Science of the Total Environment 569–570 (2016) 798–814

Contents lists available at ScienceDirect

Science of the Total Environment

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

Addressing the local aspects of global change impacts on stream metabolism using frequency analysis tools

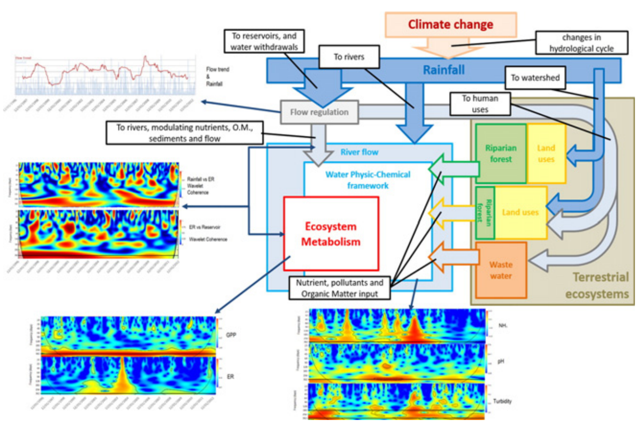
Jonatan Val [a,b,c,*], Rosa Pino [b], Enrique Navarro [c], David Chinarro [b]

[a] FACOPS Foundation, Cuarte de Huerva 50410, Zaragoza, Spain
[b] Research Institute for Environment and Sustainability of San Jorge University, Villanueva de Gállego 50830, Zaragoza, Spain
[c] Pyrenean Institute of Ecology (CSIC), Av. Montañana 1005, 50059, Zaragoza, Spain

HIGHLIGHTS

- The impact weight of non-climatic drivers over stream metabolism was determined.
- Innovative frequency analysis techniques were applied to metabolism time series.
- Flow management degree is the main impact on river ecosystem metabolism.
- There has been a high macrophyte colonization in sites with higher pressures.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 May 2016
Received in revised form 20 June 2016
Accepted 21 June 2016
Available online 5 July 2016

Editor: D. Barcelo

Keywords:
River metabolism
Wavelet transform
Wavelet entropy
Water quality
Spills impact
Land uses
Flow management

ABSTRACT

Global change, as a combination of climate change, human activities on watersheds and the river flow regulation, causes intense changes in hydrological cycles and, consequently, threatens the good ecological status of freshwater biological communities. This study addresses how and whether the combination of climatic drivers and local human impacts may alter the metabolism of freshwater communities.

We identified a few factors modulating the natural water flow and quality in 25 point spread within the Ebro river Basin: waste water spills, industrial spills, reservoir discharges, water withdrawals, agricultural use, and the presence of riparian forests. We assessed their impacts on the freshwater metabolism as changes in the annual cycle of both gross primary production—GPP – and ecosystem respiration—ER –. For this purpose, daily data series were analyzed by continuous wavelet transformation, allowing for the assessment of the metabolic ecosystem Frequency Spectrum Patterns (FSPs).

Changes in the behavior of ecosystem metabolism were strongly associated with local characteristics at each sampling point, however in 20 out of 25 studied points, changes in metabolic ecosystem FSP were related to climatic change events (the driest period of the last 140 years). The changes in FSP indicate that severe impacts on how biological communities use carbon sources occur as a result of the human water management – too much focus on human needs – during intense climatic events.

* Corresponding author at: Apartado de Correos n° 6, 50410 Cuarte de Huerva, Zaragoza, Spain.
E-mail addresses: jval@biodiversa.es, jval@usj.es, jovalpu@gmail.com (J. Val), rpino@usj.es (R. Pino), enrique.navarro@ipe.csic.es (E. Navarro), dchinarro@usj.es (D. Chinarro).

http://dx.doi.org/10.1016/j.scitotenv.2016.06.178

Results show that local factors, and specially the flow regulation, may modulate the impact of global change. As example those points exposed to a more intense anthropization showed a clear disruption – and even disappearance – of the annual FSP. This information may help managers to understand the action mechanisms of non-climatic factors at ecosystem level, leading to better management policies based on the promotion of ecosystem resilience. The method here presented may help on improving the calculation of ecological flows to maintain the river metabolic annual cycles as close as possible to the natural ones.

1. Introduction

Climate change is causing alterations in hydrological cycles that lead to diverse impacts and risks. These changes are further conditioned by an interaction with non-climatic drivers of change and responses to water management (Jiménez Cisneros et al., 2014). The Intergovernmental Panel on Climate Change (IPCC) reports (IPCC, 2014) reflect that problems caused by climate change have not been adequately taken into account in relation to the analysis, management, or policy relating to water resources.

Many non-climatic drivers affect freshwater resources at all scales. Water resources, both in terms of quantity and quality, are severely affected by human activities, particularly through agricultural practices, land use change, wildfires, construction and management of reservoirs, emissions of pollutant substances, and wastewater treatment (Allan, 2004; Doll, 2009; Santos et al., 2015, 2014; Valle Junior et al., 2015). In order to evaluate the relationship between climate change and freshwater ecosystems, it is necessary to address how the extent and intensity of these non-climatic drivers modulate the impacts of climate change.

The rate of production and use of organic carbon in freshwater ecosystems by measuring river metabolism are a widespread method that provides the direct estimate of the food base that determines life-supporting capacity (Mulholland et al., 2001; Young et al., 2008). Therefore, metabolism occurring at streams can be a good indicator of perturbations associated with global climate change and anthropogenic pressures (Reid et al., 2006; Roberts et al., 2007; Uehlinger, 2006; Williamson et al., 2008).

There is a wide variety of river metabolism studies analyzing the influence of numerous parameters (position from headwater to river mouth, influential species, light availability, temperature, nature of substrate, turbidity, pH, nutrients, organic pollution, toxic chemicals, riparian vegetation, channelization, or flow actuation) and their impact on stream metabolism (see the review of (Young et al., 2008). However, most of these studies focus on a single point or cover a period of maximum two years; only one encompassed 16 years (Uehlinger, 2006). The duration of the study is of utmost importance, as there may be other climatic and/or anthropogenic factors acting at higher time and spatial scales, which may be affecting metabolic responses of the studied parameters (Val et al., 2016a).

To address this issue, time series analysis is a useful tool to study behavior of one variable $y(t)$ through time $t \in T$. The classical analysis of time series is attained in the time domain and based on statistic models such as moving average, autocorrelation, and autoregression (Box et al., 2015).

The concomitant ecological processes in an ecosystem can be characterized by non-stationary signals (i.e. its frequency or spectral contents are changing with respect to time in contrast with stationary ones, which does not change). Although a simple stationary stochastic model could briefly represent the system, the non-stationarity signal requires complex models to characterize and study the phenomena thoroughly to reveal or better understand cause–effect relationships. The classical Fourier transform (FT), with sines and cosines base functions, is not suitable for the analysis of a non-stationary signal. However, wavelet techniques provide improved solutions for time-scale analysis through the convolution operation between the signal and a set of scaled and shifted versions of a base function with specific properties called wavelet mother. Wavelet transformation provides the frequencies contained in the signal and sheds light about the moment at which each frequency is present (Mallat, 1999).

Shifts in both frequency and amplitude (this is called the Frequency Spectrum Pattern or FSP) occurring in ecosystem respiration (ER), gross primary production (GPP) and other physic-chemical variables as pH or NH_4, during a determined period; may be related to changes in the function or structure of biological communities that are measured as changes on the use of carbon sources by organisms (Val et al., 2016a), from here onwards we will call these changes as “community changes”. In this last mentioned study, based on global averaged trend data from the same 25 locations as in this study, allowed for detecting global behavior patterns at river basin metabolism level, where several periods of climatic change and human basin management events were isolated (see supporting information Fig. S0). In the current study, we have analyzed these periods along with the characterization of local conditions for each sampling site, because is essential to understand how communities respond to global change impacts when we further consider local characteristics.

The 25 locations here studied presented a great variability of non-climate drivers of the river metabolism and are spread over the Ebro watershed. In addition to this wide spatial scale also a long time period has been considered: 15 years of stream metabolism data at 15 minute resolution calculated by frequency analysis methods.

2. Materials and methods

2.1. Study site

The Ebro River Basin is located in the Northeast of the Iberian Peninsula and covers an area of 86,100 km^2 (Fig. 1). It rises in an Atlantic humid climate, flows through a dry continental climate in its middle region, and ends in a Mediterranean climate. Irrigation is the main use of water at the Ebro Basin. Currently, an area of 906,000 ha is irrigated, with an estimated total water demand of 7793 Hm^3/year. Total population in the region is 3,226,921 inhabitants. Another important factor is the severe control of the flow in the basin; there are 187 dams, retaining 85% of the average annual flow of the entire basin, mainly for the supply of hydroelectric and agricultural needs (Batalla et al., 2004; Magdaleno and Fernandez, 2011).

Within the study period (1996 to 2012), the basin has suffered the most severe drought in the last 140 years (Garcia-Herrera et al., 2007), in the hydrological year 2004–2005. Furthermore, there were three large floods, in 2003, 2007, and 2008, and several periods of strong human modification of river flow dynamics: 2000 to 2003, 2005 to 2006, and 2008. A detailed description of the different flow periods and the influence on basin metabolism are described in our recent work (Val et al., 2016a).

2.2. Data acquisition

Required data for the calculation of metabolic parameters; dissolved oxygen, water temperature and flow, as well as pH, turbidity, and NH_4, were obtained from an automatic water quality monitoring system (SAICA) of the Ebro Hydrographic Confederation (CHE). CHE automatic sampling stations take data from these physicochemical parameters