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Towards a more comprehensive assessment of river corridor conditions: A comparison between the Morphological Quality Index and three biotic indices

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ABSTRACT

River management and planning of restoration actions require a detailed analysis of stream conditions. However, most biotic and hydromorphological indices that have been developed for implementing the European Water Framework Directive (WFD) are characterized by limited spatial and temporal scales of application. In addition, the indices based on the biological quality elements defined by the WFD are sensitive to water quality but not to hydromorphological alterations. To overcome these limitations, alternative hydromorphological and biotic indices have recently been developed.

In this study we compared the results obtained with the Morphological Quality Index (MQI) to those of three biotic indices, the Odonate River Index (ORI) and two BQE-based indices, in seven rivers of northern Italy. MQI and ORI resulted highly and significantly correlated, and alterations of river functionality and continuity were the most relevant impacts affecting dragonfly assemblages. Conversely, no significant relationships were found between the MQI and both BQE-based indices and assemblages. The significant correlation between MQI and ORI can be explained by the correspondence of the spatial scale of application (i.e. the whole river corridor). In contrast, the lack of correlation between the BQE-based indices and MQI can probably be attributed to the different spatial scales at which the indices work.

The results of this study underline the importance of evaluating the lateral dimension of the river corridor and the need to apply reach-scale indices to achieve a comprehensive evaluation of river corridor conditions and to define appropriate management actions.

1. Introduction

Rivers and floodplains are generally diverse and dynamic ecosystems and are characterized by significant habitat heterogeneity that ultimately depends on the functionality of geomorphic river processes (Steiger et al., 2005; Choné and Biron, 2016). It is also widely accepted that a complex physical structure and the correct functioning of river processes maintain and promote well-structured biotic assemblages (Elosegi et al., 2010; Garcia et al., 2012; Wyżga et al., 2012). At the same time, rivers and floodplains are impacted by human activities and as a result are affected by multiple stressors including water pollution, hydromorphological alteration, land use change and invasive species (Tockner et al., 2010; Vörösmarty et al., 2010). The assessment of the ecological conditions of rivers and floodplains is therefore a crucial step for adopting appropriate management measures and for planning restoration projects aimed at improving these ecosystems. In the European Union, the assessment procedures are defined by the Water Framework Directive 2000/60/EC (WFD; European Commission, 2000), which defines the "ecological status" of rivers by considering biological, physical-chemical and hydromorphological elements.

The WFD introduced the term "hydromorphology", defined as the recent umbrella discipline that links hydrology and fluvial geomorphology. Several tools have been developed in Europe and worldwide to assess hydromorphology and methods for physical habitat assessment are the most common approach (Belletti et al., 2015). These methods generally consist of surveying, characterisation and classification of physical habitat elements, mainly focusing on in-stream features. Among them are the River Habitat Survey (Raven et al., 1997) and several derived methods (e.g. the national German method; LAWA, 2000). Although physical habitat assessments often collect data on features (e.g. shading, organic matter, refuge areas) that can be helpful in establishing links between river morphology and biota, they are

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affected by a series of limitations (Belletti et al., 2015). First, the spatial and temporal scales of application are not appropriate for a sound diagnosis and comprehension of morphological alterations. The spatial scale of application is limited in terms of the considered river length (i.e. a few hundred meters) and these methods focus exclusively on present river conditions. However, it is recognized that morphological alterations at site scale stem from processes that act on wider spatial scales (i.e. reach or catchment scale) and/or took place in the past, which may have consequences for the present state (e.g. sediment mining, wood removal, construction of levees and bank protections) (Fryirs et al., 2008; Rinaldi et al., 2013). Second, the other major shortcoming of physical habitat assessments is the limited use of sound geomorphological approaches and tools (e.g. remote sensing and GIS analysis), which would permit analysis at a wider spatial and temporal scale (Belletti et al., 2015).

On the other hand, morphological assessment methods are generally carried out at larger spatial scales, namely the reach scale (i.e. a length in the order of a few kilometres with homogeneous morphological characteristics and boundary conditions), and generally evaluate the entire river corridor, considering the active channel and its adjacent floodplain. These methods also take into account recent and historical channel adjustments using maps and remote sensing analysis and consider river processes (e.g. sediment transport and bank erosion) (Belletti et al., 2015). Examples of morphological assessment methods are the River Styles Framework (Brierley and Fryirs, 2005) and the Morphological Quality Index (MQI, Rinaldi et al., 2013).

As for the biological aspects, the WFD requires the assessment of different organism groups (i.e. benthic macroinvertebrates, benthic diatoms, aquatic macrophytes and fish) called biological quality elements (BQEs) to define the ecological status of rivers. These organisms were selected because they are widely considered good indicators of water quality, the alteration of which was the main pressure acting on rivers in developed countries in the last decades (Armitage et al., 1983; Friberg, 2014). Recent studies showed that BQE-based metrics and indices that were developed for the implementation of the WFD and that are used for standard assessment and monitoring are sensitive to water quality alteration. Conversely, their response to hydromorphological degradation is generally weak or absent (Hering et al., 2006; Friberg et al., 2009; Marzin et al., 2012; Dahm et al., 2013). Moreover, the effects of river restoration actions showed contrasting results on the BQEs (Kail et al., 2015): several studies reported a lack of response or a weak response (e.g. Lepori et al., 2005; Jähnig et al., 2009; Haase et al., 2013). In contrast, other studies found a significant positive effect on richness and abundance of benthic macroinvertebrates, aquatic macrophytes and fish (Miller et al., 2010; Schmutz et al., 2014; Ecke et al., 2016).

The other significant shortcoming of the WFD-compliant biotic indices is that their standard application is limited to flowing channels, i.e., sampling sites are generally located along the main channel, and side channels and lentic sites within the river corridor are not considered within the sampling protocols. The need for an appropriate assessment of the entire fluvial corridor that also considers the lateral dimension of the river system, has become a priority for both the scientific community and water managers in recent years (Reyjol et al., 2014). It is evident that relying exclusively on the BQE-based indices and metrics does not allow a comprehensive assessment of the ecological conditions of the whole river corridor. An incomplete evaluation could lead to incorrect planning in river management and restoration actions, with the risk of inappropriate use of economic resources.

In addition to BQEs, other bioindicators have been used to evaluate the condition of riparian areas and floodplains, such as ground beetles and riparian vegetation (Van Looy et al., 2005; Jähnig et al., 2009; Gumiero et al., 2015). However, the lack of standardized, cost-effective and widely accepted indices that summarize the ecological status of river reaches is a major limitation for their application.

Odonata is another taxon that has been used for the assessment of aquatic ecosystems (Chovanec and Waringer, 2001; Simaika and Samways, 2009; Monteiro Júnior et al., 2015). Dragonflies fulfil the requirements of a good bioindicator (Chovanec and Waringer, 2001; Simaika and Samways, 2012) and due to their amphibiotic life cycle, which consists of aquatic larval stages and aerial adults, dragonflies provide information about the ecological integrity and habitat heterogeneity of the aquatic breeding sites and surrounding terrestrial areas. Odonata breeding sites consist of a large variety of lentic and lotic sites: from mountain creeks to large lowland rivers, and from small, temporary ponds, to large wetlands and brackish lagoons (Corbet, 2004). Some of the main limiting factors for dragonflies assemblages in streams are low water temperatures and absence of aquatic and riparian vegetation (e.g. very active braided reaches) (Golfieri et al., 2016). After the emergence, teneral dragonflies generally disperse and feed in the surrounding areas, until they are mature and return to aquatic sites for reproduction. Another advantage of surveying dragonflies is that sampling and identification are relatively easy, at least for adults, and less time consuming compared to the other above-mentioned bioindicators. Because the Odonata offer these characteristics, several dragonfly-based indices were developed to assess the condition of streams and wetlands: Dragonfly Biotic Index (Simaika and Samways, 2009); Odonata Index of Wetland Integrity (Kutcher and Bried, 2014); Dragonfly Association Index (Chovanec et al., 2015); and the "*Odonata* Community Index – Corsica" (Berquier et al., 2016). The Odonate River Index (ORI; Golfieri et al., 2016) was specifically developed to evaluate the ecological integrity of the whole corridor of rivers in northern Italy. In contrast, most of the other above-mentioned indices focus only on the main channel. Only the Dragonfly Biotic Index (Simaika and Samways, 2009) is not spatially constrained and can therefore be applied in reach-scale river assessments.

The aims of this study are: (i) to investigate the relationship between a morphological assessment method (i.e. MQI) and a dragonfly-based index (i.e. ORI); (ii) to investigate the relationships between MQI and two indices based on BQEs (i.e. diatoms and benthic macroinvertebrates) for a subset of the case studies. The underlying research hypothesis is that MQI and ORI, which are tools developed to evaluate the condition of the whole river corridor, should be correlated, while the site-scale BQE-based indices might not be correlated with MQI. Another objective of the study is (iii) to identify the morphological alterations that affect the assemblages and three biotic indices considered.

2. Materials and methods

2.1. Case studies

The study was carried out in seven Italian Alpine rivers: three of these (Chiese, Sesia and Stura di Demonte rivers) drain from the central-western Alps, while the others (Adige, Brenta, Meduna and Tagliamento rivers) drain from the eastern portion of the Alps (Fig. 1). The rivers were chosen because they present different morphological and ecological conditions and cover a wide gradient of human impact: the Tagliamento River and the Stura di Demonte River exhibit a high level of naturality, due to their large and relatively undisturbed fluvial corridors (CIPRA, 1992; Tockner et al., 2003), while the Adige and Chiese rivers present degraded conditions due to widespread interventions of channelization and alteration of the hydrological regime (Comiti, 2012; Nardini and Pavan, 2012). The Brenta, Meduna and Sesia rivers are characterized by an intermediate degree of human impact. A total of fifteen river reaches were selected: 3 reaches along the Brenta River and 2 reaches along each of the other rivers. All study reaches were located in the alluvial plains and their physical and morphological characteristics are summarized in Table 1.

The chemical status of the water in the study reaches was classified as "high" or "good" (i.e. meaning absence or limited pollution and/or eutrophication) by the regional environmental agencies (ARPA), which