EVOLUTION OF THE ACTIVE CHANNEL AND THE VEGETATION ISLANDS IN A SANDY RIVER

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River Tiétar is a braided river with multiple channels that intertwine, forming rods of material inside the channel and which act as natural obstacles to flowing water. In these bars, as well as in other points of the channel, fluvial islands of vegetation can be created. The sediments of this river are composed almost entirely by sand, and thus river flows allow a greater dynamic character due to the easy drag of this type of sediment during floods. In this study, we have analyzed through digitalization of aerial photographs the evolution over time of the river channel, the vegetation islands and the riparian vegetation that surrounds it, in order to describe how has been its evolution over time. Also, the composition and structure of vegetated islands was measured in field work. On the other hand, a hydrological analysis was carried out to analyze the causes of observed changes and to forecast the evolution of this ecosystem in the future.

Results show that the River Tiétar has been increasingly colonized by woody riparian vegetation (mainly *Salix salvifolia* and *Fraxinus angustifolia*) both within its lateral channel bars and in the island bars since 1956, when most of the channel was bare sand. According to hydrological analyzes, this increase in vegetation is facilitated by a reduction in average flows and a lower frequency and intensity of large floods / floods, together with an increase of summer flows from nearby irrigation farming fields. Vegetated Islands show a dynamic pattern of movement inside the channel similar to those made by 'amoebas'. Islands showed an ecological succession from only pioneer *S. salvifolia* in the early stages to a more diverse mature stage including also *F. angustifolia, Sambucus nigra* and *Celtis australis.*

With these data, we have been able to conclude that future trends show almost total riparian colonization of the active channel by vegetation, thus creating a new ecosystem of continuous vegetation bands without islands. We predict that the vegetation encroachment within the channel will reduce the mobility or river the dynamism since the vegetation root system would not allow the channel to change position after the floods. Therefore, the present braided river would be transformed into a single channel meandering one before 18 years.

INTRODUCTION

Often river complexity is not understood and the idea that rivers should be a single and stable water channel that flows downstream into the sea persists. Contrary to this idea, still there are some rivers that exhibit a different geomorphological structure. This is the case of Tietar River, whose sandy substrate allows a more dynamic and unstable channel. Its bottom materials accumulate in sandbars associated with incipient vegetation become natural obstacles diverting the current to one or both sides. Some vegetated bars are formed in the center of the channel and thus, become islands giving a braided structure to the river. Braided rivers are characterized by wide channels with rapid and continuous changes in sedimentation and in bars position (Martín Vide, 1997). Within these bars, islands of vegetation can be developed, as discrete areas of woody vegetation surrounded by channels filled with water or exposed gravel (Ward et al. 1999).

Once, woody vegetation colonizes these islands and it is established is able to resist hydrogeomorphic constraints to a certain point. This can generate feedbacks by modifying the hydrogeomorphic environment. (Hortobayi et al. 2017). This is possible because the vegetation root system increases the resistance to erosion, stability of sediments and organic matter (Pollen et al., 2004). Also, the vegetation canopies reduce flow velocities, leading to sediment retention, especially during high flows events (McKenney et al., 1995; Bennett et al., 2008). As a result, vegetation will influence the resistance of landforms to hydrogeomorphic disturbances and enhance their recovery after destructive dominated flood events, therefore also affecting the persistence of biogeomorphic landforms, i.e., ecological resilience (Hortobayi et al. 2017).

There is a great amount of research that links establishment of vegetation with water flows in rivers. (Gurnell 2005, Corenblit 2007, Osterkamp y Hupp 2010)). Floods affect riparian vegetation by mechanical damage and also produce geomorphological impacts that involve the destruction and creation of sand/gravel bars removing and depositing substrates. Besides, floods are a main factor for propagule transportation and vegetation recruitment. Indeed, the relationship between flows dynamics and woody vegetation is crucial for seeds dispersal at the correct moment (Bendix-Hupp 2000) and thereafter provides humidity for colonization. Frequent high flow events bring on deposition of sediments that provide suitable substrate for the germination of vegetation (Benn and Erskine 1994). Moreover, periodic floods increase the germination rate of riparian species (Westbrooke-Florentine 2005)

On the other hand, flow regulation by dams produces an alteration of the equilibrium between channel morphology and riparian vegetation (Nadler and Schumm 1981, Gonzalez del Tanago et al. 2015). The decrease in flow magnitude produces an increase of vegetation within the river channel (Bejarano, Sordo-Ward, Erskine 1999, Gonzalez del Tanago et al. 2015) especially when flow is reduced over many years, the vegetation may establish in the base of the channel (Corenblit et al 2007). But also, common ecological responses for damming are failure of seedling establishment, increased success of alien species, species richness reduction and vegetation encroachment into channels (Aguiar et al. 2014).

Vegetation encroachment has been reported as an indicator of the ecological response to the alteration of natural flows (Gurnell 2005). The invasion of vegetation into the channels of the rivers has a negative impact on fluvial processes, on morphology of the channels and on aquatic ecology. The restoration of more natural flow regimes that flood should prevent the invasion of terrestrial vegetation in river channels, essential for the management and restoration of rivers (Miller et al. 2013).

Our initial hypothesis is that observed changes in the geomorphological dynamics shown by land cover changes on the channel and the riparian system is due to the modification of the hydrological regime produced by the presence of Rosarito Reservoir. In order to verify this hypothesis, we have set the following objectives: a) to quantify the evolution of the river channel and its main land covers, comparing river historical conditions previous to the reservoir with those conditions from immediately after until current state; b) to describe how the flow regime influences the vegetation encroachment in the channel, the island formation and evolution; c) to predict future fluvial trends and geomorphic status.

METHODS

Study area.

The Tiétar River is major tributary of the Tajo River and is located in the central-west of the Iberian Peninsula, running westwards parallel to the Sierra de Gredos on its southern slope. The climate is Mediterranean with softy winters, low frequent frosts, without precipitations in summer and strong rains in autumn and spring.

River Tietar runs within an open valley receiving on the right torrential tributaries with steep slopes (gorges), and on their left sandy streams. River Tietar channel presents nowadays a braided structure, with small islands covered by riparian vegetation and sandy bed.

Study area is a fluvial segment in the coordinates 40°01’24.18” N y 5°01’24.19”O with a length to 4.8 kilometres and with a width to 102 meters approximately, a slope to 1.003% and a width of the riparian vegetation to 34 meters. The vegetation of the river islands is set up by 5 main species *Salix salvifolia*, *Populus nigra*, *Fraxinus angustifolia*, *Sambucus nigra* and *Celtis australis*.

The studied segment is 30 km downstream Rosarito dam. Rosarito Reservoir became operational in 1959, has a storage capacity 856000 m^3 that represents a regulation capacity of 0.11 per year. The Tietar floodplain is intensively used for agriculture and the water from Rosarito is used for its irrigation.

Data analysis

A digital analysis of the fluvial segment on historical aerial photographs and orthophotos (PNOA) was carried out using the ArcMap Geographic Information System Analysis (GIS) software. In this analysis we distinguished five different land covers: woody vegetation islands, herbaceous vegetation, bare sand, water, and woody vegetation on lateral banks (riparian vegetation). The analysis was carried out in photos from different years: 1956, 1973, 1980, 2006, 2010, 2012 and 2016. Although aerial photos were all from summer, they were taken at different low flow conditions, we combined water, sand and herbaceous covers into a single one (active channel). The analysis of mean flows, peak floods and droughts changes on River Tietar were done based on daily flow data records of the years 1952 to 2016 from Rosarito (EA.3127) gauging station (*ceh-flumen64.cedex.es*).

RESULTS

The surface occupied by each land cover types (woody vegetated islands, woody vegetated lateral bars, herbaceous, bare sand and water) along the analyzed aerial photos from 1956, 1973, 1980, 2006, 2010,2012 and 2016 are shown in figure 1 and quantified in table 1

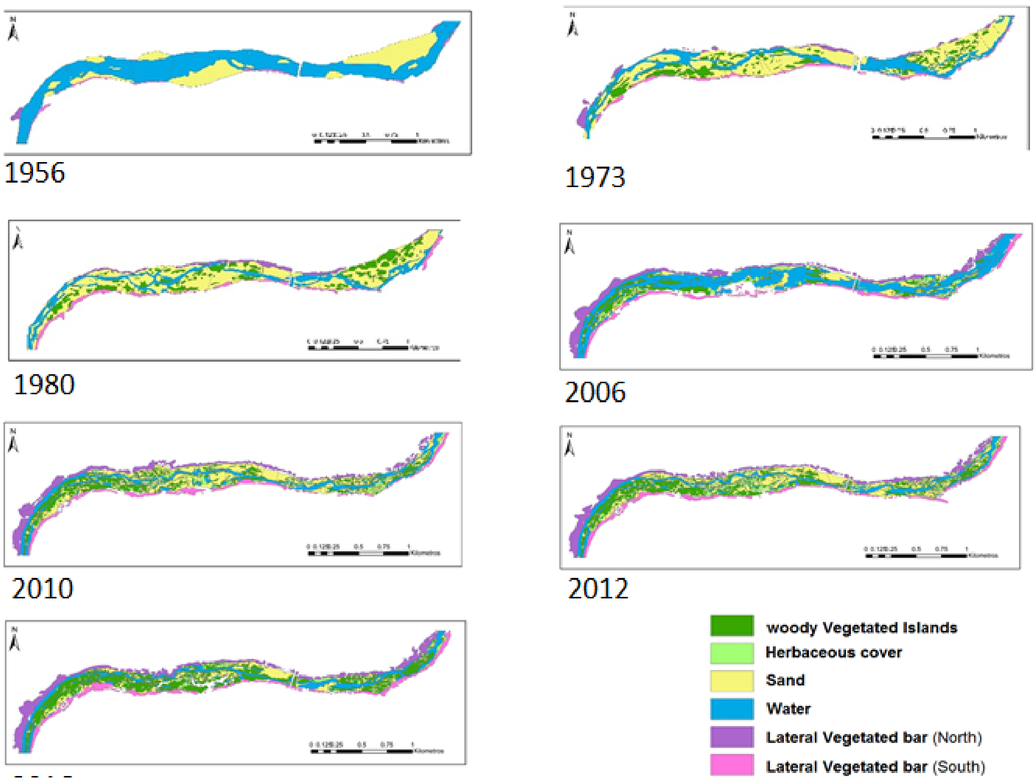

Figure 1.- Land covers areas of the studied River Tietar segment along the years 1956, 1970, 1980, 2006, 2010, 2012 y 2016.

The analyzes show a clear increase in the areas occupied by woody island vegetation within the river channel throughout the time period studied while the active channel shows a clear regression (figure 2). Although, this process is not uniform along time. The rate of riparian vegetation encroachment is significantly during the first years of study (1956-1980), being 0.75 Ha/year for islands and 0.41 for lateral bars. But from 1980 to 2000 this growth stabilizes and even vegetated islands suffer a reduction. Nevertheless, from 2006 to 2016 the increase in riparian vegetation is greatly accelerated, in both lateral bars (0.37 Ha/year) and specially in islands (1.86 Ha/year).

Table 1.- *Evolution of land cover areas (Ha) of the river channel in the R. Tietar studied segment.*

	1956	1973	1980	2006	2010	2012	2016
Vegetated Islands	0.0	14.6	17.5	11.6	18.1	21.4	30.3
Vegetated lateral bars	3.8	12.1	13.2	24.4	23.2	24.2	28.0
Active channel	101.9	75.5	72.3	61.0	56.4	53.1	39.6
TOTAL	105.7	102.2	103.0	97.0	97.7	98.7	98.0

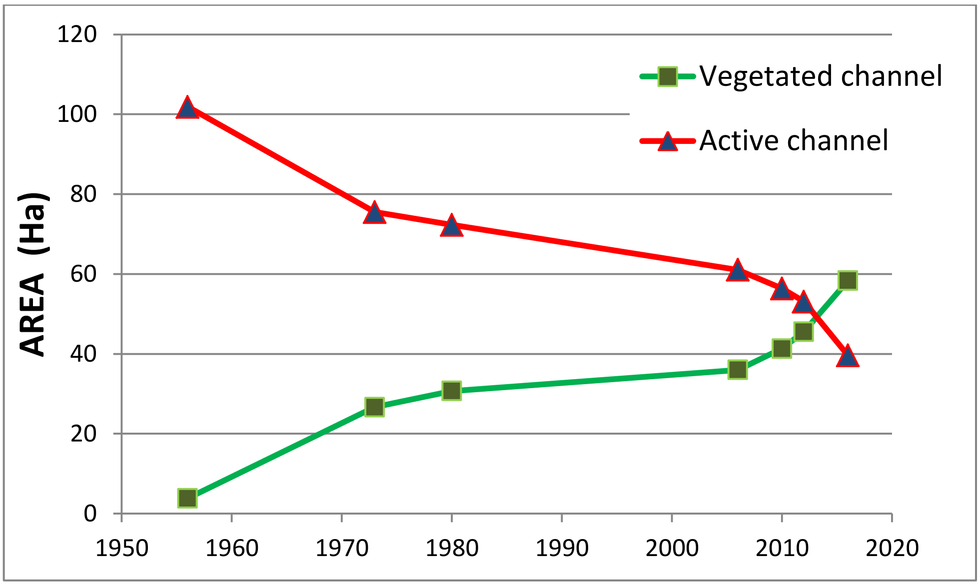

Figure 2.- Evolution of the R. Tietar channel area occupied by riparian vegetation (including lateral bars and islands) and the active channel (water, bare sand and herbaceous cover).

Flow alteration analysis

The changes in the hydrological regime from the historical period to the current period are analyzed. In order to find out how the flow regime alteration has influenced on the observed riparian vegetation changes we have compared historical flows with nowadays ones. Main flow regime traits that are expected to mainly control riparian vegetation are shown in figure 3. These were annual peak flows that may be responsible for flushing away rooted plants, and summer drought conditions represented by average summer flows that are responsible for desiccation stress (if low) or for vegetation encroachment support (if high).

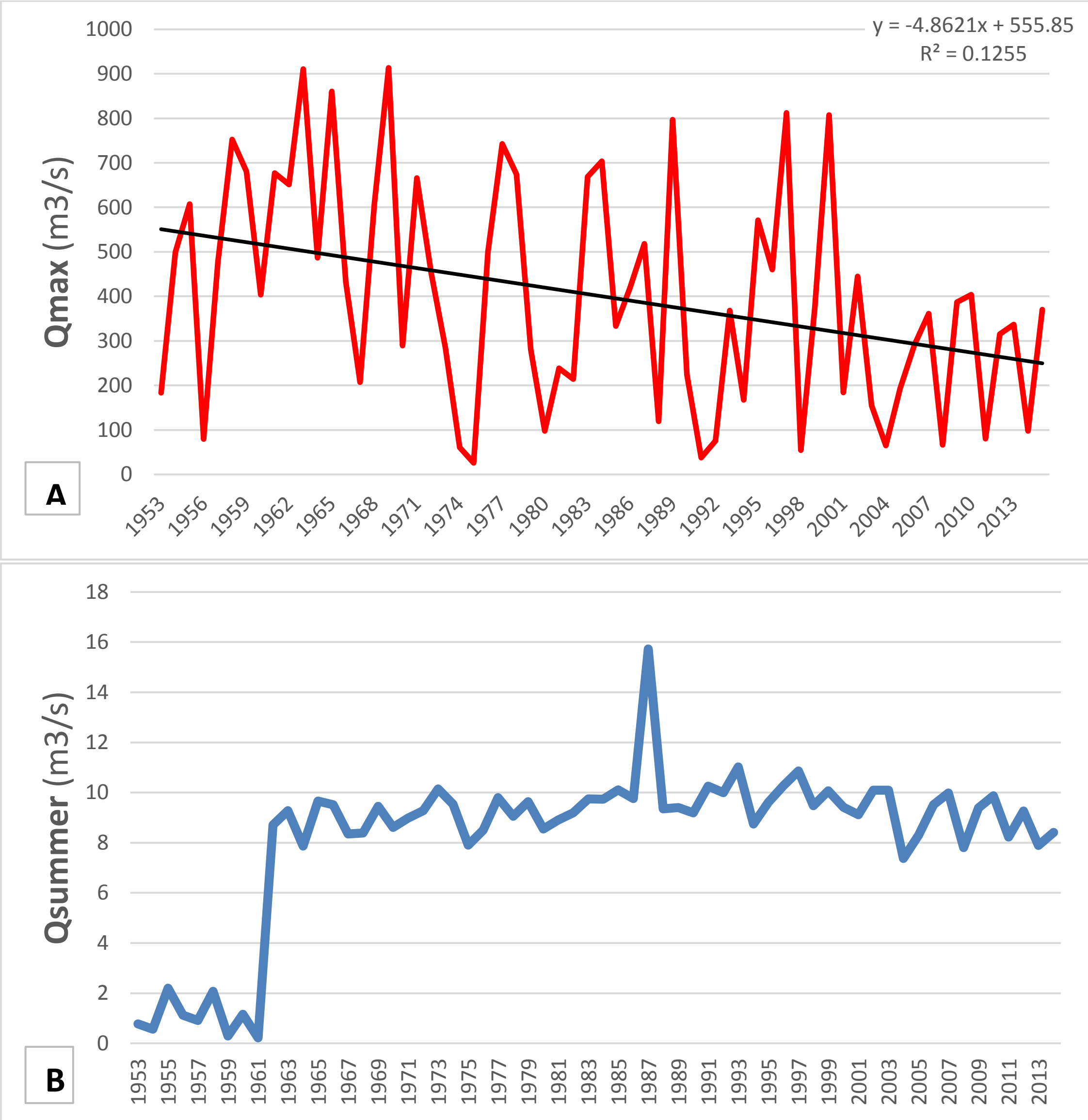

Figure 3.- Evolution of the River Tietar Flow regime below Rosarito Reservoir: A) Maximum annual daily flow; B) Mean Summer daily Flow (average from July, August and September).

Maximum annual flows (Figure 3A) show a clear decreasing trend with a marked drop from 2001. During the first two decades (1953-1961) maximum annual flows average value was 540 m3/s, while the last decades (2001-15) was 250 m3/s. Mean annual flows showed a similar reduction pattern as maximum annual flows, from 40 m3/s initially to 17 m3/s in the last decades. On the contrary, mean summer flows (figure 3B) released by Rosarito Dam reflects clearly the use of water since the irrigation infrastructure was operational until now. Indeed, the average values of summer flows before irrigation (1953-1961) were 1 m3/s, whereas since its entry into operation rose to 9 m3/s and has almost remained constant until today.

DISCUSSION

We have seen River Tietar is subject to a vegetation encroachment process, which starts in 1956 when the woody vegetated surface represented less than 4% of the channel and was restricted to lateral bars, up to the present time, in which it occupies 60%. In a global perspective, the hydrological changes that justify these changes are found in the decrease of maximum flows and in the increase in summer flows. The peak flow decreases allow to reduce woody vegetation mortality by uprooting, tearing and dragging the trees (Irvine-West 1979; Polzin-Rood 2006; Stokes 2008; Mayence 2010). Taking into account the poor cohesion of sand that form the main substrate of the Tietar River, we can suppose that peak flows are important limiting factor for this vegetation.

The riparian vegetation in Mediterranean rivers is usually limited by the natural summer drought, coinciding with high temperatures that often produce desiccation stress in plants (Gonzalez de Tánago et al. 2015, Bejarano et al. 2012). The fact that Rosarito Reservoir regulation releases high flows in summer that represent ten times the natural flows, allows humid riparian soils that enhance vegetation intensive growth favored by the high temperatures, and therefore the expansion of its coverage in the channel.

However, we have seen that this encroachment process has not taken place in a uniform way over time, nor can we always relate it to hydrological changes. We can therefore establish stages that help us explain the response of vegetation:

a) 1953-1961: absence of vegetation, low summer flows and large floods

b) 1962-1973: development of vegetation associated with a large increase in summer flows, but with large floods

c) 1974-2000: slight decrease in the encroachment of the vegetation, with medium floods and high summer flows

d) 2001-2016: large vegetation encroachment associated with low floods and high summer flows

In the first period the absence of vegetation is in agreement with the flow conditions (drought in summer and flushing flows during the rest of the year). The respond of riparian vegetation with a significant encroachment ratio (1.34 Ha per year) during the second period is also consistent with improved drought conditions caused by a sharp increase in summer. Also, the great vegetation encroachment (2.23 Ha per year) occurred during the last period can be explained by the optimum hydrological conditions (reduced maximum flows and high summer flows). However, in the third period (1974-2000) flow conditions are insufficient to explain the low encroachment rates (0.28 Ha per year) presented, and other factors should be consider. In the past, extensive grazing impacted its riparian vegetation, and gravel mining affected certain river areas. Although these pressures are not active at present, specially sand abstraction, has occurred during the third period.

What trends are we going to see in the future? Will there continue to be islands?

To answer these questions, we rely on the latest trends we see in the River Tietar. In figures 2 and 3 we see that in the last 18 years both patterns, the flow regime and the response in the vegetation encroachment, have clearly change. The average of the maximum flows stabilizes in 250 m3/s, while the summer flows show a slight tendency to decrease. On the contrary, vegetation encroachment is triggered in an exponential increase (2.23 Ha/y) that obviously has a boundary in one hundred hectares of surface that is the channel area in the studied segment.

CONCLUSION

Therefore, we predict that, unfortunately, the woody vegetation will occupy almost the entire channel, the vegetated islands will disappear in a continuous woody corridor, and the active channel will be reduced to a single channel. And this will take less than 18 years.

REFRENCES

Aguiar, F. C., Fernandes, M. R., Fabião, A., Bejarano, M. D., Nilsson, C., Merritt, D. M., ... & Martins, M. J. (2014) Riparian Forests in a Context of Flow Disturbance: New Tools and Approaches to Support Ecological Research.

Bejarano, M. D., & Sordo-Ward, A. (2011). Riparian woodland encroachment following flow regulation: a comparative study of Mediterranean and Boreal streams. Knowledge and Management of Aquatic Ecosystems, (402), 20.

Bejarano, MD, M. Gonzalez del Tanago, D. Garcia de Jalon, M. Marchamalo, A. Sordo-Ward & J. Solana-Gutierrez. 2012 Responses of riparian guilds to flow alterations in a Mediterranean stream. Journal of Vegetation Science 23, 443-58. Doi: 10.1111/j.1654-1103.2011.01360.x

Bendix, J., & Hupp, C. R. (2000). Hydrological and geomorphological impacts on riparian plant communities. Hydrological processes, 14(16), 2977-2990.

Benn, P. C., & Erskine, W. D. (1994). Complex channel response to flow regulation: Cudgegong River below Windamere Dam, Australia. Applied Geography, 14(2), 153-168.

Bennett, S. J., Wu, W., Alonso, C. V., & Wang, S. S. (2008). Modeling fluvial response to instream woody vegetation: implications for stream corridor restoration. Earth Surface Processes and Landforms, 33(6), 890-909.

Carter Johnson, W. (2000). Tree recruitment and survival in rivers: influence of hydrological processes. Hydrological Processes, 14(16- 17), 3051-3074.

Corenblit D., Tabacchi E., Steiger J., & Gurnell A.M. (2007). Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: a review of complementary approaches. EarthScience Reviews 84(1–2), 56–86.

Gonzalez del Tánago, M., Bejarano, M. D., García de Jalón, D., & Schmidt, J. C. (2015). Biogeomorphic responses to flow regulation and fine sediment supply in Mediterranean streams (the Guadalete River, southern Spain). Journal of Hydrology, 528, 751-762.

Erskine, W. D., Terrazzolo, N., & Warner, R. F. (1999). River rehabilitation from the hydrogeomorphic impacts of a large hydroelectric power project: Snowy River, Australia. River Research and Applications, 15(13), 3-24.

Gurnell, A., Goodson, J., Thompson, K., Mountford, O., & Clifford, N. (2007). Three seedling emergence methods in soil seed bank studies: implications for interpretation of propagule deposition in riparian zones. Seed Science Research, 17(3), 183-199.

Hortobágyi, B., Corenblit, D., Steiger, J., & Peiry, J. L. (2017). Niche construction within riparian corridors. Part I: Exploring biogeomorphic feedback windows of three pioneer riparian species (Allier River, France). Geomorphology.

Irvine, J. R., & West, N. E. (1979). Riparian tree species distribution and succession along the lower Escalante River, Utah. The Southwestern Naturalist, 331-346.

Louise Polzin, M., & Rood, S. B. (2006). Effective disturbance: seedling safe sites and patch recruitment of riparian cottonwoods after a major flood of a mountain river. Wetlands, 26(4), 965-980.

Martín Vide, J.P. (1997) "Hidráulica Fluvial. Conceptos generales sobre morfología, dinámica y el transporte de sedimentos en ríos aluviales. Ecuaciones y métodos de uso más extendido para su evaluación y cálculo.". Editorial Escuela Colombiana de Ingeniería y Publicaciones UPC, Barcelona.

Mayence, C. E., Marshall, D. J., & Godfree, R. C. (2010). Hydrologic and mechanical control for an invasive wetland plant, Juncus ingens, and implications for rehabilitating and managing Murray River floodplain wetlands, Australia. Wetlands Ecology and Management, 18(6), 717-730.

McKenney, R., Jacobson, R. B., & Wertheimer, R. C. (1995). Woody vegetation and channel morphogenesis in low-gradient, gravel-bed streams in the Ozark Plateaus, Missouri and Arkansas. In Biogeomorphology, Terrestrial and Freshwater Systems (pp. 175-198).

Miller, K. A., Webb, J. A., de Little, S. C., & Stewardson, M. J. (2013). Environmental flows can reduce the encroachment of terrestrial vegetation into river channels: a systematic literature review. Environmental management, 52(5), 1202-1212.

Nadler, C. T., & Schumm, S. A. (1981). Metamorphosis of South Platte and Arkansas Rivers, eastern Colorado. Physical Geography, 2(2), 95-115.

Osterkamp, W. R., & Hupp, C. R. (2010). Fluvial processes and vegetation—glimpses of the past, the present, and perhaps the future. Geomorphology, 116(3-4), 274-285.

Pollen, N., Simon, A., & Collison, A. (2004). Advances in assessing the mechanical and hydrologic effects of riparian vegetation on streambank stability. Riparian vegetation and fluvial geomorphology, 125-139.

Roques, L., Corenblit, D., Steiger, J., Gurnell, A. M., & Tabacchi, E. (2009). Control of sediment dynamics by vegetation as a key function driving biogeomorphic succession within fluvial corridors. Earth Surface Processes and Landforms, 34(13), 1790-1810.

Stokes, K. E. (2008). Exotic invasive black willow (Salix nigra) in Australia: influence of hydrological regimes on population dynamics. Plant Ecology, 197(1), 91-105.

Ward J. V., Tockner K., Edwards P. J., Kollmann J., Bretschko G., Gurnell A. M., Petts G. E., & Rossaro B. (1999). A reference river system for the Alps: the 'Fiume Tagliamento'. Regulated Rivers Research & Management 15 (13): 63–75.

Westbrooke, M. E., & Florentine, S. K. (2005). Rainfall-driven episodic flood events: are they a major factor in moulding New South Wales arid land vegetation patterns?. Australian Geographer, 36(2), 171-181.