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Impacts of land use conflicts on riverine ecosystems

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ABSTRACT

Starting from a diagnosis of areas with different environmental land use conflicts located in various rural sub-basins of the River Sordo basin (northern Portugal), the present study analyzed the ecological quality of surface water in small mountain streams to establish a relationship between land use, water and aquatic biota. Environmental land use conflicts were set up on the basis of land use and land capability maps, coded as follows: 1 – agriculture, 2 – pasture, 3 – pasture/forest, and 4 – forest. Land capability was assessed by the ruggedness number methodology (*RN*). The difference between the codes of capability and use defines a conflict class, where a negative or null value means no conflict and a positive value means class *i* conflict. Within and without the conflict areas, ecological quality of surface water was evaluated by the metrics EPT taxa, $IPtI_N$ index, diversity of Shannon–Wiener and Evenness index. Macroinvertebrate communities are strongly correlated to conflict classes, because sites without (reference sites) or with minor physicochemical and hydromorphological degradation (Class 1) presented high diversity, evenness, EPT taxa and $IPtI_N$ index, while more impacted sites (Class 2) presented an ecological status not fulfilling the demands of the European Union Water Framework Directive (2000/60). The present study indicates a significant impact of land use on water quality which has straight influence on the distribution of biota, emphasizing the key role of riparian vegetation in the conservation of aquatic ecosystems. The highest impacts on macroinvertebrate assemblages were associated with changes in water quality parameters such as temperature, oxygen saturation (%), turbidity, total suspended solids (TSS), nitrates, phosphates and sulphates, conductivity and dissolved oxygen, as well as hydromorphological alterations driven by the total absence of riparian vegetation as a consequence of terrace building, agriculture and the resectioning/reinforcement of the banks associated with the culture of vine. Macroinvertebrates proved reliable to distinguish conflict classes and separate seasons. The main conservation measures required to improve the conflict areas in the short and medium term mainly include the adoption of agroforestry practices as these not only improve the quality of water and soil, maintaining land resources over a long period of use, but also brings many benefits to the landowner.

Introduction

The use and occupation of land with disregard for the soil characteristics, together with the lack of conservation strategies, has led to a quick rise in erosion worldwide. The increase in soil erosion reduces cropland productivity and amplifies the pollution levels of surface water bodies (rivers and lakes). In the sequel, wildlife habitats may suffer a loss above their tolerance limits, compromising the sustainability of ecosystems and the social-economic development (Lal and Stewart, 1990; ISRIC/UNEP, 1991; Pimentel, 1993; Pimentel et al., 1995; Pimentel and Kounang, 1998; Valle Junior et al., 2010). In the present study the focus is put on the potential impacts of land use conflicts on riverine ecosystems. According to Agroconsultores and Coba (1991), in traditional Portuguese agrarian systems land uses comply with the land capability set up on the

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basis of soil features (depth, fertility) and local environmental conditions (topographic slope, water availability). However, in some rural areas the current land use deviates from those established by land capabilities generating different land use conflicts with consequences on soil erosion intensity (Mello Filho, 1992; Pacheco et al., 2014) and groundwater quality (Valle Junior et al., 2014b). The accelerated soil losses result from a human misuse of the land and are no longer being compensated by the geologic substrata or by the alluvial contributions (Pimentel, 2006). The same author highlights that soil is being lost at rates 10–40 times faster than the rate of soil renewal, endangering future human food security and environmental quality. The degradation of groundwater quality is related to amplified washouts of nutrients (e.g. nitrate) in the conflict areas, relative to the washouts in no conflict areas. Governments and international organizations are familiar with these threats, the reason why sustainable development has been a topic on their political agenda over the last four decades (e.g. Stockholm Declaration, 1972; World Conservation Strategy – IUCN, 1980; World Commission on Environment and Development – WCED, 1987, known as the Brundtland Report; United Nations Conference on Environment and Development – UNCED, 1992). Invariably, the proposed solutions to the problem were strongly focused on the rational use of soils and prevention of water pollution, as these resources are essential for human life and concomitantly are scarce and vulnerable (Pearce et al., 1989; Murcott, 1997; De Wit and Verheye, 2009).

In Mediterranean countries, forest fires are probably the most important cause of desertification and surface water quality degradation (Moreno et al., 1998; Vallejo, 1997; Rubio, 1987). In Portugal, the burned area increased significantly since the 80s, and now represents more than one third of mainland Portugal (Nunes, 2012). Some intensive agricultural practices – together the effects of forest fires – contributes to the destabilizing of agrarian ecosystems, with consequences on riverine ecosystems located downwards (Roose, 1994). Other common circumstances leading to desertification and concomitant surface water quality degradation comprise the inadequate management of forest spots or the destruction of vegetation cover for the expansion of agricultural areas (Valle Junior et al., 2014a). Regardless the cause, the distinctive climate and strong relief of Mediterranean region enhanced soil erosion and surface water pollution to levels that are more catastrophic than those observed in other regions around the world. According to Corine Land Cover (2007), a large proportion of continental Portugal (43%) is at high risk of soil erosion, being covered by arid, acidic, sandy, and sometimes rocky soils (Portugal, 2014). In this study, land use conflicts, not compensated by proper soil conservation practices, are an additional degradation source of surface water.

The impacts of multiple land uses on water quality have been studied (Hascic and Wu, 2006; Langpap et al., 2008) and showed that the intensive land use activities may affect the hydrological, biological, chemical and geomorphological aspects of aquatic systems (Gergel et al., 2002; Roy et al., 2003; Thompson and Towsend, 2004; Valle Junior, 2008). Many other studies have illustrated the correlation between land use types and water quality parameters (Sliva and Williams, 2001; Oliveira and Cortes, 2005; Schoonover et al., 2005; Stutter et al., 2007). In one study by Tu (2011), the relationship was even set up by geographically weighted regression so the spatial variation in watershed characteristics and pollution sources could be properly accounted for. Understanding the influence of land use on the concentration of surface water nutrients is particularly useful when considering diffuse pollution, namely agriculture, because this knowledge is crucial for the setting up of best management practices (Mouri et al., 2011). Even more useful is the eventual capture of these practices into land use and(or) aquatic resources policies, as well as their social-economic benefits. On a broader perspective, understanding the specific interactions between land use and surface water quality enables better predictions of future impacts of land use change driven by climate change (Abler et al., 2002). Also Fidélis and Roebeling (2013) discuss the importance of a strong linkage between land use and water ecosystems to enhance the success of the Water Framework Directive (WFD, Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000). The WFD establishes a framework for Community action in the field of water policy and is said to have a strong territorial context as it establishes its implementation through river basin management plans based on natural water resources systems and associated boundaries, instead of on administrative boundaries (EEA, 2012).

Several indicators have been used to evaluate human actions within river watersheds (Turner, 1990; Li and Wu, 2004; Cortes et al., 2002; Oliveira and Cortes, 2005; Cortes et al., 2013). Among these indicators one may refer biological quality elements such as the macroinvertebrates. The advantage of using these proxies has been documented (Hellawell, 1986; Rosenberg and Resh, 1993; Southerland and Stribling, 1995; Hauer and Resh, 1996) and associated to the limited migration patterns, a sessile mode of life, and the sensitivity to numerous environmental factors, of macroinvertebrates (Oliveira and Cortes, 2005; Fernández-Díaz et al., 2008; Pérez-Bilbao and Garrido, 2009; Benetti and Garrido, 2010). As reported in Mandaville (1979) and Lucadamo et al. (2007), the use of biotic indices based on macroinvertebrates are about five times more frequent than the use of any other indicator, and the frequency keeps growing. Worldwide, biomonitoring programs have been developed to detect ecosystem degradation, prioritize conservation areas and evaluate restoration progress.

Notwithstanding the impacts of land use on the quality of surface water have been assessed by a considerable number of researches, only a few studies attempted to make a diagnosis on the ecological status of river ecosystems in areas where environmental land use conflicts exist (Valle Junior, 2008; Valle Junior et al., 2013). The main purposes of this paper are: (1) to identify areas of land use conflict in a small river basin of northern Portugal (River Sordo basin), following the method proposed by Mello Filho and Rocha (1992), Pissarra et al. (2004) and Valle Junior (2008). This method requires the prior assessment of land capability. In this study, land capability was assessed by the ruggedness number (*RN*) approach (Strahler, 1952). The *RN* is the product of basin relief (combination of hillside slope with its length) and drainage density. The *RN* is viewed by Slaymaker (2010) as a potential indicator for the hazardousness of a basin, mainly when related to runoff and sediment mobilization, erosion on hillsides and fluvial erosion; (2) to investigate the ecological status of River Sordo surface waters within and without the conflict areas, based on physicochemical parameters and benthic macroinvertebrates. The seasonal variation of macroinvertebrate distribution and of physicochemical variables are addressed as secondary purposes; (3) to propose measures for soil conservation and surface water protection, which should be implemented in the near future within conflict areas; (4) to provide the first outcome of a model designed for the expeditious screening of land use conflicts and their consequences on surface water quality, which requires limited amount of data and is easily transportable from one region to another.

Materials and methods

Study area

The River Sordo basin, which is integrated in the large River Douro basin, is located in the region of Trás-os-Montes, NE Portugal. With an area of approximately 51.2 km^2, the basin is located between the northern latitudes of 41°16′ 05.57″–41°20′ 12.81″ and the western longitudes of 7°55′ 21.82″–7°45′ 42.45″, covering a