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River eutrophication: Irrigated vs. non-irrigated agriculture through different spatial scales

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ABSTRACT

The main objective of this study was to determine how spatial scale may affect the results when relating land use to nutrient enrichment of rivers and, secondly, to investigate which agricultural practices are more responsible for river eutrophication in the study area. Agriculture was split into three subclasses (irrigated, non-irrigated and low-impact agriculture) which were correlated to stream nutrient concentration on four spatial scales: large scale (drainage area of total subcatchment and 100 m wide subcatchment corridors) and local scale (5 and 1 km radius buffers). Nitrate, ammonium and orthophosphate concentrations and land use composition (agriculture, urban and forest) were measured at 130 river reaches in south-central Spain during the 2001–2009 period. Results suggested that different spatial scales may lead to different conclusions. Spatial autocorrelation and the inadequate representation of some land uses produced unreal results on large scales. Conversely, local scales did not show data autocorrelation and agriculture subclasses were well represented. The local scale of 1 km buffer was the most appropriate to detect river eutrophication in central Spanish rivers, with irrigated cropland as the main cause of river pollution by nitrate. As regards river management, a threshold of 50% irrigated cropland within a 1 km radius buffer has been obtained using breakpoint regression analysis. This means that no more than 50% of irrigation croplands should be allowed near river banks in order to avoid river eutrophication. Finally, a methodological approach is proposed to choose the appropriate spatial scale when studying river eutrophication caused by diffuse pollution like agriculture.

1. Introduction

Land use transformation from natural to human dominated systems has globally caused environmental impacts, making land use analysis a useful indicator of changes in stream ecosystems (Meyer and Turner, 1994). One of the most extended impacts produced by landscape modification is eutrophication of rivers, lakes and marine ecosystems (Lund, 1967; Omernik et al., 1981; Smith, 2003). Eutrophication produces changes in community composition and the proliferation of filamentous algae which leads to a decrease in dissolved oxygen levels, water quality, fish death and often to a global loss of biodiversity (Carpenter et al., 1998; Quinn, 1991; Smith et al., 1999). In order to plan effective prevention measures against eutrophication, a deep understanding of the relationship between land cover and stream conditions is needed. However, this relationship is characterized by numerous factors and environmental variables operating and interacting through different scales, both spatial and temporal (Frissell et al., 1986). Thus, several questions may arise when

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assessing the relationship between stream conditions and surrounding landscape. For instance: 1) which land use classes may be analysed? 2) which spatial scale/s would be the most appropriate (e.g. catchment, riparian buffers, circular buffers, among others)? and 3) how may this spatial perspective influence the interpretation of results? In this paper, we have studied the influence of land uses on river nutrient concentration focussing on different agricultural practices (Section 1.1). In addition, we have analysed how different spatial scales may affect the results and how to identify which scale is the most appropriate in this type of studies (Section 1.2).

1.1. Agricultural land use

Regarding the first issue, the land uses most commonly studied as causes of river eutrophication have been both agriculture and urban (Osborne and Wiley, 1988; Townsend et al., 1997; Von Schiller et al., 2008). Whereas urban effluents cause point pollution, agriculture often causes the most important source of non-point or diffuse pollution worldwide. However, the level of eutrophication impact depends on the kind of agriculture, for instance irrigated cropland vs. non-irrigated. Irrigation allows crops to grow in permanently water-scarce or temporarily water-stressed environments, such as in Mediterranean countries and other semi-arid areas worldwide (World Water Assessment Programme, 2009). Since the increase in population and demand for food, along with expected climate change over the next decades, suggest an increase in irrigation surface and water demand in arid and semi-arid areas (Tilman, 2001; World Water Assessment Programme, 2009), the control of diffuse pollution in this future scenario will be an important challenge, thus making the identification of land uses responsible for freshwater eutrophication a real need.

Few studies have been published comparing the eutrophication impact caused by different agricultural land use classes. For example Johnson et al. (1997) compared rowcrop vs. non-rowcrop agriculture in North America whereas Lassaletta et al. (2009) compared arable lands, permanent crops, pastures and heterogeneous areas in Spain.

According to the Spanish National Statistics Institute (www.ine.es), irrigated agriculture is more intensive than non-irrigated in terms of production due to the artificial supply of water and fertilizers to croplands. This technique increases the export of nitrogen compounds to ground- and surface waters, making irrigated agriculture the main cause of eutrophication in Spanish rivers (Álvarez-Cobelas et al., 2010; Berzas et al., 2004; Cavero et al., 2003).

In this paper, we analyse the effect of some land uses (agriculture, urban and forest) on river eutrophication, taking into account three classes of agricultural land use with different expected impact intensities: irrigated, non-irrigated and low-impact agriculture.

1.2. Spatial scale

Regarding spatial scale, some authors have suggested that the influences of land uses on stream ecosystems and water quality must be analysed at the catchment scale (Omernik et al., 1981; Richards and Host, 1994; Roth et al., 1996) whereas others have argued that land uses located closer to the stream (i.e. reach scale, local buffers, riparian corridors) are more important (Harding et al., 1998; Nerbonne and Vondracek, 2001). Recent studies suggest that a multiple spatial scale approach could be a necessary step to identify the appropriate framework (e.g. Chang, 2008; Tran et al., 2010). In a multi-scale approach, different spatial scales would provide different land use datasets and therefore different results. In order to correctly interpret the results, some issues must be taken into account to select the appropriate spatial scale: (1) spatial autocorrelation between sites and (2) the lack of a wide range of values (%) for each land use class. Autocorrelated data violate the assumption of independence of most standard statistical procedures such as correlation analysis (Legendre, 1993). In many cases, when working with large scales (e.g. subcatchment drainage area or subcatchment riparian corridors) autocorrelation is caused by overlapping of subcatchment drainage areas of consecutive downstream sites. The effect of overlapping on statistical analysis is also known as pseudoreplication (Hurlbert, 1984) and the consequence is an increase in the statistical power (higher correlations than expected) but not in the biological or ecological significance (Townsend et al., 1997).

The second issue is a consequence of working with land use percentage values. Frequently, datasets include land use classes that cover a wide range across the impact gradient (i.e. sites with low, medium and high percentages of agriculture) while other land uses (e.g. urban) only reach low percentages within subcatchments (for example 10–20% as maximum). In addition, as land uses are quantified in percentages of a surface, the higher the percentage value for one land use, the lower percentage value for the remaining land uses. The statistical consequence is a masking effect of classes reaching low cover percentage by those more extended in the subcatchment.

In this study, we relate land uses to nutrient concentration in rivers through four different spatial scales (total drainage area, 100 m wide corridors, and 5 and 1 km radius buffers upstream sites) in order to identify the most appropriate spatial framework. The novelty of this research lies in testing new spatial scales (1 and 5 km upstream buffers) and comparing the eutrophication effect caused by two kinds of agriculture common in Mediterranean countries: irrigated vs. non-irrigated croplands. Hence, the main aims are: (1) to demonstrate that spatial scale affects the results of studies relating land use to stream condition; (2) to determine which type of agriculture (irrigated vs. non-irrigated) is more responsible for river eutrophication and to define pressure thresholds (3) to propose a method to select the most adequate spatial scale to assess the eutrophication impact by diffuse pollution.

2. Material and methods

2.1. Study area

This study was carried out within the boundaries of the Spanish administrative region of Castilla-La Mancha (south-central Spain). The study area includes the upper and middle reaches of five large river basins: Tajo, Guadiana, Guadalquivir, Júcar and Segura. This region currently has the lowest