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Global change impacts on river ecosystems: A high-resolution watershed study of Ebro river metabolism

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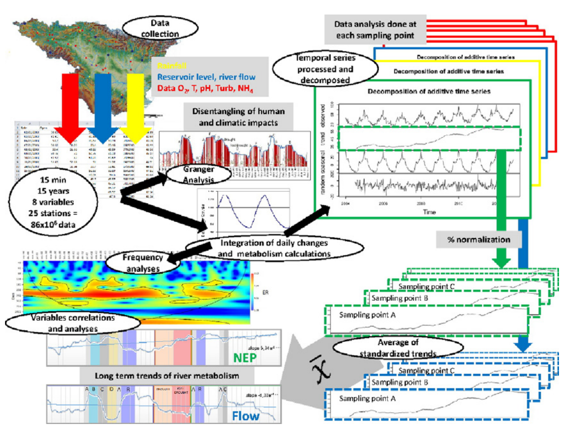
HIGHLIGHTS

- Whether and how global change impacts on stream metabolism has been analyzed.
- A high-resolution watershed study, analyzing over 86 million data has been assessed.
- For the first time climate and human effects are disentangled and studied in a real basin.
- Flood effect after a prolonged drought led to a reset of the ecosystem community.
- The previous state of the river community is essential for the recovery after floods.

GRAPHICAL ABSTRACT



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ABSTRACT

Global change is transforming freshwater ecosystems, mainly through changes in basin flow dynamics. This study assessed how the combination of climate change and human management of river flow impacts metabolism of the Ebro River (the largest river basin in Spain, 86,100 km^2), assessed as gross primary production—GPP—and ecosystem respiration—ER.
In order to investigate the influence of global change on freshwater ecosystems, an analysis of trends and frequencies from 25 sampling sites of the Ebro river basin was conducted. For this purpose, we examined the effect of anthropogenic flow control on river metabolism with a Granger causality study; simultaneously, took into account the effects of climate change, a period of extraordinary drought (largest in past 140 years).
We identified periods of sudden flow changes resulting from both human management and global climate effects. From 1998 to 2012, the Ebro River basin was trending toward a more autotrophic condition indicated by P/R ratio. Particularly, the results show that floods that occurred after long periods of low flows had a dramatic impact on the respiration (i.e., mineralization) capacity of the river.
This approach allowed for a detailed characterization of the relationships between river metabolism and drought impacts at the watershed level. These findings may allow for a better understanding of the ecological impacts

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provoked by flow management, thus contributing to maintain the health of freshwater communities and ecosystem services that rely on their integrity.

1. Introduction

Global change (GC) is transforming river ecosystems, mainly through changes in basin flow dynamics resulting from the increase in the frequency and intensity of floods and droughts (IPCC, 2014). These changes are further conditioned by an interaction with non-climatic drivers of change and responses to water management (Jiménez Cisneros et al., 2014).

Due to intensive exploitation of water resources and the modification of basins, rivers have experienced significant transformations through simplification of channel networks, dam construction, human modification and destruction of riparian forests, water abstraction, pollution, and the introduction of invasive species (Allen and Ingram, 2002; Nilsson and Berggren, 2000; Ward and Stanford, 1995). Several studies indicate that flow rates of the Iberian basins, including the Ebro, have declined during the second half of the twentieth century as the result of climate change coupled with anthropogenic effects (Lorenzo-Lacruz et al., 2012; Sabater, 2010; Santos et al., 2015). All these impacts will considerably modify the characteristics of watersheds by affecting the distribution and survival of freshwater biological communities and ecosystem productivity (Heath et al., 2014; Lorenzo-Lacruz et al., 2012; Winder et al., 2011).

River metabolism, which is one of the most integrative ecosystem functions (Rodriguez-Iturbe et al., 2011), is highly sensitive to many anthropogenic and natural stressors at different levels of ecological organization (Bunn et al., 1999) and often used to assess ecosystem health. One approach is the assessment of the relationship between gross primary production (GPP) and ecosystem respiration (ER) (Mulholland et al., 2001; Young et al., 2008). This ratio provides information about the organization of ecological communities and how energy flows through food webs, thus being a good indicator of perturbations associated with GC and anthropogenic pressures (Roberts et al., 2007; Uehlinger, 2006; Williamson et al., 2008). However, disentangling the contributions of human vs. climate drivers is still challenging (Jiménez Cisneros et al., 2014; Sabater, 2010).

There are several studies on river metabolism describing the expected patterns in GPP and ER in relation to the natural variation and responses to environmental stressors, such as position from headwater to river mouth, influential species, light availability, temperature, nature of substrate, turbidity, pH, nutrients, organic pollution, toxic chemicals, riparian vegetation, and channelization or flow actuation (Young et al., 2008, review). However, these factors are studied at local scales and for short periods of time (maximum 2 years).

The only long-term study of river metabolism was performed in the Swiss Alps during a period of 15 years (Uehlinger, 2006). The study area has a high frequency of floods that greatly influence river metabolism depending on the season, due to the mountainous river dynamics and scarce human management. The results of this study indicated that a substantial inter-annual variation in ecosystem metabolism can be expected when discharge patterns largely differ between years. Consequently, the study of large basins exposed to the impacts of both human regulation and climate change may provide major insights into river metabolism dynamics.

In the study of complex natural systems, inferring causal relationships between their elementary components, means a significant defy. Nevertheless, it is crucial to understand the underlying physical rules and establish the intervention procedures to influence the overall behavior of the system. In order to investigate the influence of GC on freshwater ecosystems in Ebro river basin, we conducted an analysis of trends and frequencies of biological and physico-chemical variables potentially affected by GC. Hence, we have analyzed the long-term trend (15 years) of the Ebro metabolism, based on the standardization and integration of 15-min-resolution measurements (about 86 million data) for different environmental variables at 25 locations of the basin (Fig. 1). This approach allows to examine the effect of human flow control on river metabolism with a Granger causality test at basin scale. The period studied included a period of extraordinary drought (the largest in the past 140 years), associated with the atmospheric circulation that allows for assessing the effects of one of the main impacts related to climate change. Finally, application of continuous wavelet transformation (CWT) allows to examine how seasonality of the river metabolism was affected by GC drivers.

2. Materials and methods

2.1. Study area

The Ebro River Basin is located in the Northeast of the Iberian Peninsula; it covers 86,100 km^2 and is inhabited by 3.2 million people. The Ebro River rises in an Atlantic humid climate and flows through a dry continental climate in its middle region, ending in a Mediterranean climate. Irrigation is the main water use at the Ebro Basin; 906,000 ha are irrigated, with an estimated total water demand of 7370 hm^3/year. Another important factor is the intense control of the flow in the basin which has 187 dams, retaining 85% of the average annual flow of the entire basin. The main uses of these facilities are the supply of hydroelectric and agricultural needs (Batalla et al., 2004; Magdaleno and Fernandez, 2011). Because of this diversity of environments, impacts, and its large size, the Ebro basin is a suitable study area to address GC effects at a regional scale.

This study covers the period from 1998 to 2012. To characterize flow management in the whole basin, we used 24 h accumulated rainfall data from 86 weather stations. For the metabolism study, we used data taken every 15 min over a period of up to 15 years (June 1998 to May 2012) in 25 sampling stations located throughout the Ebro basin (Fig. 1). These data were obtained from the managing body of the basin, the Hydrographic Confederation of the Ebro (CHE).

2.2. Assessing the role of flow and droughts on the intensity of global change impacts

Flow is the main driver of change in the metabolic and physico-chemical parameters, as previously indicated at smaller temporal and spatial scales (Hunt et al., 2012; Marcarelli et al., 2010; Roberts et al., 2007; Uehlinger, 2006; Young et al., 2008). Disentangling human-induced flow and extraordinary climate-induced flow changes from ‘normal’ flow dynamics is a difficult issue. There are mainly two natural factors affecting flow dynamics: rainfall and the riverbed geology. While the first one can be modified by abnormal climatic events, such as variations in atmospheric circulation patterns induced by climate change, the second one remains constant. All other factors influencing flow dynamics are human induced (reservoir control, water withdrawals, irrigation. . .).

In this context, to study the effects of climate change on river ecosystems, we have taken into account the exceptional weather conditions occurring during hydrological year 2004–2005, where unusual precipitations during each month of this hydrological year were detected (Garcia-Herrera et al., 2007). Furthermore, in this study, these changes