Science of the Total Environment 603–604 (2017) 639–650

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Combined effects of water stress and pollution on macroinvertebrate and fish assemblages in a Mediterranean intermittent river

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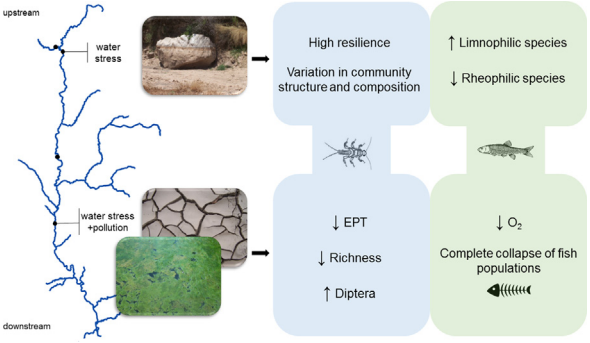
HIGHLIGHTS

- The effects of multiple stressors on aquatic biota are still poorly understood.
- Intermittent rivers are highly susceptible to chemical stress and water scarcity.
- We compared biotic responses to different levels of water stress and pollution.
- Combined stressors affect negatively macroinvertebrates and fish.
- Future efforts should focus on untangling stressors interactions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 30 March 2017
Received in revised form 9 June 2017
Accepted 9 June 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Stressor
Biota
Instream habitat
Drought
Water quality
Intermittency

ABSTRACT

Water stress is a key stressor in Mediterranean intermittent rivers exacerbating the negative effects of other stressors, such as pollutants, with multiple effects on different river biota. The current study aimed to determine the response of macroinvertebrate and fish assemblages to instream habitat and water chemistry, at the microhabitat scale and at different levels of water stress and pollution, in an intermittent Mediterranean river. Sampling was conducted at high and low summer discharge, at two consecutive years, and included four reaches that were targeted for their different levels of water stress and pollution. Overall, the macroinvertebrate fauna of Evrotas River indicated high resilience to intermittency, however, variation in community structure and composition occurred under acute water stress, due to habitat alteration and change in water physico-chemistry, i.e. water temperature increase. The combined effects of pollution and high water stress had, however, pronounced effects on species richness, abundance and community structure in the pollution impacted reach, where pollution sensitive taxa were almost extirpated. Fish response to drought, in reaches free of pollution, consisted of an increase in the abundance of the two small limnophilic species, coupled with their shift to faster flowing riffle habitats, and a reduction in the abundance of the larger, rheophilic species. In the pollution impacted reach, however, the combination of pollution and high water stress led to hypoxic conditions assumed to be the leading cause of the almost complete elimination of the fish assemblage. In contrast, the perennial Evrotas reaches with relatively stable physicochemical conditions, though affected hydrologically by drought, appear to function as refugia for fish during high water stress. When comparing the response of the two biotic groups to combined acute water stress and pollution, it is evident that macroinvertebrates were negatively impacted, but fish were virtually eliminated under the two combined stressors.

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http://dx.doi.org/10.1016/j.scitotenv.2017.06.078
0048-9697/

1. Introduction

The traditional assessment of river ecosystem health solely through the use of water chemistry measurements as indicators for the aquatic quality status has been largely replaced by biological assessments coupled with physicochemical measurements, in which biotic elements, i.e. aquatic flora and fauna, are used for detecting ecosystem impairment (Karr et al., 1986; Reynoldson and Metcalfe-Smith, 1992; Dolédec and Statzner, 2010; Johnson and Ringler, 2014). Using this approach, biota reflect overall ecological quality, rather than solely chemical degradation; furthermore, it is possible to identify the biological effects of degradation and the ecological factors driving anthropogenic ecosystem impairment (Johnson and Ringler, 2014). In Europe, biological assessments have been incorporated in EU and member state legislation framework under the EU Water Framework Directive (WFD, European Commission, 2000) in order to manage and protect all rivers, lakes, coastal and transitional waters; this led to the development of new indicators incorporating the effects of multiple stressors (e.g. Haury et al., 2006; Mondy et al., 2012; Lazaridou et al., 2016).

Several studies have evaluated the effects of different stressors on stream assemblages of various aquatic taxa, with macroinvertebrate assemblages, and to a lesser degree fishes, being routinely used in biomonitoring programmes, as they are integrally linked to both physical and chemical instream characteristics (Karr et al., 1986; Sawyer et al., 2004; Hering et al., 2006; Johnson and Ringler, 2014; Schinegger et al., 2016). These studies have used various assemblage-specific metrics and biotic indices, however, the life histories, habitat requirements, and physical and chemical tolerances of macroinvertebrates and fishes can vary significantly, both within and between biotic assemblages and that may cause differences in their responses to environmental degradation (Hering et al., 2006; Johnson and Ringler, 2014). For example, previous studies comparing their responses to different stressors have revealed the strong response of both groups to organic pollution, due to their susceptibility to the accompanying oxygen depletion (Hering et al., 2006), their high sensitivity to morphological degradation of their habitat (Marzin et al., 2012) or the similarity of their response to instream habitat and land use, in addition to water quality (Sawyer et al., 2004). Other studies, although indicating a similar response to water chemistry, revealed differences in their sensitivity to physical habitat characteristics, such as substrate quality (Johnson and Ringler, 2014); others showed differences in spatial scale response, with macroinvertebrate communities being more responsive to localised degradation, or to impairment of mountain streams as opposed to lowland streams, in comparison to fish (Hering et al., 2006; Flinders et al., 2008) while some studies indicated the lower fish metric response compared to that of macroinvertebrates to stress (Dahm et al., 2013).

Currently, research efforts focus on unraveling the effects of multiple human stressors and their impacts on lotic biotic assemblages (Arenas-Sánchez et al., 2016; Schinegger et al., 2016). A recent study aiming to address the multiple stressor effects on fish assemblages at the continental scale (Europe), indicated that among the 73% of impaired sample sites across Europe, >64% were affected by two or more stressors, highlighting the importance of research on the effects of the interplay of multiple stressors, when assessing the responses of biological indicators (Schinegger et al., 2016). A number of studies have also assessed the potential effects of multiple stressors (land use, micropollutants, drought) on stream macroinvertebrate assemblages and traits (Bonada et al., 2007a, 2007b; Boulton, 2003; Sánchez-Montoya et al., 2007, 2010; Tockner et al., 2010; Sabater et al., 2016) with some focusing on the interplay of water scarcity and pollution (Petrovic et al., 2011; Arenas-Sánchez et al., 2016).

Several studies have shown that during desiccation, decreased water flow leads to decreased water surface area and chain reactions in physicochemical parameters, such as increased water temperatures and anoxia which, in their turn, affect adversely aquatic biota (Acuña et al., 2014, Petrovic et al., 2011). When desiccation is combined to exposure to pollutants, the two stressors may act synergistically on stream biota (for a review of such effects on macroinvertebrates based on experimental studies, see Holmstrup et al., 2010). In a more recent review of relevant field and experimental studies on a variety of organisms, Arenas-Sánchez et al. (2016) have stressed that the impact of hydrological alteration is more relevant for aquatic communities, however they also pointed out that in some cases the presence of chemical pollution may lead to exacerbated ecological risks. Similarly, Sabater et al. (2016) concluded that flow variation had a significantly stronger influence on the studied macroinvertebrate community than pollutants, while Bollmohr and Schulz (2009) had shown a strong negative correlation between organophosphates and macroinvertebrate community structure, despite some effects also of low flows. Studies in fish are even more limited than those on invertebrates; Crosa et al. (2001) evaluated the combined effects of hydrological seasonality and insecticide pollution, reporting however no significant effects. Matono et al. (2012), however, in a recent study using field data from two Iberian basins, showed that fish assemblage variability was associated to both hydrological fluctuation and nutrient/organic load. They also showed that, at the more disturbed sites, low flow enhanced the pressures exerted on the fish assemblages due to water quality deterioration. More field studies and complementary experimental ones are required to evaluate the effects of each of the co-occuring stressors, as well as the interactions between these stressors. Furthermore, future studies should include, together with bacteria and algae, also macroinvertebrates and fishes, as both experimental and field studies using these groups, are still very limited. Finally, another challenge is a new spatial approach, as studies need to be conducted at different spatial scales, since there is variation in ecological dynamics and community responses at the habitat, reach or basin scale.

Intermittent rivers and streams dominate surface runoff in arid and semi-arid areas of Mediterranean Europe and are extremely sensitive to hydrological and other anthropogenic pressures (for a recent review see Skoulikidis et al., 2017a). These aquatic systems constitute one of the least known types of fluvial ecosystems, yet their importance has been acknowledged only during the last decades (Acuña et al., 2014; Datry et al., 2014; Leigh et al., 2016). Intermittent rivers encompass a remarkable hydrogeomorphological diversity and function as biodiversity hotspots, hosting often a unique, endemic and extremely range restricted fauna (Larned et al., 2010; Bonada and Resh, 2013; Skoulikidis et al., 2017a). However, though many Mediterranean rivers naturally exhibit a non-perennial flow regime (Bonada and Resh, 2013), increased pressures on water resources for agricultural, industrial, urban and touristic use are radically changing the natural flow regime of many perennial rivers converting them into “artificially intermittent” rivers (Benejam et al., 2010; Skoulikidis et al., 2011, 2017a). Seasonal variability in temperature and rainfall in Mediterranean climate regions is considered to be an evolutionary factor that regulates stream communities and their ecological traits (Stamou, 1998; Gasith and Resh, 1999; Cid et al., 2017). The duration of the wet and dry periods is highly variable, seasonally and spatially, and has a strong influence on stream communities as, prolonged droughts may prevent the successful recovery of stream communities (Bêche et al., 2009). This high variability in environmental conditions across time and space at intermittent ecosystems makes the interpretation of biological monitoring more difficult, in order to distinguish between natural hydrological variability and anthropogenic alterations, such as nutrient/organic load and sediment load (Matono et al., 2012). The expected increase in artificial desiccation, combined with water quality and habitat deterioration under current climate change scenarios, dictate the study of species-specific environmental requirements, habitat preferences and limitations of the biota in these aquatic systems in order to assist specific conservation and restoration actions.

The objective of this study was to determine the response of macroinvertebrate and fish assemblages to instream habitat and water physicochemical characteristics at different levels of water stress and pollution, in an intermittent Mediterranean river. We designed our