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Quantifying the contribution of riparian soils to the provision of ecosystem services

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HIGHLIGHTS

- Habitat type is the main driver explaining riparian soil physicochemical variability.
- Riparian areas do not necessarily deliver greater ecosystem services.
- LiDAR data can support the identification of key areas to target to increase riparian shade.
- Riparian function can be largely predicted from neighbouring land use/soil type.

GRAPHICAL ABSTRACT

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ABSTRACT

Riparian areas, the interface between land and freshwater ecosystems, are considered to play a pivotal role in the supply of regulating, provisioning, cultural and supporting services. Most previous studies, however, have tended to focus on intensive agricultural systems and only on a single ecosystem function. Here, we present the first study which attempts to assess a wide range of ecological processes involved in the provision of the ecosystem service of water quality regulation across a diverse range of riparian typologies. Specifically, we focus on 1) evaluating the spatial variation in riparian soils properties with respect to distance with the river and soil depth in contrasting habitat types; 2) gaining further insights into the underlying mechanisms of pollutant removal (i.e. pesticide sorption/degradation, denitrification, etc.) by riparian soils; and 3) quantify and evaluate how riparian vegetation across different habitat types contribute to the provision of watercourse shading. All the habitats were present within a single large catchment and included: (i) improved grassland, (ii) unimproved (semi-natural) grassland, (iii) broadleaf woodland, (iv) coniferous woodland, and (iv) mountain, heath and bog. Taking all the data together, the riparian soils could be statistically separated by habitat type, providing evidence that they deliver ecosystem services to differing extents. Overall, however, our findings seem to contradict the general assumption that soils in riparian area are different from neighbouring (non-riparian) areas and that they possess extra functionality in terms of ecosystem service provision. Watercourse shading was highly habitat specific and was maximal in forests (ca. 52% shade cover) in comparison to the other habitat types (7–17%). Our data suggest that the functioning of riparian areas in less intensive agricultural areas, such as those studied here, may be broadly predicted from the surrounding land use, however, further research is required to critically test this across a wider range of ecosystems.

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1. Introduction

Ecosystem service-based approaches have been increasingly used to reduce pressure on natural resources and implement better land-management practices with respect to the environment (Van Looy et al., 2017). Riparian areas, the interface between land and freshwater ecosystems, are considered to play a pivotal role in the supply of regulating, provisioning, cultural and supporting services (Jones et al., 2010; Clerici et al., 2011; Aguiar et al., 2015). However, despite the fact that the number of studies referring to ecosystem services has increased by 38% in Europe over the last 20 years (Adhikari and Hartemink, 2016), riparian zones have received less attention than other land use types from an ecosystem services perspective. The few publications which have integrated an ecosystem service approach to the assessment of riparian areas have tended to address this from a modelling perspective (Clerici et al., 2014; Tomscha et al., 2017; Sharps et al., 2017). McVittie et al. (2015) proposed a model which aims to outline the fundamental ecological processes that deliver ecosystem services within riparian areas. Models provide a powerful and cost-effective tool to assess and map ecosystem services at the landscape scale; however, they do not always provide a mechanistic process-level understanding. It is therefore important that models are supported and developed with robust underpinning data to correctly identify and describe the main factors affecting ecosystem services delivery within complex landscapes (i.e. those which may contain a diverse array of different riparian typologies). Little is known, however, about how inherent riparian properties and ecosystem functioning vary across different habitats within a catchment area (Burkhard et al., 2009). This uncertainty is largely due to the majority of riparian studies being focused on single sites, typically intensive agricultural systems (i.e. arable and grasslands) as these represent a major source of pollution (e.g. from fertilizers, livestock and pesticides) and because riparian zones associated with agriculture present pollution mitigation potential (Pierson et al., 2001; Rasmussen et al., 2011; Broetto et al., 2017). However, these studies tend to overlook the fact that riparian areas are interrelated systems and therefore changes (both natural and anthropogenic) occurring in headwater riparian zones across different habitat types could also affect riparian processes occurring downstream (Harper and Everard, 1998; Charron et al., 2008).

Among the many ecosystem services attributed to riparian areas, their role in water quality enhancement has grown in recognition over the years. Water quality has become a universal problem (Stephenson and Pollard, 2008) and is nowadays considered a priority objective for EU environmental sustainability (EEA, 2012). Increased loss of phosphorus (P) and nitrate (NO_3^-) from agricultural fertilizers has led to extensive eutrophication of surface and groundwaters (EEA, 2005), and contamination by pesticides and biological contaminants (e.g. bacteria) are regularly reported (Klapproth and Johnson, 2009; Troiano et al., 2001). Riparian areas are frequently proposed as a management strategy to reduce freshwater nutrient pollution (e.g. Coyne et al., 1995; O'Donnell and Jones, 2006; Stutter et al., 2009; Aguiar et al., 2015; Sgouridis and Ullah, 2015) and could also reduce the cost of drinking water purification (Klapproth and Johnson, 2009; Meador and Goldstein, 2003; Chase et al., 2016). This pollution mitigation potential is often attributed to specific characteristics within riparian soils (Mikkelsen and Vesho, 2000; Naiman et al., 2010). Table 1 summarizes the link between riparian soil properties and the provision of ecosystem services found in the literature. A better understanding of the causal factors for ecosystem services delivery will provide an improved knowledge base on which to make land management decisions and protection policies.

Many regulating services are highly affected by environmental conditions. For example, temperature is known to directly and indirectly affect biological activity through its impact on gaseous concentrations in soil (e.g. CO_2/O_2) and in the water column (Beschta, 1997; Verberk et al., 2016). It also plays an important role in determining the rate of key ecosystem processes such as denitrification (Bonnett et al., 2013). Riparian buffers have increasingly been used as a eutrophication mitigation tool by temperature regulation through provision of shade (Nisbet and Broadmeadow, 2004; Burrell et al., 2014; Johnson and Wilby, 2015). Ghermandi et al. (2009) suggested that shading could viably be used as a management option to improve water quality conditions in small and moderately-sized watercourses. However, finding a cost-effective way to target vulnerable areas is challenging and has been poorly explored to date.

The main focus of this study is to assess the link between riparian areas and the regulating service of water purification through a wide range of ecological processes. In particular, we aim to: 1) evaluate the spatial variation in riparian soils properties (i.e. general nutrient status, soil acidity and conductivity, and microbial community size) with respect to distance with the river and soil depth in contrasting habitat types; 2) gain further insights into the underlying mechanisms of pollutant removal (i.e. pesticide sorption/degradation, denitrification, etc.) by riparian soils; and 3) quantify and evaluate how riparian vegetation across different habitat types contribute to the provision of shade. This could help identify areas especially vulnerable to excessive solar radiation and offer a cost-effective way to improve ecosystem service provision (Ghermandi et al., 2009; De Groot et al., 2012). We hypothesized that riparian areas would support a greater delivery of ecosystem services in comparison to the upslope area, but that the balance of these services would be land use specific within a catchment area.

Table 1
Summary of riparian soil characteristics and their associated provision of ecosystem services.

Ecosystem services	Causal factor	Resulting soil characteristics
Supporting services Soil formation Nutrient cycling **Regulating services** Water purification by reducing non-point source pollutants Flood and erosion regulation by slowing and spreading flood water	• Periodic sediment deposition together with flushes of organic litter during floods events • Large variation of soil chemical composition mainly due to filtration and nutrient removal from terrestrial upland and aquatic ecosystems	Heterogeneity (Mikkelsen and Vesho, 2000)
Supporting services Biodiversity **Regulating services** Carbon sequestration **Provisioning services** Shading by vegetation	• High vegetation density and diversity associated with higher moisture and organic matter content which leads to more microbial activity • Provide (roots, fallen logs) refuge for aquatic and terrestrial fauna	Biological diversity (Naiman et al., 2010)
Supporting services Soil formation **Regulating services** Carbon sequestration	• New material (organic matter fluxes and sediments) being deposited by flood events and water fluctuation • Regular inundation of soils by river water preventing horizon formation	Undeveloped soils (Zaimes et al., 2007)
Regulating services Water storage	• Their proximity with the river enhances water storage and infiltration	High moisture content (Lewis et al., 2003)
Regulating services Fast engineering resilience[a]	• Anthropogenic activities such as farming, water abstraction, livestock and deforestation • Frequent environmental disturbances such as floods or droughts	Disturbance driven (Klemas, 2014)

[a] Speed with which a system returns to equilibrium after a disturbance (Holling, 1996).