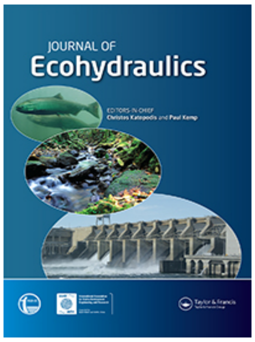

Journal of Ecohydraulics

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ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tjoe20

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To cite this article: Diego García de Jalón, Daniel Díaz-Alba, Vanesa Martínez-Fernández, Paula Lucía-Núñez & Marta González del Tánago (2023): Exploring willow decline in an over-greening riparian corridor (River Jarama, Spain), Journal of Ecohydraulics, DOI: 10.1080/24705357.2022.2162988

To link to this article: https://doi.org/10.1080/24705357.2022.2162988

JOURNAL OF ECOHYDRAULICS
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Exploring willow decline in an over-greening riparian corridor (River Jarama, Spain)

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ABSTRACT
The analysis of willow forest decline in the Jarama River has been assessed through the study of morphological river conditions in three periods (1956, 1998 and 2018) together with active channel mobility ratios and changes in channel planform and vegetation coverage. Species composition of current riparian corridors at river segment scale and monitored natural recruitment of pioneer species at local scale have been studied. Jarama River has changed from wide active wandering towards narrower meandering channels with dense and continuous riparian over-greening corridors, in which willow formations are threatened, and drought-tolerant species have colonised it. Landform evolution shows an intensive 'maturation' associated with 'anthropisation' processes during the first period, while stability dominates nowadays. Results show a generalised aging and progressive mortality of shrub willows and the expansion of forests dominated by *Fraxinus angustifolia*, likely associated to the progressive reduction of channel mobility and the lack of bare gravel bars for pioneer recruitment. The dominant willow species is *Salix salviifolia*, a drought tolerant willow that has been able to withstand the processes of 'maturation' and channel narrowing being widely distributed throughout the riparian section. On the other hand, other strict pioneer willows such as *Salix eleagnos* and *Salix purpurea* are very rare and are found in the few gravel banks that remain on the shore. Results predict a gradual disappearance of willows in the Jarama River as there is no significant recruitment, and they would last as long if those old specimens may survive.

ARTICLE HISTORY
Received 24 March 2022
Accepted 24 November 2022

KEYWORDS
Riparian vegetation; vegetation encroachment; over-greening; *Salix*; river

Introduction

Present anthropised rivers are part of the global consequences of human behaviour. The construction of dams along rivers, river channelisation, the conversion of floodplain areas into artificial surfaces (e.g. urban, agricultural and industrial uses) or the practice of gravel mining in channels are among the most relevant direct pressures on fluvial ecosystems with many examples all over the world (e.g. Gordon and Meentemeyer 2006; Graf 2006; González del Tánago et al. 2016; Calle et al. 2017).

Moreover, other human actions indirectly cause relevant alteration of rivers at watershed scale such as interbasin water transfers (Chen et al. 2001: Fazelpoor et al. 2022), the abandonment of rural areas, (e.g. García-Ruiz and Lana-Renault 2011; Scorpio and Piégay 2021); the use of pesticides and nutrients added in agriculture (e.g. Zhang et al. 2016; Parveen et al. 2017). All of these pressures, in summary, reduce the magnitude and frequency of floods, increase summer flows in the case of regulated rivers, decrease sediment supply in afforested catchments, laterally stabilize the rivers and increase the availability of the nutrients for vegetation (e.g. Shafroth et al. 2002; Nilsson et al. 2005; Merritt and Poff 2010; Lorenzo-Lacruz et al. 2012; Morán-Tejeda et al. 2012; Martínez-Fernández, González del Tánago, et al. 2017). The generalised consequences of river dynamism lead to the stabilisation and narrowing of river channels, favouring the establishment and growth of riparian vegetation with the consequent lack of bare spaces necessary for the recruitment of pioneer species as willows and poplars (e.g. Kondolf et al. 2002; Lobera et al. 2015; Martínez-Fernández, González del Tánago, et al. 2017; González et al. 2018; García de Jalón et al. 2020). Moreover, in these stabilised landforms, pioneer species adapted to disturbance regimes as Salicaceae, compete at a disadvantage with other species with also includes those with an invasive character such as the remarkable cases of expansion of non-native Tamarix and *Elaeagnus angustifolia* in regulated rivers of the western US (e.g. Shafroth et al. 2002; Merritt and Poff 2010).

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Alpine rivers that have been straightened channelised have developed alternate gravel bars to dissipate the kinetic energy. In the River Isere, these gravel bars were inexorably colonised by vegetation (Salicaceae species) since 1955 on the upper reaches affected by a major flow diversion, and sediment mining, and since 1975 on the lower ones where bars migrate intensively (Serlet et al. 2018). A similar bar pattern was found on River Rhine (Caponi et al. 2019) where in the upper reaches with more stable bars vegetation has constantly increased since 2005, while in downstream reaches bars with larger migration rates remain bare.

Riparian vegetation encroachment has often recently occurred in Spanish rivers, changing from bare sand/gravel bars to green lands covered with woody vegetation (García de Jalón et al. 2020). Although the succession of recruitment to mature vegetation is a natural phenomenon, the rate of change has been affected by human activities caused by alteration of the flow and sediment regimes, but also by a generalised eutrophication and the climate change background. This anthropogenic process with intensive vegetation encroachment is what we call 'riparian over-greening'. In this context, this paper aims to explore the main drivers inducing the progressive over-greening process in the riparian corridor and the observed willow forest decline. The results could be useful to guide managers and practitioners to resolve what factors prevent the regeneration of willows, and provide solutions for their correct recovery, particularly in the Jarama River. Antecedents on the riparian species recruitment are rare. Only Mora-Navarro (2004) studied the recruitment in a site located at the medium River Jarama founding seedlings and saplings of Salicacea (*Populus nigra*, *Populus alba*, *Salix alba*, *Salix purpurea* and *Salix salviifolia*) at densities up to 65.1 stems/m^2.

Methodology

Study area

The Jarama River has its source in the western extreme of Ayllón Mountains (Central Spain), and runs south through 190 km long to its confluence with Tajo River. Jarama River basin has an area of 11,600 km^2 being a fluvial network highly regulated mainly due to the proximity of large urban developments around the city of Madrid. The high demand of water supply is satisfied by eight large reservoirs that were constructed at the headstreams, from where water is derived through pipes and canals to the city. This water abstraction causes long river reaches to have their flow greatly reduced, as occurs downstream of the lower reservoirs El Vado reservoir (constructed in 1972) located in the Jarama River and the Atazar reservoir (constructed in 1965) in the Lozoya River, which is its main affluent. These reaches below dams were even completely dry during some years at the end of last century (Sotelo and Sotelo 2013). In addition, the Jarama river, especially in its middle and lower reaches, receives relevant amounts of urban wastewater after being treated, although containing a large amount of nutrients.

The study area is located in the middle reaches of the Jarama River below the large reservoirs, where it runs along open valleys (Figure 1). The study segment comprises a section upstream of the confluence with Lozoya River (reaches 1–3 in Figure 1) and another downstream of this confluence (reaches 4–6 in Figure 1).

Channel forms digitisation

Channel forms were manually digitised (scale 1: 2000) in the orthophotographs of years 1956, 1998 and 2018 in a GIS environment (pixel size of 0.5–1 m, 1 m and 0.25 m, respectively) with the help of a digital elevation model and the slope raster created from LIDAR point cloud (0.5 points/m^2), all these data are available at www.ign.es.

The study river segment was divided into six reaches based on their geomorphological characteristics. First, the zone occupied by the active channel in 1956 was digitised and considered as the reference for the subsequent analysis. Then, 5 cover types were digitised in 1956, 1998 and 2018 images: (i) the active channel as the area covered by water and bare gravel bars, patches with (ii) grasslands, (iii) shrubs, (iv) medium and tall vegetation and finally, and (v) anthropic areas including agricultural lands. This analysis has been carried out using ArcGIS 10.1., the toolbox Fluvial Corridor (Roux et al. 2015), and Global Mapper V.20 to extract the digital elevation model and slope from LiDAR point cloud.

Morphological parameters and indexes

Reaches were selected from those not confined running through open valley (Figure 1). For each river reach, reach length (L), slope (%), active channel area (AC), active channel width in m (ACW), and braided index (BI) calculated as the mean number of channels measured every 25 meters per reach, has been calculated in each year (Egozi and Ashmore 2008). Then, two temporal sub-periods were differentiated, the sub-period from 1956 to 1998, and the sub-period from 1998 to 2018 to calculate several indexes. First, the area of 'New

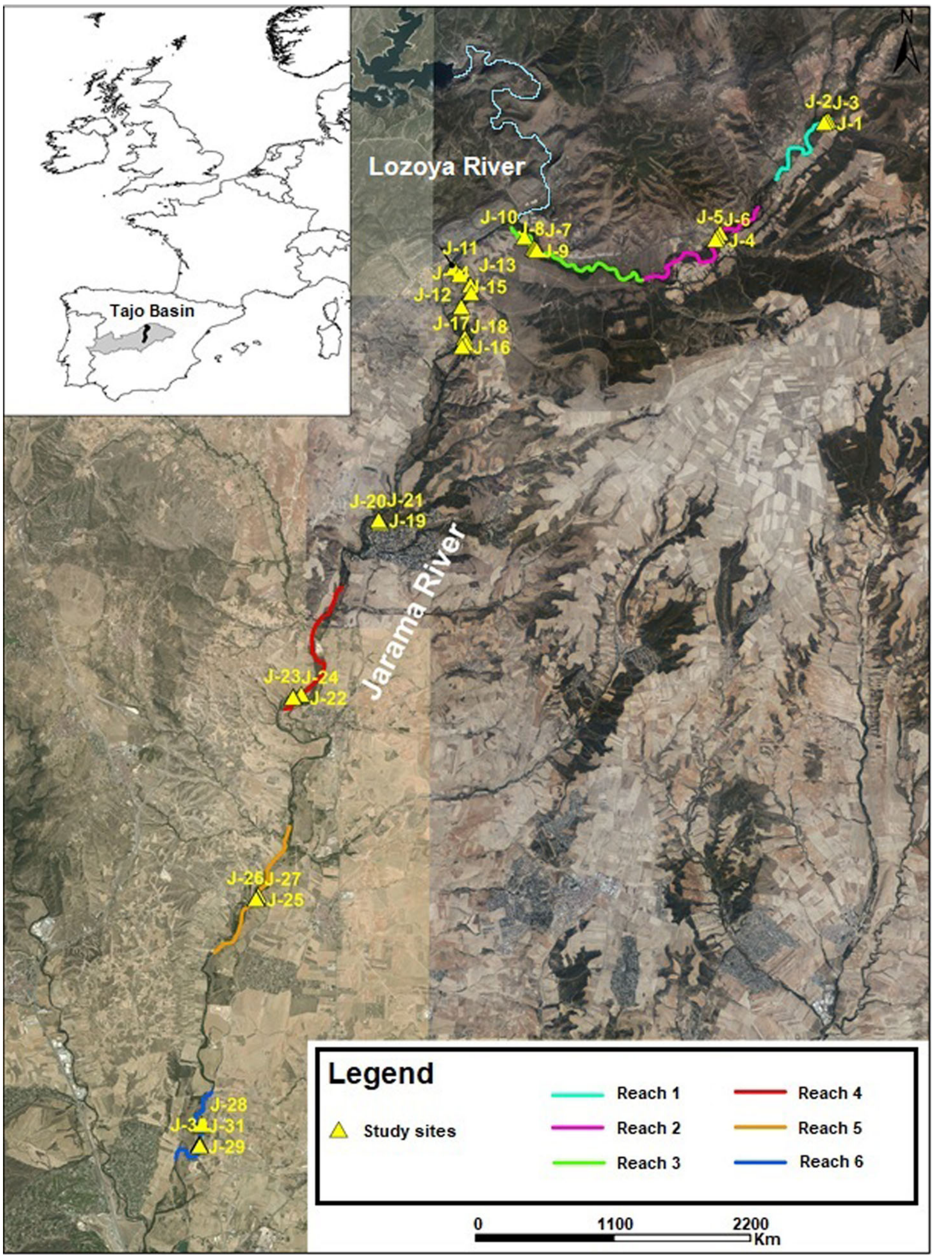

Figure 1. Aerial photo showing the Jarama River study area in the Iberian Peninsula. Reaches for the morphological study and cross-sections were riparian vegetation and *Salix* recruitment was studied are shown.

Channel', the 'Abandoned Channel' and the 'Common channel' were calculated in each year respectively as the new, abandoned and the coincident area of the active channel between two consecutive aerial images. Then, Channel Migration Index (CMI) (Sanchis-Ibor et al. 2019) was calculated following Eq. (1) with higher values indicating high mobility.

$$\mathrm{CMI} = \left(\frac{New\ \ Channel + Abandoned\ \ Channel}{Common\ \ Channel} \right) \tag{1}$$

Moreover, active channel change (ACC) was calculated following Eq. (2) (Richard et al. 2005) with negative values indicating a reduction of the active channel in that period of time, while positive values indicate an expansion of the active channel.

$$ACC = \frac{Active\ \ Channel\ \ (year2) - Active\ \ Channel\ \ (year1)}{year2 - year1} \quad ha/year \tag{2}$$

Hydrological data and analysis

Mean daily discharge data from gauges close to the studied reaches (http://hercules.cedex.es/anuarioaforos/default.asp) were analysed (Figure 1). Particularly data from gauge station #3051 (Algete) were used to analyse flow patterns during the study period. Unfortunately, the series was incomplete for the period 1949–1969. These data were estimated from station #3052 (Mejorada) located several kilometers downstream station #3051 (see Figure 1) and from #3062 (Espinillos) at Henares River (affluent in between).

According to the date of analysed aerial images, three ten year periods were considered: 1946–1956 (before first photo), 1962–1972 and 2008–2018 (before last photo). Characteristics of mean, maximum and minimum annual flows were analyzed for the three periods.

Evolution of landforms and vegetation cover

Five transition classes were defined in order to analyse the temporal evolution of cover types in the fluvial zone (based on Corenblit et al. 2010): *Maturation* process is the transition to a more mature stage as any change that leads to the natural succession in the evolutionary sense of a natural vegetation mass, for example, the natural growth of a mature forest or the change from active channel to shrub patches; *Rejuvenation* which is the inverse change, that is, the regression to pioneer stages of the community; *No change* category represents an unalterable transition in vegetation cover or landforms, particularly we defined *permanent active channel* as those areas remaining as Active Channel areas; *Anthropisation* is defined as the change from natural cover, either bare gravel bar or riparian vegetation cover to anthropic cover such as crops or urban areas; and *Naturalisation* as the transition from anthropic areas to natural covers, either bare gravel areas or vegetated areas.

Riparian vegetation inventory and analysis

Riparian vegetation was inventoried along 31 transects (6 m wide) perpendicular to the main channel, along the middle reaches of Jarama River. Each individual was characterised by the distance from the shore, the diameter at breast height, and the dynamic zones of vegetation-hydromorphology interactions in which they were found following Gurnell et al. (2016). A total of five lateral zones were defined by these authors based on the hydromorphological constraints that are typically found in rivers where soil moisture, flow disturbance regime and riparian vegetation interactions are the key elements. Zone 1 is the perennially inundated zone where the main interaction processes take place between aquatic plant growth, water flow velocity, and erosion or sedimentation of the river bed. Zone 2 and Zone 3 are frequently inundated and both are fluvial disturbance dominated, with coarse sediment and erosion processes being frequent in the former while finer sediment deposition domain in the latter. Zone 4 is occasionally inundated without significant sediment dynamics, then riparian plants used to vary according to the inundation tolerance. Finally, Zone 5 presents a soil moisture regime dominated where the inundation is absent and plants depend on local soil moisture conditions.

Each transect was geolocated by GPS and later at the desk, the altitudinal profile was inferred from the digital elevation model already described, then the position of each individual plant was determined along with its altitude.

Vegetation recruitment analysis

The analysis of riparian species considering both seedlings and saplings was done in two ways: One based on the vegetation inventory transects described before, in which specimens of detected saplings (height < 1.5 m) were located on the cross section and the elevation of plant relative to the water level in the river was measured. The second method consisted on traveling along the riverbed in the study segment searching for suitable habitats for the colonisation and establishment of seedlings, such as gravel and sand bars. In the habitats where seedlings were found, experimental plots (5–10 m^2) were established in June to evaluate saplings survival until the end of September. Plots were marked with metal pegs, delimited with rope and located at different distances between 0 and 2.50 m from the shore. In each plot the number of seedlings and saplings was counted, each plant was identified at species level and its height (cm) was measured. In addition, the presence or absence of herbaceous cover inside the plot was indicated, and the substrate size was characterised by the 50th percentile of the average diameter of at least 100 gravels (D_{50}).

Once field data were taken, the total density (number of individuals/m^2) and the mean height per specie within each plot were calculated. By comparison between June and September data, the rate of survival (September density/June density) was calculated and particularly when the survival rate is greater than 1 the excess would correspond to recruitment in summer. We evaluate the edaphic capacity of the plot by means of the freddle index that quantifies the size of the spaces between the substrate particles. This index is calculated as the ratio of the median diameter of gravels between the dispersion coefficients of the diameter distribution.

Results

Morphological conditions and evolution

Results from the morphological characterisation of Jarama River (Table 1) show that upstream reaches (i.e. R1, R2 and R3) are more confined and present the highest slopes of the river (>0.4%), while the

Table 1. Morphological parameters of the studied reaches in Jarama River: active channel width (ACW) and braided index (BI).

			ACW (m)			BI		
Reach	Length (km)	Slope (%)	1956	1998	2018	1956	1998	2018
R1	3.21	0.47	94.9	38.0	13.1	1.31	1.23	1.15
R2	5.02	0.44	142.9	12.7	11.5	1.44	1.05	1.00
R3	5.11	0.41	104.1	18.2	9.3	1.26	1.16	1.11
R4	4.59	0.24	148.1	17.0	14.9	1.42	1.05	1.05
R5	4.49	0.27	269.1	29.1	18.3	1.98	1.26	1.16
R6	3.10	0.23	137.4	19.5	15.7	1.62	1.14	1.00

reaches located downstream the confluence with Lozoya River (i.e. R4, R5 and R6) present lower slope values (<0.3%). All reaches presented braiding index higher than 1.20 in 1956 reaching maximum values of 1.98 in the case of R5. Results show a steady decrease of active channel width and braiding index along the studied period for all reaches, with the first sub-period presenting a higher width reduction.

Regarding indexes of channel mobility (Figure 2B), CMI in the first sub period was considerably higher ranging from 1.72 in R1 to 11.52 in R5, while in the second period the mobility has been considerably reduced ranging from 0.20 in R2 to 2.46 R1. The process of channel narrowing can be seen in the negative values of ACC for all reaches with maximum loss for the initially widest reach (i.e. R5) (Figure 2A).

Flow regime trends in the study area along the three analysed periods

Figure 3 shows daily average flows for two analysed periods, corresponding to the decades before studied aerial images and a third one intermediate. Table 2 presents average values of mean, maximum and minimum annual flows for each period. Average daily discharge has decreased practically throughout the entire year. Mean annual flow decreased during the last two periods, with a cumulative decrease in both cases (8.7% and 55.3%, respectively) regarding the first one (Table 2). Maximum flows for the last period show a clear reduction not only in magnitude (54%) but also in the duration of the year period when they occur (it used to be from November–June, and nowadays is from February–May). On the other hand, the average annual minimum flow increased along periods, with an increase of 14.2% in the second period, and specially an increase of 419% in the last period compared to the first one.

Evolution of landform and vegetation cover

An example of the distribution of different landform and vegetation cover types along a Jarama R. reach (R3) is shown in Figure 4. Dealing with its evolution along time, it is observed that in the years 1956 and 1998 maturation processes of the corridor are very predominant, with more than 50% of the surface showing this process in R1, R2, R3 and R5 (Figure 5). In the rest of the reaches, this process exceeds 40% of the surface. The anthropisation process is quite evident in downstream sections, being around 30% of the surface in R5 and R6. On the other hand, a certain percentage of rejuvenated channel is found (any change that leads to a natural regression towards earlier stages of the successional stage, for example, transformation from grassland to active channel) in the lower reaches characterised by a wide valley and more active channel platform. Finally, the maintenance of unchanged forms also represents a high percentage in this time interval, although it is much more evident between 1998 and 2018.

In the second stage analysed, from 1998 to 2018, after the dominance of the maturation processes in the first subperiod, a stage without changes (around

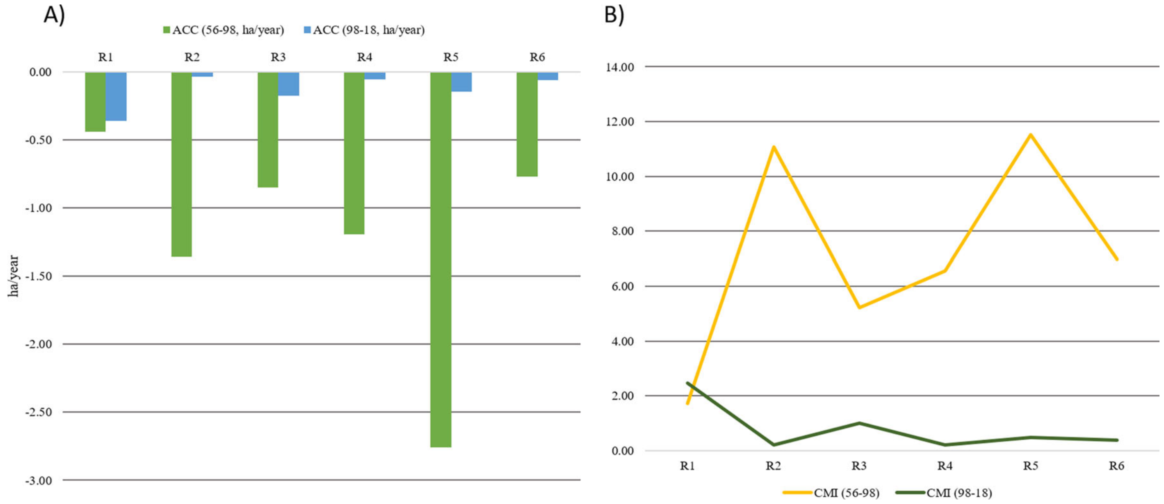

Figure 2. Active channel change (ACC) (left diagram) and Channel Migration Index (CMI) (right diagram) values for the sub periods analysed, from 1956 to 1998 and from 1998 to 2018.

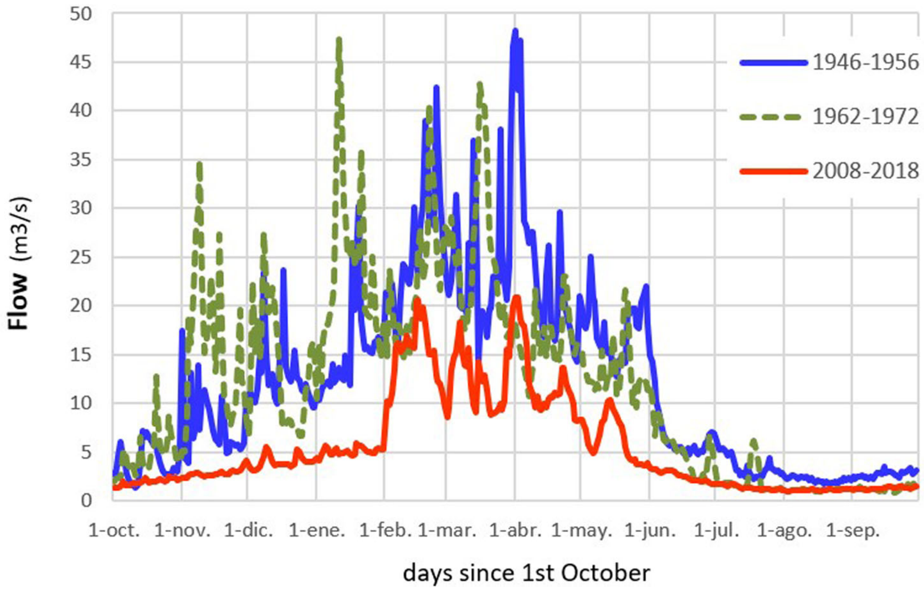

Figure 3. Average daily flow (m^3/s) data along the studied period considering three different subperiods: 1946–1956 (before first aerial photo); 1962–1972; 2008–2018 (before last aerial photo).

Table 2. Characteristic discharges estimated for the studied periods. % of cumulative change has been estimated in relation to the first period.

	Period		
	1946–1956	1969–1979	2008–2018
Average annual flow (m^3/s) (% *change*)	12.2	11.2 (−*8.7*)	5.5 (−*55.3*)
Maximum annual flow (m^3/s) (% *change*)	138	177 (+*28.1*)	64 (−*54.0*)
Minimum annual flow (m^3/s) (% *change*)	0.17	0.20 (+*14.2*)	0.6 (+*419*)

60%) of channel forms occurs, maintaining the landforms present in 1998. The maturation process decreases as well than anthropisation, although they account for a large percentage of the total. It should be noted that in this period naturalization increases due to the renaturalisation of certain previously anthropised spaces. Finally, in the lower sections, an increase in rejuvenation can be seen (around 10% of the surface in sections R5 and R6).

Riparian vegetation

Results of woody species inventory included 1120 individuals that were identified and whose location in the transects was determined. The woody vegetation composition of the Jarama riparian system includes 25 species and it is clearly dominated by ash (*Fraxinus angustifolia*) with the 25% of the individuals (Figure 6). Willow brushes are dominated by *S. salviifolia*, an endemic species adapted to drought (14%), but also pioneer engineering willows are present as *S. eleagnos* (2.2%) and *S. purpurea* (0.7%). The only willow tree present is *Salix fragilis*, although rare (2.3%). Poplars are represented by *P. nigra* (11.2%) and *P. alba* (10.1%). Other drought tolerant species are *Tamarix* spp. (11%) that also may behave as a pioneer engineering specie; *Crataegus monogyna* (6.6%) a zoochorian specie, and *Ulmus minor* (6.5%).

Most of the species lack of a tendency on their longitudinal distribution, but *Alnus glutinosa*, *Salix eleagnos* and *S. purpurea* are more frequent and abundant upstream of Lozoya River confluence (i.e. sections from J-1 to J-10 in Figure 1) than downstream. On the contrary, *S. fragilis* and *U. minor* are more frequent on the lower sections.

Density of woody vegetation resulted greater on the upstream sections (i.e. J-1 to J-18) than on the lower ones with mean values of 1.1 ind./m and 0.4 ind./m, respectively. The species located at a lower elevation with respect to the water level were *A. glutinosa*, *S. eleagnos*, *S. salviifolia* and *S. fragilis* (on average 0.42, 0.60, 0.73 and 0.98 m respectively), while the ones at higher elevation were *P. alba*, *U. minor* and *C. monogyna* (2.15 m, 1.72 m and 1.69 m).

Regarding the zones defined based on the conceptual model of vegetation-hydrogeomorphology interactions (Gurnell et al. 2016) in the Jarama River, Zone 3 (i.e. fluvial disturbed dominated with finer sediment deposition) domains representing 60% on average of the area, followed by Zone 4 (i.e. inundation dominated zone) covering 25% of the area on average, while Zone 2 (fluvial disturbed dominated with coarse sediment erosion and deposition) represents 8% of the area on average and Zone 5 (Soil moisture regime dominated Zone) with only 6% on average are scarce. Although most

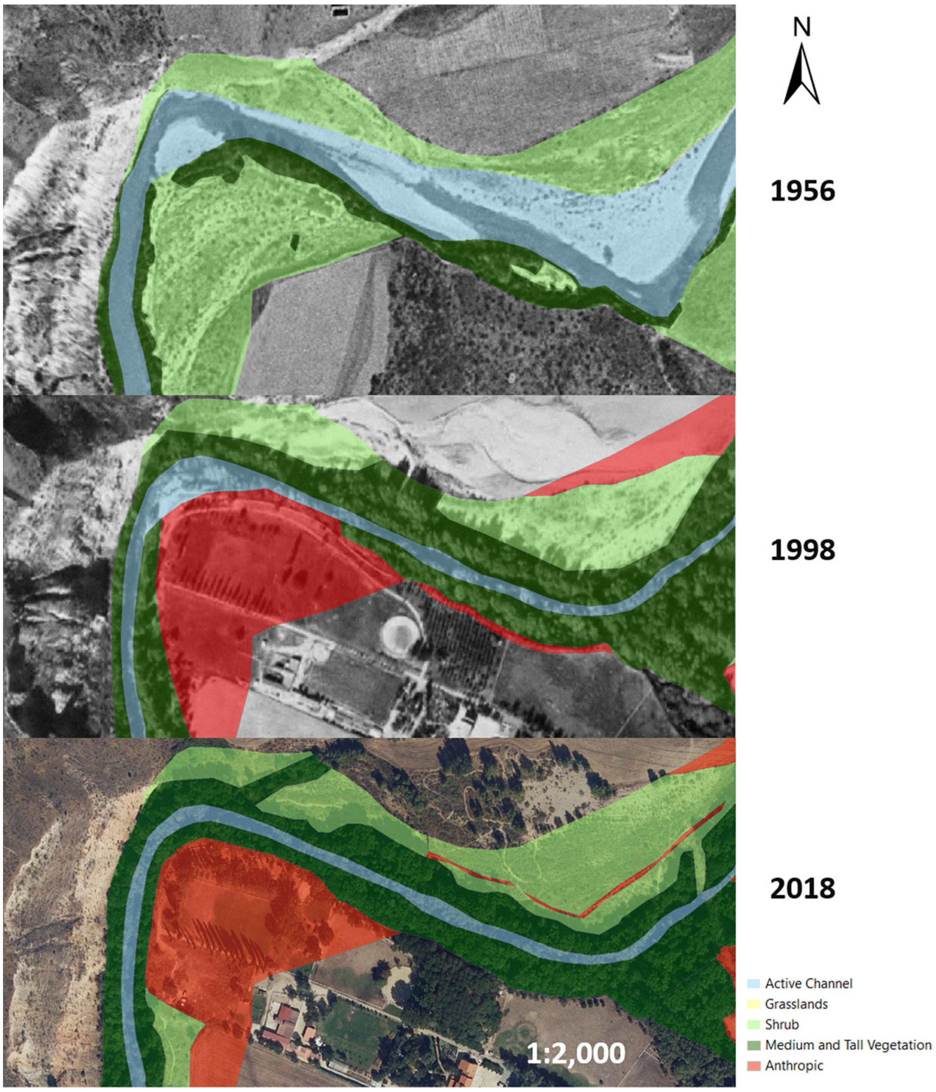

Figure 4. Distribution of different landform and vegetation cover types along a reach (R3) of River Jarama in the studied aerial photographs.

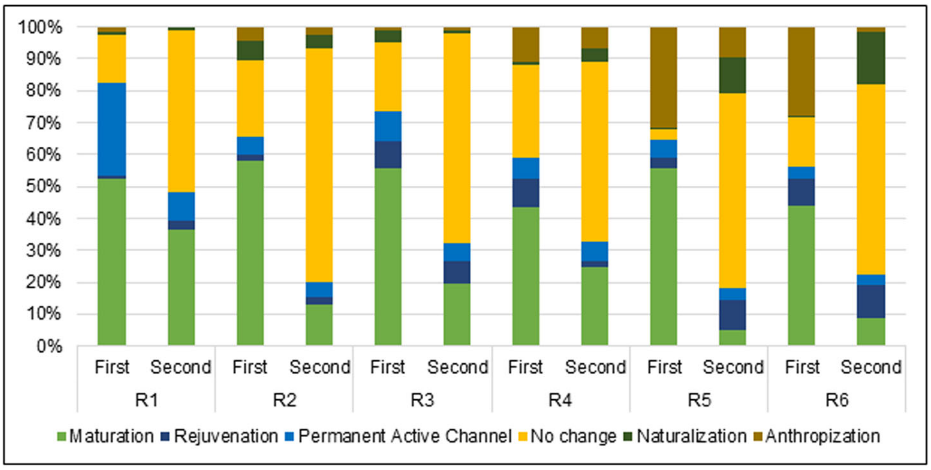

Figure 5. Proportion of area for each transition type in each of the river reaches during the First (since 1956–1998) and the Second period (since 1998–2018).

species are present in all zones, *S. eleagnos* and *S. fragilis* show a marked preference for Zone 2 (coarser sediment erosion and deposition) which is frequently inundated and present high sediment dynamics, while *P. alba*, *S. purpurea*, and *U. minor* individuals prevail in more stabilised areas such as the Zones 4 and 5, which are occasionally and rarely inundated respectively, where the inundation tolerance and the remaining soil moisture are the primary controls for vegetation. Of course, the

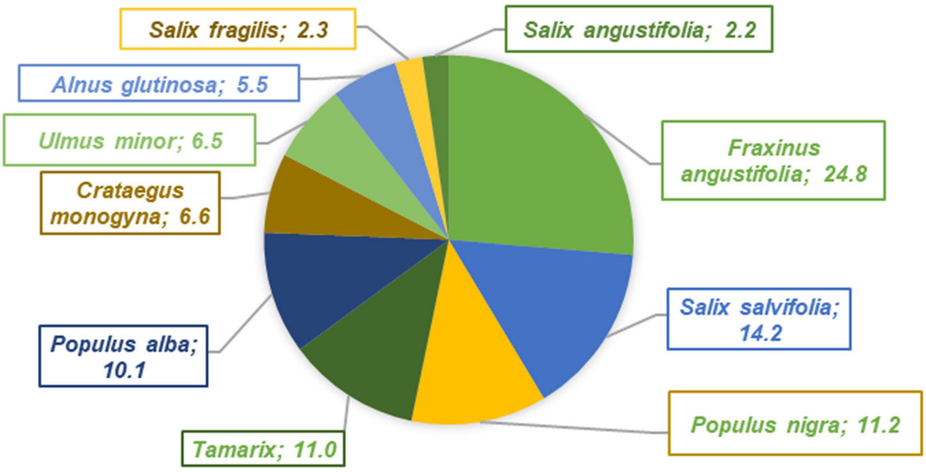

Figure 6. Composition (%individuals) of main woody riparian species in the Jarama River.

distribution of these zones on cross-sections interacts with the gradient associated with the distance to the water (Figure 7) and this is also reflected in the species distribution due to its different ecological requirements.

Recruitment

In the analysis of the composition of transects, riparian recruitment was found in only 11 cross-sections (mainly below the confluence of the Lozoya River) of the 31 performed. Saplings were found only from seven riparian species and two hillside species (*Juglans regia* and *Acer monpessulanum*). The riparian species with the most abundant recruitment was *F. angustifolia* with 72 specimens distributed in 10 cross-sections, followed by *P. alba* with 30 individuals at only 4 sections and *P. nigra* presenting 19 individuals at six sections. Other species with recruitment were *U. minor* (12 individuals), *C. monogyna* (9 individuals), *S. salviifolia* (8 individuals) and *A. glutinosa* (4 individuals).

During the journeys along the river reaches, very few areas were found with recruitment of riparian vegetation woody species. Areas that could potentially host riparian regeneration were either covered with herbaceous plants that stifle only any attempts at riparian seed germination or covered by a dense canopy of mature forest whose shade also prevented any germination. Specifically, during the visit to various reaches of the Jarama river close to El Molar town (Reach 5), where the Mora-Navarro (2004) plots were located, no indication of regeneration was found. Exceptionally we were able to find some small areas with some riparian recruitment where we were able to establish only five plots all located upstream from Lozoya River confluence (Reach 3).

Table 2 shows the results of the analysis of the studied plots comparing before and after summer. We see that almost all the species present in the Jarama River recruit. Again, the ash (*F. angustifolia*) presents greater recruitment densities, but also *S. salviifolia*, *A. glutinosa* and *P. nigra* seedlings abound in the plots. Greater survival rates were found for *S. salviifolia*, *A. glutinosa* and *Tamarix* sp., while *P. alba*, *P. nigra* and *S. eleagnos* present greater mortalities. On the contrary, *P. alba* and *F. angustifolia*

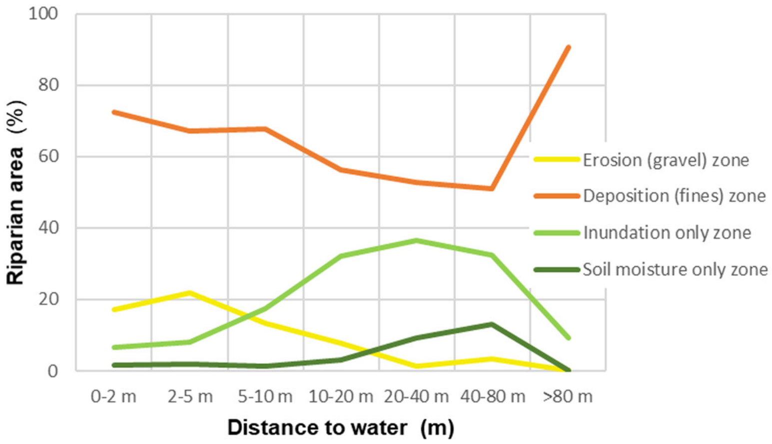

Figure 7. Distribution of vegetation-hydromorphology interaction zones along lateral cross-sections, indicating their percentage area at different ranges of distance to water edge.

show greater length growth while *Tamarix*, *S. salviifolia* and *P. nigra* had negative growth due to grazing (field observation).

Discussion

The Jarama River has experienced considerable changes since 1956, both in the braiding of its channels and in the colonisable unvegetated bars, conditioning the current composition and the structure of the vegetation. The reduction in braided index along the two subperiods characterizes a transformation from a wandering river to a single channel river due to the highly alteration of flows by dams, with a decrease of maximum discharges and the increase of minimum discharges that favours the establishment and growth of vegetation cover. This pattern of river simplification and stabilization in reponse to flow homogenization by dam regulation has been shown in North America rivers (Poff et al. 2007). Moreover, this river was highly affected by gravel mining since 1960s (Uribelarrea et al. 2003) which led to an incision of the riverbed as well a severe decline in the area occupied by gravel bars. They quantified that in 1999 more than 30% of the alluvial floodplain was affected by mining operations. Then, after 1960s changes in the Jarama River were mainly due to the combined effect of flow regulation and mining. Changes in Jarama River were similar to other rivers in the Mediterranean region, in which the synergistic effect of several pressures reduced the number of channels and the dimension of active channel (e.g. Segura-Beltrán and Sanchis-Ibor 2013; Martínez-Fernández, González del Tánago, et al. 2017; Batalla et al. 2018). Associated with changes in braided index, the narrowing process of active channel, mainly in the first period with losses of 1.23 ha/year were strongly associated with changes in channel forms and the loss of secondary channels, which is in agreement with Uribelarrea et al. (2003). Channel Migration Index decreased between 1956 and 2018, demonstrating a high loss of mobility zone associated with the active channel. Only Reach 1, a confined reach, show similar values between these years. CMI reduction is a symptom of active channel decreasing dynamism, and this trend was also found in other Mediterranean rivers (Magdaleno and Fernández 2011; Sanchis-Ibor et al. 2019; Fazelpoor et al. 2021). All these variables and indicators show a trend toward the stabilisation of islands and floodplains observed in the temperate context on several rivers (Liébault and Piégay 2002; Gurnell and Petts 2006; Corenblit et al. 2010). Stabilisation of ancient active channels or bars generate a process that conduces to the encroachment of vegetation (O'Briain 2019; García de Jalón et al. 2020). Maturation process, transition from initial or pioneer geomorphic phase to a more complex structures (i.e. biogeomorphic phase based on Corenblit et al. 2010), is the dominant change in the first period studied, coinciding with the decline of active channel, the reduction of channel mobility and the transformation into a single channel. Additionally, no signs of naturalisation were found in the first period studied but an anthropisation process affected downstream reaches. In the second period, the processes associated to the stabilisation of the channel forms predominated, due to the low capacity for change and probably to the increase in plant density (i.e. encroachment) and soil formation, increasing the resistance of the canopy against the erosive action of floods (Ishikawa et al. 2003; Tal et al. 2004). All these changes are related to several pressures associated with the loss of dynamism, reducing transition to actives areas which is of great importance in the temperate context and essential for the pioneer vegetation that colonizes these spaces (Corenblit et al. 2007; Rivaes et al. 2013; González del Tánago et al. 2016) (Table 3).

Consistent with the decrease of bare gravels bars where disturbance-adapted species as willows used to inhabit, which is in agreement with the relatively low proportion of Zone 2 (coarser sediment erosion and deposition) within the fluvial corridor (8% on average), very few areas were found with recruitment of riparian vegetation woody species during field campaigns. Even in those zones where intensive recruitment was found in the past by Mora-Navarro (2004), the present study does not detect regeneration. *S. eleagnos* and *S. fragilis* show a marked preference for Zone 2 (coarser sediment erosion and deposition) which is exposed to frequent flood disturbance, while *P. alba, S. purpurea,* and *U. minor* individuals dominate more stabilised areas such as the Zones 4 and 5, which are occasionally and rarely inundated respectively. The regeneration of *Salix* species, among other riparian species here analysed, although restricted to small areas in the riparian corridor, still takes place in the Jarama River. Then, either problems with parent trees availability, seed dispersal or viability seems to be absent. Therefore, main obstacle for the successful regeneration of Salix species is link to the lack of adequate areas for recruitment, such as bare gravel bars and sand bars, greatly reduced by the intense gravel mining activities several decades ago together with the construction of dams.

Releasing large pulse flows from dams and reservoirs has been proposed previously in other regions as a cost-effective solution to reactivate the creation of safe-sites where *Salix* can regenerate (e.g. Dixon

Table 3. Density and mean length of saplings found in the five studied plots, before (June) and after (September) the summer, showing survival ratio and mean length growth.

		June		September			
		Density (ind/m^2)	Height (cm)	Density (ind/m^2)	Height (cm)	Survival (%)	Length Growth (%)
Plot 1	*Alnus glutinosa*	2.20	**22.8**	3.02	**28.5**	138	25.1
	Populus nigra	0.27	**20.0**	0.27	**20.0**	100	0.0
Plot 2	*Populus alba*	1.40	**24.2**	0.47	**31.3**	33	29.4
	Alnus glutinosa	1.25	**14.4**	1.25	**12.4**	100	−13.6
	Salix eleagnos	1.25	**16.4**	0.78	**13.3**	63	−18.8
	Populus nigra	0.93	**30.3**	0.78	**17.8**	83	−41.3
	Fraxinus angustifolia	0.62	**15.6**	1.25	**23.6**	200	51.5
	Salix purpurea	0.16	**11.0**	0.31	**35.0**	200	218.2
	Salix salviifolia	0.16	**21.0**	1.09	**15.2**	700	−27.8
Plot 3	*Salix salviifolia*	3.03	**34.9**	2.42	**31.6**	80	−9.7
	Populus nigra	0.40	**21.0**	0.20	**8.5**	50	−59.5
	Alnus glutinosa	0.20	**20.0**	0.61	**16.6**	300	−17.2
	Salix fragilis	0.00	–	0.20	**28.0**	–	–
	Fraxinus angustifolia	0.00	–	0.40	**22.5**	–	–
	Salix eleagnos	0.00	–	0.20	**32.0**	–	–
Plot 4	*Fraxinus angustifolia*	5.26	**36.24**	7.57	**36.24**	144	0.0
	Alnus glutinosa	0.42	**35.00**	0.42	**35.00**	100	0.0
	Populus nigra	0.00	-	0.21	**22.00**	–	–
Plot 5	*Populus nigra*	2.68	**21.0**	2.35	**18.8**	88	−10.3
	Salix salviifolia	1.34	**30.0**	1.68	**25.4**	125	−15.4
	Salix eleagnos	0.67	**35.0**	0.67	**27.0**	100	−22.9
	Tamarix	0.67	**44.5**	1.01	**34.7**	150	−22.1
	Fraxinus angustifolia	0.34	**11.0**	0.34	**10.0**	100	−9.1

et al. 2015; Johnson et al. 2015; Glenn et al. 2017). Given the high level of vegetation encroachment presenting by this fluvial system, may other proactive measures such the reconnection with secondary channels or the removal of some vegetation could help in the recovering process in such a simplified system. Longitudinal and lateral connectivity are also essential for the promotion of *Salix* establishment (Hughes et al. 2012; González et al. 2018). To recover this connectivity, managers could undertake actions to eliminate weirs or levees and other embankments that constraint the channel dynamism and impede its natural migration, which resulted to some extend successful in previous applications (e.g. Rohde et al. 2005; Martínez-Fernández, González, et al. 2017)

Conclusions

The geomorphic trajectory that the Jarama River has followed is clear. Active channel narrowing and transformation of branched sections into single channel processes, associated with a great loss of its mobility, took place mainly at the end of the twentieth century. Landform evolution shows an intensive 'maturation' associated with anthropisation processes that dominate during this first period, while stability ('no change' process) dominates in this 21th century. On the contrary, the 'rejuvenation' process is practically negligible.

Analysis of the riparian transects showed a dominance of the fine deposition zones (60% on average) even at water margins, while the erosional gravel zones (which is the characteristic habitat of the pioneer willow species) were very scarce (8% on average).

The dominant willow species is *S. salviifolia*, a drought tolerant willow that has been able to withstand the processes of 'maturation', channel narrowing and the loss of channel mobility being widely distributed throughout the riparian section. On the other hand, other strict pioneer willows such as *S. eleagnos* and *S. purpurea* are very rare and are found in the few gravel banks that remain on the shore.

Riparian recruitment along surveyed sections was only found below Lozoya River confluence but did not include willows except for a few specimens of *S. salviifolia*. On the contrary, recruitment plots were only possible to establish at reach 3, upstream Lozoya River confluence. In these plots, recruits of *S. salviifolia* and *S. eleagnos* were found in remarkable densities, although recruits of *S. purpurea* and *S. fragilis* were also present.

The overall scenarios here described are predicting a gradual disappearance of the willows in the Jarama River as there is no significant recruitment along the Jarama River, and they will last as long if those old specimens germinated in the period from 1960 to 1990 may survive.

Acknowledgements

This research was supported by the project SAUCERES (PGC2018-098416-B-I00) of the Ministry of Science, Innovation and Universities. VMF was funded by a "Juan de la Cierva" research contract (Spanish MINECO grant no. FJC2018-035451-I) at the National Museum of Natural Sciences, CSIC, Spain. Authors would like to thank the two anonymous reviewers whose comments greatly improves this manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

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