Assessing the ecological effects of water stress and pollution in a temporary river - Implications for water management

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HIGHLIGHTS
• Pollution and water stress effects on communities and metrics were examined
• Pollution mostly affected diatoms, macrophytes and macroinvertebrates
• Water stress and the combined effect of the two stressors mostly affected fish
• Different temporal effects of water stress were observed on the four biotic groups
• Management decisions should be based on both pollution and temporal water stress data

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ABSTRACT
Temporary rivers are dynamic and complex ecosystems that are widespread in arid and semi-arid regions, such as the Mediterranean. Biotic communities adapted in their intermittent nature could withstand recurrent drought events. However, anthropogenic disturbances in the form of water stress and chemical pollution challenge biota with unpredictable outcomes, especially in view of climate change. In this study we assess the response of the biotic community of a temporary river to environmental stressors, focusing on water stress and pollution. Towards this aim, several metrics of four biotic groups (diatoms, macrophytes, macroinvertebrates and fish) were applied. All biotic groups responded to a pollution gradient mainly driven by land use, distinct functional groups of all biota responded to water stress (a response related to the rheophilic nature of the species and their resistance to shear stress), while the combined effects of water stress and pollution were apparent in fish. Biotic groups presented a differential temporal response to water stress, where diatom temporal assemblage patterns were explained by water stress variables of short-time response (15 days), while the responses of the other biota were associated to longer time periods. There were two time periods of fish response, a short (15 days) and a long-time response (60–75 days). When considering management decisions, our results indicate that, given the known response of river biota to pollution, biomonitoring of temporary rivers should also involve metrics that can be utilized as early warnings of water stress.

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1. Introduction

Research on temporary rivers has vastly increased during the last decade (Datry et al., 2011, 2014; Acuña et al., 2014; Skoulikidis et al., 2017). Temporary streams and rivers, are among the most dynamic, complex and diverse freshwater ecosystems, but also among the most threatened ecosystems (Larned et al., 2010; Acuña et al., 2014). Though located in all geographical regions, they are by far the dominant river type in arid and semi-arid areas (McDonough et al., 2011; Acuña et al., 2014). Temporary rivers occupy more than one third of the planet’s land surface and host about 30% of the world population (Tzoraki and Nikolaidis, 2007; Arenas-Sánchez et al., 2016). They are vulnerable to natural drought and anthropogenic water stress (Larned et al., 2010; Acuña et al., 2014); in most European Mediterranean rivers, the combination of extensive water abstraction, river fragmentation, and climate change has dramatically reduced river runoff (UNEP/MAP, 2003). The Intergovernmental Panel on Climate Change (IPPC) predicts that the trend of increasing temperatures and reduced annual precipitation will lead to prolonged drought events (IPCC Core Writing Team et al., 2014). Mediterranean temporary rivers encompass a remarkable hydrogeomorphological diversity, as well as a unique native fauna, adapted to natural drought events (Gasisith and Resh, 1999; Lake, 2003; Matthews and Matthews, 2003), but are sensitive to the disturbance caused by the anthropogenic increase in the frequency and severity of water stress episodes (Magalhães et al., 2007; Datry et al., 2014). Mediterranean river basins are becoming drier (annual precipitation decreased up to 20% during the 20th century), with more extreme events than a century ago (García-Ruiz et al., 2011). Moreover, the recent drought that began in 1998 in the eastern Mediterranean Levant region, is likely the worst drought of the past nine centuries, as concluded by a recent NASA (National Aeronautics and Space Administration) study, aiming to reconstruct the Mediterranean’s drought history (Cook et al., 2016). All the above bring temporary rivers to the spotlight in view of climate change and its effects on river communities.

Mediterranean temporary rivers are subjected, apart from water stress, also to nutrient enrichment from industrial and urban wastewaters, and organic pollution from agricultural activities (Meybeck, 2004; Vörösmarty et al., 2010). Water intermittency can accentuate the effects of pollution stressors by affecting the dilution and self-purification capacity of the receiving aquatic systems (Karaouzas et al., 2011; Sabater et al., 2016). Furthermore, high seasonal flow fluctuation due to natural variation and over-abstraction, influences the physicochemical and biological characteristics of these ecosystems (Barceló and Sabater, 2010; Arenas-Sánchez et al., 2016; Skoulikidis et al., 2017; Kalogianni et al., 2017). The absence of long-term biological data related to environmental data at large spatial scales in temporary rivers has so far limited the understanding of biota responses to single and multiple pressures.

The effects of chemical and water stress on biotic communities appear to be both complex and temporally and spatially variable (Arenas-Sánchez et al., 2016; Sabater et al., 2016). Aggregates of organisms such as biofilm, macrophytes, invertebrates, or fish have specific responses to various stressors, related to their habitat requirements and life-cycle (Sabater et al., 2007; Johnson and Hering, 2009; Johnson and Ringler, 2014). The joint exposure to pollution and water stress may produce cumulative impacts on the aquatic biotic assemblages, as they are subjected to a concomitant habitat shrinkage, water quality deterioration and increased competition for limited resources (Magalhães et al., 2002; Magoullick and Kobza, 2003). Pollution and water stress can have pronounced effects on macroinvertebrate and fish species richness, abundance and community structure (Larned et al., 2010; Petrovic et al., 2011; Arenas-Sánchez et al., 2016; Kalogianni et al., 2017). On the other hand, the response of macrophytes and benthic diatoms to multiple stressors in temporary ecosystems is much less studied. There is still a large uncertainty on how hydrological variation and chemical pollution affect aquatic communities under varying environmental conditions and how co-occurring stressors affect the community structure of the various freshwater biota (Navarro-Ortega et al., 2014; Sabater et al., 2016).

The aim of this study was to assess the response of the biotic community of a temporary river to environmental stressors, focusing on water stress and pollution. The community under study consisted of four biotic groups, namely benthic diatoms, macrophytes, benthic macroinvertebrates and fish. To test the effects of the different stressors, we applied two approaches, retaining different information levels. We first investigated for stressors’ effects and their interactions in metrics commonly used for each biotic group, including biological quality and diversity indices. We then applied a community-based approach where we considered the effects of the stressors for the whole community of each biotic group. Considering the physiological differences of the four biotic groups used in the present study, we also hypothesized that their reaction to water stress would be time dependent. We expected that our integrative approach would lead to a deeper understanding of communities in temporary rivers and would further inform and enhance management decisions.

2. Materials and methods

2.1. Study area

This study was conducted in the Evrotas River (36°48’15”N–22°41’45”E, Southern Peloponnese, Greece, Fig. 1). The Evrotas basin is representative of a large fraction of Greek territory drained by temporary rivers (up to 43%, Tzoraki and Nikolaidis, 2007). It is a medium-sized (2,418 km²), mid-altitude (150–600 m) Mediterranean basin, with several ephemeral and intermittent streams discharging into the main channel of the river (Vardakas et al., 2015; Karaouzas et al., 2017). The climate, discharge and precipitation of the Evrotas basin follow a predictable seasonal pattern, similar to other Mediterranean rivers (Gasisith and Resh, 1999) with hot and dry summers and cool, wet winters. However, flow intermittency in Evrotas is highly dependent on the hydrological/meteorological conditions of the preceding year(s) that inevitably also affect the intensity of water abstractions. Water abstraction for field irrigation is the dominant anthropogenic pressure in the Evrotas River Basin leading to the artificial desiccation of several sections in late summer-early autumn (Skoulikidis et al., 2011). The geographical, geological, hydrological and ecological features of the Evrotas watershed are described in detail elsewhere (Karaouzas et al., 2017; Kalogianni et al., 2017; Vardakas et al., 2017a).

Samplings were conducted at four sites on the main channel of Evrotas River in June 2014, July 2015, June 2016 and September 2016 targeting for different levels of water stress and water quality degradation (Fig. 1). The two upstream sites (Uskol and Dskol) are relatively undisturbed and typologically similar, with Uskol located in a perennial river section, while Dskol located 1.2 km downstream, is an intermittent site drying out partially during late summer (Fig. 1). The other two sites (Vivari and WWTP) are located in the middle section of the Evrotas River with a wider active channel and higher discharge than the upstream sites; the spring-fed Vivari is a relatively undisturbed perennial site, while the WWTP site, located 20 km downstream, dries out in periods of extreme drought. Vivari receives diffuse agricultural pollution and minor pollution from animal husbandry (Fig. 1). The heavily impacted WWTP receives diffuse pollution from agriculture and point source pollution from the Sparta Wastewater Treatment Plant and from cesspool waste dumping, plus seasonal pollution from olive mill and orange juice processing wastewaters.

2.2. Environmental data collection and biota sampling

Water physicochemical parameters, i.e. dissolved oxygen (D.O. mg/L), water temperature (°C), conductivity (μS cm⁻¹), were measured at each site using a Portable multiparameter Aquaprobe AP-200 with a GPS Aquameter (Aquaread AP 2000). Water samples for nutrient
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