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Impact of climate extremes on hydrological ecosystem services in a heavily humanized Mediterranean basin

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ABSTRACT

Climate change projections in the Mediterranean region are associated with more frequent extreme climate conditions, which could alter water availability and impact the delivery of ecosystem services. We assess the change in the delivery of three hydrological ecosystem services, one provisioning (water), and two regulating (water purification and erosion control), in the heavily humanized Llobregat River basin (Catalonia, NE Spain) in recently observed extreme wet and dry years. Results indicate that impacts on the delivery of services were especially important in dry years. The main sources of water supply were located in the northern part of the basin and they were the most affected by annual rainfall reduction. Drinking water and hydropower production were highly threatened in dry years, when benefits were almost 100% reduced with respect to the benefits obtained in normal years. The regulating service water purification provided higher benefits in dry years, when water quality was more likely to be compromised due to a decreased dilution capacity. Water purification benefits in normal years increased 127% in dry years. According to our results, no benefit was provided by water purification in wet years. Collectively, our findings emphasize that hydrological ecosystem services in semi-arid basins which are subject to chronic human pressure are very sensitive to the climate conditions of extreme years. We also find a spatial decoupling among areas of service supply and areas where the service is demanded. Management efforts in Mediterranean basins should consider both of these aspects.

1. Introduction

Humans receive an array of benefits from the natural environment in the form of goods and services (Daily, 1997). Many ecosystem services are derived from freshwater and are commonly referred to as hydrological ecosystem services. These benefits are often regulated by terrestrial ecosystems and include provisioning services such as water supply for drinking, power production, industrial use and irrigation (Brauman et al., 2007), as well as regulating services such as water purification and erosion control (de Groot et al., 2010).

The provision of hydrological ecosystem services is strongly dependent on watershed characteristics. Topography, land use/land cover (LULC), and climate have governing roles on the delivery of services (Brauman et al., 2007). Climate is one of the major shaping factors in semi-arid basins, which present larger extremes than more humid areas. In semi-arid basins, climate is characterized by: (1) low annual precipitation but high intensity storms with significant spatial variability, (2) high potential evaporation, (3) low annual runoff with short-term high volume runoff, and (4) runoff losses in ephemeral channels (Branson et al., 1981). Both average conditions for normal and extreme years are important indicators of the hydrological regime in semi-arid regions, and therefore, both need to be considered when assessing services at the basin scale.

Climate change is expected to intensify the hydrological cycle in semi-arid areas through the global increase in temperature, the concentration of rainfall in shorter periods of the year, and the more extended droughts (Hisdal et al., 2001). The Mediterranean region has been globally identified as one of the most vulnerable to global change (Schröter et al., 2005). Different potential impacts are projected for the region, including increased temperatures and reduced vegetation. Associated human impacts through changes in ecosystem services could include drinking water shortages, increased risk of forest fires, shifts in the distribution of species, and agricultural losses among others (Schröter et al., 2005).

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Mapping of ecosystem services has been a major topic at the regional to global scale (Eigenbrod et al., 2010), and often has been based on proxy-based maps (Costanza et al., 1997; Chan et al., 2006; Nelson et al., 2009). Several studies have assessed the effects of human changes on LULC, but less have focused on the impact of climate conditions in extreme years (Schröter et al., 2005; Metzger et al., 2008). There are some examples of the effects of extreme wet and dry years on water availability in areas of high water demand (Booker, 1995; Guo et al., 2000; Delpla et al., 2009). However, these effects are poorly understood in heavily humanized systems. Even in watersheds receiving large human pressures we can identify areas that deserve a higher protection since they are naturally providing ecosystem services that otherwise would need to be obtained artificially. Understanding how average climate conditions in extreme years affect these areas is essential to sustain a particular level of services' delivery in the context of climate change. However, it is important to keep in mind that future extreme years for the Mediterranean area under global change could look nothing like the recent extremes assessed here. The ability of ecosystems to mediate hydrologic response to climate extremes is unclear yet, potentially important, and likely not linearly related to the delivery of hydrological services under average climate conditions in normal years.

In this paper we assess the effects of recently observed extreme wet and dry years on the delivery of hydrological ecosystem services in a Mediterranean basin. Any disturbance to the hydrological regime is expected to impact annual water availability as well as nutrient and sediment dynamics in the basin. The Llobregat basin (Catalonia, NE Spain), an area of 4950 km^2, is typical of semi-arid conditions and constitutes an example of a highly populated, highly impacted and severely exploited area in the Mediterranean region. We apply a spatially explicit modeling tool to evaluate the delivery of three ecosystem services, one provisioning (water), and two regulating (erosion control and water purification), in the basin. These are essential services in semi-arid areas, where water scarcity can constrain water-reliant activities. In the Llobregat basin, water scarcity is exacerbated by its extractive use for industry, human consumption, and agriculture. These activities contribute to the degradation of water quality (Sabater et al., 1987; Terrado et al., 2009; López-Doval et al., 2010). Erosion is also a major concern in many semi-arid areas worldwide, and is expected to increase under increasing land-use changes and flood frequency. In this study, we are interested in determining which parts of the basin would be the most impacted by the effect of average climate conditions in extreme years. We expect some of the assessed benefits to largely decrease under water scarcity, in particular those related to water provisioning.

2. Materials and methods

2.1. Study site

The Llobregat basin (Catalonia, NE Spain) covers an area of 4950 km^2 (Fig. 1). The river, which is 156.5 km long, has its headwaters in the Pyrenees mountains and flows southward into the Mediterranean Sea near the city of Barcelona. It is the main water

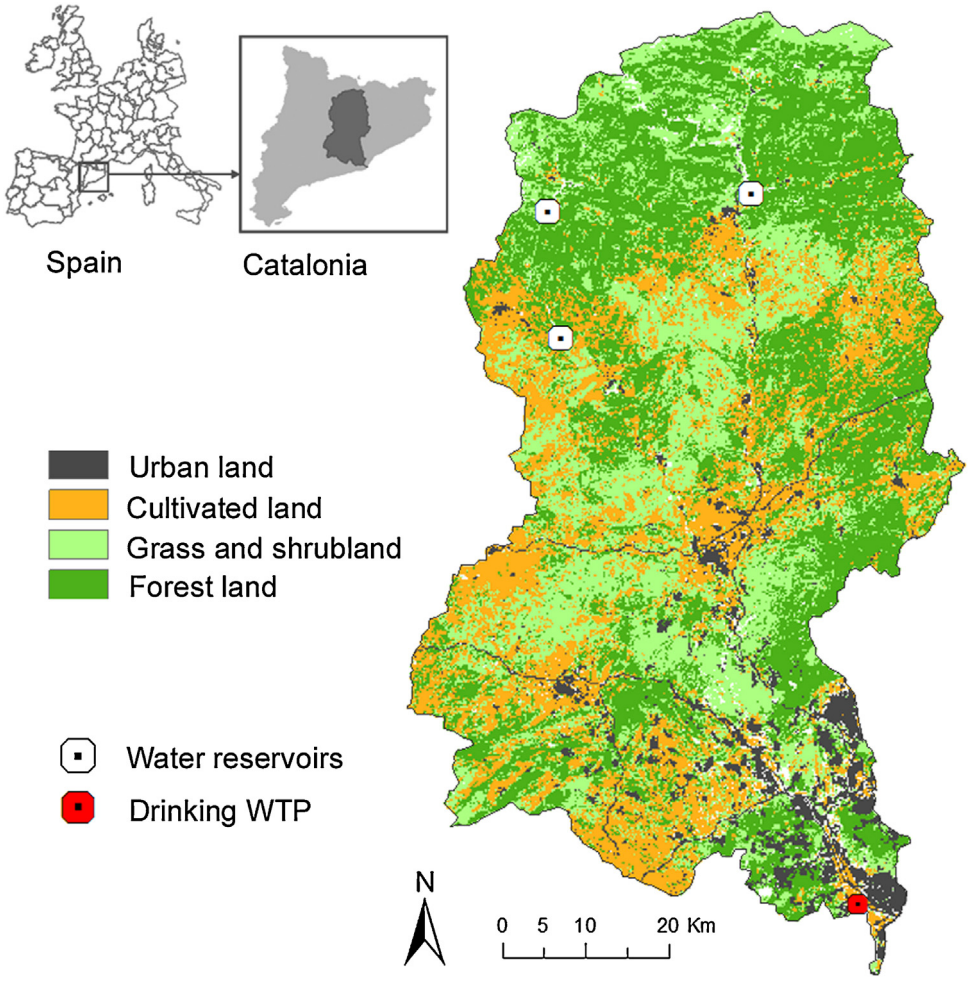

Fig. 1. Overview map and land use land cover of the Llobregat basin.