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Riparian responses to extreme climate and land-use change scenarios

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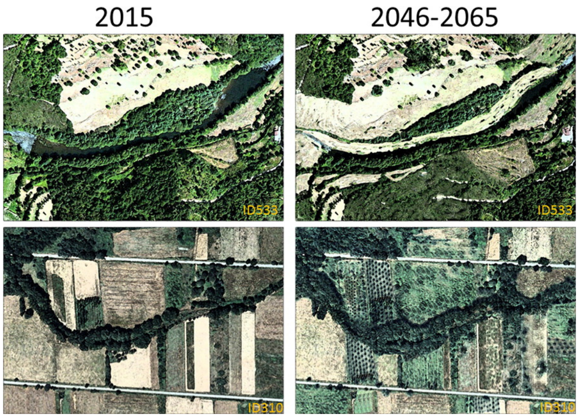
HIGHLIGHTS

- Riparian projections were driven differently by hydrological and land-use changes
- Drastic water scarcity will promote riparian narrowing
- Severe floods and droughts will differently affect the riparian functionality
- Future land-use occupation may benefit the riparian connectivity and complexity

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change will induce alterations in the hydrological and landscape patterns with effects on riparian ecotones. In this study we assess the combined effect of an extreme climate and land-use change scenario on riparian woody structure and how this will translate into a future risk of riparian functionality loss. The study was conducted in the Tâmega catchment of the Douro basin. Boosted Regression Trees (BRTs) were used to model two riparian landscape indicators related with the degree of connectivity (Mean Width) and complexity (Area Weighted Mean Patch Fractal Dimension). Riparian data were extracted by planimetric analysis of high spatial-resolution Word Imagery Layer (ESRI). Hydrological, climatic and land-use variables were obtained from available datasets and generated with process-based modeling using current climate data (2008–2014), while also considering the high-end RCP8.5 climate-change and "Icarus" socio-economic scenarios for the 2046–2065 time slice. Our results show that hydrological and land-use changes strongly influence future projections of riparian connectivity and complexity, albeit to diverse degrees and with differing effects. A harsh reduction in average flows may impair riparian zones while an increase in extreme rain events may benefit connectivity by promoting hydrologic dynamics with the surrounding floodplains. The expected increase in broad-leaved woodlands and mixed forests may enhance the riparian galleries by reducing the agricultural pressure on the area in the vicinity of the river. According to our results, 63% of river segments in the Tâmega basin exhibited a moderate risk of functionality loss, 16% a high risk, and 21% no risk. Weaknesses and strengths of the method are highlighted and results are discussed based on a resilience perspective with regard to riparian ecosystems.

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1. Introduction

Despite the consensual worldwide appeal for a reduction in CO_2 emissions, the projections of the United Nations Framework Convention on Climate Change (UNFCCC), which are based on current emission trends, show that extreme climate change scenarios are increasingly plausible. Unless drastic CO_2 emission-cutting measures are taken immediately, the so-called high-end or extreme scenarios, developed on the assumption of exceptional global warming (global average above 2 °C), will represent the most likely temperature and precipitation patterns for the 21st century (Beniston, 2007). However, despite this new reality, few studies have addressed the impacts and vulnerabilities of ecosystems on/to such extreme climate changes (but see IMPRESSIONS, http://www.impressions-project.eu/, RISES-AM, http://www.risesam.eu/ and HELIX, http://www.tyndall.ac.uk/HELIX).

Climate change will also affect human activities, and the associated socioeconomic drivers will generate profound landscape changes (Purkey et al., 2008; Alcamo et al., 2007), but there is limited experience with land-use modeling under future climate scenarios, compared to emission or energy scenarios. This is particularly evident given the scarceness of spatially explicit projections for the land-use component at global and regional scales. The latest IPCC report referred to the major vulnerability of the agricultural and forestry sectors in the Iberian Peninsula to climate-change (Kovats et al., 2014). In particular, the expected reduction in precipitation will reduce suitability for rainfed agricultural production and augment water demand for crop irrigation (IPCC, 2014). However, increased irrigation may not be feasible because of projected declines in total runoff and groundwater recharge (Rounsevell et al., 2005, 2006; Olesen et al., 2011). This combination is likely to reduce the more water-demanding land-uses, especially intensive agricultural ones (IPCC, 2014). Shifts in forest species distributions, changes in growth rates and phenology, and increased fire and storm damage are also among the probable responses of forests to climate change (Affolter et al., 2010).

Riparian forests are crucial ecosystems in drought and scarcity situations, since they are responsible for numerous processes that influence water quantity and quality. Among the diverse ecosystem services and functions provided by these ecotones, the regulation of river discharges, the filtering of runoff sediments and pollutants from agricultural areas and the regulation of groundwater dynamics are considered critical to an efficient and integrated water resource management (Malanson, 1993; Naiman et al., 2005). Because they represent the interface between freshwater and terrestrial systems, they are highly vulnerable and responsive to climate-change-induced flow regimes and land-use alterations (Camporeale and Ridolfi, 2006; Hoffman and Rohde, 2011; Dufour et al., 2015; Flanagan et al., 2015). Most of the knowledge about the effects of climate-change on these ecosystems comes from the physiological and phenological responses of specific riparian species used as surrogates to assess the systems' vulnerability to climate-driven changes (Rood et al., 2003; Perry et al., 2012; Stromberg, 2001; Stromberg et al., 2010; Singer et al., 2012; Rodríguez-González et al., 2014). More recent research used dynamic hydro-vegetation models to describe the evolution of riparian woodlands and flow relationships with vegetation stages facing climate change (e.g. Rivaes et al., 2013, 2014), and to explore the future distribution of species' functional traits in different climate change scenarios (Catford et al., 2012; Rocha et al., 2015). Nevertheless, most studies rely on the single-hydrological perspective, and particularly lack the well documented influence of land-use change on the establishment of riparian structural and compositional patterns (Allan, 2004; Aguiar and Ferreira, 2005; Burton et al., 2005; Hooke, 2006; Fernandes et al., 2011). Recently, Aguiar et al. (2016) have supported the awareness that riparian changes are driven by both land-use and hydrological changes, although the authors found it difficult to disentangle the diverse sources of variation. A growing number of authors have emphasized the importance of combining multiple co-occurring stressors in order to produce a reliable response to climate-change by freshwater communities (Delpa and Rodrigues, 2014; Mantyka-Pringle et al., 2014; Santos et al., 2015). Additionally, the majority of studies concerning the impact of hydrological and land-use changes on the riparian vegetation structure have focused on a local-scale analysis. Efficient modelling tools using a multi-stressor approach developed at a basin-scale are thus needed in order to improve the efficiency of decision-making regarding the water scarcity issue.

Ecological riparian functionality, defined as the capacity of riparian ecotones to provide ecosystem functions, goods and services, is sustained by two main structural and compositional characteristics: connectivity, and complexity (Malanson, 1993; Capon et al., 2013). High lateral and longitudinal connectivity enables and regulates changes in materials, energy and biota, while high compositional heterogeneity supports the provision of habitat functions. Planimetric image analyses, derived from automated remote-sensing delimitations or visual interpretations, are alternative methods for characterizing riparian structural and compositional attributes, supported by the premise that spatial arrangements regulate ecological processes (Schuft et al., 1999; Apan et al., 2002; Johansen and Phinn, 2006; Yang, 2007). Among the distinct landscape descriptors with the ability to characterize vegetation structure, lateral width is considered a proxy for fragmentation and connectivity patterns, and has been successfully used for riparian modelling purposes in a large-scale analysis (Abood et al., 2012; Clerici et al., 2013). On the other hand, landscape metrics related with spatial form and shape complexity have also been related with compositional characteristics, especially floristic diversity and species richness (Moser et al., 2002), and with the presence of exotic species or monotypic compositional galleries (Fernandes et al., 2011).

Based on these assumptions, the main objective of this study is to assess riparian responses under an extreme climate and land-use change scenario, using two landscape indicators expressing riparian connectivity (riparian Mean Width) and riparian patch shape complexity (Area Weighted Mean Patch Fractal Dimension - AWMPFD). We additionally sought to combine the individual trajectories of the two riparian indicators into a single and spatially explicit measure of the risk of the riparian functionality loss, for the 2046–2065 time slice. Mean Width and AWMPFD indicators were used as proxies for the provision of the ecosystem services and functions related with water quantity and quality. Boosted Regression Trees (BRTs) were used to calibrate the empirical models and assess the relative importance of climatic, hydrological and land-use alterations in the riparian shifts under the high-end scenarios. Since there is a substantial risk that future climate change might be more extreme than the expected outcome under most scenarios, here we predict riparian response under the worst case scenario. By using the outcome of the upper frontiers of change as the basis to mitigation and adaptation we are ensuring that decision-making will potentially be more capable of coping with a wider range of scenario of change.

2. Methods

2.1. Study area

The study was conducted in the Tâmega catchment of the Iberian Douro basin, located in northern Portugal (Fig. 1), in a temperate oceanic sub-Mediterranean region (Ninyerola et al., 2005). The climate is characterized by an average monthly temperature of between 12 °C and 17.5 °C and an average precipitation of between 700 and 1300 $mm \cdot yr^{-1}$(Ninyerola et al., 2005). According to the National Water Information System (SNIRH), the pluvial hydrological regime of Tâmega river has a period of maximum precipitation occurring during December and January (monthly average of 170 mm) and a period of minimum precipitation during July and August (monthly average of 15 mm) (Amarante meteorological station, data series 1980–2016; available at: http://snirh.pt/). The Tâmega basin drains an area of 3316 km^2 and has an average annual flow of 70.31 m^3/s (INAG, 2010)