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Research article

Long-term monitoring for conservation management: Lessons from a case study integrating remote sensing and field approaches in floodplain forests

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ABSTRACT

Implementing long-term monitoring programs that effectively inform conservation plans is a top priority in environmental management. In floodplain forests, historical pressures interplay with the complex multiscale dynamics of fluvial systems and require integrative approaches to pinpoint drivers for their deterioration and ecosystem services loss. Combining a conceptual framework such as the Driver-Pressure-State-Impact-Response (DPSIR) with the development of valid biological indicators can contribute to the analysis of the driving forces and their effects on the ecosystem in order to formulate coordinated conservation measures. In the present study, we evaluate the initial results of a decade (2004–2014) of floodplain forest monitoring. We adopted the DPSIR framework to summarize the main drivers in land use and environmental change, analyzed the effects on biological indicators of foundation trees and compared the consistency of the main drivers and their effects at two spatial scales. The monitoring program was conducted in one of the largest and best preserved floodplain forests in SW Europe located within Doñana National Park (Spain) which is dominated by *Salix atrocinerea* and *Fraxinus angustifolia*. The program combined field (*in situ*) surveys on a network of permanent plots with several remote sensing sources. The accuracy obtained in spectral classifications allowed shifts in species cover across the whole forest to be detected and assessed. However, remote sensing did not reflect the ecological status of forest populations. The field survey revealed a general decline in *Salix* populations, especially in the first five years of sampling –a factor probably associated with a lag effect from past human impact on the hydrology of the catchment and recent extreme climatic episodes (drought). In spite of much reduced seed regeneration, a resprouting strategy allows long-lived *Salix* individuals to persist in complex spatial dynamics. This suggests the beginning of a recovery resulting from recent coordinated societal responses to control excessive water extraction in the catchment, highlighting the need for continuing long-term monitoring. The DPSIR framework proved useful as a conceptual tool in analyzing the entire environmental system, while both field and remote sensing approaches complemented each other in quantifying indicator trends, improving the monitoring design and informing conservation plans.

1. Introduction

Multiple pressures threaten biodiversity worldwide and alterations in floodplains are expected from the interaction of global change and escalating water use, particularly in water deficit areas (Vörösmarty et al., 2010). In the Mediterranean region, floodplain forests are resource-rich habitats that support a wide range of ecosystem functions and services which extend far beyond the area they occupy (Stella et al., 2013). Floodplain forests provide ecosystem services, such as those related to water quality, microclimate, wildlife habitats, an energy base for the food web and flood

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mitigation (MEA, 2005). In spite of their importance, floodplain forests have shrunk significantly due to human impacts at the local and the catchment scale. They are therefore a top-priority target for conservation, management and restoration (Stella et al., 2013). In Europe, the assessment and restoration of degraded riparian areas has become mandatory within the Water Framework Directive and the Biodiversity Strategy to 2020 in the context of the Aichi targets (González del Tánago et al., 2012).

Reliable conservation and restoration of floodplain forests require coordinated actions to reduce the pressures that degrade their status but also to assess ecosystem effects through an adaptive management approach that enhances their resilience to human induced changes (White and Stromberg, 2011; Sanders and Kirschbaum, 2015). Long-term monitoring of riparian plant communities is critical in this respect, not only in order to track biological responses to multiscale anthropic and environmental changes, but also to identify early warning signals of prospective changes in ecosystem functions and services (Cardinale et al., 2012; Ström et al., 2012). A long-term floodplain forest monitoring program is a valuable means of assessing drivers and the effects of pressures, where subtle changes would otherwise remain undetected; it provides scientifically valid information and makes projections about future structure and composition. It is therefore an important tool in adaptive management (Sanders and Kirschbaum, 2015).

Implementing an effective long-term monitoring program of floodplain forest changes is challenging and these type of studies are scarce (but see Nguyen et al., 2015; Sanders and Kirschbaum, 2015). Firstly, this is because a long-term monitoring program is highly resource-demanding. In addition, there is a significant complexity inherent to the dynamics of floodplain systems which integrate multiple spatial (catchment, segment, reach) and temporal scales of variation (Dufour and Piégay, 2009); and finally, it is difficult to document the long-term consequences of changes such as land use and climate change and to pinpoint environmental drivers of deterioration (Nguyen et al., 2015). In order to achieve this, establishing an integrative conceptual framework, such as the drivers–pressures–states–impacts–responses (DPSIR) approach (EEA, 2005), might help to draw links between environmental and anthropogenic drivers on biotic elements, so that more effective conservation strategies can be defined. In a long-term monitoring program, this general framework can be used to evaluate the effects of driving forces and their associated pressures on the state of the environment and their impact on ecosystem functions, as well as to evaluate the effects of societal responses taken during the monitoring period (Haberl et al., 2009).

In addition, the proper choice of reliable, well validated biological indicators (Gumiero et al., 2015) in the design and improvement of monitoring programs is a top-priority goal in conservation management if we are to adequately assess the impact of environment changes on species and subsequently respond with adaptive actions (Haberl et al., 2009). Foundation species (Dayton, 1972) provide a suitable opportunity for such an approach due to their tight relationship with the habitat and their influence on other species in the ecosystem (Corenblit et al., 2011). Foundation riparian trees, such as Salicaceae, interact with environmental change by modulating fluvial system processes (flow velocity, sediment deposition) and consequently affect the physical habitat of other species (Karrenberg et al., 2002). As such, different foundation tree canopies often correspond to different understory communities. Monitoring them is highly worthwhile in order to be able to track alterations liable to have an effect at the community and ecosystem level (Ellison et al., 2005). The use of foundation species as an indicator provides an insight into key ecosystem processes, and allows for management based on information obtained by monitoring these processes.

This study documents the first decade of results from a long term monitoring program in the floodplain forests of Doñana National Park. The main goals of the present study are: 1) to summarize the main drivers and pressures affecting the Doñana floodplain forests within a DPSIR framework; 2) to set up a baseline trend of the dominance, abundance and health (i.e. balanced population structure) of foundation trees to use in the analysis of the environment impact of water availability and pressures from catchment land uses; 3) to test the consistency of trends in foundation trees across indicators analyzed through two monitoring approaches based on remote sensing and field sampling, respectively; and, 4) to assess the utility of the monitoring program for conservation management within a DPSIR framework. We hypothesized that 1) the recent historical (last 20 years) withdrawals of superficial and phreatic water in the La Rocina stream catchment have led to a quantifiable compositional and structural change in foundation tree indicators given the different water requirements of the dominant species and 2) the changes registered at a local scale with field indicators should correspond with dominance shifts in foundation species at the landscape scale by remote sensing imagery analysis.

2. Materials and methods

2.1. Study site description

The Doñana marshes are one of the largest protected wetlands in Europe with an area of 340 km^2, of which 300 km^2 are included in Doñana National Park (Morris et al., 2013; Díaz-Delgado et al., 2010; García Novo et al., 2006). With a typical Mediterranean climate, the flooding cycle starts in September and usually reaches peak levels during the end of boreal winter subject to rainfall variability. The dominant clay and silt substrates of the Doñana marshes are soaked with the first showers and a shallow water layer spreads over the floodable area (Fig. 1). The tributary river network streams into the marshes maintaining water levels as runoff flows in the catchments. Mediterranean water courses vary dramatically during the cycle either causing fast and intense floods or remaining completely dry for long periods.

La Rocina feeds the Doñana marshes from the west collecting runoff and groundwater across 400 km^2 of a sandy catchment. Average annual water discharge from La Rocina to the marshes is about 40 hm^3 (Manzano et al., 2005). While marshes are included in the Doñana National Park, La Rocina and a surrounding 500 m buffer have a minor protection status, limited to the downstream 12 km of its total 19 km length. The floodplain forest canopy is mainly dominated by *Fraxinus angustifolia* Vahl. and *Salix atrocinerea* Brot., with open flooded areas being more abundant as the stream approaches the marshes. Within the forest, each species is generally dominant at opposite positions along a gradient of hydroperiod and flooding frequency: *Salix* is dominant in more flooded areas and *Fraxinus* in the transition to upland vegetation. This stand represents the largest area of a well-preserved Ibero-Atlantic floodplain forest with a Mediterranean climate (Rodríguez-González et al., 2008). Several endemic and threatened species are found in the La Rocina wetland forest. These include *Frangula alnus* Mill. subsp. *baetica* (Willk. & É. Rev.) Rivas Goday, *Rorippa valdes-bermejoi* (Castrov.) Mart.-Laborde Castrov, *Utricularia exoleta* R. Br., *Mycropyropsis tuberosa* Romero Zarco y Cabezudo, and *Carex elata* subsp. *tartessiana* Luceño & Aedo.

Following the establishment of the Doñana National Park in 1969, intensive agriculture progressively developed in the surrounding countryside (Haberl et al., 2009) with intensive farming of greenhouse crops irrigated with water pumped from Doñana's

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