REVIEW

Invasive alien plant species, riverbank instability and hydraulic risk: what do we know about *Amorpha fruticosa*, *Arundo donax* and *Reynoutria japonica*?

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ABSTRACT

The spread of invasive alien plant species (IAPs) poses a serious threat to the biodiversity and effectiveness of rivers and drainage canals. Nevertheless, the reasons for the implications of increasing presence of IAPs on the stability and effectiveness of flood defences are still unclear. To point out the current knowledge on the topic, a systematic review was performed focusing on three of the key riparian IAPs: *Amorpha fruticosa*, *Arundo donax* and *Reynoutria japonica*. We searched for articles in the Scopus database, focused on the links between the three target species and hydrology and geomorphological processes. Only 7 papers were found containing what we were looking for. All the three target species are true «engineer plants», significantly regulating the edaphic and functional peculiarities of colonised environments, which correspond in the present case to river embankments. *A. fruticosa* slows down the water flow speed, increasing the flood risk; the extremely superficial *A. donax* root systems weaken bank stability, whereas *R. japonica* promotes soil erosion due to its peculiar roots' morphology and extremely rapid biological cycles. This work shows that, despite clear evidence of the significant negative impacts mediated by the three IAPs of concern, the available levels of knowledge are wholly insufficient. In order to develop effective management strategies for riparian contexts globally, further investigations are needed urgently. Future research should focus on the structural/functional impacts of IAPs in riparian environments, not forgetting the additional effects of global changes and human impact on rivers and their functions.

INTRODUCTION

Biological invasions are one of the most serious issues ecosystems are facing around the world, especially in so-called developed countries and in a scenario of global change (Pyšek *et al.*, 2020). Alien plant species, particularly invasive ones (IAPs = invasive alien plants), transform ecosystems by altering biotic communities and trophic balances (Rodríguez-Merino *et al.*, 2018). In addition, invasion processes often lead to drastic reductions in species richness or to communities largely or even entirely consisting of IAPs (Viciani *et al.*, 2020). In particular, riparian and freshwater habitats are among the most threatened globally (Brundu, 2015) and among the most affected by biological invasions (Pyšek *et al.*, 2010; Bolpagni, 2021). In many cases, IAPs invade riverbanks or wetlands first (Pyšek and Prach, 1994), especially when these have already been altered by human activities (Brundu, 2015; Malavasi *et al.*, 2018; Boscutti *et al.*, 2022), and then spread to surrounding environments.

In economically developed countries, most marshes and wetlands have been gradually reclaimed and natural watercourses rectified and regulated with riverbanks and flood-control reservoirs. Consequently, in hyper-exploited lowlands original aquatic ecosystems have been replaced by drainage canals, often arranged in extensive networks (Bolpagni *et al.*, 2020; Montanari *et al.*, 2020, 2022), and/or impaired rivers. Indeed, lowland lotic systems are impacted by their use as waterways, dammed for generating hydropower and for preventing floods (Shevchyk *et al.*, 2021), filled with domestic and industrial wastewater, and polluted by fertilisers and pesticides largely used in agriculture (Viaroli *et al.*, 2018). In addition, lotic ecosystems are often forced to flow into increasingly smaller riverbeds, delimited by embankments built in past centuries and continuously raised in height and reinforced. This fact is becoming increasingly important in recent decades due to the increased frequency of extreme weather events, resulting in increased flooding intensity and magnitude with greater risk in densely populated areas such as the Po Valley (Krellenberg *et al.*, 2013; Morelli *et al.*, 2014). Recently, the presence of *Arundo donax* L. rhizomes is considered to be one of the possible flaws which favoured local instability that triggered concentrated erosion and riverbank breach during the 2020 Panaro River flood (Ceccato and Simonini, 2023).

Despite drainage canals resulting in heavily altered waterways, they could act as ecological corridors in areas deeply impacted by human activities, providing alternative habitats for species which have become rare or threatened (if not even extinct) in the surrounding countryside (Goulder, 2008; Tölgyesi *et al.*, 2022). However, since rivers and drainage canals also are easily invaded by alien plants (Montanari *et al.*, 2020, 2022; Buldrini *et al.*, 2023), they contribute to the further spreading of these invaders. Their management is, in fact, generally geared toward protecting the land from flooding risk and providing water for irrigation (Bolpagni, 2020; Montanari *et al.*, 2020): the riparian vegetation is periodically cut and pruned to keep the hydraulic section constant and assure effective drainage, which may contain the growth of alien species but nonetheless facilitates spreading through the dispersal of propagules.

All this results in riparian ecosystems characterised by a trivial flora consisting of ruderal and generalist species (Montanari *et al.*, 2020, 2022) and colonised by paucispecific, poorly structured vertically riparian vegetation dominated by IAPs (Celesti-Grapow *et al.*, 2010; Viciani *et al.*, 2020). This could lead to significant hydraulic issues considering the inherent characteristics of IAPs, such as their aptitude for very rapid and efficient propagation (Spencer *et al.*, 2013; Lavoie, 2017; Delai *et al.*, 2018; Drazan *et al.*, 2021; Sciuto *et al.*, 2022) and allelopathic effects on native species (e.g. Kowarik and Säumel, 2007; Serniak, 2016). Indeed, the potential for hydrochorous dispersal can promote the longitudinal spread of several IAPs, which form uninterrupted stands many hundreds of metres long. This greatly amplifies the problems of managing these species and local hydraulic issues.

Under these conditions, traditional methods of invasive species containment (e.g., repeated cutting with removal of plant material) are not only ineffective and extremely expensive, but also dangerous, because they could further facilitate their spreading, besides potentially damaging man-made infrastructures. This is especially true for the underground portions of invasive species, which are able to weaken riverbanks significantly. Therefore, it is necessary to consider the possible reciprocal links between the presence and spreading of invasive riparian plants and the hydraulic and/or geomorphological conditions of invaded ecosystems: an essential step to develop effective control actions. This article aims to present the results of a systematic review of research carried out on the topic focusing on three of the most critical riparian IAPs on a European scale: *Amorpha fruticosa* L., *Arundo donax* L. and *Reynoutria japonica* Houtt.

METHODS

To systematise the available knowledge on the interlinks between the presence and spreading of the three target IAPs (*A. fruticosa*, *A. donax* and *R. japonica*), and the hydro-geomorphological characteristics of colonised habitats, the Scopus citation database (https://www.scopus.com; last access 28 October 2024) was queried. The following keyword strings were used: for *A. fruticosa* «*Amorpha fruticosa*» OR «false indigo» OR «indigo-bush» OR «indigobush» AND hydrology OR geomorphology OR hydraulic OR instability OR flood*; for *A. donax* «*Arundo donax»* OR «giant cane» OR «elephant grass» OR «arundo» OR «Spanish cane» OR «Colorado river reed» OR «giant reed» OR «wild cane» AND hydrology OR geomorphology OR hydraulic OR instability OR flood*; and for *R. japonica* «*Reynoutria japonica*» OR «*Fallopia japonica*» OR «*Polygonum cuspidatum*» OR «*Polygonum bambusa*» OR «*Polygonum japonicum*» OR «Japanese knotweed» OR «renouée du Japon» AND hydrology OR geomorphology OR hydraulic OR instability OR flood. The selected scientific papers were then subjected to analysis according to a «prioritisation» approach according to their actual relevance to the objectives of the investigation. The selection process was articulated as follows:

i) an initial screening of the titles and keywords of the publications;
ii) a subsequent screening by reading the abstracts of the papers thematically consistent with the topic of interest;
iii) reading and analysing the articles in their entirety only if the investigated research topic was substantially consistent with the possible existence of ecosystem relationships between the presence and local spreading of the three target species and the hydro-geomorphological characteristics of the colonised river systems;
iv) the contributions deemed of interest were, finally, analysed by means of critical reading of the texts and extrapolation of a range of information considered useful to explore the ecological relationships between the presence/diffusion of *A. fruticosa*, *A. donax* and *R. japonica* with the hydraulic and/or geomorphological peculiarities of invaded ecosystems. For this last step, the matrix method approach proposed by Klopper *et al.* (2007) was followed, which involves the creation of an evaluation matrix. According to this method, the header of each column of the matrix should focus on the parameters/descriptors that are potentially useful in categorising the selected papers, to allow a better understanding of their relevance to the objectives of the analysis.

Tab. 1 shows the parameters used to analyse the scientific papers extracted from the Scopus database, the corresponding acronyms and their explanation. Each article was categorised by virtue of the geographic area (*Geo data*) of study (location of vegetation stands, areas and/or rivers analysed, reporting the information of the reference continent). *Habitat type* indicates the type of habitat under study to which the article data refer. *Main topic* refers to the main topic of the study to which the article data refer. *Hydro-Links* clarifies whether the article verified the existence of possible interdependencies or mutual effects of the target species in relation to the hydraulic/geomorphological aspects; the *Results* parameter summarises the main results obtained from the work. Finally, the *Ind val* parameter indicates whether the species can be considered as an indicator of hydrological arrangement or disruption (YES).

RESULTS AND DISCUSSION

Overall, the Scopus database query allowed the identification of 36, 118 and 21 articles of potential interest for *A. fruticosa*, *A. donax* and *R. japonica*, respectively. Of these, after preliminary screening, only 12, 20 and 26 articles respectively were consistent with the objectives of the review. These 58 articles were thoroughly analysed and categorised as shown in Tab. 1. Specifically, for *A. fruticosa*, only two contributions found significant interrelationships between the presence of the species and hydro-geomorphological aspects (Kiss *et al.*, 2019; Grabić *et al.*, 2022; Tab. 2). Similarly, there are two relevant papers for *A. donax* on the topic, namely Spencer *et al.* (2013) and Stover *et al.* (2018; Tab. 2). For *R. japonica* three articles reported a relation between the presence of the species and a significant increase in bank and riverbed erosion, especially in winter (Arnold and Toran, 2018; Colleran *et al.*, 2020; Matte *et al.*, 2022; Tab. 2). Specifically, Colleran *et al.* (2020) even define *R. japonica* as «autogenic geomorphologic engineer species» and «erosion catalyst».

Amorpha fruticosa L.

Amorpha fruticosa (Fabaceae) is a shrub, 1-2(-6) m tall, bearing numerous branches, with compound leaves formed by 13-17 elliptic leaflets and spike-like linear inflorescences (1 × 10-15 cm) with many small purple flowers (Pignatti *et al.*, 2017-2019). It is native to North America, but it has spread across Asia and Europe from the 18th century as an ornamental plant. It is now generally accepted to be among the most invasive alien species in Europe (CABI, 2017). The present literature review confirmed that *A. fruticosa* not only is a crucial invasive *taxon*, but rather a «transformer species» capable of widespread invasion of disturbed areas (Szigetvári, 2002; Protopopova *et al.*, 2006; Pellegrini *et al.*, 2021). It forms impenetrable shrublands, facilitating consolidation and stabilisation of soils and slopes, preventing erosion (Grabić *et al.*, 2022). This is mainly due to its dense canopy capable of intercepting rainfall and the large quantity of dead plant material produced every year, which covers the soil surface. Indeed, the species is widely used for forestry and prevention of land degradation, as well as for restoration of impacted habitats (Yin, 1993). Therefore, although there is a lack of specific studies in this regard – particularly concerning the potential instability of the bank induced mainly by the slope and the erosive action of the watercourse – it is reasonable to assume that *A. fruticosa* may play the same role along riverbanks. In Europe, the species typically colonises riparian thickets and abandoned lands, as is widely observed along rivers and canals and in associated riverine areas (e.g., in Hungary – Delai *et al.*, 2018; or in Romania – Kucsicsa *et al.*, 2018).

Tab. 1. List of parameters/descriptors investigated, and their explanation.

Parameter	Explanation	Abbreviation	Explanation
Geo data	Indication of the continent where the study was carried out - to which the paper data refers	Eur	Europe
		Asi	Asia
		AmS	South America
		AmN	North America
		Oce	Oceania
		Afr	Africa
		Glo	Global
Habitat type		*Lak*	Lake
		Pon	Pond
		WetL	Wetland
		Lot	Lotic
		AnyH	Any
Main topic	Indication of the main topic of the study - to which the paper data refer	*EnvG*	Environmental gradients
		ComS	Community structure
		AntPr	Anthropic pressure
		BioI	Biotic interactions
		Inv	Invasiveness
		SpCh	Specific characteristics
		OthTop	Other
Hydro-Links	Answer YES or NO = whether or not the paper deals with possible interdependencies or mutual effects of the target species on hydraulic/geomorphological aspects		
Results	In case the answer above is YES = the main results obtained from the paper are to be summarised		
Ind val	In case the answer above is YES = the main results obtained from the paper are to be summarised		

Tab. 2. Parameters/descriptors of the papers selected by matrix method approach (see Tab. 1 for the meaning of acronyms).

First Author	Journal	Year	Target Species	Geo data			Country/State	Habitat type		Eco-system	Main topic					OthTop
				Eur	AmN	Glo		Lot	AnyH		EnvG	ComS	BioI	Inv	SpCh	
J. Grabić	Ecol. Evol.	2022	*Amorpha fruticosa*			x	n.a.		x	n.a.		x	x	x	x	Control techniques
T. Kiss	Sci. Tot. Environ.	2019	*Amorpha fruticosa*	x			Hungary	x		River Tisza and adjacent wetlands				x	x	
D.F. Spencer	J. Freshw. Ecol.	2013	*Arundo donax*		x		California	x		Cache Creek and Stony Creek						
J.E. Stover	Geosciences	2018	*Arundo donax*		x		California	x		Santa Clara River	x				x	
B.P. Colleran	River Res. Appl.	2020	*Reynoutria japonica*					x		River						Autogenic geomorphological engineer species. Erosion catalyst. Overland erosion follows autumnal death = banks exposed to winter floods. Under-land erosion by inhibition of the regeneration of native species, that provide structural support to the banks.
R. Matte	River Res. Appl.	2022	*Reynoutria japonica*		x		Québec	x		River						
E. Arnold	Water	2018	*Reynoutria japonica*		x		Pennsylvania	x		Creek						Greater erosion in reaches dominated by *R. japonica* than in those dominated by trees. In a 9.5-month monitoring period, there was 29 cm more erosion on banks that were also incised, and 9 cm more erosion in banks with little incision.

In addition, since the species has a hydrochorous dispersal, colonisation along river courses is very rapid and extensive. Only damming can block the transport of propagules downstream (Shevchyk *et al.*, 2021), reducing the colonisation efficiency of the species. Shrublands dominated by *A. fruticosa* appear to slow down water flow speed significantly (0.5 to 0.0 m/s in Hungary, along the River Tisza; Sándor and Kiss, 2007), given that each individual produces up to 5-10 suckers that sprout directly from the roots (Miháli and Botta-Dukát, 2004), with obvious consequences in case of flood. The high density of suckers and basal branches induces a significant slowdown in flow due to the reduction in cross-sectional area of colonized lotic environments. Control of *A. fruticosa* infestation seems to be more effective and less expensive if implemented through moderate to intense grazing (of leaves, young shoots, young plants and fruits consumption), resulting in reduced potential for spreading (Grabić *et al.*, 2022).

Arundo donax L.

Arundo donax (Poaceae) is a giant perennial bamboo-like grass with culms generally 2-5 m high and 3-5 cm in diameter, leaves numerous, lanceolate (1-6 × 10-50 cm), and fusiform inflorescences 30-50 cm long (Pignatti *et al.*, 2017-2019). In the Mediterranean basin, it is considered an archaeophyte, formerly regarded as a native species because of its presence and traditional use since ancient times (Atzei, 2003; Pignatti *et al.*, 2017-2019). Indeed, the species is native to tropical and temperate regions of the Old World and in the Mediterranean area it shows genetic uniformity with a robust morphotype distinguishable from Asian plants confirming a remote domestication and suggesting an East Asian origin (Hardion *et al.*, 2014; CABI, 2024). Currently, it is listed among the 100 worst invasive alien species on a world scale (Lowe *et al.*, 2000). Stover *et al.* (2018) showed that *A. donax* does play a role in decreasing river/canal banks stability because this species has very superficial root systems, which generally do not go deeper than 30 cm. Only roots with a diameter of less than 10 mm and especially finer roots (1-3 mm) reach greater depths, however not exceeding 90 cm. In addition, the maximum area occupied by roots occurs in the first 10 cm of soil. Consequently, when *A. donax* grows near the water-land ecotone, the first 10-20 cm of soil are a hard, resistant layer of soil attached to the roots superimposed to more erodible layers (where *A. donax* roots are not present), underlying just below the species' rhizosphere. In these situations, embankments can easily be damaged during high stage and flood events, with soil blocks mixed with *A. donax* roots sliding into the active channel, facilitating lateral erosion and, in the long term, hydraulic and structural slope instability processes.

Furthermore, the stability of the banks decreases if riparian forests are progressively replaced by stands of *A. donax*. According to Stover *et al.* (2018), through direct observations on a 30° sloping coarse sand and gravel embankment, under unsaturated conditions, it emerged that in the presence of the species, the safety factor (understood as the ratio between resisting and driving forces acting on the riverbank) decreases as the height of the embankments increases (approximately 0.75 for 3 m high embankments, approximately 1.60 for embankments 1 m high). Conversely, riparian willows (measured in particular on *Salix laevigata* Bebb) always offer a notably higher safety factor (about 1.15 for 3 m high riverbanks, about 2.70 for 1 m high riverbanks), having deeper and better distributed root systems over the entire riverbank height (Cushman and Gaffney, 2010). It has also been estimated that, in the presence of *A. donax* communities, the flowing speed of the current drops by 46-57%. The danger is lesser if *A. donax* grows in anastomosed sections or along slow-flowing channels, without significant variations in the hydraulic section of the watercourse (Spencer *et al.*, 2013). For all of these reasons, it is correct to classify *A. donax* as a transformative species (*sensu* Pyšek *et al.*, 2004) and include it among the 100 worst invasive species globally (GISD, 2024).

Reynoutria japonica Houtt.

Reynoutria japonica – native to Japan, China and Korea – is a perennial rhizomatous herb 0.7-2(-2.5) m tall, with erect, ramified branches, alternate ovate leaves 12×7-17(-18) cm, with cuspidate-acuminate apex. The inflorescence is an axillary, terminal panicle, with flowers functionally unisexual: the same individual bears flowers of both sexes or only female ones (Pignatti *et al.*, 2017-2019). According to Colleran *et al.* (2020), *R. japonica* can be considered an engineering and an «erosion catalyst» species. During the autumn, the death of plant aerial parts exposes riverbanks to winter flooding, resulting in enhanced soil erosion. At the same time, potential instability of the riverbank body is caused by the inhibition of growth and regeneration of native species (being them massively shaded by *R. japonica*, see Dommanget *et al.*, 2019), which provide structural support to the banks. Erosion induced by the presence of *R. japonica* is 92-290% higher than under uninvaded conditions (Matte *et al.*, 2022), with peaks during winter and particularly evident in incised banks (Arnold and Toran, 2018). Rhizomes of *R. japonica* have a rhytidome, so they do not have root hairs and are unable to bind soil and plants. In addition, the species' rhizomes displace the roots of native species and disrupt the structure they provide to the soil, thus amplifying bank erosion, especially during floods. In fact, after rainfalls the sediment load of streams is much higher downstream of a dense *R. japonica* stand than upstream (Colleran *et al.*, 2020). The species, which forms large monospecific and extremely dense stands, also influences erosion because of its peculiar shape and habitus: higher stem density corresponds to greater soil loss (Matte *et al.*, 2022).

Water's erosive forces create propagules through stem and rhizome fragmentation (Pignatti *et al.*, 2017-2019). Indeed, very small fragments (a few centimetres) are sufficient to give rise to a new individual (Brock and Wade, 1992; Barni *et al.*, 2010). Significant floods can create large amounts of propagules, facilitating downstream spreading over long distances along riverbanks. It has been shown that *R. japonica* invasion is primarily due to erosion induced by the species itself (Colleran *et al.*, 2020).

The impacts of *R. japonica*-mediated invasion are exacerbated by the allelopathic effects of the species on nearby native plants, inhibiting their germination and growth (Vastano *et al.*, 2000; Siemens and Blossey, 2007; Serniak, 2016). Litter decomposition also has phytotoxic effects on other species (Moravcová *et al.*, 2011). All of this significantly increases the potential of *R. japonica* as an invasive species and erosion catalyst, justifying – similarly to *A. donax* – its inclusion in the list of the 100 worst invasive species globally (GISD, 2024).

Balancing benefits and harms in controlling IAPs

The challenges posed by the progressive accumulation of IAPs require substantial reprogramming of biodiversity conservation and natural capital management strategies (Guareschi *et al.*, 2024). Among other things, there is a need to develop methodologies that can provide robust risk assessments associated with «intensive management» programmes of IAPs, with a view to «sustainable invasive species management» as proposed by Larson and colleagues (2011). In this regard, there is a growing awareness concerning the potential damages attributable to the control/eradication activities rather than to the IAPs presence and impacts, both in the academic (Schmiedel *et al.*, 2016; Hussner *et al.*, 2017; Vimercati *et al.*, 2020) and practical, technical (Barthod and Boyer, 2019; Dommanget *et al.*, 2019) contexts.

It is necessary, therefore, not to overlook the cultural, nutritional, and pharmacological value of IAPs in planning control and management interventions. Indeed, in several cases, the management of IAPs must strike a balance between containing negative effects on the environment and ecosystems and exploiting species characteristics that could be beneficial to human needs. For example, of the three species discussed here, *A. donax* has been traditionally used since at least the Neolithic period in many parts of the Mediterranean countries (Cianfaglione *et al.*, 2022), whereas *R. japonica* has high potential as forage, a source of food for human use, and in the pharmaceutical industry (Chatel *et al.*, 2019). All these aspects cannot be underestimated when defining the most appropriate strategy for managing the risks associated with the spread and establishment of an IAP.

CONCLUSIONS

The spread and establishment of IAPs in riparian contexts are increasingly worrying issues, posing significant concerns about the embankments' integrity in time and space thus the increase of flood risk. Moreover, riparian IAPs have huge repercussions on the conservation of biodiversity and functionality of lotic ecosystems. Despite this general awareness, the level of knowledge available on riparian IAPs ecology appears to be very poor, as demonstrated for *A. fruticosa*, *A. donax* and *R. japonica*. The present review offers some insights, suggesting a key role played by the structure and organisation of root systems of herbaceous or shrub riparian IAPs in influencing the stability/instability of river/canal banks. More attention will have to be paid to the presence of IAPs in riparian settings in the coming years, to fully understand the implications of their spreading on the instability of river/canal banks, thus ensuring sufficient knowledge to devise effective control/management strategies. At the same time, it will be necessary to deepen in terms of sustainability the management strategies of the three target IAPs, so as to pursue actions that are truly beneficial to the conservation of riparian biodiversity, as well as reducing the risk of disasters by increasing hydraulic safety.

REFERENCES

Arnold E, Toran L, 2018. Effects of bank vegetation and incision on erosion rates in an urban stream. Water 10:482.

Atzei AD, 2003. [Le piante nella tradizione popolare della Sardegna].[Book in Italian]. Carlo Delfino Editore, Sassari, p. 161-174.

Barni E, Siniscalco C, Soldano A, 2010. Piemonte, p. 27-34. In: L. Celesti-Grapow, F. Pretto, E. Carli, C. Blasi (eds.), Flora vascolare alloctona e invasiva delle regioni d'Italia.[Book in Italian]. Casa Editrice Università La Sapienza, Roma.

Barthod L, Boyer M, 2019. [Un sac, des gants, un croc de jardin: le déterrage précoce, une technique douce contre l'envahissement des rivières par les renouées asiatiques].[Article in French]. Sciences Eaux & Territoires 27:56-61.

Bolpagni R, 2020. Linking vegetation patterns, wetlands conservation, and ecosystem services provision: from publication to application. Aquat. Conserv. Mar. Freshw. Ecosyst. 30(9): 1734-1740.

Bolpagni R, 2021. Towards global dominance of invasive alien plants in freshwater ecosystems: The dawn of the Exocene? Hydrobiologia 848:2259-2279.

Bolpagni R, Laini A, Buldrini F, Ziccardi G, Soana E, Pezzi G, Chiarucci A, Lipreti E, Armiraglio S, Nascimbene J, 2020. Habitat morphology and connectivity better predict hydrophyte and wetland plant richness than land-use intensity in overexploited watersheds: evidence from the Po plain (northern Italy). Landscape Ecol. 35:1827-1839.

Boscutti F, Lami F, Pellegrini E, Buccheri M, Busato F, Martini F, Sibella R, Siura M, Marini L, 2022. Urban sprawl facilitates invasions of exotic plants across multiple spatial scales. Biol. Invasions 24:1497-1510.

Brock JH, Wade M, 1992. Regeneration of Japanes knotweed (*Fallopia japonica*) from rhizome and stems: Observation from greenhouse trials. Proc. 9th Intern. Symp. on the biology of weeds, Dijon, p. 85-94.

Brundu G, 2015. Plant invaders in European and Mediterranean inland waters: profiles, distribution, and threats. Hydrobiologia 746:61-79.

Buldrini F, Pezzi G, Barbero M, Alessandrini A, Amadei L, Andreatta S *et al.*, 2023. The invasion history of *Elodea canadensis* and *E. nuttallii* (Hydrocharitaceae) in Italy from herbarium accessions, field records and historical literature. Biol. Invasions 25:827-846.

CABI, 2017. Invasive Species Compendium *Amorpha fruticosa* (false indigo-bush). CAB International, Wallingford. https://doi.org/10.1079/cabicompendium.5001 [accessed 28 October 2024]

CABI, 2024. Invasive Species Compendium *Arundo donax* (giant reed). CAB International, Wallingford. https://doi.org/10.1079/cabicompendium.1940 [accessed 28 October 2024]

Ceccato F, Simonini P, 2023. The effect of heterogeneities and small cavities on levee failures: The case study of the Panaro levee breach (Italy) on 6 December 2020. J Flood Risk Manage. 16(2):e12882.

Celesti-Grapow L, Pretto F, Carli E, Blasi C, 2010. [Flora vascolare alloctona e invasiva delle regioni d'Italia].[Book in Italian]. Casa Editrice Università La Sapienza, Roma: 210 pp.

Chatel G, Duwald R, Piot C, Draye M, 2019. [Valorisation chimique et économique des renouées asiatiques: quelle stratégie pour une gestion durable?].[Article in French]. Sciences Eaux & Territoires 27:102-107.

Cianfaglione K, Longo L, Kalle R, Sõukand R, Gras A, Vallès J, Svanberg I, Nedelcheva A, Łuczaj Ł, Pieroni A, 2022. Archaic food uses of large graminoids in Agro Peligno wetlands (Abruzzo, Central Italy) compared with the European ethnobotanical and archaeological literature. Wetlands 42, 88.

Colleran B, Lacy SN, Retamal MR, 2020. Invasive Japanese knotweed (*Reynoutria japonica* Houtt.) and related knotweeds as catalysts for streambank erosion. River Res. Appl. 36:1962-1969.

Cushman JH, Gaffney KA, 2010. Community-level consequences of invasion: impacts of exotic clonal plants on riparian vegetation. Biol. Invasions 12:2765-2776.

Delai F, Kiss T, Nagy J, 2018. Field-based estimates of floodplain roughness along the Tisza River (Hungary): The role of invasive *Amorpha fruticosa*. Appl. Geogr. 90:96-105.

Dommanget F, Évette A, Martin F-M, Piola F, Thiébaut M, Rouifed S, Dutartre A, Sarat E, Lavoie C, Cottet M, Rivière-Honegger A, Boyer M, 2019. [Les renouées asiatiques, espèces exotiques envahissantes].[Article in French]. Sciences Eaux & Territoires 27:8-13.

Drazan D, Smith AG, Anderson NO, Becker R, Clark M, 2021. History of knotweed (*Fallopia* spp.) invasiveness. Weed Sci. 69:617-623.

GISD, 2024. International Union for the Conservation of Nature - Global Invasive Species Database 2024. Available at http://www.iucngisd.org/gisd/100_worst.php [accessed 21 January 2024]

Goulder R, 2008. Conservation of aquatic plants in artificial watercourses: are main drains a substitute for vulnerable navigation canals? Aquat. Conserv. 18(2):163-174.

Grabić J, Ljevnaić-Mašić B, Zhan A, Benka P, Heilmeier H, 2022. A review on invasive false indigo bush (*Amorpha fruticosa* L.): nuisance plant with multiple benefits. Ecol. Evol. 12:e9290.

Guareschi S, Mathers KL, South J, Navarro LM, Renals T, Hiley A, Antonsich M, Bolpagni R, Bortolus A, Genovesi P, Jere A, Madzivanzira TC, Phaka FM, Novoa A, Olden JD, Saccó A, Shackleton RT, Vilà M, Wood PJ, 2024. Framing challenges and polarized issues in invasion science: toward an interdisciplinary agenda. BioScience in press:biae084.

Hussner A, Stiers I, Verhofstad MJJM, Bakker ES, Grutters BMC, Haury J, van Valkenburg JLCH, Brundu G, Newman J, Clayton JS, Anderson LWJ, Hofstra D, 2017. Management and control methods of invasive alien freshwater aquatic plants: a review. Aquat. Bot. 136:112-137.

Kiss T, Nagy J, Fehérváry I, Vaszkó C, 2019. (Mis) management of floodplain vegetation: the effect of invasive species on vegetation roughness and flood levels. Sci. Tot. Environ. 686:931-945.

Klopper R, Lubbe S, Rugbeer H, 2007. The matrix method of literature review. Alternation 14(1):262-276.

Kowarik I, Säumel I, 2007. Biological flora of Central Europe: *Ailanthus altissima* (Mill.) Swingle. Persp. Plant Ecol. Evol. Syst. 8:207-237.

Krellenberg K, Müller A, Schwarz A, Höfer R, Welz J, 2013. Flood and heat hazards in the Metropolitan Region of Santiago de Chile and the socio-economics of exposure. Appl. Geogr. 38:86-95.

Kucsicsa G, Grigorescu I, Dumitraşcu M, Doroftei M, Năstase M, Herlo G, 2018. Assessing the potential distribution of invasive alien species *Amorpha fruticosa* (Mill.) in the Mureş Floodplain Natural Park (Romania) using GIS and logistic regression. Nat. Conserv. 30:41-67.

Larson DL, Phillips-Mao L, Quiram G, Sharpe L, Stark R, Sugita S, Weiler A, 2011. A framework for sustainable invasive species management: Environmental, social, and economic objectives. JEMA 92(1):14-22.

Lavoie C, 2017. The impact of invasive knotweed species (*Reynoutria* spp.) on the environment: review and research perspectives. Biol. Invasions 19:2319-2337.

Lowe S, Browne M, Boudjelas S, De Poorter M, 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database. The Invasive Species Specialist Group - Species Survival Commission of the World Conservation Union (IUCN): 12 pp.

Malavasi M, Acosta ATR, Carranza ML, Bartolozzi L, Basset A, Bassignana M *et al.*, 2018. Plant invasions in Italy: an integrative approach using the European LifeWatch infrastructure database. Ecol. Indic. 91:182-188.

Matte R, Boivin M, Lavoie C, 2022. Japanese knotweed increases soil erosion on riverbanks. River Res. Appl. 38:561-572.

Mihály B, Botta-Dukát Z, 2004. Biological invasions in Hungary - Invasive plants. Budapest, Hungary: Természet BÚVÁR Alapítvány Kiadó, 408.

Montanari I, Buldrini F, Bolpagni R, Laini A, Dalla Vecchia A, De Bernardini N, Campione L, Castellari I, Gizzi G, Landi S, Chiarucci A, 2020. Role of irrigation canal morphology in driving riparian flora in over-exploited catchments. Comm. Ecol. 21(2):121-132.

Montanari I, De Bernardini N, Gizzi G, Bolpagni R, Buldrini F, Campione L, Castellari I, Landi S, Spiezia L, Chiarucci A, 2022. Flora and plant communities across a complex network of heavily modified water bodies: geographical patterns, land use and hydrochemical drivers in a temperate overexploited floodplain. Lands. Ecol. Eng. 18:367-380.

Moravcová L, Pyšek P, Jarošik V, Zákravský P, 2011. Potential phytotoxic and shading effects of invasive *Fallopia* (Polygonaceae) taxa on the germination of native dominant species. NeoBiota 9:31-47.

Morelli S, Battistini A, Catani F, 2014. Rapid assessment of flood susceptibility in urbanized rivers using digital terrain data: Application to the Arno river, case study (Firenze, Northern Italy). Appl. Geogr. 54:35-53.

Pellegrini E, Boscutti F, Alberti G, Casolo V, Contin M, De Nobili M, 2021. Stand age, degree of encroachment and soil characteristics modulate changes of C and N cycles in dry grassland soils invaded by the N_2-fixing shrub *Amorpha fruticosa*. Sci. Tot. Environ. 792:148295.

Pignatti S, Guarino R, La Rosa M, 2017-2019. [Flora d'Italia, 2ª edizione].[Work in Italian]. Edagricole – Edizioni Agricole di New Business Media srl, Bologna: 4 voll.

Protopopova VV, Shevera MV, Mosyakin SL, 2006. Deliberate and unintentional introduction of invasive weeds: a case study of the alien flora of Ukraine. Euphytica 148(1-2):17-33.

Pyšek P, Bacher S, Chytrý M, Jarošík V, Wild J, Celesti-Grapow L *et al.*, 2010. Contrasting patterns in the invasions of European terrestrial and freshwater habitats by alien plants, insects and vertebrates. Glob. Ecol. Biogeogr. 19(3):317-331.

Pyšek P, Hulme PE, Simberloff D, Bacher S, Blackburn TM, Carlton JT *et al.*, 2020. Scientists' warning on invasive alien species. Biol. Rev. 95(6):1511-1534.

Pyšek P, Prach K, 1994. How important are rivers for supporting plant invasion?, p. 19-26. In: L.C. de Waal *et al.* (eds.), Ecology and management of invasive riverside plants. Wiley, Chichester.

Pyšek P, Richardson DM, Rejmánek M, Webster GL, Williamson M, Kirschner J, 2004. Alien plants in checklist and floras: towards better communication between taxonomists and ecologists. Taxon 53:131-143.

Rodríguez-Merino A, García-Murillo P, Cirujano S, Fernández-Zamudio R, 2018. Predicting the risk of aquatic plant invasions in Europe: how climatic factors and anthropogenic activity influence potential species distributions. J. Nat. Conserv. 45:58-71.

Sándor A, Kiss T, 2007. [A 2006. tavaszi árvíz okozta feltöltődés mértéke és az azt befolyásoló tényezők vizsgálata a Közép-Tiszán, Szolnoknál].[Article in Hungarian]. Hidrol. Közlöny 87(4):19-24.

Schmiedel D, Wilhelm EG, Roth M, Scheibner C, Nehring S, Winter S, 2016. Evaluation system for management measures of invasive alien species. Biodivers. Conserv. 25:357-374

Sciuto L, Licciardello F, Barbera AC, Cirelli G, 2022. A GIS-based multicriteria decision analysis to reduce riparian vegetation hydrogeological risk and to quantify harvested biomass (Giant reed) for energetic retrieval. Ecol. Indic. 144:109548.

Shevchyk TV, Dvirna TS, Shevchyk VL, 2021. On the distribution pattern of *Amorpha fruticosa* L. in the region of the Kanevskaya Hydroelectric Power Plant (Ukraine) in connection with hydrochory. Russ. J. Biol. Invasions 12(2):213-218.

Serniak L, 2016. Comparison of the allelopathic effects and uptake of *Fallopia japonica* phytochemicals by *Raphanus sativus*. Weed Res. 56:97-101.

Siemens TJ, Blossey B, 2007. An evaluation of mechanisms preventing growth and survival of two native species in invasive Bohemian knotweed (*Fallopia* × *bohemica*, *Polygonaceae*). Am. J. Bot. 94:776-783.

Spencer DF, Colby L, Norris GR, 2013. An evaluation of flooding risks associated with giant reed (*Arundo donax*). J. Freshw. Ecol. 28(3):397-409.

Stover JE, Keller EA, Dudley TL, Langendoen EJ, 2018. Fluvial geomorphology, root distribution, and tensile strength of the invasive giant reed, *Arundo donax* and its role on stream bank stability in the Santa Clara River, southern California. Geosciences 8:304.

Szigetvári Cs, 2002. Initial steps in the regeneration of a floodplain meadow after a decade of dominance of an invasive transformer shrub, *Amorpha fruticosa* L. Tiscia 33:67-77.

Tölgyesi C, Torma A, Bátori Z, Šeat J, Popović M, Gallé R *et al.*, 2022. Turning old foes into new allies—harnessing drainage canals for biodiversity conservation in a desiccated European lowland region. J. Appl. Ecol. 59(1):89-102.

Vastano BC, Chen Y, Zhu N, Ho CT, Zhou Z, Rosen RT, 2000. Isolation and identification of stilbenes in two varieties of *Polygonum cuspidatum*. J. Agric. Food Chem. 48:253-256.

Viaroli P, Soana E, Pecora S, Laini A, Naldi M, Fano EA, Nizzoli D, 2018. Space and time variations of watershed N and P budgets and their relationships with reactive N and P loadings in a heavily impacted river basin (Po river, Northern Italy). Sci. Tot. Environ. 639:1574-1587.

Viciani D, Vidali M, Gigante D, Bolpagni R, Villani M, Acosta ATR et al., 2020. A first checklist of the alien-dominated vegetation in Italy. Plant Sociol. 17(1):29-54.

Vimercati G, Kumschick S, Probert AF, Volery L, Bacher S, 2020. The importance of assessing positive and beneficial impacts of alien species. NeoBiota 62:525-545.

Yin Q (1993) Shrub of soil and water conservation - *Amorpha fruticosa*. Agric. Sci. Technol. Communication 11:30-31.