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).

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:

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

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

Fig. 1. – Bebezar and Guadajoz river basins maps in the Guadalquivir Basin. Each basin is subdivided into sub-basins from the sampling points of fish species inventory.

Table 1
Description of the Factorial Scoring Model (FSM) factors. Modified from De Vente et al., 2005.

Factor	Score	Description
Topography	1	Very gentle slopes near main rivers; elevation difference <200 m within 5 km
	2	Moderate slopes near main rivers; elevation difference 200–500 m within 5 km
	3	Steep slopes near main rivers; elevation difference >500 m within 5 km
Vegetation cover	1	Good contact cover of the soil (> 75% surface protected)
	2	Moderate contact cover (25–75% protected surface)
	3	Poor contact cover (< 25% protected)
Gullies	1	Percentage of gullies area occupied in the sub-basin < 0.3%
	2	Percentage of gullies area occupied in the sub-basin < 1%
	3	Percentage of gullies area occupied in the sub-basin > 1%
Lithology	1	Dominant limestone, sandstone or conglomerate (low weathering degree)
	2	Dominant Neogene sedimentary deposits (gravels, etc.)
	3	Strongly weathered (loose) material loams and/or marls
Basin shape	1	Elongated basin shape with one main river channel
	2	Between elongated and (semi-) circular basin shape
	3	(Semi-) circular basin shape with many rivers draining to the mouth

Table 2

Description of the mesologic characteristics, fish community and sediment variables of Bembézar and Guadajoz basins.

	Bembézar basin					Guadajoz basin				
	Minimum	Percentile 10	Median	Percentile 90	Maximum	Minimum	Percentile 10	Median	Percentile 90	Maximum
Accumulated area (km^{-2})	14.43	22.54	71.55	450.18	1015.88	6.19	25.68	119.71	2236.74	2409.56
Altitude (m.a.s.l.)	73	201	337	496	581	94	155	390	668	1068
Average slope (%)	0.175	0.268	0.553	1.373	5.210	0.030	0.145	0.565	1.095	2.720
Channel width (m)	4.2	5.7	10.6	19.7	44.1	4.7	6.9	11.2	26.2	40.3
Wetted width (m)	1	2.105	4.645	7.45	8.83	0.7	1.54	3.4	8.56	10.3
No. of native species	0	0	3	5	6	0	0	1	2	2
No. of alien species	0	0	0	1	2	0	0	0	0	1
Richness	0	0	3	6	8	0	0	1	2	3
Total fish density (ind m^{-2})	0	0	1.16	2.05	2.69	0.00	0.00	0.47	1.98	2.59
Ls density (ind m^{-2})	0	0	0.28	1.50	2.14	0.00	0.00	0.45	1.97	2.59
Ia density (ind m^{-2})	0	0	0.48	1.63	2.21	–	–	–	–	–
Sp density (ind m^{-2})	0	0	0	0.09	1.43	–	–	–	–	–
Pw density (ind m^{-2})	0	0	0	0	0.97	–	–	–	–	–
Cp density (ind m^{-2})	0	0	0	1.38	1.75	0.00	0.00	0.00	0.02	1.28
Il density (ind m^{-2})	0	0	0.12	1.44	2.27	–	–	–	–	–
Ah density (ind m^{-2})	0	0	0	0.37	2.12	–	–	–	–	–
Cc density (ind m^{-2})	0	0	0	0	0.62	–	–	–	–	–
SSY (t km^{-2} y^{-1})	366	528	701	867	1,154	58	321	921	1,341	1,825
ASY$_T$ (t y^{-1})	15,675	18,248	35,260	206,934	658,890	11,289	21,573	75,558	714,857	1,157,363
ASY$_F$ (t y^{-1})	11,756	13,686	26,445	155,200	494,167	8,467	17,413	57,202	553,626	885,505
SS$_F$ (mg l^{-1})	950	1,101	2,102	6,411	7,361	400	735	2,093	4,753	12,790

each gauging station. There were one gauging station in Bembézar basin (with series of 9 years) and in Guadajoz basin two (with series of 41 and 39 years). Absolute sediment load was obtained as the coefficient of the ASYT and ASYF, in mg/l and the corresponding water inflowing at each sampling site.

The Bembézar and Guadajoz rivers are flow-regulated by reservoirs. Guadajoz river has been affected by the trapping effect of two reservoirs: Víboras reservoir in the head and the Vadomojón reservoir in the middle of the basin. Nevertheless, the two reservoirs in the Bembézar river have not affect to the sediment yield estimation because there are situated downstream from the lowest fish sampling site.

Sediment trapping is one of the most important effects of a reservoir (Verstraeten and Poesen, 2000). The Heinemann index was used to estimate the sediment retained by each reservoir. It is a method to predict trap efficiency, using data on a mid to long-term basis. It considers trap efficiency as a function of the capacity/annual inflow ratio (Verstraeten and Poesen, 2000).

For the Guadajoz river, the average sediment retention of a hydrological year (October to September) was calculated, being 92% for the Víboras reservoir and 94% for the Vadomojón reservoir. Therefore, the sediment load contribution is reduced to an 8% and 6% in sampling points below reservoirs, no. 23 and no. 36 respectively (Fig. 1). From the percentage that is not retained by the reservoirs, the finest sediments have been considered to pass (Kondolf, 1997).

2.2. Fish communities

The fish populations of both basins were evaluated in composition and abundances at 52 reaches in each basin (Fig. 1). Fish were sampled by electrofishing in wadeable river reaches 100–300 m in length, depending on its width, during two hours (wading upstream with one or two anodes using 240 V pulsed direct current). Collection via electrofishing began at a shallow riffle, or other physical barrier at the downstream limit of the sample reach, and terminated at a similar barrier at the upstream end of the reach. All data were standardized to river segments of 500 m2 for comparative analysis. All fishes were treated carefully and after being analyzed they were returned to the water (Fernández-Delgado et al., 2014).

The greatest representation of native species in the Bembézar river were *Luciobarbus sclateri*, *Pseudochondrostoma willkommii*, *Cobitis paludica*, *Iberochondrostoma lemmingii*, *Anaecypris hispanica*, *Squalius alburnoides* and *S. pyrenaicus*, all of them Iberian endemic species. On the other hand, a non-native species, *Cyprinus carpio*, was also found. However, in the Guadajoz River, the only dominant and abundant species was Luciobarbus sclateri, but others like *Cobitis paludica*, *Squalius pyrenaicus*, *Cyprinus carpio* and *Pseudochondrostoma willkommii* were scarce and present in only 1–4 sites.

2.3. Data analysis

Generalized Additive Models (GAM) were used to assess the influence of sediments on the density of every fish species. Generalized additive models (GAMs) are non-parametric modifications of GLM where each predictor is included in the model as a non-parametric smoothing function. Since the GAM are a sort of GLM, maximum likelihood methods apply instead of least squares estimation, and they do not assume normally distributed populations of the response variable and of the error terms from the fitted models, allowing other types of distribution besides normal. Therefore, GAMs are often used in the treatment of biological data (Quinn and Keough, 2002), and are useful when there are one or more continuous explanatory variables but there is no *a priori* reason to choose a particular parametric form that describes the relationship between the response variable and the explanatory variables. They have also been used by Mostafavi et al. (2014) for similar purposes as ours.

Log(density [ind. m^{-2}] + 1) of every fish species was used as the response variable of the GAMs. Mesologic variables including sub catchment accumulated area, altitude, reach slope, channel width and wetted width, along with sediment yield and load variables were input as potential explanatory variables of the models. In order to avoid multicollinearity, prior correlation matrices (see Supplementary materials) allowed us to remove correlated (|r-Pearson| ≥ 0.7) explanatory variables from the initial GAMs. After this procedure, altitude, reach slope, cannel width, wetted width, ASY$_T$, SSY, and SS$_F$ remained as potential explanatory variables in Bembézar; but only reach slope and channel, ASY$_T$, SSY, and SS$_F$ width in Guadajoz.

With this independent potential explanatory set of variables, a stepwise backward variable selection procedure was conducted during the GAM analyses. At each step, the variable showing the highest *p*-value was removed, and GAM analysis repeated with

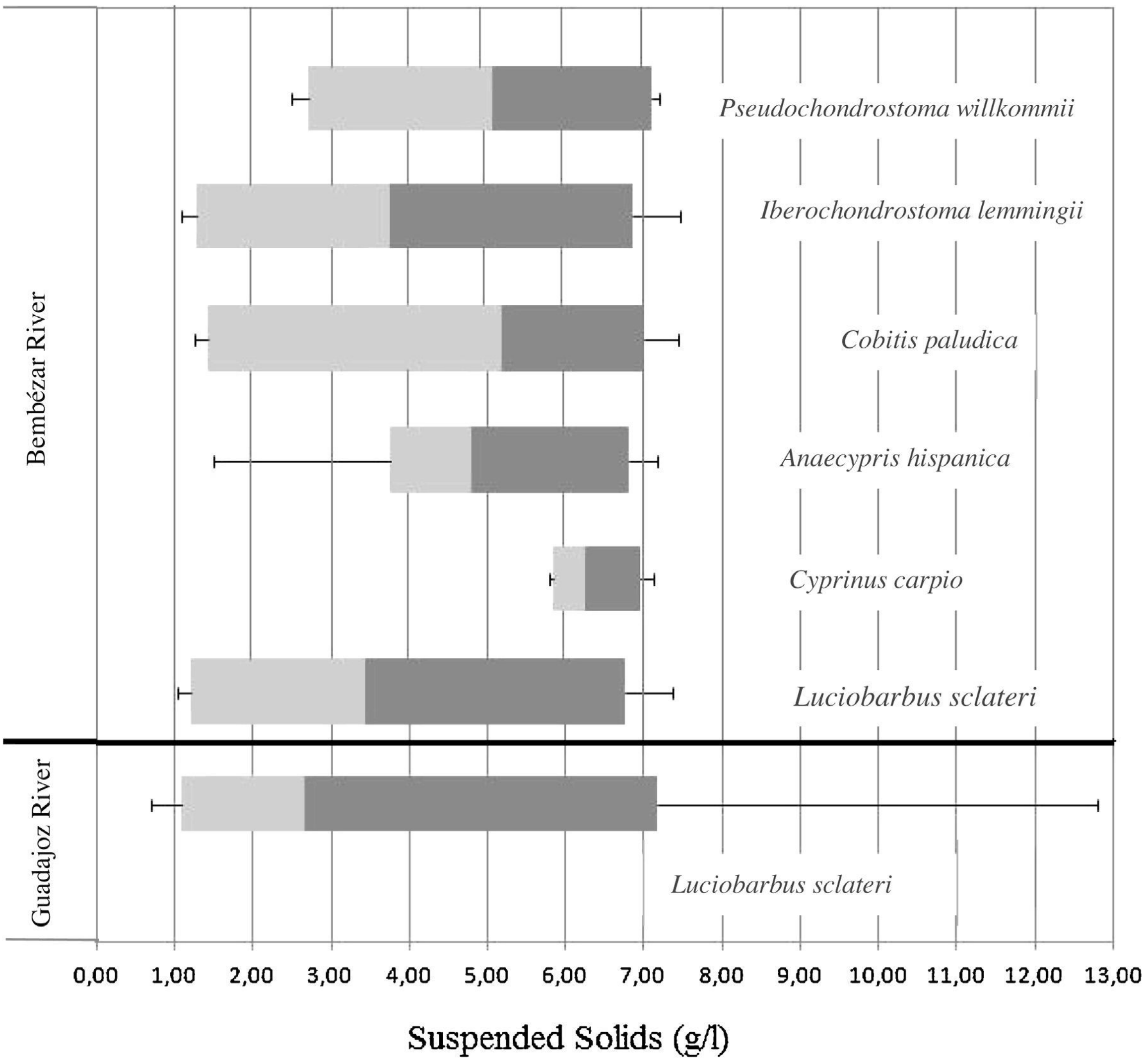

Fig. 2. – Range of tolerances to average suspended solid values for the main fish species living in the studied basins. Absolute maximum and minimum, and the 90, 50, and 10 percentile values are shown.

the remaining variables. The final model was selected when all the remaining variables had *p*-values lower than 0.05 (95% s.l.). Smooth terms were represented using penalized regression splines with smoothing parameters selected by GCV. Gaussian family models were specified. Model complexity was restricted by limiting the number of knots to 3. The GAM model form was therefore $Y = s(X_1, k = 3) + s(X_2, k = 3) + \ldots$

Analyses were conducted in R (R Core Team, 2014) using GAM function from the MGCV package (Wood, 2004).

3. Results

Observed values of mesological, fish community and sediment variables are summarized in Table 2.

3.1. Sediment production estimates

According to the sediment yield and average suspended solids range estimated values (Table 2), sediment yield in the Bembézar river basin are lower than those estimated for the Guadajoz river basin, these being almost twice higher. Mean sediment yield in Bembézar basin was 701 T/Km^2 per year, while in Guadajoz basin was 921 T/Km^2 per year.

In terms of sediment load, both basins present similar average values. This may be due to the fact that water flow in the Guadajoz river is three times higher than in Bembézar river, at the sampling points of the study.

3.2. Fish community

In Bembézar basin, densities of *Iberochondrostoma lemmingii* and *Anaecypris hispanica* were highly correlated to densities of *Luciobarbus sclateri* (r = 0.8) and *Pseudochondrostoma willkommii* (r = 0.9), respectively (see Supplementary material).

Analyzing the suspended solids ranges for different fish species (Fig. 2), extreme values may indicate the tolerance thresholds of each species to SSF estimates for both rivers. The species that present higher tolerance thresholds were *I. lemmingii*, *C. paludica* and *L. sclateri*. This last species has even much greater tolerance threshold as in the Guadajoz basin was found with abundant population at higher SS_F than in the Bembézar basin because is the only representative species throughout the Guadajoz river and it appears in higher thresholds of sediment load. *A. hispanica* appear with certain magnitude of the sediment load in the river flow. *C. carpio* appear at higher values of sediment load than the other species.

Table 3

Model characteristics of the statistically significant factors found by the GAM models and the regression coefficient for each model.

Catchment	Density (ind m-2)	p-value							R^2(adj.)	Deviance explained
		Altitude	Reach slope	Channel width	Wetted width	SSY	ASY_T	SS_F		
Bembézar	*Luciobarbus sclateri*				0,05			0,05	0,27	32,6%
	Iberocypris alburnoides				0,004				0,21	24,4%
	Squalius pyrenaicus	0,01							0,18	21,2%
	Pseudochondrostoma willkommii			0,01					0,17	20,1%
	Cobitis paludica	0,05						0,0003	0,25	28,5%
	Iberochondrostoma lemmingii	0,01		0,0001					0,34	37,4%
	Anaecypris hispanica			0,001					0,21	22,7%
	Cyprinus carpio			0,005	0,03		0,000003		0,54	58,8%
Guadajoz	*Luciobarbus sclateri*					0,002	0,03	0,0004	0,36	45,6%

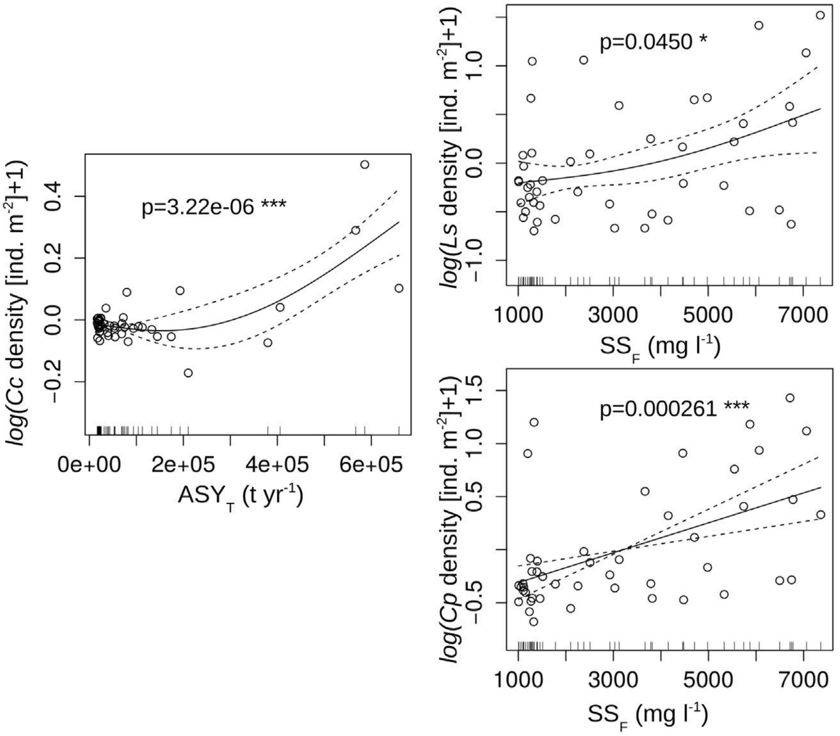

Fig. 3. – Generalized Additive Models (GAM, k = 3) predicting fish log(densities + 1) by absolute sediment yield, ASYT, and fine sediment load,SSF, in river Bembézar basin (Ls: *Luciobarbus sclateri*; Cp: *Cobitis paludica*; Cc: *Cyprinus carpio*).

3.3. Sediments effects on fishes

The best fitting of the models was found for density of *Cyprinus carpio* ($R^2 = 0.54$) in Bembézar basin, and *Luciobarbus sclateri* ($R^2 = 0.36$) in Guadajoz basin.

Densities of Luciobarbus sclateri, Cobitis paludica, Iberochondrostoma lemmingii and Cyprinus carpio were found to significantly respond to the sediment variables (Table 3). The range of values of SSY, ASYT and SSF was noticeably wider in Guadajoz (Fig. 4) than in Bembézar basin (Fig. 3). In both catchments a significant positive relation was observed when suspended fine sediment load, SSF, ranged between 1000 and 7000 (mg l-1). However, a negative effect was detected when values exceeded that range. This was observed in Guadajoz basin (Fig. 4).

No significant effect of specific sediment yield, SSY, was found in Bembézar basin, but in Guadajoz a significant (p = 0.002) negative response of *Luciobarbus sclateri* density was detected.

There was a positive significant response of *Cyprinus carpio* density to absolute sediment yield, ASYT, in Bembézar basin. A negative response of *Luciobarbus sclateri* density to this variable was also found in Guadajoz. However, this species responded positively when values of ASYT increased above the 600,000 t yr^{-1}, which is the upper limit of the range of this variable in Bembézar (Fig. 4).

4. Discussion

The sediment yield is an important indicator of land degradation and the associated reduction in soil resource. In general, values of sediments yield and load in both study basin rivers were high, greater than those often recorded in other rivers in the Iberian Peninsula. Liquete et al. (2009) measured sediments in several Catalonian basins of similar area, and observed specific sediment yields ranging between 94 and 621 T/Km2y and sediment loads ranging among 0.4 and 2,000 mg/l. Vericat and Batalla (2006) reported sediment loads ranging between 27 and 530 mg/l in the Ebro river, which has a higher basin area (85.530 Km2) and greater water flow rates. However, as these authors use different methods to measure sediments than ours, differences in results may be conditioned by them.

We found significant differences in sediment yield between the Bembézar and Guadajoz river basins. In Guadajoz river basin, lithology is mainly composed by materials recently deposited, more

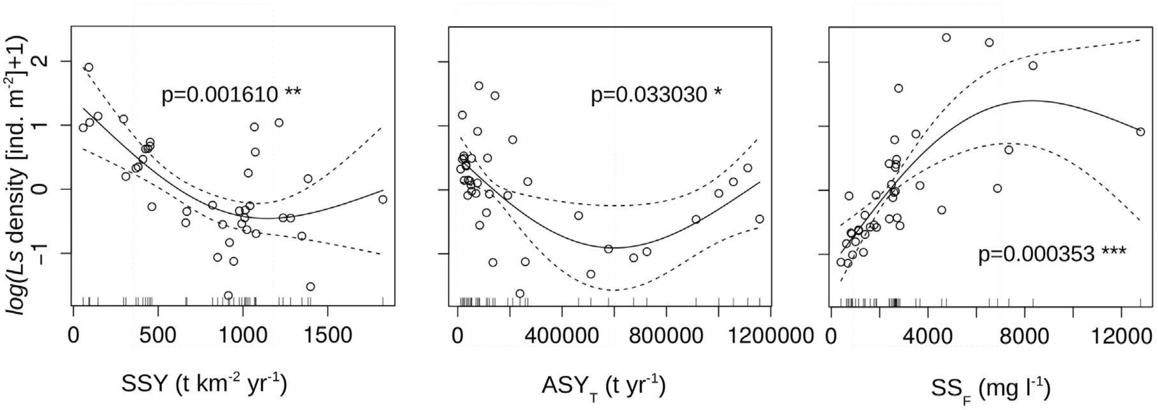

Fig. 4. – Generalized Additive Models (GAM, k = 3) predicting *Luciobarbus sclateri* (Ls) log(densities + 1) by specific and absolute sediment yields, SSY and ASYT, fine sediment loads, SSF,in river Guadajoz basin. Dashed line delimits the range of values recorded at Bembézar basin.

Table 4
Dates and magnitude of eventually episodes of extremely higher sediment load (mg/l) recorder in Valchillón (1), Castro del Río (2) and Santa Cruz (3) sampling stations in Guadajoz river (data from Guadalquivir Hydrographic Confederation).

Valchillón/Date	01/01/1996	26/05/1997	30/05/1998	29/12/2000	11/04/2002	13/10/2005	23/03/2006
Suspended solids ($mg\,l^{-1}$)	7550	5424	4272	12836	12464	9340	24160
Castro del Río/Date	23/11/2000	26/12/2000	12/01/2001	16/10/2003			
Suspended solids ($mg\,l^{-1}$)	28852	13370	10608	120980			
Santa Cruz/Date	26/12/2000	21/11/2007					
Suspended solids ($mg\,l^{-1}$)	22780	15120					

vulnerable to erosion, such as silt and clay. According to Avedaño Salas et al. (1997) many geomorphological and environmental factors, such as the nature, surface area and location of the sediment source zone, together with the relief, slope, transport system, vegetation cover, etc., affect the delivery ratio. A number of studies have shown strong relationships of water quality, water quantity, and run-off to landscape characteristics and have established the significant causal relationship with nutrient and sediment loads (Jones et al., 2001).

Multiple factors are shown to regulate the variability of suspended solids transport at the dynamic (daily) level, including runoff, relief, lithology, rainfall pattern, vegetation protection and basin size (Meybeck et al., 2003). The real values of sediments load in stream might be higher than those estimated in the Guadajoz river because stormy events, which are usual in the Mediterranean climate, have not been taken into account. These events cause high inputs in sediments from the sub-basin into the channel. In the Guadajoz river, very high concentrations of suspended solids were measured in some sampling stations of the *Guadalquivir basin water authority*. Our extremely high simulated values are in agreement with those measured in the official sampling stations (Table 4).

In addition, the land use in Guadajoz basin is dedicated to intensive olive grove, more than 70% of the total area, whereas in Bembézar basin, only less than 20% of the area supports this type of land use. According to Gómez Calero et al. (2008) erosion produced by run-off waters in soils of this sector is due to sloping tillage, and is evident in the olive stumps, indicating erosion rates about half a meter in some cases

A decrease in natural vegetation indicates a potential for future water quality problems. Agriculture on slopes of greater than 3% increases the risk of soil erosion, and this can lead to increases in nutrient and sediment loadings to surface waters (Jones et al., 2001). These olive groves generally have scarce measures to control erosion and soil conservation practices. Consequently, this land use promotes the occurrence of gullies in the slope, increasing erosion and sediment yield. According to Wood and Armitage, 1997; poor management in agricultural practices can lead to a decrease in habitat quality due to increased suspended solids and sedimentation in rivers.

According to the world rivers classification proposed by Meybeck et al. (2003), the Bembézar river basin would be in the range of "very high" in specific sediment yield (1000–5000 Kg/Km2 day) and in sediment load (2000–10000 mg/l). Guadajoz river would be in the range of "very high" in specific sediment yield, and between "very high" and "extremely high" to sediment load (> 10,000 mg/l).

The effects of suspended sediment on stream ecosystems are many and varied. According to Ryan (1991), any increase in sediment carried by a stream could have a detrimental effect on stream ecosystems as well as aesthetic values. Suspended sediment loading on streams may affect stream fauna in several ways, such as increasing drift of fauna, reducing the available habitat for benthic organisms and therefore its density (more than 50% in 24 h), and altering community structure. Reduced invertebrate density and biomass in response to fine sediment deposition can be explained by the actual reduction of interstitial space (Ryan, 1991).

These effects can also affect directly or indirectly the density of fishes. Itís reflected in the health of the population because of direct impacts and/or food chain related effects: it reduces the sustainability of spawning habitat and impedes the development of eggs, larvae and juveniles; it modifies natural patterns of fish migration (Alabaster and Lloyd, 1982); and reduces the abundance of food available due to its impact on photosynthesis and the food chain (Bruton, 1985). Benthic organisms may be smothered by silt at levels well below those having a directly harmful effect on fish. Turbidity may decrease the water temperature as more heat is reflected, which may affect temperature-sensitive species and may also affect efficiency in predation (Bruton, 1985). Under these circumstances the impact is twofold. Not only are the food items reduced in number but they are also harder for visually-feeding fish to locate (Ryan, 1991).

The excess of sediment load can clog the riverbed and bury the macrophytes, reducing the available fish habitat. Sediment also affects adversely their movement in the water as well as their growth rate, reducing disease tolerance or even killing them by clogging gillrakers and gill filaments at higher levels (Bruton, 1985).

Differences in the in fish community capacity and specific composition have been found between the studied catchments. These differences seem consistent with what is known about the conditions of fish community across the Guadalquivir river basin. In the study of Fernández-Delgado et al. (2014) relative at the distribution of fishes in Guadalquivir river basin, it is demonstrated that the right bank showed mean values of richness and density by sub-basin greater than the left bank. Mean Richness in the Guadajoz basin sites were 1.29 species, and in Bembézar was 3.6 species, while density was 48,1 ind/100 m and 69.9 ind/100 m respectively. In addition, there were a higher percentage of sub-basins fishless on the left bank (55% in Guadajoz while 34% in Bembézar basin), which clearly shows a worse state of preservation of the fish fauna in these rivers.

All considered sediment variables range more widely in Guadajoz than in Bembézar basin. When comparing the response of the densities of the sensitive species in both basins, Bembézar shows monotonic responses, whereas Guadajoz reaches some critical values. For instance, the response of *Luciobarbus sclateri* density in Guadajoz is increases monotonically until SSF reaches a value slightly above the upper limit of this variable in Bembézar basin (~70,000 mg l-1). This value can be interpreted as a tolerance threshold for the species. In this regard, the response of *Luciobarbus sclateri* density to SSF is consistent in both basins. The lack of significant response of these sensitive species densities to specific sediment yield, SSY, in Bembézar can be justified by the narrower range of values at the latter basin. Consistently, in Guadajoz basin, the response of *Luciobarbus sclateri* to SSY at the range of values between 350 and 1200 t km-2 yr-1 does not show a clear response. It only changes significantly when the range is expanded from almost 0 to 1,900 t km-2 yr-1. This observed effects reinforce the advice of Austin (2007) about the convenience of extending the study beyond the observed limits of the species to unambiguously conclude about the response curves of species to environmental gradients.

Cobitis paludica responds to SSF in a similar positive monotonic way as *Luciobarbus sclateri*, however this species is extremely scarce in Guadajoz basin. The reason for this scarcity is not clear. However it can be hypothesized that the tolerance threshold of this species to SSF is lower than for Luciobarbus sclateri, or that its response to higher values of SSF is much more pronounced. In any case, it seems clear that *Cobitis paludica* is more sensitive to sediment load than *Luciobarbus sclateri*.

C. carpio density variation is also strongly influenced by sediments. This non-native species tolerates high concentrations of fine sediments. It generates suspended fine sediments as removes accumulated bottom sediments when looking for food, which harms other species (Doadrio et al., 2011) and can cause eutrophication of water accompanied by an increase in turbidity, which leads to reduction of the ability of light penetration (Fernández-Delgado et al., 2014). Because other species are more sensitive to large amounts of sediment yield, *C. carpio* is favored and its density increases with increasing sediment yield. According to Ryan (1991), the general effect of high turbidity on fish communities is that it can favor one fish species over another and thus alter species composition.

The rest of the species present in the Bembézar did not show any significant response to the sediment yield of fine sediment load. Therefore it cannot be concluded that their absence from Guadajoz is due to the higher sediment yield of this basin. The reason for the low fish richness in Guadajoz has to be found in other factors that differ among both basins. At this point it is also unclear why *Cyprinus carpio* is lacking from the fish community in Guadajoz, since its density increases with increasing sediment yield. In this regard, differences in the geologic nature of the materials in the basins might also influence the fish community composition and abundance. The way both factors (i.e. sediments and geology) influence the fish community remains uncovered. However, considering that the range of values of sediment yield in Guadajoz includes the range in Bembézar, the complete absence of some of these less sensitive species from Guadajoz might suggest a synergistic response of fish density to sediments and geology.

It should be taken into account the effect of reservoirs on sediment yield and on fish populations. Ibañez, (1996), determinates that on a seasonal scale, the effects of the reservoirs have been the standardization of the river flow and the virtual suppression of peaks in sediment transport. Without the effect of sediment trapping by reservoirs, sediment yield estimates would be even higher than those calculated in this study, with a consequent greater negative impact on the river ecosystem. On the other hand, Lehner et al. (2011) stated that beyond flow regulation, dams also fragment aquatic habitats, impeding not only the movement of species but also the delivery of nutrients and sediments downstream. Furthermore, reservoirs provide more stable flow conditions on river segments located downstream of them, which benefits to non-natives species; some native species may succumb in these stretch or become isolated in stretches located upstream of these structures (Fernández-Delgado et al., 2014). We have found that the Mediterranean and Iberian barbel (L. sclateri) is able to survive under heavy sediment yields, possibly because has evolved in this type of Mediterranean fluvial habitat and is adapted to them, being competitive with non-native species even in degraded rivers.

The implementations of soil and water conservation programs can reverse these effects, and reduce erosion rates and river sediment loads. According to Walling and Fang (2003), reducing sediment mobilization will also reduce sediment transfer to river channels and thus sediment loads. There is a need to identify those surface waters at greatest risk to high levels of nutrient and sediment loads so that actions can be taken to reduce the risk (Jones et al., 2001). Luedtke and Brusven (1976) suggested that complete stream rehabilitation depends upon two factors: elimination of the sediment source and the ability of the stream to flush out the deposited material. In streams impacted by sediment from industrial or agricultural sources, recovery will be rapid once the input of sediments ceases and if sediment scouring occurs (Ryan, 1991).

Some studies relate a tendency to decrease in the stream flow and sediment discharge with the intensity and extent of human intervention and activities in river basins. In the study of Gao et al. (2011) showed that human activities, such as soil and water conservation programs, environmental rehabilitation campaign, construction of key water control projects and so on, appear to be the major factor of a significant decrease in annual stream flow and sediment discharge in the recent 50 years in the middle reaches of the Yellow River.

In the study of Fernández-Delgado et al. (2014), is underlined the poor state of preservation that presents the autochthonous fish community of the Guadalquivir river basin and the most urgent need to develop conservation plans for these species, otherwise there is risk of extinction in the short term.

5. Conclusions

By the estimation of the sediment yield at the sub-basin scale, the study demonstrate the relation between these estimations and the population density of some fish species presents in two different tributary rivers of the Guadalquivir River. In some fish species, the effect of sediments has a significant effect on their densities, allowing defining tolerance thresholds. In this regard, Luciobarbus sclateri is tolerant to fine sediment load until it reaches a threshold around 8,000 mg l-1. However, it is crucial to sample a wide range of values along the sediment load gradient to detect significant responses of these sensitive species.

Cobitis paludica seems more sensitive to sediment yield than *Luciobarbus sclateri*. However its response might be masked by some combined response to other factors such as geology. The combined effect of geology and sediment load might preclude the detection of a significant response of some fish species that are lacking in basins with high sediment loads (Guadajoz basin) but fail to show clear responses to this variable where it has moderate values (Bembézar basin).

With high values of sediment yield, above a median value of 75,500 t/y, as happened in the Guadajoz basin, it can be taken into account the effect of exclusion that could suffer the most sensitive species in the community to the sediment yield, as well as other factors that could modulate their density too, as latitude or the width and deep of the riverbed. *L. sclateri* is the species with greatest abundance in both rivers and a wide tolerance to sediment yield, as was been observed.

The recovery of the native fish community is likely to depend on the reduction of the sediment yield produced by erosive land uses, as well as others factors, such as flow regulation.

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