinations of multiple indices (a.k.a. multimetric approaches), or relatively complex, multivariate approaches for pattern recognition and prediction (e.g., Johnson et al., 1993). Although the use of single metric approaches is widespread in Europe, there has been a tendency towards developing more complex bioassessment methods such multimetric approaches for stream macroinvertebrate (e.g., Hering et al., 2004) and fish (Schmutz and Haidvogl, 2002) as well as the use of multivariate methods (e.g., Johnson et al., 1992) and prediction (Wright, 1995; Johnson, 2000). Two multimetric indices have also recently been developed and proposed for use in Sweden to assess the effects of nutrient enrichment on stream macroinvertebrate assemblages (AQEM-consortium, 2002; Dahl and Johnson, 2004).

One of the main arguments against the use of multivariate or predictive approaches in bioassessment is that they are considered to be too complex (requiring expert knowledge in computer software) and the information is difficult to convey to managers (Gerritsen, 1995). However, these shortcomings were refuted by Norris (1995) who argued that the complexity of using predictive approaches could be easily hidden into interactive computer software, and indeed, user-friendlier methods based on multivariate methods have been developed for use in the UK (e.g., Wright, 1995), Australia (Simpson and Norris, 2000) and Canada (Reynoldson et al., 1995). Although multimetric and multivariate methods are similar in that they use the same data (site measures) to establish the reference condition, they differ in the determination of how a site is considered to differ from the reference population. Multimetric methods classify reference sites based on geographic and physical attributes (i.e. stream types), whereas multivariate methods use the biological assemblage to establish the variance expected to occur in the reference condition. Moreover, when determining if a test site deviates from the expected, multimetric approaches use the species × site matrix by calculating a number of metrics and summing these into a site-score. Multivariate methods, on the other hand, rely mostly on the information within the species × site matrix to determine whether a test site differs, and metrics are generally calculated for diagnostic once a test site is shown to differ. In other words, stress-specific metrics are calculated afterwards to determine what types of stressors may be causing the test site to deviate from the expected condition.

Although there has been considerable debate, in particular in the US, regarding the use of multimetric and multivariate methods (e.g., Gerritsen, 1995; Norris and Hawkins, 2000), few studies have compared the performance of different assessment methods for detecting ecological change (e.g., Fore et al., 1996; Reynoldson et al., 1997; Furse et al., 2006; Herbst and Silldorff, 2006). The aim of this study was to evaluate the performance of three methods (single metric, multimetric, and multivariate) commonly used in bioassessment to detect the effects of human-induced nutrient-enrichment stress on stream (riffle) macroinvertebrate assemblages. In addition, as site assessment may vary with sampling season, we also determined if discrimination varied between samples taken in spring and autumn.

## 2. Methods

### 2.1. Study area

Fifteen stream sites situated in the mixed forest region of southern Sweden were sampled as part of a European-financed project (Hering et al., 2004) (Fig. 1). The mixed forest region is an area of intense agriculture, and hence streams in this region are often affected by diffuse (i.e. non-point source) nutrient enrichment (e.g., Wilander et al., 2003). The 15 study streams were classified into stream types using criteria defined by the EU Water Framework Directive (European Commission, 2000). Accordingly, stream sites were classified by: ecoregion (according to Illies, 1978), size (based on catchment area), geology, and altitude (Table 1). All of the streams studied here are situated on siliceous geology, with altitudes ranging from 15 to 200 m a.s.l. (mean altitude = 74 m a.s.l.). Catchment areas ranged from 32 to 1005 $km^2$ (mean catchment area = 210 $km^2$), however, all stream sites with the exception of one were situated in catchments $<500$ $km^2$.

The stream sampling sites were selected *a priori* to represent a gradient in nutrient enrichment using both biological and chemical data. Pre-classification showed that 10 of the 15 sites were classified into four classes of ecological quality ranging from bad to good, while the five remaining sites were considered as having no or only minimal human-generated impacts (Hering et al., 2004) and hence were pre-classified as reference sites. The criteria used in the selection of these reference sites were partly taken from Hughes (1994) and Wiederholm and Johnson (1997), and more explicitly specified in Hering et al. (2004). Since preliminary classifications were based on existing data of varying quality it was deemed necessary to reclassify the sites after sampling to achieve a suitable nutrient enrichment gradient. Reclassification was based on stream characteristics (e.g., hydromorphology) and water chemistry. In brief, the final stream gradient consisted of the streams that were relatively well buffered (pH ranged from 6.02 to 7.98, conductivity ranged from 6 to 155 mS/m), but had total phosphorus concentrations (TP) ranging from 6 to 2200 μg/L (Table 1). Benthic macroinvertebrate abundance ranged from 154 to 4858 individuals per $m^2$. Dahl et al. (2004) examined this dataset, and showed only small differences in chemical composition and biota between the two seasons (spring and autumn). However, here we analyze the data both separately for the two different sampling seasons as well as pooled for spring and autumn.

### 2.2. Nutrient enrichment gradient

Principal component analysis (PCA) on centred and standardized variables was used to assess correlatively the structure of the environmental data and to reduce the structure to a lower number of environmental gradients as linear combinations of