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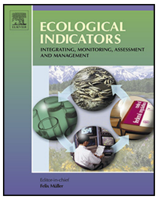

Land-use coverage as an indicator of riparian quality

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ABSTRACT

Sustaining or restoring riparian quality is essential to achieve and maintain good stream health, as well as to guarantee the ecological functions that natural riparian areas provide. Therefore, quantifying riparian quality is a fundamental step to identify river reaches for conservation and/or restoration purposes. Most of the existing methods assessing riparian quality concentrate on field surveys of a few hundreds of metres, which become very laborious when trying to evaluate whole catchments or long river corridors. Riparian quality assessment obtains higher scores when riparian vegetation consists of forested areas, while land-uses lacking woody vegetation typically represent physical and functional discontinuities along river corridors that undermine riparian quality. Thus, this study aimed to analyse the ability of riparian land-cover data for modelling riparian quality over large areas. Multiple linear regression and Random Forest techniques were performed using land-use datasets at three different spatial scales: 1:5000 (Cantabrian Riparian Cover map), 1:25,000 (Spanish Land Cover Information System) and 1:100,000 (Corine Land Cover). Riparian quality field data was obtained using the Riparian Quality Index. Hydromorphological pressures affecting riparian vegetation were also included in the analysis to determine their relative weight in controlling riparian quality. Linear regression showed better predictive ability than Random Forest, although this may be due to our relatively small dataset (approx. 150 cases). Forest coverage highly determined riparian quality, while hydromorphological pressures and land-use coverage related to human activities played a smaller role in the models. While acceptable results were obtained when using high-resolution datasets, the use of Corine Land Cover led to a poor predictive ability.

1. Introduction

Riparian zones present sharp gradients in environmental factors, ecological processes and biological communities (Gregory et al., 1991). The vegetation in these areas carries out several ecological and hydrological functions: trapping sediments and chemicals from valley slopes, moderating stream temperature, supplying organic matter to the channel, supporting riparian and aquatic wildlife, controlling bank erosion, mitigating floods and serving as biological corridors (Naiman et al., 2005; Tabacchi et al., 1998). The conservation of riparian areas in good quality is crucial for maintaining many important ecological functions in rivers, including many services provided to society (Hruby, 2009; NRC, 2002). Despite this, riparian areas are commonly under huge anthropogenic pressure due to land-use transformation and the frequent occurrence of hydromorphological pressures. Both limit the processes shaping riparian landforms and the extent and composition of riparian vegetation (Naiman et al., 2005; Poff et al., 2011).

The importance of finding a balance between socio-economical development and fluvial ecosystem preservation is reflected in the increasing number of studies relating riparian buffer width with riparian functions (e.g. Hawes and Smith, 2005), as well as in the environmental legislation worldwide (e.g. Water Framework Directive and Habitats Directive in Europe, Clean Water Act in USA, Streamside Protection Regulation in Canada).

To define riparian quality in terms of the characteristics and dimensions that allow maintaining riparian functions, not only qualitatively but also quantitatively, is central for the management of riparian areas. Several methodologies for assessing riparian quality in an easy and fast way currently exist (for a review see Fernández et al., 2011), such as the Proper Functioning Condition (Prichard et al., 1999), the Visual Assessment of Riparian Health

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Abbreviations: CLC, Corine Land Cover; SIOSE, Spanish Land Cover Information System; CRC, Cantabrian Riparian Cover map; RQI, Riparian Quality Index; BLF, BroadLeaf Forest; PAS, PASture land; AGR, AGRicultural land; UHD, Urban and Human Development; PRES, hydromorphological PRESsures.

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(Ward et al., 2003), the Qualitat del Bosc de Ribera (Munné et al., 2003), the Rapid Appraisal of Riparian Condition (Jansen et al., 2005) or the Riparian Quality Index (hereafter RQI; González del Tánago et al., 2006; González del Tánago and García de Jalón, 2011). These methods analyse riparian plant communities in terms of extension, structure and naturalness and consider riparian forests as the optimal vegetation formation for riparian areas. Thus, they record information on the presence, absence or abundance of woody vegetation attributes (e.g., width, continuity, composition, regeneration). Most of them evaluate also the presence of artificial structures limiting riparian functions and processes (e.g. embankments and bank reinforcements). All these methods are applied within homogeneous river reaches not longer than 500 m. However, critical items in riparian management, such as flood risk assessment or riverine species conservation, cannot be understood without a continuous evaluation of the riparian corridor. As the existent field-based methods demand too much time and resources to cover large catchments or long river corridors, some authors have used remote sensing techniques instead, such as Light Detection and Ranging (LIDAR) data or satellite images (e.g. Gurung et al., 2009; Ivits et al., 2009; Magdaleno et al., 2010).

Some products derived from remote sensing are nowadays easy to obtain. In particular, some remote-sensing-derived land-cover data are nowadays available over large areas. As they also include periodical updates, they potentially constitute a good data resource for monitoring riparian quality over time. Although several authors have recently analysed the relationships between land cover and stream and riparian ecological status (e.g. Ivits et al., 2009; Wasson et al., 2010), none has yet drawn attention to the capacity of land-use data to model riparian quality. This may be feasible, as the optimal vegetation formation of riparian areas in temperate and tropical regions is riparian forests (except in alpine landscapes above the tree line), while other land-uses (shrubs, herbaceous or urban surfaces) typically represent physical and functional discontinuities along river corridors. In this study we analyse the ability of available riparian land-cover data for modelling riparian quality over large areas by (i) comparing the performance of linear (multiple linear regression) and non-linear (Random Forest) techniques, and (ii) determining the optimal spatial scale of land-use coverage data.

2. Materials and methods

2.1. Study area

This study was conducted on rivers belonging to the Natura 2000 Network in the region of Cantabria, northern Spain (Fig. 1). Cantabrian rivers have their sources in the Cantabrian Cordillera, which runs parallel to the Atlantic Ocean coast and reaches up to 2600 m a.s.l. Northern slope rivers in this Cordillera travel nearly 50 km across deep valleys until they reach the Cantabrian Sea. The largest basins slightly exceed 1000 km^2 of catchment area and 20 $\text{m}^3\,\text{s}^{-1}$ of mean daily flow, with highly variable valley widths that rarely surpass 2000 m in most of the middle and upper courses. On the other hand, rivers placed in the southern slope of the Cordillera belong to more extensive and complex river systems which flow into the Mediterranean and the Atlantic. They have more gentle reliefs and broader maximum valley widths than the northern basins. Our study river network encompasses rivers located both on northern and southern slopes.

Cantabria has a humid oceanic temperate climate with an average annual temperature of 14 °C and an average annual precipitation exceeding 1200 mm. Vegetation follows the biogeographic division imposed by the Cantabrian Cordillera into Eurosiberian (Northern slope) and Mediterranean (Southern slope) types (Rivas-Martínez et al., 2004). Vegetation in the Cantabrian rivers is dominated by alder groves (*Alnus glutinosa*). Willow groves formed by *Salix atrocinerea* (Northern Cantabrian cordillera) and *S. cantabrica* (Southern Cantabrian cordillera) replace alder groves on shallow soils and at sites with high flow fluctuations. Other willows such as *S. eleagnos* and *S. alba* can also dominate riparian forests when flow fluctuations are extreme or quite constant, respectively. At high altitudes alder groves are replaced by formations dominated by ash (*Fraxinus excelsior*) or hazelnuts (*Corylus avellana*), while in steep valleys the typical mixed Atlantic forests of beech (*Fagus sylvatica*) and oak (*Quercus robur* and *Q. pyrenaica*) might dominate the riparian vegetation. Finally, when riparian forests are impaired by human activities, the vegetation is usually dominated by shrubs (*Rubus* sp., *Rosa* sp., *Crataegus monogyna*, *Prunus spinosa*), or even pasture formations.

2.2. River network and riparian zone extent

The river network and its riparian zone were derived following the procedure described by Benda et al. (2011) using the analysis toolkit “NetMap” (www.netmaptools.org; Benda et al., 2007, 2009). Hence, the network was delineated using flow directions inferred from a 5-m DEM, using the algorithms described by Clarke et al. (2008). In low relief areas, drainage was enforced using GIS data on channel locations. The surface that intersects valley walls at a height of two times the river bankfull depth was considered the riparian zone in this study. This geomorphological criterion was selected because this surface roughly corresponds to the 50 years flood, which has been indicated as an optimal hydrological descriptor for riparian areas coinciding with the first terrace or other upward sloping surface (Ilhardt et al., 2000). To assign bankfull depth, the channel network was divided into a set of channel segments (500–1000 m) and split again at confluences, as they are supposed to produce changes in channel bankfull depth (Benda et al., 2004). Bankfull depth was estimated for each segment using a regional regression of drainage area and mean annual precipitation to field measured bankfull depths ($P < 0.001$; $R^2 = 0.12$; for more detailed information see Benda et al., 2011 and Fernández et al., 2012). To derive riparian zone extent, DEM cells were classified according to elevation above the channel. Each cell within a 1500-m radius of a channel was associated to the closest channel cell by using a cost distance function where distance increases not only with the geographical distance, but also with slope and elevation change (to ensure that DEM cells are correctly assigned to the channel they drain into, which sometimes is not the closest in terms of geographical distance). The elevation difference between each valley floor cell and the associated channel location was normalised by bankfull depth (dividing the elevation difference by the bankfull depth associated to that channel segment). Then, a surface above the channel was delineated using the elevation equivalent of two bankfull depths for every channel segment.

To link land-cover and riparian quality information the study area was partitioned into discrete units. These units were called “units of analysis” (Fig. 1). As RQI was applied over homogeneous river reaches not longer than 500 m, that length was used as a splitting criterion. Hence, the river network (retrieved as a single feature GIS polyline) was split again from mouth to source for the main channels and from confluence to source for tributaries using ArcGis software (ESRI, 2011). Then, the polygon covering the riparian area was cut using lines perpendicular to the river centrelines at each river reach end. This resulted in almost 1300 units of analysis ranging from 0.5 to 8 ha. The width between the river bank and the riparian area external boundary ranges from 7 to more than 500 m, depending on valley morphology.