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Response of fish communities in rivers subjected to a high sediment load

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ABSTRACT

Erosion and sediment yield are a significant problem in the Guadalquivir River basin. Such phenomena are largely driven by a land use devoted to intensive cultivation of olive trees, with a large socioeconomic influence in Andalusia. This sediment overload in rivers causes serious impacts on all fluvial ecosystem components.

In this study we assess the chronic effect of sediment yield on fish communities at 104 river sites located in two different sub-catchments – the Bembézar and Guadajoz rivers – both with different lithological composition and erosion rates. Sediment yield was estimated using a semi-quantitative Factorial Score Model (FSM), developed specifically for Spanish rivers. The fish populations of both basins were evaluated in composition and abundances by the study of Fernández-Delgado et al., 2014. The influence of sediment yield on the fish community was analyzed using General Additive Models.

The sediment yield was higher in the Guadajoz basin (921 T/Km2 per year) than in Bembézar (701 T/Km2 per year). In the former, fish communities were poorer in both fish density and diversity, with *Luciobarbus sclateri* as the only substantially present species and a significant relationship between sediment yield and load, and fish density. In contrast, in the Bembézar basin, sediment yield was correlated with total fish density, including *Luciobarbus sclateri, Pseudochondrostoma willkommii, Cobitis paludica, Iberochondrostoma lemmingii, Anaecypris hispanica*, and *Cyprinus carpio*. Intermediate values of sediment yield led to maximum densities, while those higher decreased the density of these species.

1. Introduction

The freshwater ecosystem of many rivers in the Guadalquivir basin is deeply affected by excessive loading of fine sediments. It is produced mainly by the high erosion rate that occurs in land use devoted to the intensive agriculture of olive grove. These erosion rates are favored by the scarcity of soil conservation practices. According to Marques et al., 2008, the weak protection provided by the broad framework of olive plantation and the lack of coverage prompted by the labors, cause significant losses of soil after the stormy events, very common in the Mediterranean climate (Marques et al., 2008)

Sediment yield is also conditioned by basin characteristics such as lithology, vegetation density or topography. In Mediterranean environments, these characteristics lead to increased vulnerability to erosion, considered higher than in many other climates. In addition, according to De Vente and Poesen, 2005, the sediment transport modeling is particularly difficult due to the intermittent flows, the discontinuity of flow and a large irregularity of rainfall conditions.

Poor management in agricultural practices can lead to a decrease in habitat quality due to increased suspended solids and sedimentation in rivers (Wood and Armitage, 1997). The negative impact of sediment yield in aquatic ecosystems is well documented: suspended solids potentially reduce primary production and affect the rest of the food chain in the ecosystem, by means of altering the water chemistry, increasing turbidity, limiting light penetration and decreasing water temperature. Sedimentation modifies bottom substrate by altering the conditions of its upper surface, clogging and reducing the interstitial habitat. Even more, in extreme cases, fine sediments "suffocate" the riverbed completely, change channel morphology and reduce the interchange of water and metabolites with surface water, thus bringing an end to the aquatic flora (Ryan, 1991).

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Mediterranean rivers often have a peculiar behavior due to their ephemeral nature and high sediment yields recorded, however, poor information can be found on examining the effects of these sediment yields at basin scale. Walling and Fang (2003) found that sediment load data are lacking for rivers in many areas of the world, particularly in developing countries where changing sediment yields might be expected. The most widespread impacts of sedimentation are associated with fine sediments eroded from agricultural fields and these impacts are often difficult to quantify (Walling, 1990). No comprehensive approach exists to evaluate potential loadings to streams based on landscape composition and pattern across regional scales (Jones et al., 2001).

The objective of this study is to estimate the sediment yield and sediment load in two tributary basins of the Guadalquivir River, and to determine the sediment load influence on fish community composition and density. As we are using mean annual estimation of sediment yields, the impacts of sediments that we are assessing have chronic character. This paper presents a different point of view of most studies dealing with the effects of sediments on fish, based mainly on acute effects (Alabaster and Lloyd, 1982; Bruton, 1985; Ryan, 1991; Berkman and Rabeni, 1987; Osmundson et al., 2002; Sutherland et al., 2002) as here we evaluate chronic effects at which fishes has already been adapted.

2. Methodology

The study area includes two tributaries of the Guadalquivir River, on opposite sides and having different lithology: Bembézar and Guadajoz (Fig. 1).

The Bembézar river basin is on the right bank, it has a length of 126 km and occupies an area of 1960 km^2. The river flows through Sierra Morena, incised in deep ravines, characterized by a short and quick course, almost torrential, a strong erosive power as consequence of the steep slopes from the headwaters to the confluence to the Guadalquivir River and a fluvial regimen with marked summery low flow. The ground is constituted by slate, schist, blank quartzite and volcanic materials. Also, there is limestone formations from the Cambric, sometimes dolomitized and dissolutive phenomena associated. It ends with detritic materials easy to crumbly. Erosive process and soil dragging are the predominant phenomena, even in low slope areas.

The Guadajoz river basin is on the left bank and presents an area of 2410 km^2 and a length of 176.1 km. The corrugated morphology of the basin is configured by the plentiful loamy and clayey materials that fill the depression, with wide valleys of river system, rolling hills and without great reliefs. Loamy materials occupy the lower areas. The calcareous materials are on the most relevant topographic zones, where the altitude can reach 600 m, the karstic morphology is been developed by intense fracturation processes and dissolution phenomena. The divide line between both zones is coincident with the course of the Guadajoz River. Drainage network is dendritic type, quite dense in some sectors; which shows evident erosive process of impermeable grounds and remontant gully erosion. Fertile soil of valleys and terraces has a greater agricultural potential.

2.1. Evaluation of sediment load

Sediment loads were quantified on an empirical model based on GIS data. Different models can be found to estimate sediment yield (Vanmaercke et al., 2015). For application at the basin scale, the holistic approach of the semi-quantitative models is regarded as an advantage over the traditional, reductionist, and often physics-based models (De Vente and Poesen, 2005). The *Factorial Score Model* (FSM) was used to estimate sediment yield at the basin scale of this study. This model handles semi-quantitative variables. The main reason for using it was because this model is based on a dataset of measured sediments accumulated in 60 Spanish reservoirs, explaining 72% of the variability found in reservoir sedimentation rates (De Vente et al., 2005). It is the closest approximation to the actual production of sediment measured in the field among semi-quantitative models

To estimate the sediment yield, the FSM uses five factors: lithology, vegetation cover, topography, basin shape, and the presence of gullies. A score is given for each factor, with a score of 1 indicating an expected low contribution to soil erosion, sediment production and delivery to the stream; a score of 2, a moderate contribution; and a score of 3, a high contribution. Summaries of the characteristics of the model and each factor can be seen in Table 1.1.

A problem with these holistic semi-quantitative models is the use of grouped variables to characterize the basin. Therefore, it can be difficult to determine a rating for each factor that characterizes the entire drainage basin in large basins with a wide variation in environmental conditions (De Vente and Poesen, 2005). To avoid this homogenization of the basins characteristics, each basin was divided into sub-basins, according to the network of the sampling sites used by Fernández-Delgado et al. (2014) to assess the current status of fish community. Thus, the analysis of the model factors was performed at the sub-basin level. In the end, each basin had a total of 52 sub-basins, which were defined by 52 fish sampling reaches (Fig. 1).

A Geographic Information Systems tool was used to determinate the area of each sub-basin in relation with the sampling point and the water that drains to that point by run-off, established by watershed lines. Presence of gullies, vegetation cover and sub-basin shape (sub-basin factors used in the FSM) were detected and evaluated from aerial photographs from 2011 (PNOA, www.ign.es) and GIS was used also to analyze and quantified them.

The method used by the FSM to characterize the gullies, was found somewhat ambiguous for adequately determining the weight of this factor on the specific sediment yield estimation. More specific ranges for gullies were used in the model to improve the accuracy of the quantitative description of this factor, based on the percentage of the sub-basin area occupied by all gullies present in the sub-basin. This new classification proposal from the standard FSM approach can be seen in Table 1.

As soon as the factors scores were determined for each sub-basin, the *FSM Index* is calculated by multiplying the five scores. Mean annual area-specific sediment yield (henceforth Specific Sediment Yield, *SSY*), in Tones •Km-2 •year-1, was calculated using the formula and parameters given by the model, introducing the value of the *FSM Index* and the area of each sub-basin:

$$\mathrm{SSY} = 4139{\bullet}Area^{-0.44} + 7.77{\bullet}FSMIndex^{-310.99} \quad (1)$$

Absolute Total Sediment Yield (ASYT) was obtained from *SSY* estimates of each sub-basin, in Tones/year, as well as the fraction of Absolute Fine Sediment Yield (ASYF), which are those that have impacts on the ecosystem. According to Rinaldi et al. (2011), the coarse fraction relative to the total sediment varies between 0.15 and 0.33. In this study, a fraction of 0.75 fines present in ASYT for each sub-basin was used as an intermediate value.

Sediment yield contributions of the sub-basins that are upstream and the accumulation areas of the influent watersheds were added to the SSY value obtained at every sub-basin, based on a stream flow diagram. By doing so, we were able to estimate an average value in sediment yield, in specific and absolute terms for each of the sub-basin where fish data were available.

Absolute total and fine sediment loads (SST and SSF) were also estimated. For this purpose, the average flow per unit area in both rivers was calculated using the database of gauging stations from the official network (CEDEX) and the area of the drainage basin of