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Effects of riverine landscape changes on pollination services: A case study on the River Minho, Portugal

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ABSTRACT

Riverine landscapes provide numerous ecosystem services, of which pollination is essential to increase the yield, quality, and stability of crops and the biodiversity of wild flora. Pollinators' behaviour and their community dynamics are often affected by the spatial distribution of floral and nesting resources at the landscape scale, and are thus sensitive to land-use land-cover (LULC) changes and management practices.

The main objective of this study is to understand how changes in riparian vegetation and LULC at River Minho affect pollination services. For this, an approach based on the temporal analysis of historical cartography (1898) and current satellite imagery (2016) was used. We developed a novel Pollination Suitability Index for Riverine Landscapes (PSIRL) using LULC data as a proxy of habitat suitability for insect pollinators. PSIRL scores were derived from expert judgment of the local habitat conditions, floral diversity and field surveys. The PSIRL values obtained for both periods were compared using pairwise T-tests.

We detected an overall reduction of the pollination services in the riverine landscape of River Minho from 1898 to 2016. However, at local level we observed gains and losses of pollination suitability as a result of distinct LULC changes. There was a marked decrease in the PSIRL in the most downstream and upstream riverine sections due to generalized conversion of scrublands, broadleaved-forests and heterogeneous agricultural areas to artificial surfaces and managed forests dominated by maritime pine and eucalyptus. However, in the middle section of the river, the area occupied by scrublands, riparian and broadleaved forests increased, resulting in an increase of the foraging resources for insects, and a consequent increase of the PSIRL.

This index can be used to monitor and capture changes in the pollination suitability of complex riverine landscapes and support further land and river management decisions. The historical cartography proved to be a valuable source of information to characterize LULC change and hence to assess the evolutionary trajectory of pollination ecosystem services, at global and local level.

1. Introduction

Pollination is an essential ecosystem service that increases the yield, quality, and stability of 75% of globally important crops (Klein et al., 2007) and safeguards the conservation of wild plant populations (Potts et al., 2010).

Social bees (Hymenoptera: Apidae) are generally regarded as the most important insect pollinators. In particular, the European honeybee (*Apis mellifera* L.) is considered responsible for 80% of the global agricultural pollination services (Carreck and Williams, 1998). Recently, the dominance of honeybees in providing crop pollination services has been questioned (Breeze et al., 2011; Rader et al., 2016). In fact, several studies have shown that wild pollinators such as the solitary bees, hoverflies, bee flies, butterflies, moths, some beetles and some wasps also provide important pollination services (e.g. Garibaldi et al., 2013; Rader et al., 2016). Their individual behaviour, population biology, and community dynamics are affected by the spatial distribution of floral resources at the landscape scale (Kremen et al., 2007). A widespread concern about the health of ecosystems in Europe brought attention to the vulnerability of pollinator species (Potts et al., 2010; Breeze et al., 2014). Several European countries are presently vulnerable to pollination declines. For example, in the UK, during the last 50 years there has been considerable reduction in the diversity and distribution of wild bees, butterflies and hoverflies (Thomas et al., 2004; Biesmeijer et al., 2006; Carvell et al., 2006). The intensification of agricultural and urban land-use and the consequent loss and fragmentation of natural habitats

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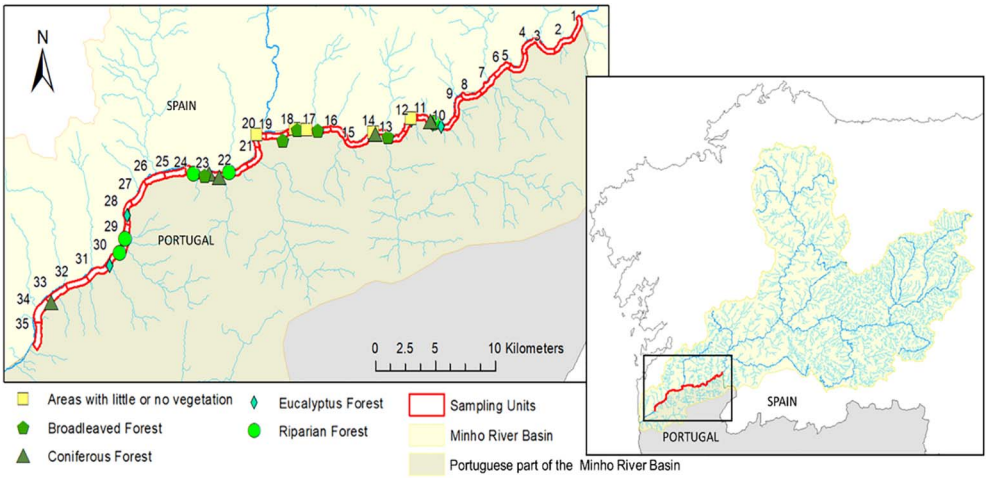

Fig. 1. Right frame: Geographical location of River Minho basin and river network. Left frame: Geographical location of the studied river section, image sampling units (red boxes) and insect pollinators' field sites (colored circles according to land-use class). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

have been point out as the main source for this widespread decline of insect pollinators (Verboven et al., 2014; Cole et al., 2017). In particular, changes in landscape plant composition (floral diversity and abundance) play a significant role in the abundance, diversity, and community composition of insect pollinators (DeFries et al., 2004; Potts et al., 2006; Bennett and Isaacs, 2014). Thus, measures of pollination services can be attained by assessing the value of landscapes via the availability of forage resources (nectar and pollen) required for supporting the pollinator communities.

Semi-natural habitats, such as riparian buffer strips, road verges (Cole et al., 2015; 2017), and hedgerows (Hannon and Sisk, 2009) provide resources for insect pollinators and are particularly relevant in agriculture-dominated landscapes (Garibaldi et al., 2011; Kennedy et al., 2013; Munyuli et al., 2013).

Riparian forests are complex ecosystems characterized by a high diversity and abundance of plant species (Naiman et al., 1993; Sabo et al., 2005; Corenblit et al., 2007). Riparian vegetated areas and wetlands support more pollinator's species richness and diversity than dry adjacent lands, especially those dominated by monoculture (Ricketts, 2004; Cunningham et al., 2012; Munyuli et al., 2013; Kuglerova et al., 2014). Complex floral-bee interactions have been observed in riparian habitats and were found to be related to the high variability and seasonal availability of floral and nesting resources (Williams and Kremen, 2007; Williams, 2011; Cole et al., 2015; 2017). Spatial attributes of riverine zones, such as connectivity, i.e., the degree to which the landscape facilitates or impedes movement among resource patches (Taylor et al. 1993) and geomorphological diversity, (i.e., the presence of islands and sand bars in the fluvial system) (Exeler et al., 2009) are also considered critical to support pollinator populations. These spatial attributes can improve pollinators movements and operate from local to entire landscape scale (Williams and Kremen, 2007). However, as far as we know there are no studies that simultaneously determine the relative contribution of different habitats nearby fluvial areas to the provision of foraging resources for pollinators, or that explores their changes over time. Research at large temporal and spatial scales is also critical to understand the processes driving pollinator populations at the landscape scale.

Across Europe, riverine areas have been heavily impacted by human intervention, due to continuous land-use and land cover (LULC) changes that have resulted in the generalized degradation of riparian ecosystems (Gumiero et al., 2013). However, the changes in ecosystem services may result not only from LULC intensification but also from land abandonment (Schneiders et al., 2012). In Portugal, reductions in intensive agricultural land-use and its conversion to forests and scrublands have been related to the recovery of riparian areas, due to fewer interventions in vegetated riverine habitats (Aguiar et al., 2016).

Image-based methods using satellite imagery, aerial photography or derived thematic maps are usually used to assess LULC changes. However, these methods are limited in the time-window where the analysis can be performed. Historical cartography can provide an alternative source of data to characterize the landscape history (Skalos and Engstová, 2010). When combined with contemporary remote-sensed data, it enables the assessment of LULC trends and related ecosystem services availability change over time (Burgi et al., 2015; Frélichová and Fanta, 2015).

In this study, we hypothesize that LULC changes in the riverine areas of River Minho affect, either positively or negatively, the habitat suitability for insect pollinators. Additionally, we questioned how local landscape alterations near fluvial corridors will affect broad-scale pollination services.

We used cartographic historical data from 1898 for the River Minho, allowing us to assess historical changes in LULC over more than 100 years. We compared past LULC from the 19th century with contemporary LULC retrieved from Soil Occupation Map for Portugal 2007 (COS 2007) and ESRI World Imagery map. We then related the changes in LULC in a riverine landscape with habitat suitability for insect pollinators. For this assessment, so-called 'Pollination suitability indices' are increasingly being used. There are several indices available in the literature, however they were developed for broad-scale assessments (e.g. Burkhard et al., 2009; Zulian et al., 2013; Vogiatzakis et al., 2015), or particular landscapes, such as agro-ecosystems (e.g. Kennedy et al., 2013) and arid environments (Zoccali et al., 2017). To our knowledge, there are no pollination suitability indices available for riverine areas. We developed a Pollination Suitability Index for Riverine Landscapes (PSIRL) derived from expert judgment based on the local habitat conditions, floral diversity and field monitoring. This index can be used to monitor and capture changes over time in the pollination suitability of complex riverine landscapes and support further land and river management decisions.

2. Materials and methods

2.1. Study area

The study was conducted in the Portuguese part of River Minho, a Northern Iberian river that borders Spain and Portugal (Fig. 1). The study area comprises 67 km along the river, in a 300 m buffer including the riparian zone and adjacent lands. The region has a temperate oceanic sub-Mediterranean climate influenced by the Atlantic Ocean and is characterized by mild temperatures (12–17.5 °C) and an average precipitation between 700 and 1300 mm/year (Ninyerola et al., 2005).

The floodplains are occupied by a complex land use matrix dominated by small-scale agriculture, orchards, vineyards and scrublands, and in nutrient-poor soils by forests of maritime pine (*Pinus pinaster*