# USING HYDROSCAPES TO MAXIMIZE THE BENEFITS OF RIPARIAN CORRIDOR RESTORATION FOR MULTIPLE RIVER ECOSYSTEM SERVICES

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Riparian corridors play a major role in determining river ecosystem functioning as they control bank erosion and river morphology, they generate habitat heterogeneity within the channel, banks and floodplain, they influence nutrient and organic matter inputs, they buffer against sharp changes in water temperature and they constitute an important habitat for many riverine species. However, the assessment of riparian corridor conservation status has rarely been achieved continuously for entire river networks and linked to the provisioning of different river ecosystem services. This prevents the elaboration of catchment restoration planning that maximizes the provision of multiple ecosystem services. In this study we have assemblage a large spatial scale (120.000km2) database from northern Spain which incorporates different riverine ecosystem components. We delineated and characterized Hydroscapes for all the major river networks included in the study domain and produced a continuous conservation status riparian corridor assessment. This diagnosis was then used to prioritize river reaches for riparian restoration which maximized bank erosion protection, water temperature control, nitrate runoff and enhanced floodplain habitats.

## Introduction

Riparian zones develop several ecological and hydrological functions which are basic for river ecosystems. Despite this, riparian areas are under huge pressure due to land-use transformation and human infrastructures. Moreover, there is a growing consensus that a catchment scale perspective that considers the complete fluvial landscape is critical for successful river restoration. Different catchment approaches have been recently developed that encompass the analysis of many fluvial landscape characteristics for restoration purposes (Benda et al. 2011), but no for riparian vegetation. Most methods assessing riparian quality are based on recording woody vegetation attributes (e.g., width, continuity, composition, regeneration) within homogeneous river stretches not longer than 500 meters, what prevents a continuous evaluation of the riparian corridor (Fernández et al. 2014). One of the major drawbacks to evaluate riparian quality for entire river networks is the lack of a common consensus to delineate riparian zones, whose limits are fuzzy. However, different recent approaches based on GIS technologies allow delineating these areas following hydro-geomorphologic criteria (Fernández et al. 2012). These approaches allow producing riparian quality maps to whole catchments and, thus, relationships among riparian quality data and the provisioning of different ecosystem services (e.g., bank erosion control) can be explored at large scales. In the present study we aim to (1) delineate riparian zones for entire river networks using hydro-geomorphological criteria, (2) produce a riparian quality model based on land cover of woody vegetation and field observations and, finally, (3) prioritization of river reaches for riparian restoration by linking riparian quality to the provisioning of 4 ecosystem services: bank erosion control, control of nutrient runoff and water temperature and enhanced floodplain habitats.

## Methods

In order to define a spatial framework to integrate all the available information, we developed a Synthetic River Network (SRN) using flow directions inferred from a 25-m digital elevation model (DEM) with the NestStream software (Miller, 2003). The SRN was finally composed by 87417 river stretches, with an average length of 500 m (from 16 to 800 m). Predictor variables describing several environmental attributes (climate, geology, topography, land cover, hydrologic and anthropic) were extracted from existing databases provided by several national and regional organizations and modelled from previous work in the study area (Peñas, 2014).

Riparian zones were delineated by deriving the geomorphologic floodplain surfaces that best matched the 50-yr flood, following Fernández et al. (2012). The criteria used to obtain those surfaces were 0.75 times the bankfull depth (BFD) for river reaches contained in open and concave valley types and 1.25 times the BFD for river reaches on V-shaped valley types (Fig. 1). Riparian quality was modelled using Random Forest to entire river networks following the modelling framework used in (Fernández et al. 2014). This was performed using as a response variable the riparian quality score obtained in more than 150 field sites, while predictor variables were provided by reclassifying the Spanish Land Cover Information System (SIOSE, based in SPOT-5 Satellite images) into 7 land uses.

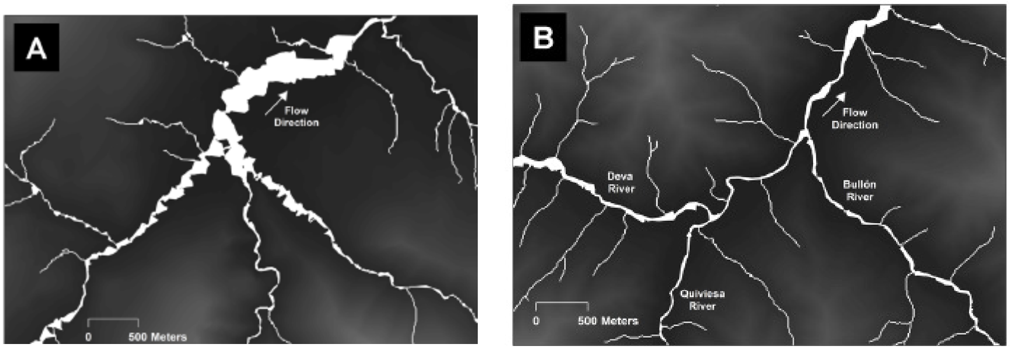


**Figure 1.** Flood-prone area at 1.25-BFD at a wide flood-prone area (A) and at a narrower flood-prone area (B).

Information on bank profiles, materials and bank erosion were derived from more than 300 river reaches sampled using the River Habitat Survey protocol. The abundance of cliffs on river banks for a given river reach was modelled for the entire river network on our study domain by using this information as a response variable and the attributes from the SRN as the predictors (see: ihrivers.ihcantabria.com, Peñas *et al*., 2014).

The water quality database was developed with information from 4 regional water agencies (Álvarez-Cabria, *et al*., In Prep.). We compiled information from 1069 sites, which were sampled from 2003 to 2009. All the variables included in this study (water temperature and nitrate concentration) were modelled with information from sites with data of at least 3 years, representing the seasonal variability of each variable. Finally, we used 297 study sites to develop the water temperature model (174 Atlantic and 123 Mediterranean) and 267 sites for nitrate concentration (196 Atlantic and 81 Mediterranean). Average seasonal (spring, summer, autumn and winter) water temperature and nitrate concentration were modelled for the entire SRN.

Moreover, different geomorphologic floodplain surfaces (1xBFD, 2xBFD and 3XBFD) were delineated for the entire SRN and floodplain extent was compared among them to determine where floodplain extend may be limited by dykes or channelizations versus natural constraints (i.e., valley walls; following Benda *et al.* (2011).

Finally, the results from all models included in the SRN were used to detect where riparian restoration might have a larger benefit controlling river bank erosion, nitrate runoff, water temperature control and, finally, recovering large extensions of floodplain woodlands.

<u>Results and conclusions</u>

The delineation of riparian areas was successfully accomplished for entire river networks and riparian quality models using the above protocol achieved good performance (Fig.2).

The link between river bank degradation and riparian quality model outputs allowed to link river reach degradation (presence of steep and eroding banks) to different land use practices that affect riparian corridor quality (less woody vegetation; Fig. 3). This result is of paramount importance for catchment restoration plans in which river reach morphology and riparian areas are usually the objective of many restoration actions, however, often they lack a more focused catchment perspective.

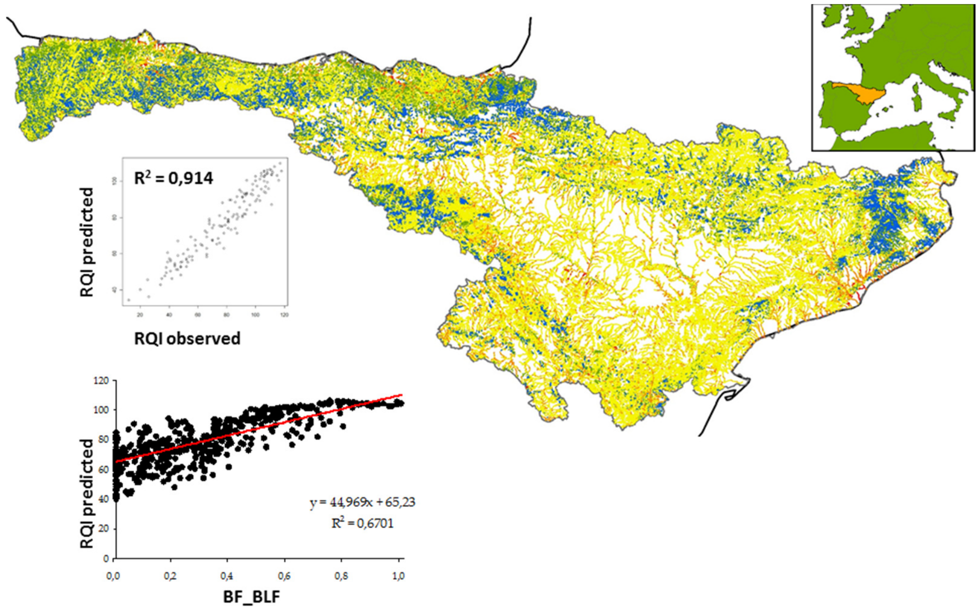


**Figure 2.** Riparian quality model results obtained using Random Forest in which the riparian quality index (RQI; González del Tánago et al., 2011) was modelled using the land use composition in the riparian zone for the rivers of the northern fourth of the Iberian Peninsula. Univariate relationship between RQI and broad-leaf forest in the riparian zone (BF_BLF) is also shown. This was obtained using the analysis capabilities of synthetic river networks (for more information see: Fernandez et al., 2012 and 2014; red river reaches: very bad conservation status, orange: bad, yellow: moderate, green: good, blue: very good)

Riparian degradation was also linked to higher nitrate concentration and water temperature (Fig. 4), mainly in agricultural areas where floodplain extent was in many cases also limited by dykes and channelization. Thus, restoring riparian corridors in human-constrained but potentially-wide valleys in river reaches where agricultural development has hardly left any woody vegetation will certainly increase the riparian functionality in these areas. This will help delivering a number of river ecosystem services that are now not being provided nor guaranteed (e.g., water quality, flood control).

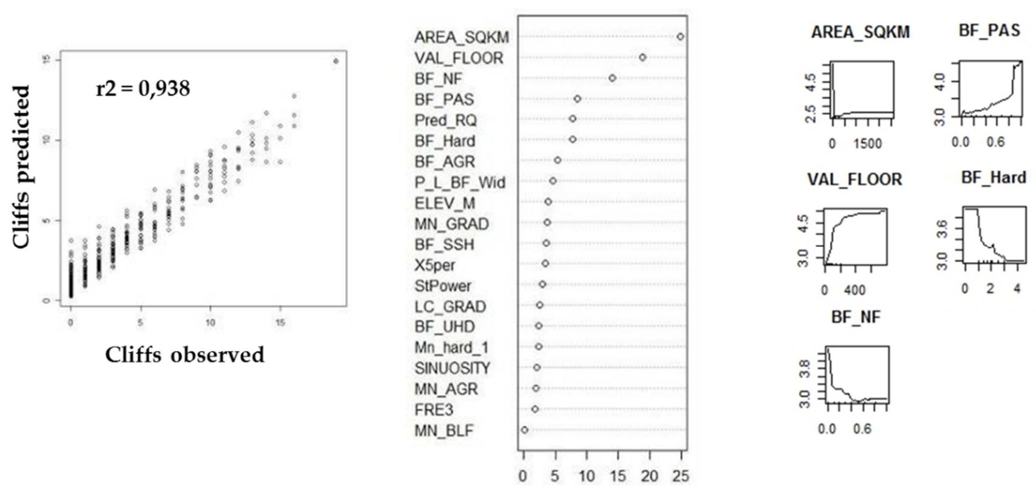


**Figure 3.** Results obtained by a Random Forest model on cliff abundance on river banks (AREA_SQKM: Catchment area in km2; VAL_FLOOR: Valley Floor Width; BF_NF: Native Forest on a 200m Buffer; BF_PAS: Pasture land on a 200m Buffer; BF_Hard: Substrate hardness on a 200m Buffer; Pred_RQ: Predicted Riparian Quality).

This study evidences the need to integrate different ecosystem components when prioritizing for river restoration projects. Moreover, there is a growing need to perform this integration at a catchment scale, so that river reaches with a larger sensitivity and where environmental benefits are maximized could be prioritized. The delivery of river ecosystem services to human societies and the conservation of river biodiversity could be enhanced if terrestrial and aquatic ecosystem service trade-offs are considered simultaneously.

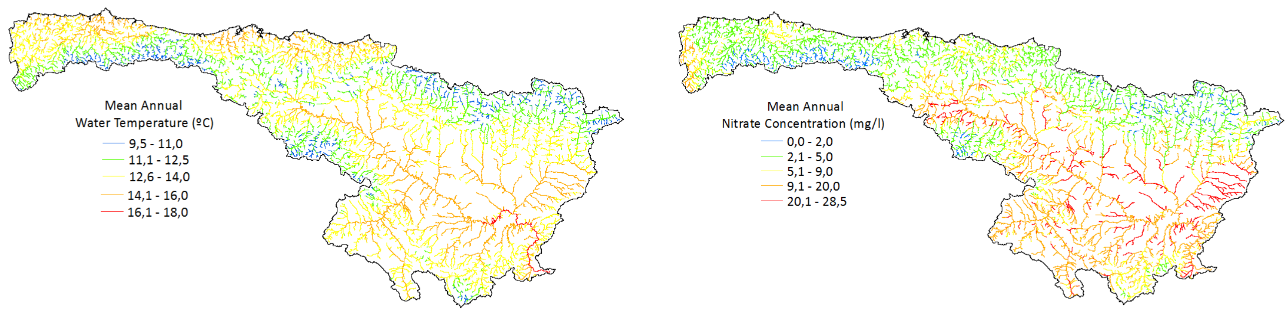


**Figure 4.** Mean annual water temperature and nitrate concentration obtained using Random Forest models in which more than 250 water quality sites were used in the northern fourth of the Iberian Peninsula (Álvarez-Cabria *et al*., In Press).

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