

Effects of non-native riparian plants in riparian and fluvial ecosystems: a review for the Iberian Peninsula

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ABSTRACT

Effects of non-native riparian plants in riparian and fluvial ecosystems: a review for the Iberian Peninsula

Riparian zones are among the natural habitats more prone to be invaded by exotic plants. In this study we review the causes and consequences of these invasions on fluvial and riparian ecosystems, as well as the effects described for the Iberian Peninsula so far. Riparian zones receive a high propagule pressure of exotic plants, their abiotic conditions are benign for plant life, and their biotic resistance from native vegetation is released by natural (floods) and anthropic (hydrological changes) disturbances. The convergence of these factors explains the high invasion rate of riparian zones. An eventual replacement of native by non-native vegetation might alter the fire regime, the depth of the water table, nutrient cycles and organic matter processing, soil properties, communities of detritivore invertebrates and vertebrates dwelling in rivers and riparian zones. In the Iberian Peninsula we found that the effects of non-native riparian plants were more often negative (e.g. alteration of the structure and activity of microbial communities) than neutral (e.g. similar decomposition rate between native and non-native litter), and rarely positive for primary production (e.g. faster litter decomposition). Our review also highlights a strong bias in the selection of target non-native species (mostly *Eucalyptus globulus*, *Ailanthus altissima* and *Robinia pseudoacacia*) and in the studied effects (mostly litter decomposition and structure and activity of microbial communities). Therefore, a reliable evaluation of the effects of non-native plants in Iberian riparian ecosystems requires extending the number of studied species and of response variables.

Key words: Biological invasions, detritivores macroinvertebrates, fire, hypotheses, invasibility, litter decomposition, microbial communities, nutrient cycle, water table depth.

RESUMEN

Efectos de las plantas exóticas de riberas en ecosistemas de ríos y riberas: revisión para la Península Ibérica

Las riberas se encuentran entre los hábitats naturales más vulnerables a ser invadidos por plantas exóticas. En este estudio se hace una revisión sobre las causas y consecuencias de estas invasiones en los ecosistemas, así como de los efectos que se han descrito en la Península Ibérica. En las riberas existe una elevada presión de propágulos exóticos, las condiciones abióticas son benignas para las plantas, la resistencia biótica de la vegetación nativa se ve relajada por las frecuentes perturbaciones y por los cambios hidrológicos causados por el hombre. La confluencia de todos estos factores explica la elevada tasa de invasión de estos ambientes. La sustitución de vegetación nativa por exótica puede generar cambios en el régimen de incendios, en el nivel freático, en los ciclos de nutrientes y procesamiento de la materia orgánica, en las propiedades del suelo, en las comunidades de invertebrados que procesan la materia orgánica y en las comunidades de vertebrados que habitan en los ríos y en las riberas. En el caso de la Península Ibérica encontramos que las plantas exóticas de ribera causan más frecuentemente efectos negativos (por ej. alteraciones de la estructura y actividad de las comunidades microbianas), seguido de efectos neutros (por ej. en la tasa de descomposición de la hojarasca) y muy pocos efectos positivos para la producción primaria (por ej. aceleración de descomposición de la hojarasca). Sin embargo, se aprecia un notable sesgo en cuanto a las especies estudiadas (mayoritariamente *Eucalyptus globulus*, *Ailanthus altissima* y *Robinia pseudoacacia*) y en cuanto a los efectos estudiados (principalmente descomposición de hojarasca y actividad y estructura de comunidades microbianas). Por tanto, una adecuada evaluación de los efectos de las plantas exóticas de riberas ibéricas requiere ampliar el número de especies consideradas y el tipo de variables respuesta.

Palabras clave: *Ciclo de nutrientes, comunidades microbianas, descomposición de hojarasca, hipótesis, incendios, invasibilidad, invasiones biológicas, macro-invertebrados detritívoros, nivel freático.*

INTRODUCTION

Riparian zones are those extending from the river margins to the limits of the area wherein community structure is influenced by flooding (Goudie, 2004). This strip of land is considered as the transition or ecotone between the aquatic ecosystem of the river and the terrestrial ecosystem of the valley (Naiman & Decamps, 1997). The proximity to the river provides riparian zones with year-round soil moisture due to a permanent water table. Additionally, sediments transported by rivers are deposited on river banks, forming fertile soils (Goudie, 2004). This high nutrient and water availability confer a higher potential primary productivity to riparian zones compared to adjacent terrestrial areas, but the proximity to the river also implies a high risk of flood disturbance. The confluence of high productivity and periodical disturbances contributes to the high biodiversity which characterizes well-preserved riparian forests, and explains their ability to provide multiple services (Vidal-Abarca Gutierrez & Alonso, 2013). For instance, riparian forests mitigate the undesired effects of river floods by laminating high discharges, reducing water energy and soil erosion, and promoting deposition of sediments. In addition, riparian forests reduce river eutrophication by absorbing part of the nutrient load carried by runoff from adjacent fields, and by casting shade on the water column (Karr & Schlosser, 1978; Naiman & Decamps, 1997; Burrell *et al.*, 2014). The shaded, humid and temperature-buffered environment created under the riparian forest canopy, along with the availability of water, offer recreational opportunities to local populations (Briggs, 1996; Vidal-Abarca Gutierrez & Alonso, 2013).

In spite of the variety of ecosystems services provided by well-preserved riparian forests, most riparian zones in highly populated regions have

been deforested and/or deeply degraded. Since the ancient times, humans have competed with vegetation for occupying the fertile riparian soils, frequently reducing the riparian forest to a narrow hedge in the waterside (Fig. 1). Another important cause of riparian forest degradation is the alteration of water fluxes and channels, either by extracting water from rivers, by altering the flooding regime through the construction of dams, or by altering the shape of the river channel to prevent ordinary floods and to gain arable land for crops (Naiman & Decamps, 1997; Vidal-Abarca Gutierrez & Alonso, 2013). A more recent threat to the integrity and functionality of riparian forests is the growing rate of invasion by non-native plant species which, as explained below, is an undesired consequence of the riparian zone properties, often exacerbated by human management. Plant invasions may reduce the diversity of the native ecosystems by displacing species and displaying a high local dominance. Changes in the vegetation composition and structure may alter key ecosystem processes involving water and nutrient cycles. Finally, the effects of invaders may propagate across the food webs altering the structure and functioning of fluvial and riparian animal communities.

The present study aims at reviewing and synthesizing the current knowledge on the causes and ecological consequences of non-native plants invading riparian zones. Specifically, in this work we present: 1) a comprehensive review of the causes explaining the vulnerability of riparian zones to invasion by exotic plants, by summarizing the multiple hypotheses available in the literature; 2) a thorough synthesis of the impacts that non-native riparian plants may cause to riparian and fluvial ecosystems, and 3) an updated review of the available knowledge on the effects that non-native plants cause in riparian and fluvial ecosystems of the Iberian Peninsula.



Figure 1. Aerial photograph of the Tajuña River (Orusco, Madrid), where the riparian zone has been occupied by crops and the riparian forest has been narrowed to a single row of trees (Image from Google Earth). *Fotografía aérea del río Tajuña (Orusco, Madrid), donde la llanura aluvial ha sido ocupada por cultivos y el bosque de ribera ha sido reducido a una fila de árboles (Imagen de Google Earth).*

INVASIVE SPECIES

Invasive species are non-native species which have been able to overcome geographical barriers (i.e. non-native, alien or exotic), establish self-sustaining populations in the new region -overcoming local abiotic and biotic filters- (i.e. naturalized), and expand rapidly from the initial introduction point (i.e. invader, Richardson *et al.*, 2000). This definition implies that the invasion is a staged process, where a series of barriers or ecological filters should be successively passed by the invasive species. A consequence of this successive filtering is that the number of species reaching each stage diminishes, so that, among all the non-native species able to reach a new region only a very small proportion finally becomes successful invaders (Williamson & Fitter, 1996; Levine *et al.*, 2004; Catford *et al.*, 2009).

Invasive species have the potential to alter the structure and functioning of the recipient community, either by causing the local extinction of native species and/or by adding novel functional traits to the community (Castro-Díez *et al.*, 2016). A decline on the local diversity is the most often reported impact of plant invasions

(Levine *et al.*, 2003; Vilà *et al.*, 2011; Pyšek *et al.*, 2012; Vilà *et al.*, 2015). However, changes in species composition also modify the phylogenetic and functional structure of the community (Cadotte *et al.*, 2011; Lapiedra *et al.*, 2015; Castro-Díez *et al.*, 2016), which in turn may alter ecological processes, such as the nutrient cycle, the water cycle or the fire regime (Le Maitre *et al.*, 1996; Levine *et al.*, 2003; Ehrenfeld, 2010; Corbin & D'Antonio, 2011; Castro-Díez *et al.*, 2014). Consequently, in the last decades there has been a growing concern on understanding how biological invasions affect biodiversity and the ability of ecosystems to supply multiple services (Charles & Dukes, 2007; Vilà *et al.*, 2010; Constan-Nava *et al.*, 2015; Hulme *et al.*, 2017), and on developing protocols for managing biological invasions (Simberloff, 2009; Hulme, 2012; Leung *et al.*, 2012; Leung *et al.*, 2014).

VULNERABILITY OF RIPARIAN ZONES TO PLANT INVASIONS

Riparian zones are among the natural habitats exhibiting a higher proportion of invasive plants,

particularly in the Mediterranean region (Hood & Naiman, 2000; Vilà *et al.*, 2001; Chytrý *et al.*, 2008). Understanding what is behind this pattern requires understanding the reasons that explain invasive success.

Multiple hypotheses have been put forward to explain the success of invaders. Some of them emphasize that certain traits confer invasive potential on species, such as the “ideal weed” (Baker, 1965; Rejmánek & Richardson, 1996) or the “novel weapon hypothesis” (Callaway & Ridenour, 2004). Other hypotheses focus on the opportunities offered by recipient communities to recently arrived species, such as the “empty niche” (Hierro *et al.*, 2005) or the “biotic resistance” (Levine *et al.*, 2004; Alpert, 2006). Certain hypotheses stress the importance of the interactions between the invader and the species in the recipient community to enhance or hamper the invasion process, e.g. the “enemy release” (Keane & Crawley, 2002) or the “missed mutualisms” (Alpert, 2006). Other hypotheses emphasize that the abiotic properties and the resource availability of the recipient ecosystem determine the chances of non-native species to become invaders, e.g. the “habitat filtering” (Darwin, 1859; Melbourne *et al.*, 2007), the “fluctuating resource” (Davis *et al.*, 2000) or the “environmental heterogeneity” (Alpert, 2006). Finally, other hypotheses focus on the introduction effort as a major driver of biological invasions, such as the “propagule pressure” (Lonsdale, 1999; Colautti *et al.*, 2006) or the “global competition hypothesis” (Colautti *et al.*, 2006).

Catford *et al.* (2009) synthesized these multiple hypotheses in three major conditions which should converge to allow a successful invasion: 1) The propagule pressure should be large enough to overcome dispersal and geographical constraints. 2) The abiotic properties of the recipient ecosystems should be hospitable enough to allow survival and reproduction of the novel species. 3) The biotic interactions between the novel and the resident species should promote invasion, or at least should not constrain it.

The particular conditions of riparian zones offer good chances for the convergence of the three above-mentioned conditions for success-

ful invasions. Firstly, rivers and riparian zones have been described as effective corridors for exotic propagules (Dyderski *et al.*, 2015). On the one hand rivers may transport large quantities of seeds and other propagules which are deposited downstream in the river bank (Tabacchi *et al.*, 2005; Kowarik & Saumel, 2008; Cabra-Rivas *et al.*, 2014). Many of these propagules come from the exotic species growing in human-created habitats which frequently occur in the proximity of the rivers, such as crops, urban gardens, roads, etc. (Tickner *et al.*, 2001; Dyderski *et al.*, 2015).

Secondly, the climatic limitations for plant growth tend to be buffered by the proximity to the river. This is especially relevant under continental Mediterranean conditions, where both summer water stress and winter frosts limit plant growth (Mittrakos, 1980). Under these limiting circumstances, only a few exotic species – those pre-adapted or coming from other similar environments- have good chances of establishment. However, the presence of a permanent water table in riparian zones mitigates the summer stress and the close canopy of riparian forests buffers extreme temperatures (Naiman & Decamps, 1997). In addition, the low soil fertility which prevents exotic establishment in many regions is also compensated by the continuous supply of organic sediments deposited in the river banks after floodwater receding. All these hospitable conditions give good chances of establishment to novel species.

An additional abiotic factor contributing to explain the high invasibility of many riparian zones is the change of water regimes caused by human management. Man has built dams, created water reservoirs, derived large quantities of river water for irrigation, industry or urban supply, and many river channels have been rectified and constrained by levees to gain arable surface protected from ordinary floods (Naiman & Decamps, 1997; Aguiar *et al.*, 2001; Vidal-Abarca Gutierrez & Alonso, 2013; Zarfl *et al.*, 2015). All these alterations decrease the magnitude and frequency of floods, reduce the transfer of sediment through channel networks, stabilize channels, increase water speed and its erosion power, decline water tables and sometimes promote salinization (Mer-

ritt & Poff, 2010; Catford *et al.*, 2011; Rundel *et al.*, 2014; Tombolini *et al.*, 2014; Lobera *et al.*, 2015). These changes can facilitate plant invasion by providing conditions that benefit non-native species, or by reducing competition from native species unsuited to the modified conditions (Aguiar *et al.*, 2001; Catford *et al.*, 2011; Cooper *et al.*, 2013; Rundel *et al.*, 2014; Liendo *et al.*, 2015). A good example of this is the dramatic invasion of Southwestern USA riparian zones by several species of saltcedar (*Tamarix* spp), a shrub of Euroasiatic origin. Although saltcedar was introduced at the end of the 19th century, its greatest expansion occurred by the 1960s, coinciding with the construction and operation of dams. The reduction of floods, the water table decline and the salinization that followed, appear to have favored saltcedar over other native species (Glenn & Nagler, 2005; Merritt & Poff, 2010).

Thirdly, biotic interactions in riparian zones should – at least – not hamper the establishment of non-native plants. Well-preserved riparian forests developed under natural water regimes may appear to exert a strong biotic resistance to the establishment of new species. However, the episodic floods open gaps that are colonized by any pioneer species, either native or non-native, able to send propagules to the gap. Therefore these communities are a mosaic of patches at different successional stages which offer chances of establishment to a wide range of life strategies (Naiman & Decamps, 1997; Geilen *et al.*, 2004). Riparian zones affected by flow regulation are even more favorable for non-native invasion because the decline of the native populations unsuited to the modified conditions reduces the biotic resistance (Catford *et al.*, 2012). Besides, the modified conditions may offer good chances of establishment to non-native species pre-adapted to the new conditions, as mentioned above (Rundel *et al.*, 2014).

IMPACTS OF PLANT INVASIONS ON FLUVIAL AND RIPARIAN ECOSYSTEMS

Biological invasions alter not only the structure but also the function of recipient ecosystems. In

the case of plant invasions of riparian forests or adjacent catchments, different types of impacts on the fluvial or riparian ecosystems have been described, such as changes in fluvial geomorphic processes and the fire regime, alteration of water and soil properties, as well as effects on other organisms through the trophic web. In the following paragraphs several examples of these impacts are described.

Changes in fluvial geomorphic processes

Riparian vegetation is known to be a relevant factor regulating fluvial geomorphic processes (Osterkamp & Hupp, 2010). Therefore, vegetation changes driven by plant invasions may also alter geomorphic processes. A well-known example is that of the saltcedar invasion in riparian areas of southwestern USA. Saltcedar develops dense and extensive thickets of roots, which makes it valuable for erosion control (Zavaleta, 2000). However, this property also enhances the trap and stabilization of sediments, enlarging islands and banks and narrowing river channels (Blackburn *et al.*, 1982; Manners *et al.*, 2014). Narrowed channels are less effective in evacuating high waters, worsening the frequency and severity of flood damage (Graf, 1978; Zavaleta, 2000). A similar example can be found in the giant reed (*Arundo donax*), a worldwide invasive species native to South Asia. The giant reed is a very tall and robust perennial grass with large, spreading clumps of thick culms up to 6 m tall. The profuse growth of its lignified rhizomes contributes to trap sediments and to narrow stream channels, becoming also in a problem for flood control (Lowe *et al.*, 2000; Sanz Elorza *et al.*, 2004; Dana Sánchez *et al.*, 2005).

Alteration of fire regime

In Mediterranean-type ecosystems riparian forests are less prone to fire than other vegetation types, due to their high soil and plant moisture and to the fast decomposition of dead plant tissues. However, when native deciduous trees are replaced by exotic trees with less tissue water content and/or slower litter decomposition, the

increased fuel load may increase the fire risk during the arid period (Levine *et al.*, 2003). A good example of this is the replacement of the native riparian forests by *Eucalyptus globulus* plantations in Portugal (Ferreira *et al.*, 2016). This species generates a thick soil layer of leaf litter and bark (Fig. 2) with extremely slow decomposition (Castro-Díez *et al.*, 2012) which easily burns when dried. Riparian forests of the Colorado River (USA) dominated by *Tamarix* spread fire and resprout faster after fires than non-invaded forests, leading to a feedback between the invader and fire (Nagler *et al.*, 2005). Forest fires leave behind unprotected soils easily eroded by floods (Shakesby, 2011). The loss of the canopy and the erosion of soils result in a drastic loss of organic matter and nutrients, part of which ends up in the water stream contributing to eutrophication (Emelko *et al.*, 2016).

Changes of water use

Invasive plant species may differ from the native vegetation in their water-use strategy. A well-known case study is that of the Australian Acacias introduced by Europeans in the Cape Region of South Africa –a naturally treeless area– for timber supply. Among other impacts,

these species take up larger quantities of water than the native vegetation and dramatically reduce the water yield from invaded catchments, even threatening the urban water supply (Le Maître *et al.*, 1996). Similarly, several species of *Prosopis* introduced in arid regions of South Africa possess deep roots which make them particularly successful in deep alluvial soils (Richardson & van Wilgen, 2004). The benefits provided by the species in terms of fodder production are counterbalanced by the depletion of the aquifers that represent an important water supply for local populations (Shackleton *et al.*, 2015). Finally, the invasion of *Tamarix* spp. in riversides of the Southwest of North America may decrease the water table due to their high evapotranspiration rates (Di Tomaso, 1998; Zavaleta, 2000).

Changes in soil properties

When plants invading riparian forests differ from natives in nutrient use strategy or in the quality and/or quantity of the produced litter, the processing of organic matter and the soil properties may be altered (Castro-Díez *et al.*, 2009; Menéndez *et al.*, 2013; Medina-Villar *et al.*, 2015; Ferreira *et al.*, 2016). For instance, in a central Spain riparian forest, soils from patches invaded



Figure 2. Thick layer of litter (bark peelings and leaves) accumulated under a *Eucalyptus globulus* plantation in Cíes Islands (Galicia, Northwestern Spain). Photo: P. Castro-Díez. *Gruesa capa de hojarasca (restos de cortezas y hojas) acumulados bajo el dosel de una plantación de Eucalyptus globulus en las Islas Cíes (Galicia, noroeste de España).* Foto: P. Castro-Díez.

by *Robinia pseudoacacia* (a N-fixing legume) showed larger amount of inorganic N than non-invaded controls (Medina-Villar *et al.*, 2016). Gutiérrez-López *et al.* (2014) reported differences in physical-chemical soil properties between patches invaded by *Ailanthus altissima* and nearby non-invaded patches. Leaves of invasive saltcedars in the Colorado River (USA) excrete salts that are deposited on the soil surface, increasing soil salinity (Merritt & Shafroth, 2012).

Alteration of populations and communities of other organisms

Changes in riparian soil properties caused by plant invasions have been associated to changes in the composition of the soil arthropod community (Gutiérrez-López *et al.*, 2014; Maceda-Veiga *et al.*, 2016). Similarly, aquatic communities feeding on litter from the riparian forest may be altered by the input of exotic litter (Martinez *et al.*, 2013; Correa-Araneda *et al.*, 2015; Ferreira *et al.*, 2015). For instance Medina-Villar *et al.* (2015) found lower colonization of exotic leaf litter by aquatic fungi and bacteria, which makes litter less palatable for macroinvertebrates. Alterations to aquatic macroinvertebrate communities may propagate up through the food web and affect the fish that feed on them (Maceda-Veiga *et al.*, 2016). More direct impacts of plant invasions may be found in those animals who find shelter and food in the riparian vegetation. For instance, Portuguese riparian forests replaced by eucalypt plantations presented lower fluvial habitat quality for native fish, which contributes to a higher abundance of exotic fish (Oliveira *et al.*, 2016). In African mesic savannas the invasion of riparian areas by the exotic shrub *Chromolaena odorata* increases shading on riverbanks, which reduces temperature of soils where Nile crocodiles dig nests for egg deposition, leading to altered sex ratios (Leslie & Spotila, 2001). Riparian corridors of Southeastern USA invaded by *Tamarix* spp. provide poorer food and habitat for many resident and migrating birds, due to the small size of their seeds and the poor shade cast by their canopies (Hunter *et al.*, 1988; Shafroth *et al.*, 2005).

EFFECTS OF NON-NATIVE PLANTS IN RIVERS AND RIPARIAN ZONES OF THE IBERIAN PENINSULA

We performed an updated literature review on the ecological effects that non-native plants (either invasive or planted) have in rivers and riparian zones of the Iberian Peninsula. In October 2016 we searched published papers on Web of Science, with no restriction of date, using the following key-words: (exotic or non-native or invasive) and (plant or tree) and (riparian or floodplain) and (Spain or Portugal or Iberian Peninsula) and ((stream or river) or (macroinvertebrate or fish or amphibians) or (leaf litter or breakdown or microbial or decomposition)). Valid studies were those comparing any variable related with the structure and function of the riparian and fluvial ecosystems between sites/treatments dominated by non-native plants and control sites/treatments with native vegetation. Results are summarized in Table 1, where effects are sorted primarily by the type of effect and secondarily by the non-native species.

To gain insight on the representativeness of the available information, we compiled a list of non-native species present in riparian zones of the Iberian Peninsula. For Spain we used a national (Sanz Elorza *et al.*, 2004) and three regional (Dana Sánchez *et al.*, 2005; Campos & Herrera, 2009; Guerrero-Campo & Jarne Bretones, 2014) catalogues of exotic invasive plants, and also checked whether the species were included in the official Catalogue of Invasive Species in Spain (Real Decreto 630/2013). In the case of Portugal we used the list of exotic plant species present in continental Portugal (Almeida & Freitas, 2006; Almeida & Freitas, 2012), downloaded from www.invasoras.pt in January 2017.

The two most studied variables used to describe the effects of non-native riparian plants were related to the processing of leaf litter (mostly litter decomposition rate, either in water or in soil), and structure and activity of microbial communities (both in soil and in water), with 10 and eight case studies respectively. Less information was found on the effects on invertebrate communities (six case studies) and soil prop-

Table 1. Summary of the paper review assessing effects that riparian non-native plants (planted or invasive) have on fluvial and riparian ecosystems. Studies were searched in Web of Science for the Iberian Peninsula, with no limitation of publication date. Most studies compared any ecosystem property between a riparian zone dominated by a non-native plant species and a control system dominated by native species. Data are primarily sorted by type of effect (grey rows) and secondarily by the non-native species. *Resumen de la revisión de artículos que evalúan los efectos de plantas exóticas de ribera (plantadas o invasoras) en ecosistemas fluviales y ribereños. Los estudios se buscaron en Web of Science para la Península Ibérica, sin restricción del año de publicación. La mayoría de los estudios comparan alguna propiedad ecosistémica entre un río o llanura aluvial dominado por una planta exótica y un sistema control dominado por especies nativas. Los datos están ordenados en primer lugar por tipo de impacto (filas grises) y en segundo lugar por especie exótica.*

Non-native species	Description of the effect	Effect type	Type of ecosystem	Location	Reference
<i>Effects on soil properties</i>					
<i>Ailanthus altissima</i>	Decreased total soil N, soil ammonia and soil organic matter	–	Terrestrial	Central Spain	(Medina-Villar <i>et al.</i> , 2016)
<i>Ailanthus altissima</i> & <i>Robinia pseudoacacia</i>	No effects on soil mineral N availability	0	Terrestrial	Central Spain	(Castro-Díez <i>et al.</i> , 2009)
<i>Ailanthus altissima</i> & <i>Robinia pseudoacacia</i>	Similar properties (pH, organic matter, N content) were found between soils incubated with non-native and native leaf litter	0	Terrestrial	Central Spain	(Castro-Díez <i>et al.</i> , 2012)
<i>Robinia pseudoacacia</i>	Increased mineral soil N	+	Terrestrial	Central Spain	(Medina-Villar <i>et al.</i> , 2016)
<i>Effects on processing of organic matter</i>					
<i>Ailanthus altissima</i>	Similar litter decomposition rate than coexisting natives in a stream	0	Aquatic	Central Spain	(Medina-Villar <i>et al.</i> , 2015)
<i>Ailanthus altissima</i>	Similar litter decomposition rate than coexisting natives <i>Fraxinus angustifolia</i> and <i>Ulmus minor</i> in a lentic ecosystem	0	Aquatic	Central Spain	(Alonso <i>et al.</i> , 2010)
<i>Ailanthus altissima</i>	Faster leaf litter decomposition in soils than a native control	+	Terrestrial	Central Spain	(Castro-Díez <i>et al.</i> , 2009)
<i>Ailanthus altissima</i> & <i>Robinia pseudoacacia</i>	Similar litter decomposition rates to coexisting native riparian tree species in soils	0	Terrestrial	Central Spain	(Castro-Díez <i>et al.</i> , 2012)
<i>Eucalyptus globulus</i>	Decomposition rate of leaf litter of the native tree <i>Alnus glutinosa</i> was slower in streams dominated by exotic plantations of <i>Eucalyptus globulus</i> than that in streams with native forests	–	Aquatic	Portugal	(Ferreira <i>et al.</i> , 2015)
<i>Eucalyptus globulus</i>	Decomposition rate of the same litter was similar in streams bordered by eucalypts and by native forest	0	Aquatic	Portugal	(Barlocher & Graça, 2002)
<i>Platanus hybrida</i>	faster decomposition of native leaf litter in reaches dominated by the non-native than in reaches dominated by native trees	+	Aquatic	NE Spain	(Menendez <i>et al.</i> , 2013)
<i>Robinia pseudoacacia</i>	Slower litter decomposition rate than coexisting native litter in a river	–	Aquatic	Central Spain	(Medina-Villar <i>et al.</i> , 2015)
<i>Robinia pseudoacacia</i>	Slower litter decomposition rate than the natives <i>Fraxinus angustifolia</i> and <i>Ulmus minor</i> in a lentic ecosystem	–	Aquatic	Central Spain	(Alonso <i>et al.</i> , 2010)
<i>Robinia pseudoacacia</i>	Slower leaf litter decomposition in soils than a native control	–	Terrestrial	Central Spain	(Castro-Díez <i>et al.</i> , 2009)

(Continued)

Non-native species	Description of the effect	Effect type	Type of ecosystem	Location	Reference
<i>Effects on invertebrate communities</i>					
<i>Acacia dealbata</i> & <i>Eucalyptus globulus</i>	No effect on the richness of collembolan communities in the soil	0	Terrestrial	Portugal	(Pinto <i>et al.</i> , 1997)
<i>Ailanthus altissima</i>	Alterated structure of soil microarthropod community	–	Terrestrial	Central Spain	(Gutiérrez-López <i>et al.</i> , 2014)
<i>Ailanthus altissima</i> & <i>Robinia pseudoacacia</i>	No effect on the structure of the invertebrate community colonizing the leaf litter	0	Aquatic	Central Spain	(Medina-Villar <i>et al.</i> , 2015)
<i>Eucalyptus globulus</i>	Reduced abundance of stream invertebrates	–	Aquatic	Portugal	(Ferreira <i>et al.</i> , 2015)
<i>Eucalyptus globulus</i>	Reduced growth of the detritivore caddisfly <i>Calamoceras marsupus</i> in presence of <i>Eucalyptus</i> leaf litter as compared to native litter	–	Aquatic	Spain	(Correa-Araneda <i>et al.</i> , 2015)
<i>Pinus radiata</i> & <i>Platanus hispanica</i>	Decreased density of total macroinvertebrates and shredders	–	Aquatic	North Spain	(Martinez <i>et al.</i> , 2013)
<i>Effects on microbial communities and activity</i>					
<i>Ailanthus altissima</i>	Decreased net nitrification and total nitrogen mineralization rates Altered soil bacterial community	–	Terrestrial	Central Spain	(Medina-Villar <i>et al.</i> , 2016)
<i>Ailanthus altissima</i> & <i>Robinia pseudoacacia</i>	Decreased fungal biomass in leaf litter decomposing in the stream	–	Aquatic	Spain	(Medina-Villar <i>et al.</i> 2015)
<i>Ailanthus altissima</i> & <i>Robinia pseudoacacia</i>	No effects on soil N mineralization	0	Terrestrial	Central Spain	(Castro-Díez <i>et al.</i> , 2009)
<i>Arundo donax</i>	Decreased abundance and diversity of the soil macro-arthropods	–	Terrestrial	NE Spain	(Maceda-Veiga <i>et al.</i> , 2016)
<i>Eucalyptus globulus</i>	Lower species richness and evenness of aquatic hyphomycetes	–	Aquatic	Portugal	(Ferreira <i>et al.</i> , 2015)
<i>Eucalyptus globulus</i>	Little effect on activity and diversity of aquatic hyphomycete in rivers	0	Aquatic	North Spain	(Chauvet <i>et al.</i> , 1997)
<i>Eucalyptus globulus</i>	Decreased richness and evenness of aquatic hyphomycetes	–	Aquatic	Portugal	(Barlocher & Graça, 2002)
<i>Robinia pseudoacacia</i>	Greater phosphomonoesterase activity and net ammonification rates No clear effect on soil bacterial composition	+ 0	Terrestrial	Central Spain	(Medina-Villar <i>et al.</i> , 2016)
<i>Effects on vertebrate communities</i>					
<i>Eucalyptus globulus</i>	Decreased fish productivity	–	Aquatic	Iberian Peninsula	(Maceda-Veiga, 2013)
<i>Eucalyptus globulus</i>	Higher abundance of fish alien species and functional alterations in the fish trophic groups	–	Aquatic	Portugal	(Oliveira <i>et al.</i> , 2016)

Table 2. List of non-native plant species invading riparian zones in the Iberian Peninsula. Species are sorted by growth form. Species with an asterisk are those for which there is bibliographic information on their ecological impacts in the Iberian Peninsula (see Table 1). *Lista de especies de plantas exóticas que invaden riberas en la Península Ibérica. Las especies están ordenadas según su forma de crecimiento. Las especies con asterisco son aquellas para las que hemos encontrado información de los impactos ecológicos que causan en la Península Ibérica (ver Tabla 1).*

Species	Family	Growth form	Reference ⁽¹⁾
<i>Acacia dealbata</i> *	Fabaceae	Tree	1,2,4,6
<i>Acer negundo</i>	Aceraceae	Tree	2,3,4,5,6
<i>Ailanthus altissima</i> *	Simaroubaceae	Tree	1,2,3,4,5,6
<i>Alnus cordata</i>	Betulaceae	Tree	5,
<i>Elaeagnus angustifolia</i>	Elaeagnaceae	Tree	2,4,5,
<i>Eucalyptus camaldulensis</i>	Myrtaceae	Tree	2,4,6
<i>Eucalyptus globulus</i> *	Myrtaceae	Tree	2,4,6
<i>Gleditsia triacanthos</i>	Fabaceae	Tree	2,4,5,6
<i>Laburnum anagyroides</i>	Fabaceae	Tree/shrub	5,6
<i>Platanus hispanica</i>	Platanaceae	Tree	3,6
<i>Pterocarya stenoptera</i>	Juglandacea	Tree	3,
<i>Robinia pseudoacacia</i> *	Fabaceae	Tree	2,3,4,5,6
<i>Buddleja davidii</i>	Buddlejaceae	Shrub	1,2,3,5,6
<i>Gomphocarpus fruticosus</i>	Asclepiadaceae	Shrub	2,4,6
<i>Lippia filiformis</i>	Verbenaceae	Shrub (procumbent)	2,5,
<i>Ricinus communis</i>	Euphorbiaceae	Shrub	2,4,6
<i>Solanum bonariense</i>	Chenopodiaceae	Shrub	2,4,
<i>Vinca difformis</i>	Apocynaceae	Shrub (procumbent)	2
<i>Araujia sericifera</i>	Apocynaceae	Vine	1,3,4,5,6
<i>Fallopia baldschuanica</i>	Polygonaceae	Vine	1,2,4,5,6
<i>Ipomoea acuminata</i>	Convolvulaceae	Vine	2,4,6
<i>Lonicera japonica</i>	Caprifoliaceae	Vine	2,3,5,6
<i>Abutilon theophrasti</i>	Malvaceae	Herb	2,3,4,6
<i>Amaranthus hybridus</i>	Amaranthaceae	Herb	2,3,4,6
<i>Amaranthus powellii</i>	Amaranthaceae	Herb	3,4,6
<i>Artemisia verlotiorum</i>	Asteraceae	Herb	2,3,5,6
<i>Arundo donax</i> *	Poaceae	Herb	2,3,4,6
<i>Aster novi-belgii</i>	Asteraceae	Herb	5,
<i>Bidens aurea</i>	Asteraceae	Herb	2,3,4,6
<i>Bidens frondosa</i>	Asteraceae	Herb	2,3,4,6
<i>Bidens pilosa</i>	Asteraceae	Herb	2,4,6
<i>Chenopodium ambrosioides</i>	Chenopodiaceae	Herb	3,6
<i>Cortaderia selloana</i>	Poaceae	Herb	1,2,3,5,6
<i>Crocsmia x crocosmiiflora</i>	Iridaceae	Herb	3,5,
<i>Cyperus eragrostis</i>	Cyperaceae	Herb	3,6
<i>Duchesnea indica</i>	Rosaceae	Herb	3,6
<i>Echinochloa crus-galli</i>	Poaceae	Herb	3
<i>Helianthus tuberosus</i>	Asteraceae	Herb	1,2,3,
<i>Helianthus x laetiflorus</i>	Asteraceae	Herb	3,6

(Continued)

Species	Family	Growth form	Reference ⁽¹⁾
<i>Impatiens glandulifera</i>	Balsaminaceae	Herb	5
<i>Oenothera biennis</i>	Onagraceae	Herb	2,5,6
<i>Oenothera glazioviana</i>	Onagraceae	Herb	2,3,5,6
<i>Paspalum dilatatum</i>	Poaceae	Herb	2,3,4,6
<i>Paspalum paspalodes</i>	Poaceae	Herb	2,3,4,6
<i>Phyllostachis spp.</i>	Poaceae	Herb	5
<i>Reynoutria japonica</i>	Polygonaceae	Herb	1,2,3,5,6
<i>Solanum chenopodioides</i>	Chenopodiaceae	Herb	3,6
<i>Solidago canadensis</i>	Asteraceae	Herb	5
<i>Solidago gigantea</i>	Asteraceae	Herb	5
<i>Tradescantia fluminensis</i>	Commelinaceae	Herb	1,2,3,5,6
<i>Veronica persica</i>	Schrophulariaceae	Herb	3,6
<i>Xanthium strumarium subsp. italicum</i>	Asteraceae	Herb	2,3,4,6

⁽¹⁾ 1-Real Decreto 630/2013; 2-(Sanz Elorza *et al.*, 2004); 3-(Campos & Herrera, 2009); 4-(Dana Sánchez *et al.*, 2005); 5-(Almeida & Freitas, 2006; Almeida & Freitas, 2012).

erties (four studies). Finally, the least explored effects were those on vertebrate communities with only two case studies.

The number of non-native riparian plant species whose impact was reported in the literature was quite low. We only found information on four out of the 12 invasive trees, one out of the 30 herbs and none out of the six shrubs and four vines present in Iberian riparian forests (Table 2). Most studies in Portugal focused on *Eucalyptus globulus*, as plantations of this species have replaced native riparian vegetation of many Portuguese rivers. In Spain, the most studied invaders were *Ailanthus altissima* and *Robinia pseudoacacia*, which easily naturalize and invade riparian forests. Fewer studies focused on other non-native species, such as *Arundo donax*, *Acacia dealbata*, *Pinus radiata* and *Platanus hybrida*, and the last two species were not included in the list of non-native plants invading riparian zones. Although the studied species probably cover the most abundant and conspicuous invaders, our review highlights the scarcity of knowledge on the impacts caused by non-tree invaders in the Iberian Peninsula.

The reported effects of non-native species widely varied across species and studies. Effects on soil properties varied from decreased to in-

creased N (Table 1). Litter decomposition was usually slower in *R. pseudoacacia* than in co-existing natives (Table 1). Four out of the six studies on invertebrate communities reported altered structure or reduced abundance of certain groups (Table 1). Effects on microbial communities were mostly negative (altered bacterial or fungal community, decreased microbial activity), and only one study reported a positive effect of *R. pseudoacacia* on the phosphomonoesterase activity (Table 1). Finally, the only two studies on vertebrate communities reported negative effects (decreased fish productivity and increased abundance of non-native fish). Overall, we found 17 negative, 14 neutral and only 4 positive effects of non-native riparian plants on the ecosystems. However, there is a clear need to extend the studies to other non-native species, especially to non-tree species.

CONCLUSIONS

Riparian zones are highly susceptible to be invaded by non-native plant species, thanks to the confluence of a high propagule pressure, hospitable abiotic conditions for plant growth and reduced biotic resistance due to natural or human-

caused disturbances. Non-native plants have the potential to alter the structure and functioning of recipient ecosystems by altering the fire regime, by changing water use and nutrient cycles, and by altering the animal communities that find shelter and food in the riparian vegetation. The current knowledge on the effects of non-native riparian plants in Iberian fluvial and riparian ecosystems revealed a higher frequency of negative effects, but also a bias of knowledge, as most studies covered only a few non-native tree species.

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