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Response of a multi-stressed Mediterranean river to future climate and socio-economic scenarios

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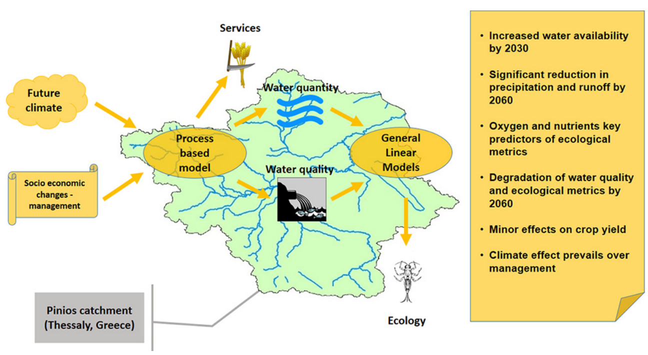
HIGHLIGHTS

- We examined the response of the Pinios river to future world scenarios.
- Abiotic state was assessed with the Soil and Water Assessment Tool.
- Macroinvertebrate metrics were assessed by employing empirical modelling.
- Results predict degradation of biotic and abiotic state by 2060.
- Climate effects prevail over future management in the basin.

GRAPHICAL ABSTRACT



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ABSTRACT

Streams and rivers are among the most threatened ecosystems in Europe due to the combined effects of multiple pressures related to anthropogenic activities. Particularly in the Mediterranean region, changes in hydromorphology along with increased nutrient loadings are known to affect the ecological functions and ecosystem services of streams and rivers with the anticipated climate change being likely to further impair their functionality and structure. In this study, we investigated the combined effects of agricultural driven stressors on the ecology and delivered services of the Pinios river basin in Greece under three future world scenarios developed within the EU funded MARS project. Scenarios are based on combinations of Representative Concentration Pathways and Shared Socioeconomic Pathways and refer to early century (2030) and mid-century (2060) representing future climate worlds with particular socioeconomic characteristics. To assess the responses of ecological and ecosystem service indicators to the scenarios we first simulated hydrology and water quality in Pinios with a process-based model. Simulated abiotic stressor parameters (predictors) were linked to two biotic indicators, the macroinvertebrate indicators ASPT and EPT, with empirical modelling based on boosted regression trees and general linear models. Our results showed that the *techno world* scenario driven by fast economic growth and intensive exploitation of energy resources had the largest impact on both the abiotic status (nutrient loads and concentrations in water) and the biotic indicators. In contrast, the predicted changes under the other two future worlds, *consensus and fragmented*, were more diverse and were mostly dictated by the projected climate. This work showed that the future scenarios, especially the mid-century ones, had significant impact on both abiotic status and biotic responses underpinning the need for implementing catchment management practices able to mitigate the ecological threat on waters in the long-term.

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1. Introduction

Mediterranean rivers are under ecological threat by a variety of pressures. Nutrient pollution, habitat fragmentation and alteration in hydrology are some of the most common problems that Mediterranean lotic systems are facing today (Milly et al., 2005; Ormerod et al., 2010; Vörösmarty et al., 2010). Specifically changes in rivers' hydromorphology along with increased nutrient loadings are known to heavily influence both the ecological integrity and the aquatic biodiversity of these systems (Gasith and Resh, 1999; Bonada and Resh, 2013; Hershkovitz and Gasith, 2013). Since most European rivers are affected by multiple stressors operating simultaneously (Ormerod et al., 2010), it is very likely that synergistic or antagonistic interactions among stressors may result in unpredictable outcomes known as "ecological surprises" (Folt et al., 1999; Hale et al., 2017). This became apparent when in many European streams and rivers the hydromorphology and/or water chemistry improved but the ecological status has remained well below the good ecological status.

Climate change is also considered a highly important pressure, especially in Southern Europe, where several studies have indicated severe impacts on rivers and streams (e.g. Liuzzo et al., 2015; Santos et al., 2015; Sellami et al., 2016). What we have learnt so far is that future climatic projections, according to the fifth assessment report of the Intergovernmental Panel on Climate Change — IPCC-5AR (IPCC, 2013), depict changes in global water cycle, with increases in disparity between dry and wet regions. Practically this means that in some areas (from 30°N to 85°N) precipitation over land is expected to increase, while from 10°S to 30°N there are predictions for notable decreases (Grover, 2015). For the Mediterranean region, future projections suggest an increase in aridity that is likely to induce a further reduction in water availability. Alterations of seasonal variability and total amount of precipitation, combined with a simultaneous raise of temperature are expected to have a remarkable impact on water cycle enhancing water scarcity and drought (e.g. Sheffield and Wood, 2008; Mariotti et al., 2008).

Under conditions of multiple stresses any restoration actions may initiate complex cause-effect chains of recovery, which are poorly understood and are not always guaranteed to have the desired outcome (Feld et al., 2011). Therefore, for the Mediterranean rivers in particular, it is crucial to understand deeply how the most common stressor of water scarcity interacts with other stressors (nutrient pollution, climate change) and to communicate this information to managers and policymakers for the adaptation of appropriate management measures that address the combined stressor effect. To ensure the good ecological quality of rivers and streams there is an additional need to be able to predict how the aquatic biota respond to various conditions (Aguiar and Ferreira, 2005; Hooke, 2006). Thus, implementing appropriate mitigation and restoration actions requires understanding both how the biota respond to multiple anthropogenic pressures at present and how biota will be affected by climate change and future anthropogenic activities.

The purpose of this article is to investigate how future scenarios of multiple stressors will affect ecological status and the delivered services of Pinios by implementing an efficient modelling approach that links a number of different abiotic and biotic components of the catchment such as hydrology, nutrients, land use, climate, management practices, ecology and ecosystem services. Our research hypothesis is based on the anticipated impact of climate change on the catchment's hydrology. We expect that projected decrease of precipitation and increase of air temperature will decrease water availability enhancing nutrient pollution and consequently affecting the benthic invertebrate communities. Macroinvertebrates were chosen as the biotic response mainly for two reasons. First, benthic invertebrates are considered an ideal group of organisms for assessing the ecological quality of rivers because of their sensitivity to changes in properties of water quality and aquatic habitat (Bonada et al., 2007; Feld and Hering, 2007; Skoulikidis et al., 2009). Macroinvertebate metrics respond to a wide array of human pressures and as a result they are used in many countries for monitoring the ecological status (Sandin and Hering, 2004; Birk and Hering, 2006). Secondly, macroinvertebrates are the most well studied biotic element in Pinios catchment. Thus, a solid empirical dataset by the Greek Ministry of Environment and previous published studies (Chatzinikolaou, 2007; Chatzinikolaou et al., 2010) is available, enabling us to study the effects of multiple stressors on an important aspect of ecology.

By multiple stressors, we mean changes of environmental factors that occur in concert and affect ecological status, water quality and quantity, and ecosystem services. The implemented modelling scheme was developed within the EU-funded project MARS (Hering et al., 2015) and aims in assessing the multiple stressor effects on biotic and abiotic indicators by linking the outcome of "abiotic" process-based models with the biota and ecosystem services through empirical modelling. Within this context, the implementation of future world scenarios enables us to evaluate different climatic projections and socioeconomic trends, in particular the ones selected for a pan-European implementation in MARS. The objectives of this study are: (i) to quantify the responses of abiotic, biotic and service-related indicators to multiple stressors in Pinios and (ii) to discuss the changes in hydrology, water quality, ecological status and the delivered services within the catchment under the different future scenarios.

2. Methods

2.1. Study area

The Pinios basin covers almost entirely one of the Greek River Basin Districts (RBDs), the RBD of Thessaly in Central Greece (Fig. 1). The basin has high relief in the western and northwestern part, and topography is smoother in the central, southern and southeastern part where the large agricultural valley is developed. The catchment (with an area of approximately 10,600 km^2) is the most important agricultural producer in Greece, with fertile soils but a very dry climate during summer. Usually, the dry periods are accompanied by high temperatures, which lead to higher evapotranspiration rates and dry soils. These conditions inversely affect both the natural vegetation and the agriculture of the region resulting in irrigation cutbacks, overexploitation of groundwater and significant losses of crop yields (Panagopoulos et al., 2014). Water overexploitation in Pinios basin may lead to low river flows (negligible during summer), the drying up of small lakes/reservoirs and low groundwater levels, which make water more expensive to obtain (deep pumping) and enhance saline water intrusion in coastal areas in the eastern part. Therefore, the most important pressure in the Pinios basin is water abstraction for irrigation. Another important environmental issue in the area is surface and groundwater nitrate pollution caused by intensive and sometimes excessive crop fertilization (Psomas et al., 2016). Climate change is also a possible future pressure due to the predicted lower precipitation and higher temperatures, especially within the dry period, when crops are growing.

2.2. Data availability

There are various sources of information and environmental data for Pinios basin such as previous projects, published and unpublished studies as well as the RBMP of the Thessaly RBD, within which, Pinios basin is entirely located. In this study we take advantage of our previous extensive work on collecting and/or deriving the necessary datasets for the basin (Panagopoulos et al., 2013, 2014; Stefanidis et al., 2016).

Precipitation, temperature and other meteorological variables are measured through point stations all across the Pinios basin from the Greek Ministry of Environment and Climate Change & the Public Power Corporation. Precipitation is available from 1975 to 2010. Annual precipitation in Pinios ranges between 390 mm and 1250 mm with an average annual depth of 760 mm and significant seasonal and monthly deviation. Reliable and adequate hydrologic time-series are available