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# Testing the response of macroinvertebrate communities and biomonitoring indices under multiple stressors in a lowland regulated river

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ABSTRACT

River systems and their communities are exposed to diverse and multiple threats. Understanding how these threats affect the behaviour of biomonitoring indices is essential in order to provide reliable tools for the management and conservation of watercourses. To this purpose we tested the relationship of the STAR_ICMi index and its metrics, LIFE index and macroinvertebrate community with hydrology, water chemistry and land use in 8 sites located along the Oglio River course (Northern Italy), a watercourse originating from a large and deep lake. Macroinvertebrates and water samples were collected seasonally from summer 2013 to summer 2015 and daily discharge data were used to calculate several indices of hydrological alteration. A subset of these variables was selected by principal component analysis for using in the data analysis. The influence of hydrology, water chemistry and land use on macroinvertebrate community structure was explored with the variance partitioning method, while their influence on biomonitoring indices was analysed in a linear mixed effect model framework. Temporal and spatial constraints were explicitly considered in both analyses. Macroinvertebrate community structure was mainly related to these last two factors and to their joint effects with water chemistry and hydrology. STAR_ICMi, its metrics (with the exception of the Shannon index) and LIFE were related to the distance from the lake outlet, a proxy of mean annual discharge, groundwater input and artificial land use. STAR_ICMi, ASPT and EPT richness were also inversely related to the flow variability in the 3 months preceding sample collection. Surprisingly LIFE index was not related to any of the hydrological variables. The results of this study highlight weakness in the current biomonitoring tools and support the need for further investigations on macroinvertebrate interrelations with environmental drivers and their spatial and temporal structure. This is essential to overcome the limitations that may affect the reliability of macroinvertebrate-based indices in aquatic biomonitoring.

## 1. Introduction

Freshwater ecosystems are subject to multiple stressors that interact to shape the macroinvertebrate community on both local and catchment scales (Ormerod et al., 2010). Stressors can act additively, synergistically or antagonistically (Folt et al., 1999; Wagenhoff et al., 2011) limiting the capability of disentangling the effect of each single perturbation. Testing the response of the macroinvertebrate community and the related biomonitoring indices to multiple stressors is, thus, crucial to provide reliable tools for the management and conservation of freshwater ecosystems.

Biomonitoring indices are widely used and tested to measure the effects of human-induced alterations on several biotic communities, such as diatoms (Potapova and Charles, 2007), macrophytes (Dodkins et al., 2005), aquatic invertebrates (Bonada et al., 2006), fish (Pont et al., 2007) and riparian communities (Munné et al., 2003). In particular, macroinvertebrates represent the most widely used bioindicator in riverine systems (Buss et al., 2015) as they have proved useful for detecting the effects of both organic pollution (Friberg et al., 2010) and, more generally, the physical habitat quality of a watercourse (e.g., Pedersen and Friberg, 2009; Doretto et al., 2018). In Europe, biomonitoring indices based on the macroinvertebrate community have been thoroughly studied following the Water Framework Directive (WFD) enactment. Accordingly, a wide range of bioassessment metrics has been developed for freshwater systems, especially for rivers. These metrics, however, have been based largely on macroinvertabrate

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responses to nutrient enrichment, and have often neglected the pivotal role of hydrology (Birk et al., 2012) even though alteration in hydrology is considered a major driver of the macroinvertebrate community (Bunn and Arthington, 2002; Dunbar et al., 2010b; Guareschi et al., 2014). This is evident when considering the European intercalibration process of macroinvertebrate-based indices, which did not take into account any metrics specifically developed to detect hydrologic alterations (Buffagni and Furse, 2006).

To fill this gap, the present study aims to evaluate the relationship between the macroinvertebrate community and the related biomonitoring indices with some of the most common anthropogenic stressors, namely hydrological alteration, water-chemistry and land use, in a lowland regulated river. In this work we refer to regulated rivers as watercourses where flows are managed to provide water for hydroelectric generation and irrigation. Specifically, the response of the macroinvertebrate community, and different macroinvertebrate-based indices and metrics, were studied in a multiannual programme. To do this, and in line with the WFD, we focused on the STAR_ICMi index (Buffagni et al., 2007), the official macroinvertebrate index for Italian rivers, which has been tested during the European intercalibration process in different countries and riverine systems. It includes several widely used metrics for biomonitoring purposes elsewhere (Laini et al., 2014; Buss et al., 2015). We also focused on the “Lotic-invertebrate Index for Flow Evaluation” (hereinafter LIFE), proposed by the Environment Agency of England and Wales (see Extence et al., 1999) as a specific biomonitoring tool that aims to link the change in riverine benthic communities to prevailing flow regimes. It has been tested and compared mainly in Northern Europe, generally UK rivers (Dunbar et al., 2010a; Monk et al., 2012; Turley et al., 2014), but has not been widely considered in Southern Europe (see Buffagni et al., 2010). Within this framework, we hypothesise that hydrological, rather than physical and chemical, properties of water and land use should affect the macroinvertebrate community structure and the outputs of biomonitoring indices.

Knowledge of ecological responses to altered flow regimes, as well as the response of biomonitoring tools in regulated rivers, are of much scientific global interest because more than 50% of large rivers worldwide are regulated and/or dammed (Nilsson et al., 2005), and thousands of major dams are now being planned or under construction (Zarfl et al., 2014).

## 2. Material and methods

### 2.1. Study area

The study was performed in the first 50 km of the lower Oglio River, a tributary of the Po River that originates from the Lake Iseo (185 m a.s.l., Lombardia Region, Northern Italy, Fig. 1). Briefly, from km 0 to 20, the lower Oglio River hosts 6 hydroelectric generation plants of the run of the river type that creates a sequence of lentic and lotic stretches (details on the Oglio basin in Guareschi et al. (2014) and Soana et al. (2011)). The remaining 20 km suffer mainly from water abstraction for agricultural uses. The minimum allowed flow in the Oglio River varied depending on the stretch, with the 5% of the annual mean discharge being the lowest allowed flow. The Oglio River is dynamically connected with groundwater, presenting contrasting effects in the first 20 km (losing) compared with the rest (gaining). These groundwater inputs along the gaining stretch are highly enriched in nitrate due to the intensive agricultural activities in the catchment (Bartoli et al., 2011; Bolpagni and Laini, 2016).

### 2.2. Macroinvertebrate sampling and indices calculation

Macroinvertebrates were collected seasonally at 8 sites from summer 2013 to summer 2015 for a total of 63 observations. The first 4 sites were located in the lotic stretches downstream of 4 distinct

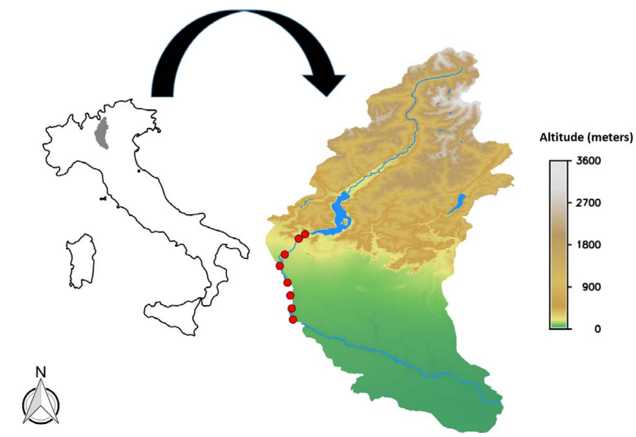


**Fig. 1.** Study area. Red dots represent the sampled sites. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

hydroelectric generation plants while the remaining 4 were located from km 30 to km 50 (Fig. 1). Macroinvertebrates were collected following the guidelines for the application of STAR_ICMi index (Buffagni et al., 2007). Briefly, 10 replicates were gathered with a Surber net of 0.05 $m^2$ frame area. Replicates were placed proportionally to the occurrence of each microhabitat. Organisms were sorted and identified in the field at family level following the taxonomic keys proposed by Tachet et al. (2010).

The STAR_ICMi is a multimetric index composed by 6 metrics: ASPT (Average Score Per Taxon), logarithm of the selected families of Ephemeroptera, Plecoptera, Trichoptera and Diptera (log(sel_EPTD +1)), total number of taxa, number of EPT taxa, 1 minus the relative abundance of Gastropoda, Oligochaeta and Diptera (1-GOLD) and the Shannon index. Furthermore, the LIFE index (Extence et al., 1999), which relies on the lentic-lotic affinity of macroinvertebrates to flow velocity, was considered. The calculation of LIFE index is performed by assigning each taxon to a flow group based on its affinity to water velocity and coarse substrata. The flow group information is combined to an abundance class to give a flow score and then LIFE index is calculated as the mean of the resulting flow scores. Calculations were performed on family level flow group.

### 2.3. Environmental variables

Water samples were collected monthly in each site, from summer 2013 to summer 2015. Dissolved oxygen saturation, pH, temperature and conductivity were measured with a multisensory probe (YSI model, 556 MPS). Water samples were processed for total suspended solids (TSS), dissolved Inorganic Carbon (DIC), ammonium ($NH_4^+$), nitrite ($NO_2^-$), nitrate ($NO_3^-$), total nitrogen (TN), soluble reactive phosphorous (SRP) and total phosphorous (TP) (APHA, 1998; APAT-CNR-IRSA, 2003). The mean of the 3 months preceding the collection of macroinvertebrate samples was used for statistical analysis.

Discharge data were provided by “Consorzio dell’Oglio”, the authority that regulates the water outflow from the Iseo Lake. Daily discharges in the investigated sites were available for the period 2009–2015 and they were used to calculate several indices of hydrological alteration (Olden and Poff, 2003; Table 1) for the 90 days preceding the collection of macroinvertebrate samples. Chemical and physical variables ($n = 12$) and hydrological variables ($n = 14$) used in this work are listed in Table 1.

Together with environmental variables measured at seasonal frequency, variables with a constant value for each site during the investigation period were calculated (Table 1). Percentages of artificial surfaces, agricultural land and forested and seminatural areas were obtained from Corine Land Cover 2012. Such percentages were