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Macroinvertebrate taxa richness uncertainty and kick sampling in the establishment of Mediterranean rivers ecological status

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ABSTRACT

Freshwater macroinvertebrates have been extensively used as environmental indicators and are the most prevalent biological group used in aquatic bioassessment in the European Water Framework Directive (WFD 2000/60/EEC), usually through several popular indices, as the Biological Monitoring Working Party (BMWP). Many of these indices are based on taxa richness, i.e. the number of taxa present in a given area, as the simplest and most common measure of biodiversity. Given the importance to the WFD of the ecological status assessment by macroinvertebrates and the consequences thereof, sampling requires careful consideration and evaluation of the associated uncertainty. In this work, carried out in a Mediterranean river, we show that after 20 sample "kicks" it was possible to estimate the true taxa richness using Clench nonlinear asymptotic models (CM). However, cumulative curves of taxa extracted with kick sampling underestimated the true number of theoretical taxa (A). In order to achieve an acceptable error a very large sample size was required, always >20 kicks. According to these criteria, sampling was clearly inefficient in most localities. The minimum effort required to achieve a significant and acceptable level of taxa richness, for 90% of A, should be between 25 and 71 kicks and for 95% of A, 52–150 kicks. Both satisfactory percentages represent a mean difference of 2 (range 0–6) and 3 (range 1–8) taxa actually not being captured from the total predicted for each locality, for 90 and 95% of the CM asymptote, respectively. This study shows that by using the 20 kicks methodology it is possible to achieve reliable true macroinvertebrate richness estimates, but the establishment of the community composition, i.e. the full taxa making up any index score, will be inaccurate to an unknown degree.

1. Introduction

The implementation of the European Water Framework Directive (WFD 2000/60/EEC; EC, 2000) requires the use of aquatic organisms or biological quality elements (BQE) to assess the ecological status of bodies of water. These BQEs include phytoplankton, aquatic flora, macroinvertebrates and fish. Among these, the freshwater macroinvertebrates have been extensively used as environmental stress bioindicators of inland water bodies for more than 100 years and are the most prevalent biological group used in aquatic bioassessment in the WFD (Rosenberg and Resh, 1993; Birk et al., 2012). Despite this long history, there have been relatively few studies to establish macroinvertebrate sampling protocols to obtain reliable field data. Birk et al. (2012) asked whether "the effort to acquire the biological data is sufficient and feasible to fulfil the WFD assessment objectives.Äs sampling greatly influences the results of bioassessment, macroinvertebrate collection must be precise and representative. At the same time, sampling has to be cost-effective (Vlek et al., 2006).

Given the importance to the WFD of the ecological status assessment by macroinvertebrates and the consequences thereof, sampling requires careful consideration and evaluation of the associated uncertainty (Carter and Resh, 2001). Without this assessment, assigning water quality status according to the WFD is extremely problematic. This is especially so in the case of indices which depend on taxa richness as the number of taxa found depends on the sampling effort (Gotelli and Colwell, 2001). Several popular indices based, directly or indirectly, on taxa richness are among the WFD indicators of ecological status, including the Biological Monitoring Working Party (BMWP) (Armitage et al., 1983) and all its derivatives. Taxa richness, defined as the number of taxa present in a given area, is the simplest and most common measure of biodiversity (Magurran, 2004). But despite their simplicity, taxonomic richness show sample size dependency, and have been shown to underestimate richness at all sample sizes, although the error diminishes as the sample size increases

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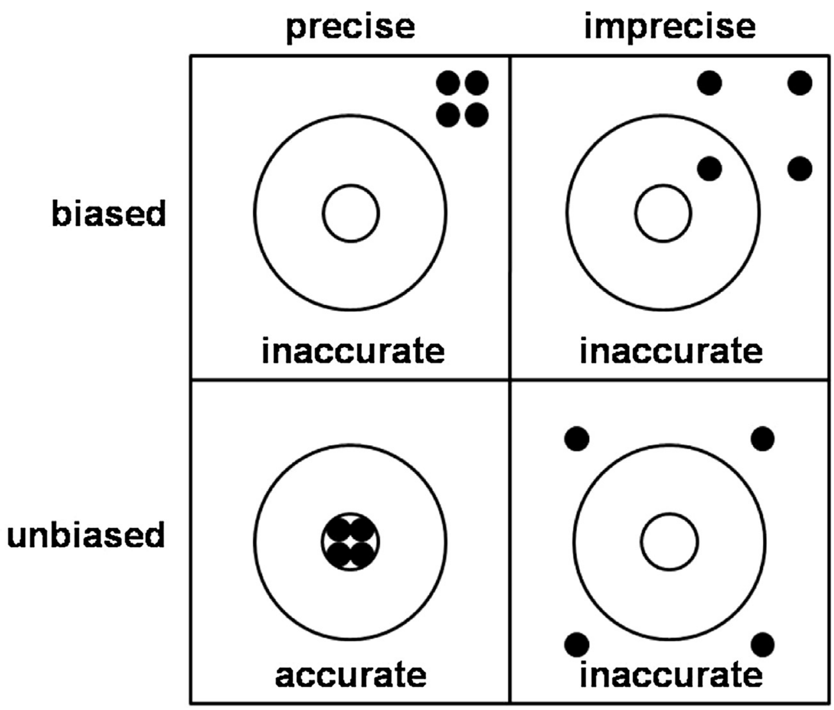

Fig. 1. Bias, precision and accuracy. Bias is the difference between the observed average richness and the accepted reference value or actual value, determining the under- or overestimates of the true value. Precision, or random error, is the variance of the observed values, independently of the accepted real value. Accuracy is defined as the total distance between the observed values and the accepted true value.

(Hellmann and Fowler, 1999; Schreiber and Brauns, 2010). Nevertheless, this drawback is rarely considered in biomonitoring.

The determination of the ecological status of water masses usually relies on the macroinvertebrate community composition rather than on taxa richness. On the other hand, the qualitative composition found will depend on the sampling effort. Thus, to measure the ecological status in an objective scientifically rigorous manner using an index derived from the community, as the aforementioned BMWP, it is essential to take enough samples to reach a minimally acceptable objective of community richness. Without taking into account the effect of sample size on measures of taxa richness, the bioassessment results are likely to yield false quality assignments that will be translated into inadequate, even harmful, management practices. It is important, then, that the methodology to determine the true value of the taxa present in a certain location should be assessed in terms of its uncertainty, including bias, precision and accuracy of measurement (Walther and Moore, 2005) (Fig. 1). Since the uncertainty depends on data measurement, conclusions could be compromised by the error committed in data gathering in terms of times, places, specialists, methodologies, etc. Determining the true value is not a simple task, especially when the number of taxa found in a community increases with the sampling effort (Baltanás, 1992; Melo and Froehlich, 2001; Magurran, 2004).

One of the most commonly used methods to collect freshwater macroinvertebrates is the semi-quantitative 'kick-sampling' (Macan, 1958), the standard procedure used in many biological quality indices (e.g. Armitage et al., 1983; Alba-Tercedor and Sánchez-Ortega, 1988; Capítulo et al., 2001; Mustow, 2002; Czerniawska-Kusza, 2005; among others). The application of this technique must be reliable in terms of its reproducibility, repeatability and accuracy. That is, the method must be able to produce the same results in a temporally and spatially homogeneous local community. To do so demands precise calibration and the definition of measurement errors, so as to refine the precision of the technique and to optimize the sampling protocols for local conditions (Bradey and Ormerod, 2002; Clarke et al., 2002; Vlek et al., 2006; Feeley et al., 2012). At the same time, methods need to be developed to correct for the effect of sampling effort on taxa richness found (Walther and Martin, 2001).

Here we present taxa richness estimation methods that yield estimates of the true richness of a location. We follow two approaches: taxa accumulation curves (TACs) and non-linear asymptotic models, which offer increased reliability for inventories, the possibility of comparison and better sampling planning (Colwell and Coddington, 1994; Thompson et al., 2003; Magurran, 2004; Chao et al., 2005). The usual kick sampling mode, based on a few samples, provides an uncertain estimate of the true taxa richness in a location. But the use of a standardized kick sampling protocol and the calculation of TACs, based on a consistent sample size, enables an estimation of the true taxa richness to be made.

The aims of this study were (i) to assess the performance of the "kick sampling" method using cumulative curves of observed macroinvertebrates taxa richness against five indicators: 1) estimated true richness through extrapolation, 2) percentage achieved with respect to the theoretical maximum [indicators 1) and 2) obtained from the total sampling effort after the calculation of nonlinear asymptotic models]; 3) bias, 4) precision and 5) accuracy; (ii) to discuss the feasibility/viability of a widely accepted sampling technique/protocol to obtain reliable inventories of the aquatic macroinvertebrate community.

2. Material and methods

2.1. Study location

The study was conducted on the river Múrtigas (Guadiana basin, SW Iberian Peninsula), a typical Mediterranean river, 81 km in length and with a 478 km^2 drainage basin. The River Múrtigas runs between 200 and 1000 ma.s.l. The area has a temperate continental Mediterranean climate (Martínez-Santos et al., 2014), with an average annual temperature between 14° and 16 °C and a mean rainfall between 800 mm and 1000 mm, concentrated in autumn