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Invasive Japanese knotweed (*Reynoutria japonica* Houtt.) and related knotweeds as catalysts for streambank erosion

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Abstract

Japanese knotweed *(Reynoutria japonica)* and the other invasive knotweeds, collectively known as knotweed *s.l.*, are significant invasives worldwide, especially of riparian areas. While *R. japonica* and other knotweed *s.l.* can reproduce sexually, their dispersal to and spread within new regions is often accomplished through vegetative reproduction from rhizome and stem fragments. Once established, knotweed *s.l.* can displace riparian plants, meaning that soil stability once provided by displaced roots is lost, carrying significant knock-on implications for watershed management. We propose that knotweed *s.l.* rhizomes both displace roots and the structure they provide to soil, and also amplify bank-erosion forces, especially during floods. Further, erosive forces create propagules, with larger flow events creating larger numbers of propagules and providing the vector for short- and long-distance downstream spread within the watershed. Induced erosion is therefore the main driver of knotweed *s.l.* invasions along waterways. As some hydrological regimes shift towards more frequent and severe storm events in response to climate change, positive feedback loops may develop in these regions between existing knotweed *s.l.* populations, sudden riverbank failure, and increased flood-related damage, with presumably significant impacts on riparian infrastructure. While the continued spread of this invasive could have significant riparian flood resiliency consequences if left unchecked, mindful action to control these plants is likely to be beneficial financially, socially, and ecologically within any invaded watershed.

KEYWORDS

dispersal, ecosystem engineer, erosion, flooding, geomorphologic engineer, knotweed, resiliency, sudden bank failure

1 | INTRODUCTION

Reynoutria japonica (Houtt.) and other invasive knotweeds are widespread across Europe and North America, and have long been known to favour habitats along rivers, roads, or disturbed areas (Conolly, 1977; Martin, 2019). They have been found south of the Equator in Australia, New Zealand, South Africa, and South America. Recent personal observations of *R. japonica* in Puerto Natales, Chile, would extend its reported range south from its nearest known neighbour in Puerto Montt, Chile (Saldana, Fuentes, & Pfanzelt, 2009) by about 1,100 km, to the sub-Antarctic climatic region. *R. japonica* and its relatives are truly invasive species with a global reach. While we sought to focus this article on *R. japonica*, due to the genetic and phenotypic complexity among and within these related species (Gammon, Baack, Orth, & Kesseli, 2010; Gammon, Grimsby, Tsirelson, & Kesseli, 2007), and given the likelihood that our argument applies to other invasive knotweeds, the term "knotweed *s.l.*" will be used throughout this paper whenever "*R. japonica*" may not be accurate.

In many invaded regions, *R. japonica* contains sterile male flowers, requiring other knotweed species to obtain pollen and produce seeds. While seeds have resulted in healthy stands of *R. japonica* (Forman & Kesseli, 2003; Gammon et al., 2010) the downstream spread of knotweed *s.l.* does not appear to be accomplished through seeds (Duquette et al., 2016; Hart, Bailey, Hollingsworth, & Watson, 1997). Knotweed *s.l.* species and hybrids primarily spread vegetatively, either by humans moving plant fragments or colonized soils, or through water transport (Dawson & Holland, 1999; Martin, 2019). While *R. japonica* can also reproduce sexually (Forman & Kesseli, 2003; Gammon et al., 2010), recruitment from seed remains the exception (Bailey, Bímová, & Mandák, 2009; Martin, 2019), and the aforementioned reproductive limitations characterize *R. japonica* as an invasive plant lacking a seedbank, restricting it to vegetative spread. While clonal reproduction is frequently associated with invasive species, this trait is important to local-scale spread and dominance (Martin, Dommanget, Lavallée, & Evette, 2020; Zobel, Moora, & Herben, 2010) prior to seedbank establishment (Martínková & Klimešová, 2016). Indeed, knotweed *s.l.* distribution studies indicate that the presence of one plant is an important predictor for the presence of another (Duquette et al., 2016), but to our knowledge, clonal dispersal has not yet been implicated in invasive spread and dominance at larger scales. In addition to the proximity of other knotweed *s.l.* plants, the presence of roads and/or rivers is also strongly indicative of knotweed *s.l.* establishment (Martin, 2019; Rouifed, Piola, & Spiegelberger, 2014). Without discounting the effectiveness of humanity in the intentional and global distribution of knotweed *s.l.*, the successful expansion of these species beyond local scales appears more reliant on transportation networks, like roads and rivers, than their own propagation capacity. This represents circumstances that do not conform to typical invasive-species characteristics.

Our explanation for how knotweed *s.l.* benefit from river networks is that it amplifies erosion along riparian corridors in several ways, resulting from interactions between stems, rhizomes, and water. By interacting with water this way, knotweed *s.l.* acts as an autogenic geomorphologic engineer: a living and growing ecosystem engineer that modifies geomorphic processes and landforms (Corenblit et al., 2011; Fei, Phillips, & Shouse, 2014; Jones, Lawton, & Shachak, 1994). Being an engineer species is a primary reason for its invasive success, and—when considered from a watershed perspective—makes it a clear, present, and critical risk to riverside communities and infrastructure. Our argument is not novel; knotweed *s.l.* being an erosion catalyst is already a widely assumed trait of knotweed *s.l.* among many land managers, and it is a commonly deployed argument for motivating action, despite the lack of primary literature on this topic (Cottet, Piola, Le Lay, Rouifed, & Rivière-Honegger, 2015; Harbaugh, 2017). By combining personal observations with a review of the literature, we hope our conclusions spur research to address the questions of the timing, process, and volume of erosion caused by knotweed *s.l.*, so that its scale of impact on riparian ecosystems, infrastructure, and communities can be appropriately assessed to aid with science-based watershed management in affected watersheds.

1.1 | Knotweed *s.l.* as ecosystem engineer

Knotweed *s.l.* is an invasive that "can transform ecosystems visually, structurally, and chemically" (Aguilera, Alpert, Dukes, & Harrington, 2010), which places it in a class of invasives that have been called "strong invaders" (Ortega & Pearson, 2005) or "transformers" (Wells et al., 1986). This ecosystem-transformation ability manifests as competitor inhibition, with knotweed *s.l.* changing the nutrient flow through topsoil (Dassonville, Vanderhoeven, Gruber, & Meerts, 2007), disturbing critical plant mutualisms that reduce shade saplings and ectomycorrhizal root-system colonization (Urgenson, Reichard, & Halpern, 2012), aided by allelopathic properties (Murrell et al., 2011). Knotweed *s.l.* also changes habitat suitability, with infested areas having generally lower invertebrate abundance and morphospecies richness (Gerber et al., 2008), significantly lower abundances of large and long-lived gastropods (Stoll, Gatzsch, Rusterholz, & Baur, 2012), and lower species richness and abundances of riparian birds (Hajzlerová & Reif, 2013). While studies of larger animal-use changes in infested habitats remain sparse, a review of all available literature suggests that knotweed *s.l.* may change habitat suitability both positively and negatively for riparian fauna (Lavoie, 2017).

1.2 | Knotweed *s.l.* as geomorphologic engineer

The erosion-resistance properties of fluvial banks are complex and currently poorly understood (Konsoer et al., 2016), however, the root systems of riparian vegetation contribute to bank cohesion (Gran & Paola, 2001), which has important implications for bank stability during floods and on flood damage to human communities and infrastructure. While invasive plants can increase bank stability (Fei et al., 2014), some, including *Miconia calvecens* (Nanko et al., 2015) and *Heracleum mantegazzianum* (Caffrey, 1994; Dodd, Waal, Wade, & Tiley, 1994; Tiley & Philp, 1994) will increase soil erodibility. Many land and river managers already assume that *R. japonica* decreases streambank stability, without scientific literature supporting this assertion (Harbaugh, 2017). This position can be justified by three entwined lines of evidence addressing overland, under-bank, and bank-face erosion within a knotweed *s.l.* stand.

The first, overland erosion, has long been assumed to take place on sites invaded by *R. japonica* following autumnal die-back, leaving banks exposed to winter floods, with no vegetative protection (Child & Wade, 2000). Further, dense stands and vegetative spread allow *R. japonica* to extirpate existing ground covers (Urgenson et al., 2012; Urgenson, Reichard, & Halpern, 2009; Wilson, Freundlich, & Martine, 2017). Since runoff and soil erosion increase as ground cover decreases (Smets, Poesen, & Bochet, 2008), the assumption that this plant increases topsoil erosion rates during floods or from overland flows caused by precipitation or snowmelt makes sense, and further, such erosion would take place between the rhizome crowns.

The second, under-bank erosion, is caused by *R. japonica* inhibiting the regeneration of native species that provide critical structural support to riverbanks during lateral expansion (Aguilera et al., 2010; Urgenson et al., 2009; Wilson et al., 2017). This inhibition eliminates the natural variety of root depths and the structural complexity that healthy root systems provide to soil. The resulting homogenization of belowground structure does not provide analogous protections against stream bank erosion as compared with root system complexes typical in non-invaded areas. The resulting lack of soil structure and shallow depth of knotweed *s.l.* rhizomes leads to under-bank erosion and subsequent bank slumping (Urgenson, 2006).

Based on our own experiences, we think that there is a third line of evidence to consider which influences bank-face erosion. Knotweed *s.l.* rhizomes (which are actually underground stems) have an outer layer of bark, and therefore lack root hairs that normally would bind soil and plant together. During removal of flood-distributed knotweed *s.l.* propagules (Colleran & Goodall, 2014, 2015), we found that removing newly established plants by hand was fastest; the lack of root hairs aided in sifting plants directly from the ground. From results showing (a) underground rhizomes as the predominant source of new knotweed *s.l.* plants and (b) the small size of most rhizomatous propagules, we hypothesize that knotweed *s.l.* rhizomes amplify the erosive effects of water, speeding their own excavation and propagation. Our data shows that while the largest rhizomatous pieces originated from the rhizome crown, most propagules that originated underground had remarkably similar lengths to those from above ground (Colleran & Goodall, 2014). This similarity implies that the soil provides no protection to the rhizomes against the flood forces, and—conversely—the banks had no protection from erosive forces where knotweed *s.l.* had eliminated other vegetation.

While the literature-supported and hypothesized means of knotweed *s.l.*-caused erosion along waterways are logically sound and based on easily observable traits, data supporting such eco-hydrological assertions are not yet utilizable by professionals for whom streambank stability is crucial (Lavoie, 2017). Below, we explore the only field studies directly connecting knotweed *s.l.* to erosion (Arnold & Toran, 2018; Hammer, 2019; Mummigatti, 2008; Secor, Ross, & Balling, 2013) and the single modelling study(van Oorschot et al., 2017) of this relationship.

These sources show that stream sediment loads increase downstream of knotweed *s.l.* after rainfall events (Mummigatti, 2008), with four times more silt on the stream bottom downstream of *R. japonica* stands than upstream (Hammer, 2019). Turbidity following storms is higher (77 vs. 54 NTU) in incised stream reaches with knotweed *s.l.* (Arnold & Toran, 2018). After 3 months of data collection, knotweed *s.l.* infested banks lost four times more soil than forested banks, and erosion was concentrated at the bottom of the bank (Secor et al., 2013) After nine-and-a-half months, there was 29 cm more erosion in incised banks, 9 cm in non-incised banks, and knotweed *s.l.*-related erosion increased during winter months(Arnold & Toran, 2018; van Oorschot et al., 2017). These field studies were relatively small, and the model was only exploratory, but the findings all align and support the existing hypothesis that knotweed *s.l.*-infestation encourages bank slumping (Urgenson, 2006) and higher erosion rates in winter months (Child & Wade, 2000). We suggest this combination of theory and evidence places invasive knotweed *s.l.* in the group of riparian species able to interact with hydrological processes to drive changes in river channel morphology, and induce a topographic signature of vegetation on river channel form (Gurnell, 2014).

Finally, the data indicate that riparian transport of knotweed *s.l.* fragments resulting in juveniles is primarily local (Boyer & Barthod, 2019) and seeds do not contribute to population growth downstream of an existing stand (Duquette et al., 2016; Hart et al., 1997). Combined with the presumed impacts of knotweed *s.l.* on bank erosion, this implies that knotweed *s.l.*-induced erosion is likely the primary means of its own spread along waterways.

2 | KNOTWEED *s.l.* IMPACTS ON A WATERSHED

If knotweed *s.l.*-induced erosion is the primary means of dispersal along waterways, the invasiveness of these species implies a positive feedback loop between bank erosion and instream flow, which would be amplified by flood events. The feedback loop (Figure 1) would operate as follows:

1. A knotweed *s.l.* plant becomes established on a streambank.
2. During growth and expansion, the loss of groundcover species and root reinforcement provided by native species increases soil erodibility at the stand, as more of the belowground system is dominated by knotweed *s.l.* rhizomes.
3. Erosive flows create rhizomatous propagules that get washed downstream to establish new plants on streambanks. Local expansions occur with non-flooding flows (sensu Boyer & Barthod, 2019); regional expansions presumably happen with flooding flows. The main mass of the knotweed *s.l.* stand may remain in place.
4. With each passing flood and the lateral expansion of stands, erosion and propagule generation increase in tandem, with larger floods causing correspondingly more erosion in infested rivers and increasing chances of sudden bank failure, all of which result in greater knotweed *s.l.* volumes in downstream reaches (sensu Pattison, Minderman, Boon, & Willby, 2017).

Accordingly, knotweed *s.l.*-infested sites on a waterway should be among the fastest eroding areas on a waterway, with the oldest and largest stands being the most susceptible to erosive forces and sudden bank failures (Figure 2). Given its large rhizome network, a stand that washes away in a sudden-bank-failure event can regrow and eventually pose another sudden-bank-failure risk in the same location.

2.1 | Riparian knotweed *s.l.* & watershed management concerns

Any region with knotweed *s.l.* infestations will eventually experience these feedback loops, and flood frequencies have been linked to the probability of finding knotweed *s.l.* in riparian areas (Pattison et al.,

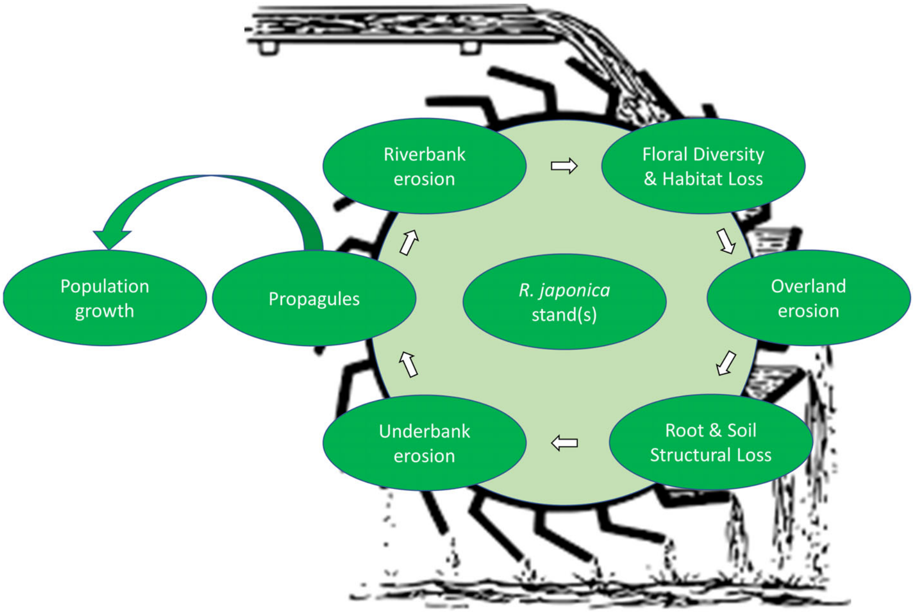

FIGURE 1 Conceptual flow diagram of how knotweed *s.l.*'s influence on ecosystems and erosion are linked, with fluvial flow driving these influences and providing effective propagule dispersal [Color figure can be viewed at wileyonlinelibrary.com]

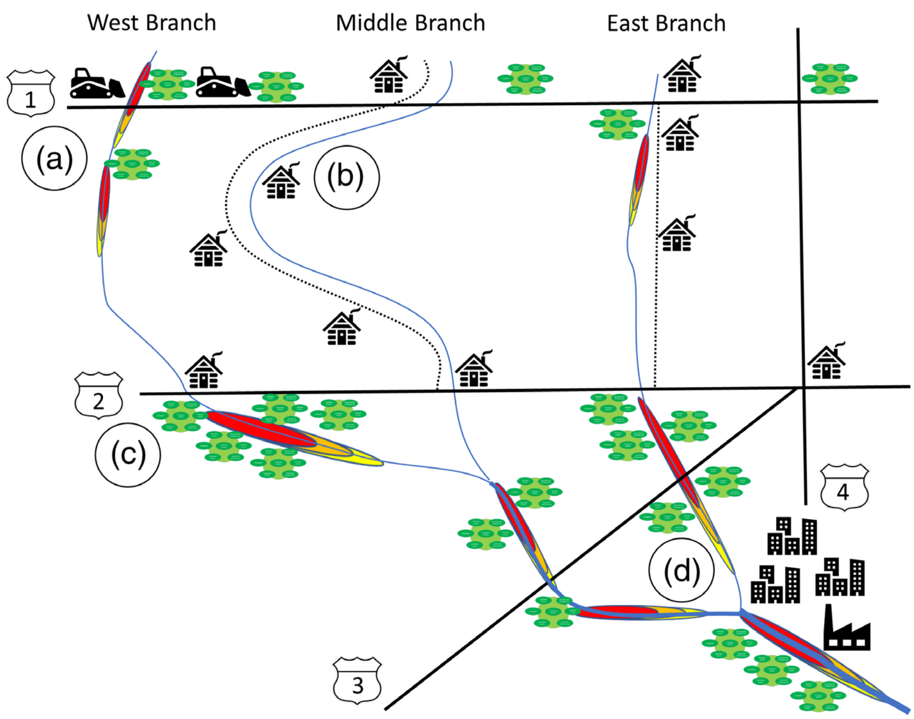

FIGURE 2 A hypothetical watershed with a network of paved and unpaved roads, illustrating how knotweed *s.l.* infests new areas and the areas at greatest risk (designated with a colour ramp extending downstream from the stand[s] portrayed). Several locations on this map are explored. (a) Construction to replace the bridge over this stream is likely to spread *R. japonica* along the road and into the stream. Construction-induced spreading increases the infestation risk for the middle branch and downstream flood-resiliency loss, while also infesting the area of the bridge abutments. (b) The middle branch is currently uninfested, but with nearby construction taking place, and stands already established along Highway 1, the potential for propagules to access the headwaters via the roadway is significant. (c) Downstream of Highway 2 on the West Branch, a significant population has become established. Its influence will reduce the resiliency of this bank to flood events. (d) In this urban area, the three branches are joined, and the riverbanks in the region are heavily infested by knotweed *s.l.*, due to upstream stands continually sending propagules downstream. Risks associated with knotweed *s.l.* induced erosion are higher than in less-developed areas due to greater waterfront development [Color figure can be viewed at wileyonlinelibrary.com]

2017). With regions like the Northeastern U.S. predicted to experience more frequent (Armstrong, Collins, & Snyder, 2012) and severe (Collins, 2009) flooding events due to climate change, knotweed *s.l.* should spread more rapidly in regions experiencing climate change induced increases in flooding, thereby making the feedback loop more apparent. We have therefore selected this region to explore one knock-on effect of knotweed *s.l.* range expansion: transportation infrastructure impacts.

In addition to the waterways—the focus so far of this paper—roadways are also important in knotweed *s.l.* infestation, since human actions along them they allow this plant to cross watershed boundaries and travelling upstream. Bridges and culverts, where roadways cross waterways are among the likeliest locations to be infested, because knotweed *s.l.* may colonize these locations from either the fluvial or transit vector (Conolly, 1977; Martin, 2019). This makes them among the likeliest locations for founding populations on otherwise "clean" roads or streams. Since bridges and culverts rely on the soil surrounding and undergirding them to provide support and protection, it is possible that knotweed *s.l.*-induced streambank erosion is an unaccounted threat to these structures, as well as to rip-rap and other bank armoring, since knotweed *s.l.*-induced streambank erosion can take place out of sight, beneath such features. Understanding the economic implications of managing this infrastructure can illustrate why knotweed *s.l.* should be of concern to a wide range of professions and be integrated into infrastructure project development processes and appropriate regulatory reviews.

It is possible to evaluate order-of-magnitude costs associated with knotweed *s.l.*-related maintenance costs versus potential roadway repair costs. For example, controlling 50 to 80 km of roadside knotweed *s.l.* (£8.67/km, Williams et al., 2010) is roughly the same price as a normal maintenance visit to a single culvert (US$ 800–1,200, Samanns, Cameli, Melchior, & da Costa, 2017), and an acre of knotweed *s.l.* control (CA$ 11,037/acre, Crystal Chadburn, Environmental Roadside Manager, British Columbia, Canada, Ministry of Transportation and Infrastructure; pers. comm) costs about the same as repairing between two and three flood-damaged culverts (US$ 3,800/culvert, Samanns et al., 2017). Order-of-magnitude comparisons like these, evaluated for local costs, could offer starting points for land managers interested in engaging with entities in charge of infrastructure maintenance and disaster-response preparations.

Given the variety of potential risks (Figure 2) associated with the knotweed *s.l.* feedback loop (Figure 1) and their potential impacts, the necessity of addressing this invasive at a watershed scale is pressing, especially since secondary knotweed *s.l.* invasion is not a question of if, but of when a dispersal opportunity presents itself (Martin, 2019). The use of preventative strategies, such as "Early Detection & Rapid Response" techniques are therefore recommended, since the alternative is the costly and not always successful attempts to eliminate well-established populations (Bashtanova, Beckett, & Flowers, 2009; Delbart et al., 2012; Kabat, Stewart, & Pullin, 2006).

3 | FUTURE RESEARCH

We recognize that our positions remain hypothetical and conceptual. Ecohydrologically-focused assessments of the knotweed *s.l.* impacts are rare (Lavoie, 2017), and we hope our arguments spur future work in this direction. Such studies could build on robust bases of complementary research, including:

1. Existing models that use a vegetation-root component, such as RipRoot (Pollen-Bankhead & Simon, 2009), as part of a process-based bank-stability model, such as BSTEM (Klavon et al., 2017) which have been used to investigate the impact of *Arundo donax* on erosion (Stover, Keller, Dudley, & Langendoen, 2018). Pairing such models with field studies or experiments would provide especially valuable insights into the relationship between these species and erosive processes.
2. Photogrammetric analyses can provide useful insights into general fluvial biogeomorphic dynamics (Hortobágyi et al., 2017), and satellite and unmanned aerial vehicles (UAVs) can accurately map knotweed *s.l.* (Martin et al., 2018). Utilizing both technologies could generate biogeomorphic insights specific to locations infested with knotweed *s.l.*
3. Establishing and conducting small field studies in various locations using standardized techniques would permit inter-regional comparisons of hydrological regimes and soil types.
4. Organizations concerned with improving road/stream crossings could integrate knotweed *s.l.*-related questions into infrastructure assessments. Culvert maintenance and flood damage costs could be correlated with knotweed *s.l.* populations along a river to develop a precautionary approach to knotweed *s.l.* infestations.
5. Evaluating the impact of knotweed *s.l.* on fluvial geomorphology, specifically evaluating the impacts of increasing infestations on the ability of vegetation-stabilized banks to corral weak flows back into the main waterway, preventing braided-channel formation (sensu Tal & Paola, 2010).

4 | SUMMARY & CONCLUSIONS

Healthy rivers manifest a diverse complexity of expected forms (Wohl, 2016) and naturally adjust following a disturbance, which make them resilient. Indeed, flood damages are more often related to river management choices than the flood itself (Hajdukiewicz, Wyżga, Mikuś, Zawiejska, & Radecki-Pawlik, 2016). Since knotweed *s.l.* seems to amplify erosive forces as a primary means of reproduction and spread (Figure 1), omitting the influence of this invasive ecological and geomorphologic engineer in fluvial- and riparian-related plans ensures communities remain blind to its potential impacts on ecosystems, public or private infrastructure and property, and climate resiliency. These impacts would affect those working in disparate areas, such as effective emergency preparation, ecological-integrity protection, and public-infrastructure security. Including knotweed *s.l.* in planning efforts would therefore integrate a wide range of management and policy concerns (González et al., 2017).

Should knotweed *s.l.* be the transformative river engineer the existing evidence suggests, it would have major ramifications on predicting where geomorphic change would occur during floods. Invasive knotweeds would catalyse erosion: they would precipitate erosive events, increase the rate of erosion, and remaining rhizomes ensure the regeneration of any lost biomass, preventing the consumption of stands by erosion.

Mindful actions taken against *R. japonica* and its relatives should provide social, environmental, and financial benefits, and be a promising first step towards biomic river restoration (Johnson et al., 2020). By mindful, we mean acknowledging the constant labour and dogged persistence needed for non-chemical control methods, as well as the negative risks and externalities associated with chemical control; while similarly acknowledging that taking no action can be worse than not accepting such challenges. Communities which choose to act mindfully will save financially in the long run, improve their flood resiliency, improve riparian and fluvial habitat value for all organisms, reduce the potential scale and scope of flood related damages, and reduce some of the uncertainty associated with fluvial hydrological dynamics (Figure 2). When compared with other available actions to increase community resiliency to flood damage, such as property buyouts or bank armoring, which commonly require long and bureaucratic planning and/or engineering processes, mindful knotweed *s.l.* control and management is less intensive and probably cheaper. The difficulties associated with successfully managing knotweed *s.l.*, however, demand constant attention and should not be taken lightly. Similarly, knotweed *s.l.* control is an excellent tool for maintaining a river on a known morphological trajectory, while also improving riparian ecological integrity. For example, *R. japonica* control could prevent the circumstances that would short-circuit normal stream evolution, such as the "4–3-4 trap" (Cluer & Thorne, 2014), when streambanks never cease incising, (i.e., when headward erosion is paired with constant bank undercutting). Rather than letting flooding and knotweed *s.l.* drive a waterway's biogeomorphological regime towards a new dynamic for which riverside communities are unprepared, *R. japonica* control can improve riparian ecological health while increasing flooding resilience, which protects riparian public and private property and infrastructure.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

NA

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REFERENCES

Aguilera, A. G., Alpert, P., Dukes, J. S., & Harrington, R. (2010). Impacts of the invasive plant *Fallopia japonica* (Houtt.) on plant communities and ecosystem processes. *Biological Invasions*, *12*(5), 1243–1252. https://doi.org/10.1007/s10530-009-9543-z

Armstrong, W. H., Collins, M. J., & Snyder, N. P. (2012). Increased frequency of low-magnitude floods in New England. *Journal of the American Water Resources Association*, *48*(2), 306–320.

Arnold, E., & Toran, L. (2018). Effects of bank vegetation and incision on erosion rates in an urban stream. *Water*, *10*(4), 482. https://doi.org/10.3390/w10040482

Bailey, J. P., Bímová, K., & Mandák, B. (2009). Asexual spread versus sexual reproduction and evolution in Japanese knotweed *s.l.* sets the stage for the "Battle of the Clones". *Biological Invasions*, *11*(5), 1189–1203. https://doi.org/10.1007/s10530-008-9381-4

Bashtanova, U. B., Beckett, K. P., & Flowers, T. J. (2009). Review: Physiological approaches to the improvement of chemical control of Japanese knotweed (*Fallopia japonica*). *Weed Science*, *57*(6), 584–592. https://doi.org/10.1614/WS-09-069.1

Boyer, M., & Barthod, L. (2019). Un sac, des gants, un croc de jardin: Le déterrage précoce, une technique douce contre l'envahissement des rivières par les renouées asiatiques. *Sciences Eaux & Territoires*, *Numéro 27*(1), 56. https://doi.org/10.3917/set.027.0056

Caffrey, J. M. (1994). Spread and management of *Heracleum mantegazzianum* (Giant Hogweed) along Irish River Corridors. In L. C. de Waal, L. E. Child, P. M. Wade & J. H. Brock (Eds.), *Ecology and management of invasive riverside plants* (pp. 67–76). Chichester, New York: John Wiley & Sons.

Child, L. E., & Wade, M. (2000). *The Japanese knotweed manual*. Chichester, UK: Packard Publishing Limited, Volume 1, 123p.

Cluer, B., & Thorne, C. (2014). A stream evolution model integrating habitat and ecosystem benefits. *River Research and Applications*, *30*(2), 135–154. https://doi.org/10.1002/rra.2631

Colleran, B. P., & Goodall, K. E. (2014). In situ growth and rapid response management of flood-dispersed Japanese knotweed (*Fallopia japonica*). *Invasive Plant Science and Management*, *7*(1), 84–92. https://doi.org/10.1614/IPSM-D-13-00027.1

Colleran, B. P., & Goodall, K. E. (2015). Extending the timeframe for rapid response and best management practices of flood-dispersed Japanese knotweed (*Fallopia japonica*). *Invasive Plant Science and Management*, *8*(2), 250–253. https://doi.org/10.1614/ipsm-d-14-00046.1

Collins, M. J. (2009). Evidence for changing flood risk in New England since the late 20th century. *Journal of the American Water Resources Association*, *45*(2), 279–290. https://doi.org/10.1111/j.1752-1688.2008.00277.x

Conolly, A. P. (1977). The distribution and history in the British Isles of some alien species of Polygonum and Reynoutria. *Watsonia*, *311*, 291–311.

Corenblit, D., Bass, A. C. W., Bornette, G., Darrozes, J., Sebastian, D., Francis, R. A., … Steiger, J. (2011). Feedbacks between geomorphology and biota controlling Earth surface processes and landforms: A review of foundation concepts and current understandings. *Earth-Science Reviews*, *106*, 307–331.

Cottet, M., Piola, F., Le Lay, Y. F., Rouifed, S., & Rivière-Honegger, A. (2015). How environmental managers perceive and approach the issue of invasive species: The case of Japanese knotweed s.l. (Rhône River, France). *Biological Invasions*, *17*(12), 3433–3453. https://doi.org/10.1007/s10530-015-0969-1

Dassonville, N., Vanderhoeven, S., Gruber, W., & Meerts, P. (2007). Invasion by *Fallopia japonica* increases topsoil mineral nutrient concentrations. *Ecoscience*, *14*(2), 230–240. https://doi.org/10.2980/1195-6860(2007)14[230:IBFJIT]2.0.CO;2

Dawson, F. H., & Holland, D. (1999). The distribution in bankside habitats of three alien invasive plants in the U.K. in relation to the development of control strategies. In J., Caffrey, P. R. F., Barrett, M. T., Ferreira, I. S., Moreira, K. J., Murphy, & P. M., Wade (Eds.), *Biology, ecology and management of aquatic plants. Developments in hydrobiology* (Vol. 147, pp. 193–201). Dordrecht, the Netherlands: Springer. Retrieved from https://doi.org/10.1007/978-94-017-0922-4_27

Delbart, E., Mahy, G., Weickmans, B., Henriet, F., Crémer, S., Pieret, N., … Monty, A. (2012). Can land managers control Japanese knotweed? Lessons from control tests in Belgium. *Environmental Management*, *50* (6), 1089–1097. https://doi.org/10.1007/s00267-012-9945-z

Dodd, F. S., Waal, L. C. d., Wade, P. M., & Tiley, G. E. D. (1994). Control and management of *Heracleum mantegazzianum* (Giant Hogweed). In L. C. de Waal, L. E. Child, P. M. Wade & J. H. Brock (Eds.), *Ecology and management of invasive riverside plants* (pp. 111–126). Chichester, UK: John Wiley & Sons.

Duquette, M. C., Compérot, A., Hayes, L. F., Pagola, C., Belzile, F., Dubé, J., & Lavoie, C. (2016). From the source to the outlet: Understanding the distribution of invasive knotweeds along a North American River. *River Research and Applications*, *32*(5), 958–966. https://doi.org/10.1002/rra.2914

Fei, S., Phillips, J., & Shouse, M. (2014). Biogeomorphic impacts of invasive species. *Annual Review of Ecology, Evolution, and Systematics*, *45*(1), 69–87. https://doi.org/10.1146/annurev-ecolsys-120213-091928

Forman, J., & Kesseli, R. (2003). Sexual reproduction in the invasive species *Fallopia japonica* (Polygonaceae). *American Journal of Botany*, *90*(4), 586–592.

Gammon, M. A., Baack, E., Orth, J. F., & Kesseli, R. (2010). Viability, growth, and fertility of knotweed cytotypes in North America. *Invasive Plant Science and Management*, *3*(3), 208–218. https://doi.org/10.1614/Ipsm-D-10-00018.1

Gammon, M. A., Grimsby, J. L., Tsirelson, D., & Kesseli, R. (2007). Molecular and morphological evidence reveals introgression in swarms of the invasive taxa *Fallopia japonica*, F. sachalinensis, and F. xbohemica (Polygonaceae) in the United States. *American Journal of Botany*, *94*(6), 948–956.

Gerber, E., Krebs, C., Murrell, C., Moretti, M., Rocklin, R., & Schaffner, U. (2008). Exotic invasive knotweeds (*Fallopia* spp.) negatively affect native plant and invertebrate assemblages in European riparian habitats. *Biological Conservation*, *141*(3), 646–654. https://doi.org/10.1016/j.biocon.2007.12.009

González, E., Felipe-Lucia, M. R., Bourgeois, B., Boz, B., Nilsson, C., Palmer, G., & Sher, A. A. (2017). Integrative conservation of riparian zones. *Biological Conservation*, *211*, 20–29. https://doi.org/10.1016/j.biocon.2016.10.035

Gran, K., & Paola, C. (2001). Riparian vegetation controls on briaded stream dynamics. *Water Resources Research*, *37*(12), 3275–3283.

Gurnell, A. (2014). Plants as river system engineers. *Earth Surface Processes and Landforms*, *39*(1), 4–25. https://doi.org/10.1002/esp.3397

Hajdukiewicz, H., Wyżga, B., Mikuś, P., Zawiejska, J., & Radecki-Pawlik, A. (2016). Impact of a large flood on mountain river habitats, channel morphology, and valley infrastructure. *Geomorphology*, *272*, 55–67. https://doi.org/10.1016/j.geomorph.2015.09.003

Hajzlerová, L., & Reif, J. (2013). Bird species richness and abundance in riparian vegetation invaded by exotic *Reynoutria* spp. *Biologia*, *69*(2), 247–253. https://doi.org/10.2478/s11756-013-0296-x

Hammer, C. F. (2019). *The impacts of terrestrial invasive plants on streams and natural and restored riparian forests in Northern New England*. A master's thesis in pursuit of a Forestry degree from the University of New Hampshire. Retrieved from https://scholars.unh.edu/cgi/viewcontent.cgi?article=2331&context=thesis

Harbaugh, B. (2017). *Ecosystem services as an outreach strategy for invasive knotweed control*. A master's theis in pursuit of a Environmental Studies degree from the Evergreen State College. Retrieved from http://archives.evergreen.edu/masterstheses/Accession86-10MES/HarbaughThesis/Final_2018.pdf

Hart, M. L., Bailey, J. P., Hollingsworth, P. M., & Watson, K. J. (1997). Sterile species and fertile hybrids of Japanese knotweeds along the River Kelvin. *Glasgow Naturalist*, *23*(2), 18–22.

Hortobágyi, B., Corenblit, D., Vautier, F., Steiger, J., Roussel, E., Burkart, A., & Peiry, J. L. (2017). A multi-scale approach of fluvial biogeomorphic dynamics using photogrammetry. *Journal of Environmental Management*, *202*, 348–362. https://doi.org/10.1016/j.jenvman.2016.08.069

Johnson, M. F., Kondolf, G. M., Westbrook, C., Thorne, C. R., Castro, J. M., Mazzacano, C. S., & Rood, S. B. (2020). Biomic river restoration: A new focus for river management. *River Research and Applications*, *36*, 3–12. https://doi.org/10.1002/rra.3529

Jones, C., Lawton, J., & Shachak, M. (1994). Organisms as ecosystem engineers. *Oikos*, *69*(3), 373–386.

Kabat, T. J., Stewart, G. B., & Pullin, A. S. (2006). Are Japanese knotweed (Fallopia japonica) control and eradication interventions effective? CEE review 05-015 (SR21). Collaboration for Environmental Evidence. www.environmentalevidence.org/SR21.html.

Klavon, K., Fox, G., Guertault, L., Langendoen, E., Enlow, H., Miller, R., & Khanal, A. (2017). Evaluating a process-based model for use in streambank stabilization: Insights on the Bank Stability and Toe Erosion Model (BSTEM). *Earth Surface Processes and Landforms*, *42*, 191–213. https://doi.org/10.1002/esp.4073

Konsoer, K. M., Rhoads, B. L., Langendoen, E. J., Best, J. L., Ursic, M. E., Abad, J. D., & Garcia, M. H. (2016). Spatial variability in bank resistance to erosion on a large meandering, mixed bedrock-alluvial river. *Geomorphology*, *252*, 80–97. https://doi.org/10.1016/j.geomorph.2015.08.002

Lavoie, C. (2017). The impact of invasive knotweed species (*Reynoutria* spp.) on the environment: Review and research perspectives. *Biological Invasions*, *19*(8), 2319–2337. https://doi.org/10.1007/s10530-017-1444-y

Martin, F. M. (2019). *The study of the spatial dynamics of Asian knotweeds (Reynoutria spp.) across scales and its contribution for management improvement*. Universite Grenoble Alps. https://www.researchgate.net/publication/334807468_The_study_of_the_spatial_dynamics_of_Asian_knotweeds_Reynoutria_spp_across_scales_and_its_contribution_for_management_improvement_-_Apports_de_l'etude_multiscalaire_des_dynamiques_spatiales_des_renoue

Martin, F. M., Dommanget, F., Lavallée, F., & Evette, A. (2020). Clonal growth strategies of *Reynoutria japonica* in response to light, shade, and mowing, and perspectives for management. *NeoBiota*, *56*, 89–110. https://doi.org/10.3897/NEOBIOTA.56.47511

Martin, F. M., Müllerová, J., Borgniet, L., Dommanget, F., Breton, V., & Evette, A. (2018). Using single- and multi-date UAV and satellite imagery to accurately monitor invasive knotweed species. *Remote Sensing*, *10*(10), 1662. https://doi.org/10.3390/rs10101662

Martínková, J., & Klimešová, J. (2016). Enforced clonality confers a fitness advantage. *Frontiers in Plant Science*, *7*(2), 1–10. https://doi.org/10.3389/fpls.2016.00002

Mummigatti, K. (2008). *The effects of Japanese Knotweed (Reynoutria japonica) on riparian lands in Otsego County, New York*. Retrieved from https://www.oneonta.edu/academics/biofld/PUBS/ANNUAL/2007/EffectsofKnotweedgrowth.pdf

Murrell, C., Gerber, E., Krebs, C., Parepa, M., Schaffner, U., & Bossdorf, O. (2011). Invasive knotweed affects native plants through allelopathy. *American Journal of Botany*, *98*(1), 38–43. https://doi.org/10.3732/ajb.1000135

Nanko, K., Giambelluca, T. W., Sutherland, R. A., Mudd, R. G., Nullet, M. A., & Ziegler, A. D. (2015). Erosion potential under *Miconia calvescens* stands on the Island of hawai'i. *Land Degradation and Development*, *26*(3), 218–226. https://doi.org/10.1002/ldr.2200

Ortega, Y. K., & Pearson, D. E. (2005). Weak vs. strong invaders of natural plant communties: Assessing invasibility and impact. *Ecological Applications*, *15*(2), 651–661.

Pattison, Z., Minderman, J., Boon, P. J., & Willby, N. (2017). Twenty years of change in riverside vegetation: What role have invasive alien plants played? *Applied Vegetation Science*, *20*(3), 422–434. https://doi.org/10.1111/avsc.12297

Pollen-Bankhead, N., & Simon, A. (2009). Enhanced application of root-reinforcement algorithms for bank-stability modeling. *Earth Surface Processes and Landforms*, *34*, 471–480. https://doi.org/10.1002/esp

Rouifed, S., Piola, F., & Spiegelberger, T. (2014). Invasion by *Fallopia* spp. in a French upland region is related to anthropogenic disturbances. *Basic and Applied Ecology*, *15*(5), 435–443. https://doi.org/10.1016/j.baae.2014.07.005

Saldana, A., Fuentes, N., & Pfanzelt, S. (2009). *Fallopia Japonica* (Houtt.) Ronse Decr. (polygonaceae): A new record for the alien flora of Chile. *Gayana Botanica*, *66*(2), 283–285.

Samanns, E., Cameli, G., Melchior, M., & da Costa, M. (2017). *NCHRP 25-25, Task 93 Long-term construction and maintenance cost comparison for road stream crossings: Traditional hydraulic design vs. aquatic organism passage design*. Retrieved from http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(93)_FR.pdf

Secor, E., Ross, D., & Balling, C. (2013). *Japanese knotweed effects on erosion rates in riparian corridors*. Retrieved from https://epscor.w3.uvm.edu/images/copies/t2.pdf

Smets, T., Poesen, J., & Bochet, E. (2008). Impact of plot length on the effectiveness of different soil-surface covers in reducing runoff and soil loss by water. *Progress in Physical Geography*, *32*(6), 654–677. https://doi.org/10.1177/0309133308101473

Stoll, P., Gatzsch, K., Rusterholz, H.-P., & Baur, B. (2012). Response of plant and gastropod species to knotweed invasion. *Basic and Applied Ecology*, *13*(3), 232–240. https://doi.org/10.1016/j.baae.2012.03.004

Stover, J. E., Keller, E. A., Dudley, T. L., & Langendoen, E. J. (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*(8), 304. https://doi.org/10.3390/geosciences8080304

Tal, M., & Paola, C. (2010). Effects of vegetation on channel morphodynamics: Results and insights from laboratory experiments. *Earth Surface Processes and Landforms*, *35*, 1014–1028. https://doi.org/10.1002/esp.1908

Tiley, G. E. D., & Philp, B. (1994). Giant Hogweed and its control in Scotland. In L. C. de Waal, L. E. Child, P. M. Wade & J. H. Brock (Eds.), *Ecology and management of invasive riverside plants* (pp. 101–110). Chichester, UK: John Wiley & Sons.

Urgenson, L. S. (2006). *The ecological consequences of knotweed invasion into riparian forests*. A master's thesis from the University of Washington. Retrieved from http://www.cfr.washington.edu/research.cesu/reports/J9W88030027-Urgenson-MSThesis.pdf

Urgenson, L. S., Reichard, S. H., & Halpern, C. B. (2009). Community and ecosystem consequences of giant knotweed (*Polygonum sachalinense*) invasion into riparian forests of western Washington, USA. *Biological Conservation*, *142*(7), 1536–1541. https://doi.org/10.1016/j.biocon.2009.02.023

Urgenson, L. S., Reichard, S. H., & Halpern, C. B. (2012). Multiple competitive mechanisms underlie the effects of a strong invader on early- to late-seral tree seedlings. *Journal of Ecology*, *100*(5), 1204–1215. https://doi.org/10.1111/j.1365-2745.2012.01995.x

van Oorschot, M., Kleinhans, M. G., Geerling, G. W., Egger, G., Leuven, R. S. E. W., & Middelkoop, H. (2017). Modeling invasive alien plant species in river systems: Interaction with native ecosystem engineers and effects on hydro-morphodynamic processes. *Water Resources Research*, *53*(8), 6945–6969. https://doi.org/10.1002/2017WR020854

Wells, M. J., Poynton, R. S., Balsinhas, A. A., Musil, C. F., Joffe, H., van Hoepen, E., & Abbott, S. K. (1986). The history of introduction of invasive alien plants to southern Africa. In A. A., Macdonald, I. A. W., Kruger, & F. J., Ferrar (Eds.), *The ecology and management of biological invasions in southern Africa: Proceedings of the National Synthesis Symposium on the Ecology of Biological Invasions* (pp. 21–35). Cape Town, South Africa: Oxford University Press.

Williams, F., Eschen, R., Harris, A., Djeddour, D., Pratt, C., Shaw, R. S., … Murphy, S. T. (2010, November). *The economic cost of invasive non-native species on Great Britain*. Wallingford UK: CABI Head Office Nosworthy Way and UK: CABI Europe - UK Bakeham Lane Egham Surrey.

Wilson, M. J., Freundlich, A. E., & Martine, C. T. (2017). Understory dominance and the new climax: Impacts of Japanese knotweed (*Fallopia japonica*) invasion on native plant diversity and recruitment in a riparian woodland. *Biodiversity Data Journal*, *5*, e20577. https://doi.org/10.3897/BDJ.5.e20577

Wohl, E. (2016). Messy rivers are healthy rivers: The role of physical complexity in sustaining ecosystem processes. In G. Constantinescu, M. H. Garcia & D. Hanes (Eds.), *River flow 2016* (pp. 24–29). Taylor & Francis Group. Retrieved from https://doi.org/10.1201/9781315644479-8

Zobel, M., Moora, M., & Herben, T. (2010). Clonal mobility and its implications for spatio-temporal patterns of plant communities: What do we need to know next? *Oikos*, *119*, 802–806. https://doi.org/10.1111/j.1600-0706.2010.18296.x

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