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Assessing the effects of multiple stressors on the functioning of Mediterranean rivers using poplar wood breakdown

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ABSTRACT

Mediterranean rivers in the Iberian Peninsula are being increasingly affected by human activities, which threaten their ecological status. A clear picture of how do these multiple stressors affect river ecosystem functioning is still lacking. We addressed this question by measuring a key ecosystem process, namely breakdown of organic matter, at 66 sites distributed across Mediterranean Spain. We performed breakdown experiments by measuring the mass lost by wood sticks for 54 to 106 days. Additionally, we gathered data on physico-chemical, biological and geomorphological characteristics of study sites.

Study sites spanned a broad range of environmental characteristics and breakdown rates varied fiftyfold across sites. No clear geographic patterns were found between or within basins. 90th quantile regressions performed to link breakdown rates with environmental characteristics included the following 7 variables in the model, in decreasing order of importance: altitude, water content in phosphorus, catchment area, toxicity, invertebrate-based biotic index, riparian buffer width, and diatom-based quality index. Breakdown rate was systematically low in high-altitude rivers with few human impacts, but showed a high variability in areas affected by human activity. This increase in variability is the result of the influence of multiple stressors acting simultaneously, as some of these can promote whereas others slow down the breakdown of organic matter. Therefore, stick breakdown gives information on the intensity of a key ecosystem process, which would otherwise be very difficult to predict based on environmental variables.

1. Introduction

Human population and per capita use of resources have been rising dramatically in the last centuries, resulting in environmental change of global proportions (Vitousek, 1994; IPCC, 2007; UNEP, 2007), which is affecting every ecosystem on earth (Millennium Ecosystem Assessment, 2005). Streams and rivers are among the most affected ecosystems (Dudgeon, 2010), especially those in highly populated areas with a shortage of water availability (Vörösmarty et al., 2010), like the Mediterranean region. Mediterranean rivers are subject to multiple stressors including regulation, pollution, changes in channel form, modification of riparian areas, and invasive exotic species (Sabater, 2008; Ricart et al., 2010). The effects of these stressors are seldom additive, but usually interact in complex ways. As a result of global environmental change, large effects are expected in river ecosystem functioning (Rockström et al., 2009), which is the base of many ecosystem services (Sweeney et al., 2004; Millennium Ecosystem Assessment, 2005). Nevertheless, most of the information available on the response of river ecosystem functioning to environmental changes derives from studies of limited spatial extent. This fact occurs because measuring ecosystem functioning simultaneously at multiple sites needs either large teams (e.g. Bernot et al., 2010) or large investments in monitoring stations (e.g. Izagirre et al., 2008). Therefore, there are still large uncertainties on the effect of multiple stressors on river ecosystem functioning.

River ecosystem functioning is not a simple variable. Ecosystems have multiple functions, which can be measured with a varied array of techniques, change at different spatial and temporal scales, and respond to environmental stressors in specific manners (e.g., Bunn and Davies, 2000; Young et al., 2008; Elosegi et al., 2010; Elosegi and Sabater, 2012). Commonly measured ecosystem functions include nutrient retention and river metabolism (e.g. von Schiller et al., 2008), processes which respond to human activities (Fellows et al., 2006; Newbold et al., 2006) at different scales (Houser et al., 2005; von Schiller et al., 2007), but which are time consuming and expensive to measure. Decomposition, usually measured as breakdown of particulate organic matter (mostly leaf litter), is another process commonly measured to assess the effects of environmental changes on ecosystem functioning (Robinson and Jolidon, 2005; Lecerf et al., 2006; McKie and Malmqvist, 2009). Breakdown of organic matter is a complex process involving leaching of soluble compounds, physical

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abrasion, colonisation by microbial bacteria and fungi, and fragmentation by invertebrate shredders (Tank et al., 2010). Therefore, it can be affected by multiple stressors, like changes in water nutrient concentration (Gulis and Suberkropp, 2003), pollution (Niyogi et al., 2001), altered hydrology (Datry et al., 2011) or changes in land uses (Hladyz et al., 2011). Some of these stressors, like increased temperatures, tend to promote breakdown (Dang et al., 2009), whereas others, like acidification, can slow it down (Dangles et al., 2004), therefore making it difficult to predict breakdown at sites subject to multiple stressors.

Breakdown plays a pivotal role in river ecosystems, as it is the initial step for detritic pathways, what led Gessner and Chauvet (2002) to advocate the use of leaf litter to measure ecosystem functioning. Nevertheless, preparing leaf litter bags is time-consuming, litter quality can be quite variable (Sariyildiz and Anderson, 2003), and physical abrasion during floods can confound breakdown dynamics (Ferreira et al., 2006a). Thus, several authors proposed to use standardized substrates instead, such as cellulose bands (Rulik et al., 2001), cotton strips (Tiegs et al., 2007) or calico (Imberger et al., 2010), as these materials are much less variable in their chemical composition and less prone to fragmentation than leaves (Egglishaw, 1972; Tiegs et al., 2007; Imberger et al., 2010). Nevertheless, some of these alternative materials are alien to river ecosystems, and thus, the rate of their degradation cannot be easily translated into the natural functioning of rivers.

A material that is common in most rivers, easy to handle, and useful to measure ecosystem functioning, is dead wood (Díez et al., 2002). Therefore, authors have measured the breakdown of wood, in the form of entire logs (Ellis et al., 1999), in the form of branches (Tank and Webster, 1998), or in the form of different types of sticks (Young et al., 2008). Breakdown of wood, like that of leaf litter, is influenced by many factors, including physical and chemical properties of wood (Díez et al., 2002), nutrients in water (Gulis et al., 2004), and water temperature (Spänhoff and Meyer, 2004). Wood breakdown is considered a slow process (Hyatt and Naiman, 2001), but small pieces with high surface-to-volume ratio can suffer important breakdown in short periods (Spänhoff and Meyer, 2004). Therefore, small wooden sticks can provide researchers a fast, easy, cheap and standardized tool to measure one important river ecosystem function (Young et al., 2008; Arroita et al., 2012-this issue).

Here we show results of one of the most extensive studies of breakdown published so far. We analysed the breakdown of wood sticks in 66 rivers spread across most of the Mediterranean Iberian Peninsula, thus representing a broad array of environmental conditions and degrees of anthropogenic stressors. Our hypothesis is that multiple stressors will affect breakdown rates in diverging directions, and thus, variance of breakdown rate will be higher at rivers most affected by human actions.

2. Material and methods

2.1. Study area

This experiment was conducted in 4 river basins in the Iberian Peninsula: Ebro, Llobregat, Júcar and Guadalquivir, which together drain a large part of the Mediterranean Iberian Peninsula (Fig. 1). Climate in these basins is typically Mediterranean, with warm, dry summers and mild, humid winters, continentality increasing from east to west, and aridity from north to south. The long history of human settlements has created a highly heterogeneous mosaic of human land uses, ranging from near natural areas in the mountains to intensively cultivated agricultural lands or to areas with intensive industry and severe pollution. A total of 76 sites were selected for the SCARCE-Consolider project (http://www.idaea.csic.es/scarceconsolider/): 24 in the Ebro, 14 in the Llobregat, 15 in the Júcar and 23 in the Guadalquivir. Most sites coincided with river reaches monitored by the Water Agencies for physico-chemical and biological characteristics, to have as much information as possible on each river reach.

2.2. Breakdown experiment

We measured the breakdown of tongue depressors ($15 \times 1.8 \times 0.2$ cm) made of untreated Canadian poplar wood (*Populus nigra x canadensis*, Moench). Sticks were individually tagged with a pirographer, dried (70 °C, 72 h) and weighed. Bunches of five depressors were tied with nylon filament to a coded plastic ring, and two weights were included to make bunches sink. Three bunches (totalling 15 sticks) were placed in each site in summer (June–July) of 2010 tied to metal bars, roots or boulders, and they were recovered after 54 to 106 days. In the laboratory, depressors were washed with tap water and brushed, dried (70 °C, 72 h) and ashed (500 °C, 5 h) to get ash free dry mass (AFDM). Leaching of sticks was simulated in the laboratory, and initial ash content determined to correct initial dry masses. 11 sticks were recovered with missing tips that were not consumed but broken, probably by some boulder transported by the water. To estimate the loss we extrapolated the total mass of the stick from the bits recovered using the area as a reference.

2.3. Data treatment

Breakdown rates were calculated according to the negative exponential model (Petersen and Cummins, 1974). Variables that describe the physicochemical, biological and geomorphological characteristics of the sites were acquired from different sources. Average channel width was calculated from 5 transversal sections measured along 1 km of channel length from aerial photographs. Aerial photographs were also used to measure the width of the riparian vegetation in 1 km reaches. Altitude, channel slope, catchment area and land uses were determined from GIS layers with Quantum GIS. Water Agencies provided hydrological (discharge and/or water level), physical (temperature, pH, conductivity, suspended solids) and chemical parameters (water content in dissolved oxygen, ammonium and, phosphorus), measured following standard procedures (APHA, 1992). Water Agencies also provided data on biological quality, namely the diatom based IPS (Cemagref, 1982) and the macroinvertebrate-based IBMWP (Alba-Tercedor and Sánchez-Ortega, 1988) for each water mass. Average values were calculated from the data available in the incubation period. When there were no available data for the incubation period (19% of the Ebro data, and 48% of the Guadalquivir), we used the data from previous years as a proxy.

Additionally, coinciding with our experiments, the SCARCE-Consolider consortium analysed the concentrations of 111 prioritary or emerging organic pollutants in water, which included endocrine disruptor compounds, pesticides, perfluorinated compounds, UV filters and pharmaceuticals. According to criteria from the EU Directive 2009/90, concentrations below the limit of quantification (LOQ) were considered half the LOQ value for each pollutant. Total toxicity of the pollutants was determined as Toxic Units (TU). Half maximal effective concentrations (EC_{50}) and median lethal doses (LC_{50}) for *Daphnia magna* (Cladocera, Crustacea) for 48 h were collected from the literature (mainly gathered from http://sitem.herts.ac.uk/aeru/footprint/en/index.htm; http://cfpub.epa.gov/ecotox/). Data for EC_{50} were more abundant than the data for LC_{50}, so we used the former as a toxicity reference in our study, as both variables were highly correlated ($r > 0.75$, $P < 0.001$). We assumed an additive toxicity of all pollutants and thus, estimated the maximal expected effect of the mixture (TU_{sum}) with the following formula (modified from Sprague, 1970):

$$\text{Toxic Units Sum} = TU_{sum} = \sum_{i=1}^{n} TU_i = \sum_{i=1}^{n} \frac{C_i}{EC_{50i}}$$

$$\log TU_{sum} = \log \sum_{i=1}^{n} TU_i$$