Response Curves of Hydrological Variables for Riparian Woody Species, Oriented to Water Management of Mediterranean Rivers in Spain

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Abstract: The spatial distribution of the main riparian woody species in two natural sites was studied in two Mediterranean rivers (Cabriel and Mijares) of the Júcar River Basin District. Five hydrological variables were considered (inundation duration, inundation duration during the growth period, continuous inundation duration, inundation frequency and plant elevation above base flow). The main species were compared, in order to assess a possible aggregation of species into functional groups or hydrological guilds. Response curves for each species and study site were constructed and compared among species. The differences were discussed by species and variables, based on the hydrological conditions and the soil types. The results are relevant for the potential definition of riparian guilds of hydrological response, as well as to integrate riparian vegetation into water management decisions, especially through the assessment of environmental flow regimes in Mediterranean rivers.

Keywords: riparian vegetation, response curves, functional groups, hydrological guilds, Mediterranean rivers, Júcar River basin.

Introduction

Riparian areas are very important in semiarid regions, which is the situation of most Mediterranean basins in the East Spain. Their habitats are characterized with a high level of biodiversity, due to the interactions of morphological and biological processes of terrestrial and aquatic ecosystems. However, they are suffering an important degradation, because many processes are altered by human activities like agriculture, channelization, urbanization, pollution, and livestock concentration. Spain is one of the countries with the greatest number of large dams per inhabitant in the world (World Commission on Dams, 2000), and flow regulation has reduced the frequency and duration of extreme hydrological events in the riparian environment, such as high flows. Flow variability is one of the main factors controlling the morphological processes and the habitat availability for seedlings establishment, as it is recognized in multiple scientific studies (Richards *et al.,* 2002).

The hydrological and hydraulic conditions in a river segment are the main drivers of the morphological processes, the presence of recruitment, and the distribution of riparian species; therefore it is possible to observe a spatial pattern of species or plant guilds, along a gradient approximately perpendicular to flow. These patterns have been studied, but in some cases without a quantitative assessment of the hydrological gradients controlling such patterns. The quantitative study of those gradients is very important in regions where water resources are scarce, and riparian vegetation should be integrated into the water management to allow its regeneration and conservation. This is the case of the Mediterranean rivers, the framework of this study, which aims to incorporate the riparian forest as one more ecological criterion in the water management decision-making.

The specific objectives of this study were:

1) To assess differences in hydrological conditions for the development of dominant riparian woody species and their potential grouping in guilds of hydrological response.

2) To show and compare response curves of elevation above base flow and four hydrological variables for dominant riparian woody species.

Materials and Methods

The study sites were selected in Mediterranean rivers of the Júcar River Basin (East Spain). Two segments were selected in unregulated sites with nearly-natural conditions, based on aerial photographs, field observation of plants diversity, availability of hydrological records and riparian quality. In the river Mijares, the segment was located near to the town of Mora de Rubielos (Teruel), and in the river Cabriel, near Carboneras de Guadazaón (Cuenca).

At each site, hydrometry was done along cross sections perpendicular to flow in order to build and calibrate a 1-dimensional hydraulic model, with the software RHYHABSIM (Jowett, 1989). The cross sections were distributed along the segments to record the topographic conditions (profile of the river bed, banks and floodplain), hydraulic and biotic conditions (presence of riparian species).

To study the spatial distribution of the main riparian species (location and elevation above water surface), a geo-referenced inventory along the same hydraulic cross sections was done. For this task a GPS (RTK) and a total station were used. The inventory followed the *line intercept method* (FIREMON, 2003), and the beginning and end of each plant's vertical projection (or crown of the tree) was recorded on each transect.

For all the individuals, the height, diameter at breast height (DBH) and diameter at ground level (DGL) were recorded. For a subsample of plants, core samples were taken using Pressler drill, which allow the estimation of their age and development of age-diameter relations by species. These relations were used to estimate the age of all the plants recorded in the inventory and therefore to calculate the lifetime period of each plant. Finally during such time period, based on daily average flow records, five variables were calculated for each plant:

- *Inundation duration* (V1), as number of days per year that water covers the whole root system. This variable is one of the most frequent in the study of hydrological responses of riparian vegetation. The average data for each plant, during its lifetime period, was considered as an independent data for the analyses (same in the following variables).

- *Inundation duration* (number of days per year) *during growth period* (V2). The growing season was estimated, in this Mediterranean area, as the period of spring and summer, i.e. approximately 6 months.

- *Continuous inundation duration* (V3), as average consecutive number of days per year when the whole root system is inundated.

- *Inundation frequency* (V4), as times per year that an independent hydrological event causes the inundation of the root system. The calculation of this variable involves estimating the flow that would cover the whole root system, and then calculate the number of separate floods that equal or exceed that value per year.

- *Plant elevation above water elevation at base flow* (V5). The base flow was calculated using the normal hydrological years. The years with an average flow between percentiles 25 and 75 were considered as normal years. The calculation was focused on the low-flow periods and the trends during that time.

For comparison among species the non-parametric Kruskal-Wallis (K-W) test was applied. To build the response curves, the frequency histograms for each variable and site were enveloped with a curve; these curves were normalized to the range 0-1, as habitat suitability indices. To fill the gaps due to the lack of data in certain intervals, we used the criteria of maintaining suitability index not smaller than 0.5 within the interquartile range of the data distribution. Intervals further than percentile 95 % were considered with null suitability (0.0).

Results

Among all the riparian woody species recorded in the field work, only those with larger sampling size were analyzed. This information is summarized in table 1.

Table 1. Sampling size of the riparian woody species in each study site, and species' codes.

Riparian specie	Code	River Cabriel (N)	River Mijares (N)
Populus alba L.	PA	294	0
Populus nigra L.	PN	116	110
Salix alba L.	SL	34	28
Salix eleagnos Scop.	SE	75	46
Salix purpurea L.	SP	76	178

The data distribution for the species mentioned above was compared, to assess a possible aggregation of species into functional groups or hydrological guilds. In a first observation, there were no evidences of groups in the river Mijares, and the proportion of outliers was relevant. Consequently, 10 % of the extreme cases were eliminated in order to clarify the pattern; the new data set was used in the box-plots shown in the right column of figure 1. In the river Cabriel, the aggregation of species was clearer, so the data were not cut (data in left column of figure 1).

In the river Cabriel, the species presented significant differences in terms of elevation above base flow (K-W p <0.01). The box-plots suggested two groups; one of *Salix alba* and *Salix purpurea,* and other with *Populus alba*, *Populus nigra* and *Salix eleagnos* (being *P. nigra*, the one with higher median in this second group).

The same groups remained with respect to the first hydrological variable, i.e. inundation duration (K-W p <0.01). However, the aggregation was not as obvious as in the previous case. In this variable, the overlap among species was higher than in the rest of the variables. Despite this overlap, there were significant differences among the 5 species in the variables 2, 3 and 4 (K-W p <0.01).

In the river Mijares, elevation above base flow suggested the presence of two groups, confirming significant differences among the four species (K-W p <0.01). A first group would be integrated by *S. alba* and *S. purpurea* and a second group by *P. nigra* and *S. eleagnos*.

In the first variable, the overlap was greater, being only highlighted *S. alba*, with a longer inundation duration (K-W p <0.05). The second variable (inundation duration during growth period) also indicated a possible grouping of *P. nigra* and *S. eleagnos*, as well as *S. alba* and *S. purpurea* (K-W p <0.05 for the test PN-SE *versus* SL-SP).

The fourth variable (inundation frequency) confirmed the same trend (K-W p <0.05) that in variable one, and the third variable (continuous inundation duration) did not indicate a statistical significance.

The fifth variable (elevation above base flow) suggested a similar pattern in both rivers, grouping *S. alba* and *S. purpurea*, nearer the water, and *P. nigra* and *S. eleagnos* (and *P. alba* only in the case of river Cabriel) in higher elevations.

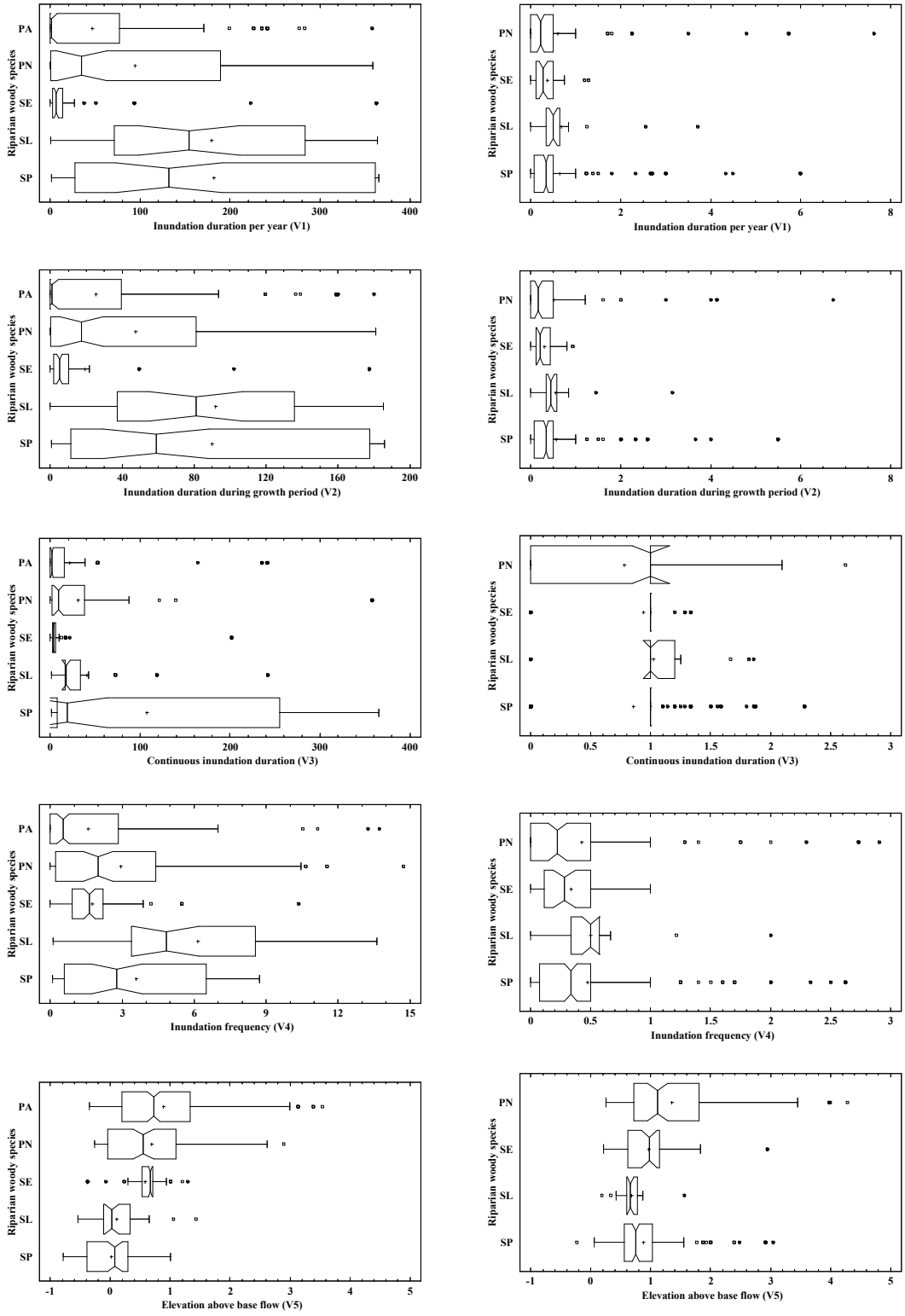

Figure 1. Boxplots of the five variables for both study sites (river Cabriel in the left and river Mijares in the right). In the axis of abscissas are represented the riparian species studied (codes detailed in table 1)

The response curves for each plant and study site were constructed and compared across sites. The response curves in the 2 natural sites were not integrated into one curve due to the evident differences between sites; therefore a curve by variable and species was obtained in each site. Here are shown the curves for the river Cabriel (Figures 2 and 3), where one more species and clearer differences were found.

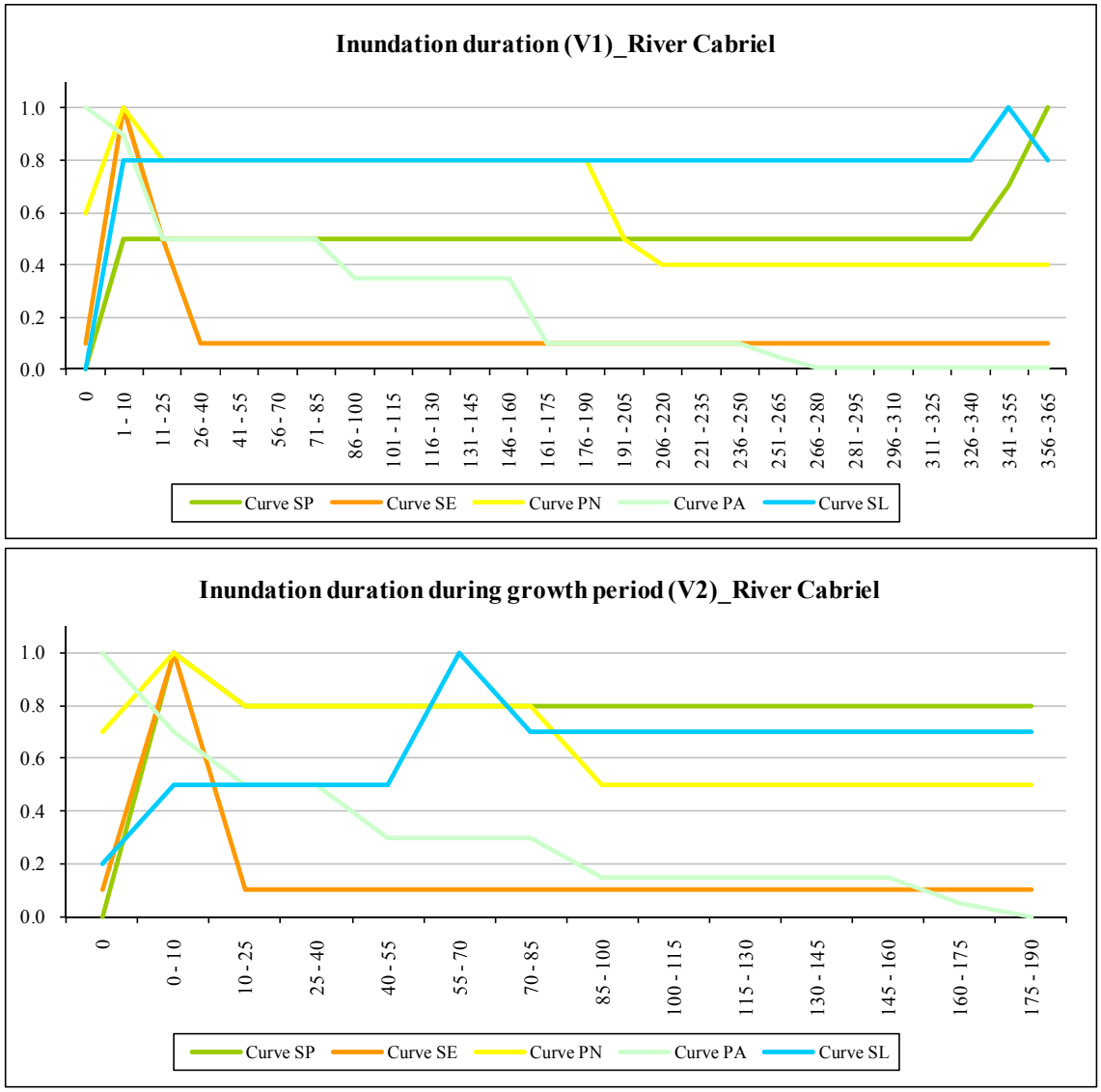

Figure 2. Response curves of the hydrological variables V1 and V2 in the river Cabriel (codes detailed in table 1).

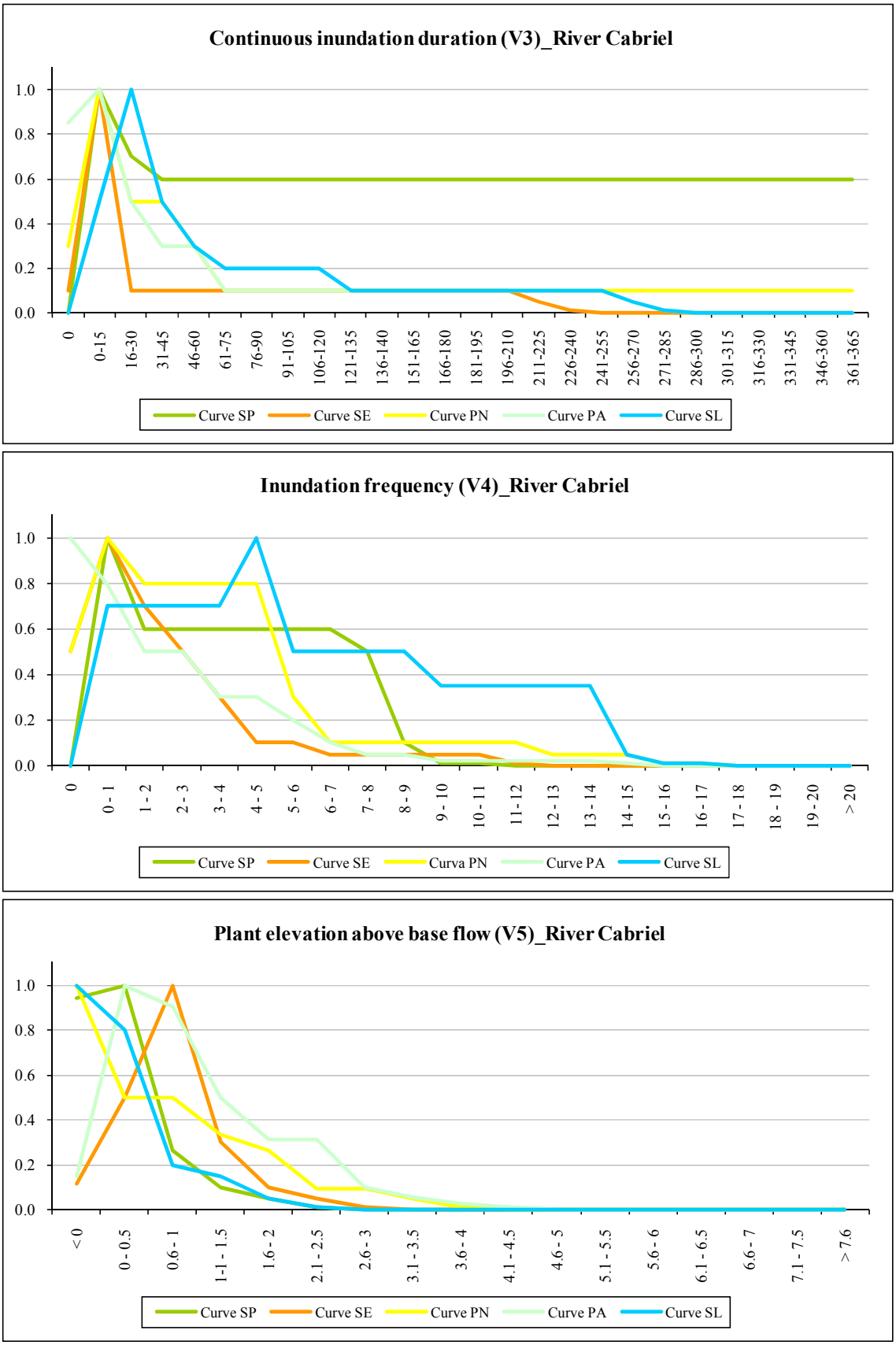

Figure 3. Response curves of the hydrological variables V3, V4 and V5, in the river Cabriel (codes detailed in table 1).

A clear overlap was identified in the response curves of hydrological variables, in the river Cabriel, mainly in the first four variables. The curve for inundation duration (total) show the difference of *S. alba* and *S. purpurea*, with longer inundation compared to the rest (with maximum suitability within 341-365 days per year). However, considering the growth period alone, only *S. alba* showed the more remarkable distribution, with longer inundation period (maximum suitability between 55-70 days). As it was mentioned before, in the fifth variable *P. nigra* and *P. alba* obtained the larger range of variability, with some individuals located higher in the banks in relation to others.

Looking at the response curves it is possible to highlight some similarities among species. Related to inundation duration (V1), *S. alba* and *S. purpurea* have showed the same behaviour. These two species are capable of resisting long periods with their roots under water. In contrast, *S. eleagnos* and *P. alba* were the species with lower number of days per year with water covering their whole root system. The same results were obtained for the variable 2 (inundation duration during growth period). Respect to the third variable a clear overlap among the species was found, but *S. purpurea* presented higher suitability for longer periods of continuous inundation; in fact, this species was dominant in the vegetated islands inside the channel, therefore, this species could be described as the species that best supports the continued flooding of their roots. Similar conclusions can be drawn about the fourth variable (inundation frequency). *S. alba* had an irregular performance related to it, which could be explained by the low sampling size and the distribution of its own dataset.

Discussion

Significant differences were found among species based on hydrological variables, being more evident differences in the variable elevation above base flow. The presence of 2 groups or potential hydrological guilds was consistent in the 2 rivers. Other studies in Mediterranean rivers found significant differences among species using the elevation above thalweg (Garófano-Gómez *et al.,* 2009), in flow-regulated sites; however, in this study we considered more species and in near-natural conditions, resulting in clearer differences.

In the assessment of hydrological variables, the use of a binomial form of inundation (yes/no) is one relevant limitation; i.e., in this study the plants were inundated when the water surface elevation was higher than the base of the plant. It means that in sites where the slope of the bank, in the cross-section, is very gentle, the plants in a wide range of the riparian zone can have a great part of their roots in the water; despite this fact, the inundation duration could be only a few days, and it depends on the rating curve developed in the hydraulic model. The fact that water table in the aquifer is considered horizontal is another limitation given the hydraulic gradient from the aquifer to the river or vice versa, and the potential effects of the capillarity fringe in diverse texture conditions. In consequence, we suggest that this empirical approach could be overpassed with the use of a gradient of inundation, e.g. the percentage of the root's elevation range that is below water table at a certain time.

Starting from data of plants location and elevation, the determination of the flow for inundation also depends on the rating curves developed in the hydraulic model. In this step, the accuracy of the model is critical to the final step of species aggregation/grouping. However, the assessment of the roughness in heterogeneous and densely vegetated habitats is one of the factors that makes difficult to get an accurate rating curve; in any case we consider that the field survey in different water conditions (low, medium, high water level in the riparian zone) is the best option far from any assessment by 1-D or 2-D hydraulic simulation.

Other physical factor, the slope of the banks, makes the rating curves more or less steep; therefore, in sites with more gradient, river Cabriel, it is more probable to find relevant differences among species. We suggest this is one of the factors that make the difference between the results in the two rivers. The other relevant factor could be the soil texture. In soils with coarse substrate and high transmissivity, the lateral hydraulic gradient can be smaller; therefore the floodplain and banks topography (i.e. elevations) is important to evaluate and compare the access of the plants to the water. However, in soils with fine texture, where the height of the capillary fringe is very relevant, the access to water is facilitated and the effect of topography is reduced in some degree. We suggest that the interaction of these 2 factors, banks slope (higher in river Cabriel) and soil texture (finer in river Cabriel) have determined the species differences in one river and not in the other.

Finally, the empirical results of plant observations gave interesting results, but also remark the practical difficulty of the development of hydrologic response guilds. Other approaches like the hydrological

modelling (Francés *et al.,* 2002; Francés *et al.,* 2007) coupled with soil moisture and riparian species physiology (Morales de la Cruz & Francés, 2009; Real *et al.,* 2010) are very promising in the study of riparian plants guilds and their spatial distribution, as well as the assessment of environmental flow regimes and water management scenarios for riparian conservation.

This study has the potential of improving the design of river restoration projects (reforestations or plantations), and of incorporating the riparian vegetation in the assessment of ecological flow regimes. Riparian forest is nowadays an element to be considered during the study of environmental flow regimes, which is explicitly recognized in the Water Framework Directive, and in the actual law and legal instruction for hydrological planning in Spain.

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