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Integrative conservation of riparian zones

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ABSTRACT

Riparian zones are the interface between aquatic and terrestrial systems along inland watercourses. They have a disproportionate ecological role in the landscape considering their narrow extent, which makes them a good example of small natural features (sensu Hunter, this issue). Characteristically, riparian zones increase species richness in the landscape and provide key services to society, such as soil fertility, water purification, and recreation. Despite the recognized importance of riparian zones for ecological, economic and social reasons, and the vast amount of scientific literature exploring measures for their conservation, current management is still failing at enabling a proper ecological functioning of these areas. The best practices for conservation of riparian zones have mostly focused on manipulating biotic and physical components (e.g. renaturalizing flow regimes, improving channel mobility, and controlling invasions of exotic ecosystem engineer species). However, these strategies face important technical, socio-economic, and legal constraints that require a more integrative approach for effective conservation. In this paper we summarize the main problems affecting riparian zones and their current management challenges. Following Hunter et al. (this issue), we review novel approaches to conservation of riparian zones, complementary to manipulating processes that reflect contemporary management and policy. These include (1) investing in environmental education for both local people and technical staff, (2) guaranteeing qualitative and long term inventories and monitoring, (3) establishing legislation and solutions to protect riparian zones, (4) framing economic activities in riparian zones under sustainable management, and (5) planning restoration of riparian zones at multiple and hierarchical spatio-temporal scales.

1. Introduction

Riparian zones are ecosystems created at the interface between terrestrial and freshwater habitats along flowing waters. They represent only a narrow portion of the landscape while contributing disproportionately to the biodiversity of the region as a whole (Sabo et al., 2005) and providing many ecosystem services ("Frodo effect", Primack and Sher, 2016), mainly due to the dynamic "edge effect" of the aquatic/terrestrial transition zone following flooding pulses (Junk et al., 1989). Therefore, riparian zones are small natural features (SNFs) with an ecological role extending beyond their area (Hunter, this issue). The conservation of riparian zones, as for many other SNFs, is acutely threatened by human activities. Flow regulation by dams, diversions and other infrastructures to reduce flood risk, and the conversion of riparian zones by agriculture, forestry, industrial and urban development are responsible for the deterioration and loss of riparian ecosystems worldwide (Hughes and Rood, 2003; Nilsson and Berggren, 2000). Up to 90% of North American and European floodplains, for example, are considered ecologically dysfunctional following human occupation (Schillinga et al., 2015; Tockner and Stanford, 2002). In Europe, the combined effect of conversion to agriculture and regulation has resulted in the disappearance of up to 88% of floodplain forests (Hughes and Rood, 2003).

Unlike other SNFs such as temporary streams (Acuña et al., this issue) or large old trees (Lindenmayer, this issue), conservation of riparian ecosystems has been the object of much research. Many studies have focused on how to manipulate riparian ecosystems to enable their conservation or restoration (e.g. renaturalization of flow regimes (Poff et al., 1997; Rood et al., 2003); restitution of channel migration

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(Rohde et al., 2005; Jähnig et al., 2009); and control of species invasions (Richardson et al., 2007; Stromberg, 2001). However, conservation strategies purely based on manipulating ecological processes face important technical–ecological, socio-economic, and legal constraints. First, after decades of impact, some rivers may have lost their capacity to positively respond to conservation actions (Cooper and Andersen, 2012; Johnson et al., 2015). Secondly, society may prioritize extractive uses and particular ecosystem services such as flood prevention or recreation over key ecological functions like wildlife habitat or nutrient filtering (Gumiero et al., 2013; Rohde et al., 2005). Thirdly, legislation may subordinate environmental goals to other interests. In Europe, for example, there are a number of socio-economic reasons (such as "overriding public interest" or "no other significantly better option") to be exempted from meeting the environmental objectives of the Water Framework Directive (European Commission, 2009). The conflict between different interests and directives usually leads to the adoption of uncoordinated measures in the management of riparian zones. For instance, in Italy, in order to save public money in flood risk prevention, private companies are allowed to remove vegetation from riparian zones for biomass production (WWF, 2016). However, this increases flood risk downstream and may generate dramatic effects on riparian wildlife (Anderson et al., 2006). Thus, conservation of riparian zones will not be possible if technical–ecological, socio-economic, and legal issues are not addressed holistically. Hunter et al. (this issue) have proposed a matrix of key conservation activities (educate, inventory, protect, sustainably manage, restore, and create) that may include incidental, voluntary, incentive, or restrictive approaches relevant to the conservation of SNFs, which we can apply to riparian zones.

The main goal of this paper is to identify and discuss conservation measures for riparian zones complementary to manipulation of biotic and physical processes that reflect management and policy directions. To achieve this goal, we (i) briefly introduce riparian zones (Section 2) and their ecological, economic, and social importance (Section 3), (ii) describe the main human impacts on riparian zones (Section 4) and current management challenges (Section 5), and, following Hunter et al. (this issue) (iii) review key measures for conserving riparian zones that will facilitate SNF conservation (Section 6).

2. What are riparian zones?

Riparian zones are the interface between terrestrial and aquatic ecosystems along inland watercourses (Naiman and Décamps, 1997). They encompass the space between the flowing water at low levels and the highest water mark where vegetation is influenced by floods, elevated water tables, and soil type. In the landscape, they function as a dendritic network of narrow-shaped corridors with flowing energy, matter and biodiversity (Gregory et al., 1991; Naiman and Décamps, 1997). Riparian zones are present in all biomes from tropical rainforests to arid and arctic deserts, and range from large floodplain–river systems draining millions of cubic meters of water annually at a continental scale (Ward et al., 2002), to small temporary streams (Acuña et al., this issue) (Fig. 1). The main abiotic and biotic characteristics of riparian zones are: (i) a flooding regime with high temporal and spatial variability that creates a landscape mosaic of both vegetated and bare fluvial landforms functioning as habitats organized hierarchically (Gurnell et al., 2016), and (ii) unique biotic communities with species that benefit from a high water and nutrient availability but that also must tolerate shear stress and temporary submersions (Naiman and Décamps, 1997). The dependence of riparian zones on the flooding regime—along four dimensions: longitudinal (upstream–downstream), lateral (hillslope-channel), vertical (hyporheic-channel bed), and temporal (Ward, 1989)—is the main singularity that makes them functionally distinct from purely terrestrial or aquatic lentic ecosystems (Tockner et al., 2000).

3. Ecological, economic, and social importance of riparian zones

Riparian zones perform multiple ecological functions, including refuge for regional biodiversity, climate regulation, flood buffering, water and nutrient filtering, shading stream channels and high primary productivity (Naiman and Décamps, 1997; Palmer and Bennett, 2006). These ecological functions are directly related to key ecosystem services provided to society (Felipe-Lucia et al., 2014; Vidal-Abarca Gutiérrez and Suárez Alonso, 2013). Many of these functions have direct economic relevance, including flood control; support for agriculture, forestry, industry and urbanization; and several outdoor recreational activities, such as visits to waterfalls and gorges, hiking, canoeing, and fishing. For instance, the economic value of the ecosystem services provided by riverine wetlands and riparian buffers in three Canadian rivers was estimated to be ca. 6000 Canadian dollars per hectare and year (Buffin-Bélanger et al., 2015).

4. Impacts on riparian zones

Riparian zones have faced profound anthropogenic modifications since the rise of civilization (Feld et al., 2011), which have been shown to affect trophic networks at every level (Mensing et al., 1998). Human activities have been centered along rivers and riparian zones because of their position in the landscape. Agriculture exploits the nutrient-rich substrates of wide floodplains, while rivers in canyons or open valleys are dammed to store water for agricultural, domestic, and/or industrial use (Graf, 2006; Hughes and Rood, 2003). Furthermore, streams have been adapted to serve as corridors for transportation, facilitating forestry, industrial, and urban development in riparian zones.

While some free-flowing rivers remain in remote headwaters, nature reserves and less populated regions (e.g. Tagliamento river in Italy, Ward et al., 1999; Merced River in Yellowstone National Park, U.S., Yochim and Lowry, 2016), most rivers and associated riparian zones in the world are severely impaired by altered flow regimes (Nilsson et al., 2005). Dams disrupt longitudinal connectivity and dramatically alter the structure and composition of riparian vegetation (Graf, 1999; Ward and Stanford, 1995). Downstream of dams, peak flows are attenuated, summer water levels are kept abnormally low (prolonged droughts following water storage in reservoirs) or high (water releases for irrigation, navigation, energy production, and recreation; Graf, 2006). Often riparian plant and animal communities cannot adjust their life cycles to such disturbance of the natural flow regime and may suffer from severe declines in their populations (e.g. collapse of riparian trees (Rood and Mahoney, 1990); decline in colonial waterfowl breeding events Kingsford and Auld, 2005) and be replaced with non-strictly riparian communities (e.g. dryland plants; Dixon et al., 2012), which may paradoxically increase alpha and beta diversity in riparian habitats as a temporary stage within an overall process of ecological degradation and homogenization (Gumiero et al., 2015). Upstream of dams, raised water tables also alter riparian habitats (e.g. replacement of woody riparian by meadow type vegetation Tombolini et al., 2014). This impact is global as virtually all rivers in industrialized regions are dammed and more dams are planned to be built in developing countries (Nilsson et al., 2005). Laterally, changes in sediment and flow regime, geomorphological alterations (e.g. channel incision), dikes, levees, ripraps, and other structures prevent channel migration (Magdaleno and Fernández, 2011), essential for vegetation regeneration (Scott et al., 1996). Vertically, river bed incision by channel embankment and gravel extraction, and groundwater overexploitation induce water tables lowering and leading to loss of plant species less adapted to water scarcity (Stromberg et al., 1996; Gumiero et al., 2015) and may favour particular functional groups (e.g. swallows and kingfishers taking advantage of exposed banks, Silver and Griffin, 2009).

In addition to stream flow alterations, pollution is a significant threat to viability of riparian zones across the globe. While measures to

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