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Impact of current riparian land on sediment retention in the Danube River Basin

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ABSTRACT

Riparian land supports multiple ecosystem services that are essential for good water quality and aquatic biodiversity, providing habitat and hydrological connectivity, and retaining pollutants and sediments. Riparian land reduces sediment fluxes in the freshwater systems by trapping sediments generated on the hillslopes before they reach the stream network, and by stabilizing stream banks. The aim of this study was to assess the impact of current riparian land in reducing sediment fluxes in the stream network of the Danube River Basin. The Soil and Water Assessment Tool (SWAT) model was used to assess sediment yields across the basin and quantify sediment retention by riparian vegetation. Europe-wide spatial information on riparian land type and extent was used to set up agricultural to riparian land ratio and the streambank reach vegetation cover. SWAT sediment simulations for current conditions, i.e. including riparian land parameterization, were calibrated and validated for the period 1995–2009. The impact of riparian land was quantified by analyzing differences in mean annual specific sediment yields between scenarios without riparian land and current conditions. Sediment yield reductions and efficiency of riparian land were quantified at several spatial scales across the basin, considering hillslopes, stream order, and administrative regions. The impact of riparian filtering in reducing sediment fluxes to the stream network at the hillslope scale was always positive, with median efficiency of 50%. Efficiency was higher where incoming sediment and water yields per unit of area were larger, and in smaller HRUs (areas lower than 10 km^2). Sediment filtering in riparian buffers was more efficient in smaller reaches, and decreased from about 17% to 5% with Strahler's order. Streambank protection was important locally in about 8% of reaches characterized by high stream power, where current streambank protection reduced potential sediment yields by more than 5 t/km^2/y, and in large reaches, like in the Sava and Danube Rivers. At the Danube outlet to the Black Sea, the reduction in sediment yield attributable to current riparian land was estimated at 480 kt/y. Although riparian efficiency declined with spatial scale in terms of sediment yield reduction, filtering of sediments in riparian buffers abated in-stream sedimentation substantially. While occupying only about 2% of the Basin, current riparian land in the Danube Basin reduces sediment fluxes in river networks by about 8% regionally, and contributes to the improvement of the ecological conditions of freshwater ecosystems.

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1. Introduction

Sediments impact freshwater aquatic habitats directly by altering turbidity, light penetration, water temperature and biologically available oxygen, and indirectly by transporting adsorbed pollutants through the freshwater network (Chapman et al., 2014; Owens et al., 2005; Rickson, 2014). The European Water Framework Directive (WFD; European Commission, 2000) demands to maintain and restore the good ecological status of freshwater bodies through implementation of Programme of Measures to reduce all significant pressures acting on aquatic ecosystems.

Restoring the good ecological status often means that multiple environmental targets are to be achieved. Planning effective strategies may be daunting given the suite of conservation actions and their potential synergic or antagonistic effects that natural resource managers should contemplate. Considering ecosystem services may help finding effective solutions (Dosskey et al., 2012). Besides the Blueprint (European Commission, 2012), several recent studies have examined how the ecosystem service approach could support the implementation of the WFD by analyzing the co-benefits of measures and facilitating the integration of policies (COWI, 2014; ESAWADI, 2010; Grizzetti et al., 2016; Vlachopoulou et al., 2014).

Management options that contribute to fulfil multiple environmental targets may be more efficient than single-purpose solutions. Riparian land, posed at the transition zone between land and water, supports a number of ecosystem services (Dosskey et al., 2012; NRC, 2002; Stutter et al., 2012). Riparian land enhances provision of clean waters by trapping sediments, nutrients and toxicants, stabilizing stream banks, attenuating floods, and providing shading and cooling. In contributing wood and litter materials, these areas offer important wildlife habitat and support food webs. Finally, their recreational services and aesthetics/sceneries are well appreciated. Pan-European assessments have shown that current riparian land abates 33% of Nitrogen and 65% of Phosphorus loads delivered from agricultural land to stream network via surface pathways (Weissteiner et al., 2013). Conversely, an assessment of sediment retention at comparable scale has not been hitherto conducted in Europe.

The beneficial role of riparian vegetation in terms of sediment retention has been extensively described in the scientific literature (Daniels and Gilliam, 1996; Dosskey et al., 2010; McKergow et al., 2003; Yuan et al., 2009). Riparian land contributes to reducing sediment fluxes in freshwater bodies via two main processes. First and foremost, riparian land acts as a buffer that traps incoming sediments produced in the land, preventing their delivery to the stream network. The effectiveness of riparian land in trapping incoming sediments depends on many factors, such as the width of riparian land in relation to hillslope areas, the amount of sediment fluxes generated on the hillslopes, the infiltration rates in the riparian buffer, and the characteristics of incoming sediments (Yuan et al., 2009). Under uniform sheet flow, sediment trapping efficiency measured under experimental conditions at the field scale could be greater than 80% (White and Arnold, 2009; Yuan et al., 2009). In addition to sediment trapping, riparian vegetation, particularly through the increase of cohesion given by root systems, helps stabilizing channel morphology and prevent stream bank erosion. Moreover, vegetation cover of the stream banks alters flow velocities and stream power near the banks, reducing the streamflow sediment transport capacity (Muscutt et al., 1993; Thorne, 1990; Wenger, 2011).

Since environmental factors may drive landscape response to management actions and implementation plans require activities both at the local and at the basin scale, the impact of management strategies should be assessed both at the local and at the basin scale (e.g. Tomer et al., 2014). Heterogeneities in the landscape may reduce riparian land effectiveness considerably, for example in the presence of concentrated runoff or in case of riparian land saturation, or where runoff is conveyed through ditches or roads, bypassing the filter (Dillaha et al., 1989; Dosskey et al., 2010; Verstraeten et al., 2006; White and Arnold, 2009). Quantification of sediment retention by riparian land at large scale is difficult to obtain (Yuan et al., 2009). Direct observations of catchment responses before and after implementation of riparian buffers (e.g. McKergow et al., 2003) are important for ex-post evaluation, but are expensive and subject to site-specific environmental conditions, thus results cannot be easily extrapolated to other sites. Despite shortcomings due to limited process knowledge, structural and data uncertainties, eco-hydrological modelling may offer insights towards assessing water related ecosystem services, particularly through scenario analysis and spatial planning (Bouraoui and Grizzetti, 2014; Guwsa et al., 2014). Modelling of riparian land can thus lead to assess its impact in isolation, in conjunction, or in alternative to other conservation actions.

The Soil and Water Assessment Tool (SWAT Arnold et al., 2012; Neitsch et al., 2011) is a comprehensive process-based integrated basin model that considers several ecohydrological functions, allowing assessments of water quantity and quality in small to large watersheds. The model comprises processes to assess trapping of pollutants in riparian buffers and streambank protection. SWAT has been used to assess impact of riparian land at the field scale in isolation or in combination with other field scale riparian models (e.g. Arnold et al., 2014; Shan et al., 2014). Several applications aimed at targeting priority areas for reducing nutrient pollution, generally focusing on the impact of riparian filtering (e.g. Chen et al., 2014; Piniewski et al., 2015). Few studies considered the extent of existing riparian land. White and Arnold (2009) mapped riparian land to consider partitioning of runoff flow into areas of concentration in local reaches. They proposed improvements in riparian filtering modelling to account for flow concentration that are currently incorporated in SWAT. Monteiro et al. (2015) assessed that loss of riparian land triggered by legislation changes generated a 34% increase of sediment yield in the Rio das Mortes Basin in Brazil. Even less applications considered the impact of riparian land on streambank protection (Cho et al., 2010; Ha and Wu, 2015; Moriasi et al., 2011). Moriasi et al. (2011) used SWAT to assess the impact of riparian stabi-