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Research paper

How to assess the impact of fine sediments on the macroinvertebrate communities of alpine streams? A selection of the best metrics

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ABSTRACT

Excessive fine sediment accumulation (i.e., siltation) in streams and rivers originates from several human activities and globally results in heavy alterations of aquatic habitats and biological communities. In this study the correlation between fine sediment and several benthic invertebrate community metrics was tested through a manipulative approach in alpine streams, where siltation mainly results as a physical alteration (i.e., the clogging of substrate interstices) without the influence of co-occurring confounding factors. We selected 12 candidate metrics, belonging to three different categories: compositional, structural and functional. We first carried out a manipulative experiment where artificial substrates were used to provide standardized conditions of siltation. All candidate metrics were calculated for each artificial substrate and the selection of the best combination of metrics was statistically performed with an information-theoretic approach. All candidate metrics were calculated both at family level and also at a mixed level (family and genus) in order to account for the systematic resolution. Then, data from a field study on alpine streams affected by mining activities were used as independent dataset for testing the performance of the selected metrics. We found that the total taxa richness, the EPT (Ephemeroptera, Plecoptera and Trichoptera) richness and the abundance of benthic invertebrates associated to rheophilous conditions and coarse mineral substrates were the most sensitive metrics. When these metrics were aggregated into a multimetric index in the validation dataset, we observed high and significant correlations between index values and the quantity of fine sediment for both taxonomic levels, especially for the mixed level. The findings of this study provide useful tools for biomonitoring the effects of fine sediment in low order, mountainous streams and contribute to improve our diagnostic ability on stressor-specific alterations.

1. Introduction

The riverbed colmation by fine sediment is one of the world-wide causes of alteration in streams and rivers (Owens et al., 2005; Wilkes et al., 2017). Excessive fine sediment inputs can originate from several anthropogenic sources, including agriculture (Benoy et al., 2012; Burdon et al., 2013), deforestation and clear-cut practices (Couceiro et al., 2010), road construction (Kaller and Hartman, 2004; Cocchiglia et al., 2012), mining activities (Smolders et al., 2003; Pond et al., 2008), damming and river flow regulation (Wood and Armitage, 1999; Crosa et al., 2010).

Fine sediment in running waters can act as a disturbance not only as suspended solids but also as settled material and negative consequences of sedimentation on all the components of lotic ecosystems have been well documented, regardless of the source (Wood and Armitage, 1997; Henley et al., 2000; Jones et al., 2012). Firstly, the deposition of large amount of fine inorganic material on the riverbed causes the loss of substratum heterogeneity and micro-habitats (i.e., spawning habitat for fish and interstitial spaces for invertebrates). A layer of fine sediment also hinders the oxygen and chemical exchanges between the bottom and the water column, producing anoxic or adverse conditions for benthic organisms (i.e., invertebrates and algae). In addition, fine sediment can cause direct damage to the aquatic organisms, clogging their respiration or feeding anatomical structures, producing an abrasive stress and dislodging them from the substrate (Bilotta and Brazier, 2008).

In the last decades, benthic invertebrates have been increasingly used in biomonitoring programs focused on physical alterations in streams, including fine sedimentation (Mebane, 2001; Cover et al., 2008; Kefford et al., 2010). Indeed, macroinvertebrates have a historical tradition as bio-indicators: their use to assess the ecological status of lotic ecosystems started at the beginning of the 20th century

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Table 1
Fine sediment biotic index recently developed with their systematic and geographical applicability details.

Index	Taxonomic resolution	Geographical area(s)	References
PSI (Proportion of Sediment-sensitive Invertebrates)	Family and species	UK	Extence et al. (2013), Glendell et al. (2014), Turley et al. (2014, 2015, 2016)
FSBI (Fine Sediment Bioassessment Index)	Genus	USA	Relyea et al. (2000, 2012)
BSTI (Biological Sediment Tolerance Index)	OTU (Operational Taxonomic Units: family, genus, species)	Oregon	Hubler et al. (2016)
$CoFSI_{sp}$ (Combined Fine Sediment Index)	Genus and species	England and Wales	Murphy et al. (2015)

(Rosenberg and Resh, 1993; Bonada et al., 2006), so that they are currently the most used group in freshwater biomonitoring around the world (Buss et al., 2015).

Recently, interesting stressor-specific biotic indices have been developed describing the structure of macroinvertebrate biological assemblages based on known or hypothesized tolerances of taxa to fine sedimentation (Table 1). For example, the PSI (Proportion of Sediment-sensitive Index), developed in the UK, scores each benthic invertebrate taxon according to its sensitivity or tolerance to fine sediment (Extence et al., 2013). The final index value is then calculated as the proportion of the most sensitive taxa in the sample (i.e., sampling station), adjusted to their range of abundance. The index ranges between 0 and 100, and based on its value five different quality classes are set, varying from completely un-affected by siltation (80–100) to heavy silted (0–20). Similar attempts have been made by Relyea et al. (2000, 2012) and Hubler et al. (2016) in USA. A different approach is proposed by Murphy et al. (2015), who assigned the scores to macroinvertebrate taxa through a multivariate statistical approach, thus overcoming the expert judgment.

Despite their strong biological and statistical bases, these indices present some critical issues. First, they are based on taxonomic identity, thus spatially dependent to geographical areas where they have been developed. The employment of selected community metrics rather than taxon-identity scores may be a good solution to overcome the biogeographical limits. This aspect introduces a fundamental question: which are the best macroinvertebrate community metrics related to fine sediment conditions? Literature data show that fine sediment affects several characteristics of macroinvertebrate communities, such as diversity, total abundance, relative abundance of functional groups and behavioral patterns (i.e., drift) (Angradi, 1999; Longing et al., 2010; Descloux et al., 2014). For example, reduction in the taxa richness and abundance of macroinvertebrates has been typically observed when high levels of siltation occur in the substrate or stream-section, especially among the most sensitive taxa (i.e., EPT – Ephemeroptera, Plecoptera and Trichoptera) (Sutherland et al., 2012; Mathers and Wood, 2016). Conversely, some taxa (i.e., Chiromomidae, Oligochaeta) could benefit from the environmental conditions provided by fine sediment (Ciesielka and Bailey, 2001; Cover et al., 2008). Also, trait-based classifications of macroinvertebrate taxa have been recently used to assess the response of macroinvertebrate assemblages to fine sediment conditions, with noteworthy results (Pollard and Yuan, 2010; Conroy et al., 2016; Wilkes et al., 2017). Many studies have demonstrated that specific functional groups of invertebrates are particularly affected by siltation (Rabeni et al., 2005; Longing et al., 2010; Doretto et al., 2016). For example, among the functional feeding groups (FFGs) several authors have observed a concomitant decrease in the abundance of scrapers and filterers along a gradient of fine sediment occurrence (Bo et al., 2007; Sutherland et al., 2012). When considering the biological and ecological traits, large body-sized, univoltine and external-gilled organisms appear especially disadvantaged by fine sediment as well as rheophilous and stony-associated taxa (Buendia et al., 2013; Bona et al., 2016).

A second problem is represented by the spatial extent. According to Larsen et al. (2009), the best spatial extent for directly relating macroinvertebrate communities to fine sedimentation is the patch-scale, since the response at the reach-scale is mediated by other factors, such as land use. However, in most cases, biotic indices were built on the basis of reach-scaled data, thus hindering the real relationship between macroinvertebrate taxa and fine sedimentation (but see Murphy et al. (2015)).

Third, in the majority of these indices benthic invertebrates are systematically identified at species level because these methods rely on species-specific sensitivity/tolerance information (Table 1). However, a similar taxonomic resolution is challenging for a routinely biomonitoring and most of the Environmental Agencies adopt a different systematic level, mainly family or genus. Moreover, species-specific data are not often available for some geographical areas or some invertebrate groups.

Fourth, to our knowledge, biotic indices measuring the response of macroinvertebrates to fine sedimentation reported in the literature mostly concern the augmentation of fine sediment in streams caused by agriculture (Turley et al., 2014, 2015; Naden et al., 2016). In lowland areas, agriculture-induced sedimentation usually results as a widespread and chronic disturbance, often coupled with organic pollution due to pesticides, fertilizes or urbanization. This may act as a confounding factor on the response of benthic invertebrate assemblages to fine sediment (Turley et al., 2016). By contrast, farming and human settlements are generally scarce in mountainous areas due to their pronounced slope and harsh conditions. Nevertheless, fine sedimentation is today recognized as a primary cause of alteration in alpine streams, originating mainly by acute, localized or episodic sources, such as logging, mining, cross-river constructions or reservoir flushing (Crosa et al., 2010; Milisa et al., 2010; Espa et al., 2015; Bona et al., 2016). These lotic environments are expected to severely suffer the consequences of fine sediment deposition as they are typically dominated by coarse substrata and erosive features (Allan and Castillo, 2007). However, currently few studies have been carried out to investigate the specific effects of fine sediment on benthic macroinvertebrates in alpine streams (but see Espa et al., 2015; Leitner et al., 2015; Doretto et al., 2017). The aims of this study are: i) to investigate what are the best macroinvertebrate community metrics responding to fine sediment deposition in alpine streams and ii) to assess how the taxonomic resolution could affect the relationship between the metrics and fine sediment. In order to investigate the relationship between macroinvertebrates and fine sedimentation at the proper scale, we built up an experimental field study in which standardized conditions of fine sediment were manipulatively determined using artificial substrata (calibration dataset) within one single alpine reach. We then tested the validity of our index on field-collected data obtained from several patches nested into different reaches in two alpine streams (validation dataset).

In particular, we aimed at constructing a multimetric index (MMI) following the algorithm suggested by Schoolmaster et al. (2013). The goal of the algorithm is to produce a maximally sensitive MMI from a given set of candidate metrics and a measure of human disturbance through an information theoretic criterion (Anderson and Burnham, 2002) to inform the process.