# Collating existing evidence on cumulative impacts of invasive plant species in riparian ecosystems of British Columbia, Canada: a systematic map protocol

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# Abstract

**Background**

Globally, the structure and functioning of foreshore and riparian ecosystems are being dramatically impacted by non-native invasive plant species. Invasive species can outcompete and replace native species, modify geochemical and hydraulic cycles, alter trophic processes, and change the composition and structure of communities above and below ground. However, these impacts are often investigated in isolation, even though one invasive species might increase or mitigate the impacts of others (i.e. cumulative impacts), potentially with cascading effects. Although cumulative impacts have long been studied within other environmental contexts, research on the cumulative impacts of invasive species is comparatively scarce. We aim to develop a protocol to systematically identify and collate evidence on the individual and cumulative impacts of a set of plant species invasive in foreshore and riparian ecosystems of British Columbia, Canada. Our primary question is: What evidence is available on the individual and cumulative impacts of invasive plants in the riparian and foreshore ecosystems of British Columbia, Canada? In addition, our systematic map will identify the strengths and gaps in knowledge pertaining to invasive plant species

impacts in foreshore and riparian ecosystems, with the ultimate goal of facilitating the development of evidence-based management strategies.

**Methods**

We identified the research topic and the primary and secondary questions with the support of stakeholders. We then devised a flexible string that allows for searching target invasive species. Using this string, we searched the literature for pilot species that aided the iterative development of the protocol. Once all target species are identified, we will carry out a systematic literature search on their impacts. We will search Web of Science and the CABI compendium for invasive species. We will include studies if they (i) refer to the target invasive species, (ii) focus on its environmental impacts and (iii) investigate such impacts in riparian ecosystems (iv) within North America (i.e. Canada & U.S.A.). We will use a two-stage screening process: titles and abstracts first, then the full manuscript. From each source, we will extract impact description, ecosystem component impacted, and magnitude and directionality of impacts. We will include a publicly available database of studies, descriptive statistics, and a narrative summary within our synthesis outcomes.

**Keywords**: *Cumulative impacts, British Columbia, Invasive species, Impacts, Riparian ecosystems, Plant invasions, Foreshore ecosystems, Protocol, Systematic maps*

# Background

## *Biological invasions in foreshore and riparian ecosystems*

Foreshore and riparian ecosystems are vitally important from ecological, cultural, and economic standpoints. Although their spatial extent is small, they are often hotspots of biodiversity, hosting rare species, and serving as refugia and corridors essential to many others (1–3). These ecosystems also provide essential functions and services such as

improving water quality, flood mitigation, and minimizing erosion (2,4,5). As such, foreshore and riparian habitats are the focus of targeted management and conservation strategies in many countries (6–9).

Despite their recognized importance, foreshore and riparian ecosystems are being impacted by many anthropogenic stressors (10). Infrastructures (e.g. dams, dyking, channelization) and water management (e.g. water diversion, irrigation, dredging) can radically modify water levels and flow and disrupt natural fluvial dynamics (1,5,11,12). Contamination and nutrient additions can alter water quality, reduce biodiversity, and promote bioaccumulation (1,13). Habitat loss through agriculture, deforestation, and development disproportionately impacts foreshore and riparian zones (1,14–16), and was estimated to be up to two-thirds in the U.S. alone (17). Additionally, freshwater ecosystems are oftentimes highly invaded by non-native species due to their proximity to human settlements and their function as dispersal corridors (14,18–21).

Invasive species can impact riparian ecosystems in various ways, but invasive plants have particularly pervasive impacts on ecosystem structure and functioning. By spreading aggressively, they displace both plant and animal native species (22–25), modify geochemical and hydraulic cycles (26,27), alter trophic processes (28), and change the composition and structure of communities above and below ground (2,29). Additionally, invasive plants alter traditional practices and resource use by Indigenous peoples (28). The cumulative impacts of invasive plants on riparian ecosystems are potentially profound, but research to quantify such effects remains limited (2,31).

Here, we aim to develop a framework for systematically collating and mapping evidence on the individual and cumulative impacts of plant species that are invasive within foreshore and riparian ecosystems, and we will apply our protocol to systems in British Columbia, Canada.

*Individual and cumulative impacts: definitions, examples and previous work*

In invasion ecology, individual impacts are defined as measurable changes caused by non-native species on a target ecosystem (32,33). They can vary greatly in type, magnitude, and directionality. For instance, some impacts might be barely detectable (e.g. gene flow through hybridization), while others can produce pronounced, observable effects (e.g. ecosystem dominance). Impacts can be direct (e.g. displacement of native species), but also mediated through other factors (e.g. competition for resources, 32). Finally, while non-native species have been investigated in large part because of their negative effects, impacts can vary along a continuum from negative to positive (33,34), and can be ecosystem or context-dependent.

Identifying an impact's directionality presents some challenges. Negative impacts are typically equated to unfavourable outcomes for humans (33). However, this approach is strongly biased by the value system and worldview of the researcher (34,35). In an effort to minimize subjectivity and value-based identifications of impact directionality, we define as negative or positive any quantifiable reduction or increase in ecosystem properties or attributes (e.g. native species richness and abundance, nutrient cycling, water quality, etc., 33). For instance, we define as positive an increase in the fitness or number of individuals of a native species but as negative its reduction.

The combination and interaction of multiple individual impacts are referred to as cumulative impacts and many definitions of this concept exist. For the Canadian Environmental Assessment Act (CEAA), they are *"changes to the environment that are caused by an action in combination with other past, present and future human actions*" (36). The Council on Environmental Quality (CEQ) suggests impacts have to be incremental (37). The most well-articulated definition is that of the European Environmental Agency (EEA), which defines them as: '*the impacts (positive or negative, direct and indirect, long-term and short-term impacts) arising from a range of activities throughout an area or region, where each individual effect may not be significant if taken in isolation. Such impacts can arise from the growing volume of traffic, the combined effect of a number of agriculture measures leading to more intensive production and use of chemicals, etc. Cumulative impacts include*

*a time dimension, since they should calculate the impact on environmental resources resulting from changes brought about by past, present and reasonably foreseeable future actions."* (38). Consistent elements among these definitions are (1) the combination of multiple individual impacts, (2) a time component and (3) the human agency. While not explicitly stated in the previous definitions, cumulative impacts also have a spatial dimension, or they can accumulate in space as well as temporally (39).

We define cumulative impacts in biological invasions as the combined effect of multiple impacts when at least one is generated by an invasive species. Cumulative impacts include recurrent impacts of a single species and the combined effect of multiple invaders, but also the compounded impact of invading species and other anthropogenic stressors (12). Our definition incorporates all the elements of previous definitions; however, it is more restrictive, as the primary focus is the impacts of invasive species. Conversely, it includes impacts of any magnitude, type or directionality.

The term 'cumulative' might imply that the total effect of multiple impacts is always greater than that of individual impacts. Multiple invaders can collectively increase native species displacement, or enhance topsoil nutrient concentration (additive impacts, 29,30). An N-fixer might increase soil nitrogen, facilitating invasions by more competitive nitrophilous species, which in turn will displace natives (multiplicative impacts, 29). However, additive or multiplicative impacts are not the only potential outcomes. Competition between two invaders might instead reduce their impact per capita. For example, an allopathic species might negatively affect both native and non-native species. In this case, one invader mitigates the impacts of another invader (39).

Despite a long history of research on cumulative impacts within environmental contexts (39), the literature on the cumulative impacts of invasive species is relatively scarce. Most work in biological invasions focuses on a single species or single direct impact (41–46). Even when multiple impacts are identified, their cumulative effect is rarely considered (31,40). This is despite previously proposed theoretical frameworks share some conceptual overlap. One such example is the invasion meltdown, which posits that

interactions among invaders might increase their impacts (47). Critically for our work, little research effort explored the cumulative impacts of invasive plant species in riparian and foreshore ecosystems. Therefore, anticipating a lack of studies on cumulative impacts, we will also include individual impacts in this systematic map.

### *Topic Identification and Stakeholder Input*

There is a clear need for work identifying the cumulative impacts of invasive species in riparian ecosystems. The Province of British Columbia, Ministry of Forests Invasive Plant Program, highlighted the need to synthesize current evidence on the impacts of invasive plant species in riparian and foreshore ecosystems within the province, to inform research and management needs. British Columbia's riparian and foreshore ecosystems are invaded by numerous highly destructive invasive plant species, such as Russian Olive (*Elaeagnus angustifolia*), Phragmites (*Phragmites australis*), Knotweeds (*Reynoutria* spp., syn. *Fallopia*), Tree of Heaven (*Ailanthus altissima*) and Canary reed grass (*Phalaris arundinacea*). While the impacts of these species have been extensively investigated (43,48–52), there is no comprehensive assessment of their cumulative impacts.

Stakeholders in the provincial government played a pivotal role in shaping the research topic and refining the scope of the systematic map. Stakeholders include the British Columbia Ministry of Forests, Agriculture and Agri-Food Canada, and the University of British Columbia. Based on their expert knowledge and the available data, they provided a list of 10-15 plant species that are invasive in the target ecosystems and geographic areas, thereby aiding in the identification of specific research questions and objectives. Input from practitioners and other researchers helped refine the approach and the methodology. Through ongoing dialogue and feedback, stakeholders were able to establish clear expectations, develop a robust methodology, and identify appropriate outcomes for the systematic map. In addition to quantifying the cumulative impacts of plant species invasive to riparian ecosystems, stakeholders have identified two additional aspects as essential. First is

the development of a reproducible protocol that can be employed in future systematic studies of invasive species impacts. Second is the investigation of how the cumulative impacts of invasive species will vary under current climate change scenarios.

Protocols are a crucial aspect of developing a project, particularly in the case of systematic work (53). Good protocols need to be transparent, detailed and reproducible, allowing other researchers to replicate their work (53–56). In this case, we do not simply want to describe our procedure for mapping the existing literature, but we specifically aim to provide a tool that is sufficiently flexible and reproducible to be applied in the investigation of other invasive species or ecosystems.

Climate change is a key contributor to the cumulative impacts of invasive species across both terrestrial and aquatic ecosystems. However, the nature and magnitude of its effect of invasive species' impacts is often unclear. Interactions between particular invasive plants and the diverse facets of climate change are challenging to predict and likely species- and context-dependent (57). For instance, while the ranges of many non-native invasive species may expand as temperature rises (58), others may contract or shift in response to both abiotic and biotic factors (57,59). Nevertheless, strategies for mitigating negative impacts are sorely needed. A key first step is synthesizing the diverse and extensive research on this topic.

Here, we present a reproducible systematic map protocol (53) for screening, collating, and describing research on the impacts of priority invasive plants in riparian and foreshore ecosystems, and we will apply it to systems in British Columbia. Given their efficacy and comprehensiveness, systematic maps are increasingly common in environmental management (54). Through the systematic map process, we will identify knowledge clusters and gaps (i.e. areas of high and low concentration of the research effort), and synthesize results within the context of current climate change scenarios. Key outputs will include (1) a robust analytical framework for qualitatively predicting – based on the best available evidence – the cumulative impacts of invasive plants under changing climates and followed by (2) a more detailed assessment for a selection of priority invasive plant species

(identified by the BC Ministry of Forests Invasive Alien Plant Program). These outputs will have high utility for policy, planning and strategic, evidence-based decision management of ecosystems impacted by priority invasive plant species in British Columbia.

## Objective of the review

We aim to systematically collate and map evidence on the individual and cumulative impacts of a selection of plant species invasive to riparian ecosystems in British Columbia, Canada.

### *Primary question*

What evidence is available on the individual and cumulative impacts of invasive plants in the riparian and foreshore ecosystems of British Columbia, Canada?

### *Components of the primary question*

- **Population**: Riparian and foreshore ecosystems in British Columbia
- **Exposure**: non-native plant species invasive to riparian and foreshore ecosystems of British Columbia
- **Comparator**: No impact or absence of invasive plant species.
- **Outcome**: A synthesis of both the individual and collective cumulative impacts of the selected invasive plant species

### *Secondary question*

We will describe variations in the research effort with regard to:

- Geography and fluvial systems investigated
- Invasive species
- Impacts and their directionality (negative, positive, or neutral)
- Impacted ecosystem components
- Type of study (e.g. correlational, experimental, etc.)

- Time (did the level of knowledge change over time?)

Additionally, we will delineate potential changes in impact magnitude by species under current climate change scenarios based on the available literature.

# Methods

## *Search string*

We will conduct multiple systematic searches, one for each of our focus species. For each search, we will use as keywords the scientific name of a species and "impact", formatted for Web of Science (WOS). For example:

*Elaeagnus angustifolia* AND impact*

The selected search string is purposely broad. Searches including keywords associated with the target ecosystem (riparian, foreshore, freshwater, wetland, aquatic, etc.) and geographic area (British Columbia, Canada, North America, etc.) were deemed to be too restrictive. A broader search allows for capturing additional studies that either use different keywords or investigate impacts in different circumstances and yet might be relevant to the target ecosystem.

We tested the comprehensiveness of searches using two pilot species, the Russian Olive (*Elaeagnus angustifolia*) and the Canary Reed Grass (*Phalaris arundinacea*). For each species, we selected 5 primary articles, which used a variety of keywords (e.g. impact, effect, alter, change, consequence, see Appendix 1 for the full list). Then, we used the search strings to extract studies from WOS and we extracted references from CABI and review studies for pilot species. All studies were detected by search strings. These two species aided the iterative development of the protocol and will be included in the systematic map.

*Bibliographic sources*

We will conduct searches in WOS, accessing the core database using an institutional licence (University of British Columbia). The core database assigns metadata to a study based exclusively on the information provided by the publisher and journal. Since other databases assign additional metadata to a study, some material might go undetected despite meeting our criteria. We will expand our search to all databases and then refine it to the core collection. This will identify studies that match our keywords across all databases but are only present in the core collection, and thus accessible to the authors (Mathew Vis-Dunbar, UBC librarian, pers. comm. 2023). Additionally, we will screen all references in the CABI Invasive Species Compendium factsheet for each species, except for references in the *Distribution References* section. Review studies that fit the criteria for inclusion will be used as sources as well, and references extracted and screened.

We will also scope organization websites across North America at different administrative levels. We will assess international (outside Canada), federal (Canada), provincial (British Columbia) and local (regions within British Columbia) organizations. We will search for the focus species name and the word “invasive” in the following organization websites:

- Canadian Weed Society
- British Columbia Inter-Ministry Invasive Species Working Group
- Canadian Council of Invasive Species
- Invasive Species Centre
- Okanagan Basin Waterboard
- North American Invasive Species Management Association (NAISMA)
- The National Environmental Coalition on Invasive Species (NECIS)
- United States Department of Agriculture (USDA)
- National Invasive Species Council

- All local associations in British Columbia (e.g. Boundary Invasive Species Society, East Kootenay Invasive Species Council, Okanagan and Similkameen Invasive Species Society, etc.)

We will conduct the same query in the following searchable catalogues of government documents:

- Canadian Federal Science Library Network
- Legislative library of British Columbia

These sources will allow for capturing also the grey literature. WOS identifies dissertations and conference proceedings, especially if expanding searches to all databases, while the CABI, review papers and organizational websites will identify technical reports. Accessing multiple databases will help reduce location and index biases (i.e. not all journals are indexed in all databases, incomplete or poor indexing, 46).

### *Screening and inclusion criteria*

The screening process will include two stages. First, we will screen titles and abstracts. If the information is insufficient to make a decision, we will assess the full manuscript as well. These steps will be applied to all studies, regardless of the source they were extracted from. A single reviewer will conduct the screening (FM). A random subset of studies will also be assessed by a second reviewer (JP) at both stages (Stage 1 = 5%, Stage 2 = 10%). We will appraise consistency using Cohen's kappa statistics and set 0.6 as a threshold (60,61). If consistency is below the cut-off limit, screening and inclusion criteria will be adjusted for clarity. All disagreements will be discussed and resolved. Any study authored by one of the systematic reviewers that meets the criteria for inclusion will be assessed by the other reviewer at every stage of the process.

We will screen both commercially published and grey literature, but not personal communications or expert opinions. Including grey literature reduces the risk of publication and citation biases (i.e. significant results are more likely to be published and cited than non-

significant results, 46,48). We will consider only material in English. To minimize language bias (i.e. significant results are more likely to be published in English, 46,48), we will assess the title and abstract if translated into English. Studies were included irrespective of the magnitude, type or directionality of the impact (negative, positive or neutral), and irrespective of the statistical significance of reported results. This will help reduce the prevailing paradigm bias (i.e. a bias towards studies supporting the prevailing paradigm; in this case, invasive species' impacts are extensive and negative, 26,46,48). The time span includes all studies up to the day the search will be conducted, countering temporal bias (i.e. older studies might be overlooked, 46,54). Finally, we will include studies regardless of study design (e.g. experimental, observational, etc.).

We will include studies if they:

(1) Refer to the non-native invasive plant species searched. We defined as invasive widespread, impactful non-native species.

(2) Focus on its abiotic and biotic impacts. We defined impacts as measurable changes caused by non-native species on a target ecosystem.

(3) Investigate such impacts in riparian and foreshore ecosystems. Riparian ecosystems are defined as areas adjacent to streams or rivers (flowing water), while foreshore ecosystems are defined as the land adjacent to still (non-flowing) water bodies.

(4) within North America (i.e. Canada & U.S.A.).

We will include all studies in North America because many environmental conditions and invasive species will be shared between British Columbia and other regions within Canada and the U.S. However, including all studies in North America might capture information not relevant to British Columbia. For instance, studies might investigate the impacts of invasive plant species on abiotic and biotic components absent in our study system. Such cases will be excluded, and exclusions justified. Similarly, we will justify all other exceptions (63).

### *Study Validity Assessment*

We assessed the validity of each study based only on the eligibility criteria.

### *Data coding*

For each study at the full-text screening stage, we will provide the following information:

1. Bibliographic information
    a) Authors list
    b) Article title
    c) Publication year
    d) Bibliographic source
2. Inclusion criteria
    a) Exposure: Focuses on target species (Y/N)
    b) Exposure: Focuses on abiotic and biotic impacts (Y/N)
    c) Population: Focuses on riparian and foreshore ecosystems (Y/N)
    d) Population: Within North America (Y/N)
3. Screening stage
    a) Excluded at full-text stage
    b) Included
    c) Exceptions
4. Additional information
    a) Duplicate (Y/N)
    b) Notes

For included studies only, we will provide also the following information:

1. Bibliographic information

a) Authors list
b) Article title
c) Publication year

2. Information on impacts
    a) Impact description
    b) Ecosystem component impacted (e.g. species, soil, etc.)
    c) Magnitude of impact
    d) Impact direction (negative, positive, neutral)

3. Additional information
    a) Geographic region
    b) Study Design (i.e. field or laboratory experiment, correlation or direct observation)
    c) Notes

We will compile subsection *3c. Exceptions* on a case-by-case basis. For included studies, we will provide information by impact so that if a study investigated more than one, there will be a number of entries equivalent to the number of impacts assessed.

### *Meta-data extraction*

Studies included in the systematic literature map will undergo a full-manuscript screening to identify the investigated impact (or impacts). We will provide a description of the investigated impacts and the ecosystem component impacted. Then, we will categorize impacts by their magnitude and directionality. Impacts magnitude will be assessed following previous work, modified to include both positive and negative impacts (31–33):

- **Minimal**: The impact is unlikely or negligible.

- **Minor**: It causes changes in the fitness of individuals in the native biota, but no changes in native population densities.
- **Moderate**: It causes changes in the population densities of native species, but no changes to the structure of communities or the abiotic or biotic components of ecosystems.
- **Major**: It causes the local or population extinction/introduction of at least one native species, and leads to reversible/transient changes in the structure of communities and the abiotic or biotic components of ecosystems.
- **Massive**: It leads to the replacement and local extinction/introduction of multiple native species, and produces irreversible changes in the structure of communities and the abiotic or biotic components of ecosystems.

### *Synthesis and presentation*

For each species, we will provide a first database with all studies included at the full-text screening and a reason for exclusions at this stage. A second database with the studies included in the map, along with a graphical representation of the screening process. Both databases will contain corresponding coded metadata (see *Data Coding* section). We will import studies included in the review into a reference manager and share them as a public library to facilitate accessibility. We will develop a graphical representation of riparian ecosystems, representing identified impacts and their magnitude and directionality for each species. Then, we will create a matrix combining multiple species (as rows) and impacts (as columns) to illustrate the collective impacts of the focus species. Descriptive statistics will be used to answer secondary questions. We will provide the geographic distribution of studies, visualize publication trends over time, and illustrate differences in species and impacts research effort. We will use co-occurrence matrices to identify research effort biases (64). Lastly, we will provide a narrative synthesis of results for both main and secondary questions. The narrative synthesis will focus on (i) species and impact prioritization, (ii)

clusters and gaps in present knowledge, (iii) predicted variations in impact magnitude and direction under current climate change scenarios, and (iv) avenues for future research.

## *Ethics approval and consent to participate*

Not applicable.

## *Consent for publication*

Not applicable.

## *Availability of data and materials*

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

## *Competing interests*

The authors declare that they have no competing interests.


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## *Authors' contributions*

FM drafted the protocol with input from JP and CM. All authors read and approved the final manuscript.


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## *References*

1. Poff B, Koestner KA, Neary DG, Henderson V. Threats to Riparian Ecosystems in Western North America: An Analysis of Existing Literature. JAWRA Journal of the American Water Resources Association. 2011;47(6):1241–54.
2. Stella JC, Rodríguez-González PM, Dufour S, Bendix J. Riparian vegetation research in Mediterranean-climate regions: common patterns, ecological processes, and considerations for management. Hydrobiologia. 2013 Nov;719(1):291–315.
3. Ragan K, Schipper J, Bateman HL, Hall SJ. Mammal use of riparian corridors in semi-arid Sonora, Mexico. The Journal of Wildlife Management. 2023;87(1):e22322.
4. Koundouri P, Boulton AJ, Datry T, Souliotis I. Ecosystem Services, Values, and Societal Perceptions of Intermittent Rivers and Ephemeral Streams. In: Intermittent Rivers and Ephemeral Streams. Elsevier; 2017. p. 455–76.
5. Patten DT. Riparian ecosytems of semi-arid North America: Diversity and human impacts. Wetlands. 1998 Dec 1;18(4):498–512.
6. Knopf FL, Johnson RR, Rich T, Samson FB, Szaro RC. Conservation of Riparian Ecosystems in the United States. The Wilson Bulletin. 1988;100(2):272–84.
7. Erős T, Kuehne L, Dolezsai A, Sommerwerk N, Wolter C. A systematic review of assessment and conservation management in large floodplain rivers – Actions postponed. Ecological Indicators. 2019;98:453–61.
8. Fryirs KA, Zhang N, Duxbury E, Ralph T, Fryirs KA, Zhang N, et al. Rivers up in smoke: impacts of Australia's 2019–2020 megafires on riparian systems. Int J Wildland Fire. 2022 Jun 16;31(7):720–7.

9. Brierley GJ, Hikuroa D, Fuller IC, Tunnicliffe J, Allen K, Brasington J, et al. Reanimating the strangled rivers of Aotearoa New Zealand. WIREs Water. 2023;10(2):e1624.

10. Stella JC, Bendix J. Chapter 5 - Multiple Stressors in Riparian Ecosystems. In: Sabater S, Elosegi A, Ludwig R, editors. Multiple Stressors in River Ecosystems. Elsevier; 2019. p. 81–110.

11. Airoldi L, Beck M. Loss, Status and Trends for Coastal Marine Habitats of Europe. In: Gibson R, Atkinson R, Gordon J, editors. Oceanography and Marine Biology. CRC Press; 2007. p. 345–405. (Oceanography and Marine Biology - An Annual Review; vol. 20074975).

12. Johnson PT, Olden JD, Vander Zanden MJ. Dam invaders: impoundments facilitate biological invasions into freshwaters. Frontiers in Ecology and the Environment. 2008;6(7):357–63.

13. Chiu MC, Leigh C, Mazor R, Cid N, Resh V. Anthropogenic Threats to Intermittent Rivers and Ephemeral Streams. In: Intermittent Rivers and Ephemeral Streams. Elsevier; 2017. p. 433–54.

14. Greene SL. A Roadmap for Riparian Invasion Research. River Research and Applications. 2014;30(5):663–9.

15. Post GC, Chang H, Banis D. The spatial relationship between patterns of disappeared streams and residential development in Portland, Oregon, USA. Journal of Maps. 2022 Dec 1;18(2):210–8.

16. Sweeney BW, Bott TL, Jackson JK, Kaplan LA, Newbold JD, Standley LJ, et al. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences. 2004;101(39):14132–7.

17. Swift BL. Status of Riparian Ecosystems in the United States. JAWRA Journal of the American Water Resources Association. 1984;20(2):223–8.

18. Aguiar FCF, Ferreira MT. Plant invasions in the rivers of the Iberian Peninsula, south-western Europe: A review. Plant Biosystems. 2013;147(4):1107–19.

19. Arianoutsou M, Delipetrou P, Celesti-Grapow L, Basnou C, Bazos I, Kokkoris Y, et al. Comparing naturalized alien plants and recipient habitats across an east–west gradient in the Mediterranean Basin. Journal of Biogeography. 2010;37(9):1811–23.
20. Kowarik I, Säumel I. Water dispersal as an additional pathway to invasions by the primarily wind-dispersed tree Ailanthus altissima. Plant Ecol. 2008;198(2):241–52.
21. Pysek P, Prach K. Plant Invasions and the Role of Riparian Habitats: A Comparison of Four Species Alien to Central Europe. Journal of Biogeography. 1993;20(4):413–20.
22. Barnes WJ. The Rapid Growth of a Population of Reed Canarygrass (Phalaris arundinacea L.) and Its Impact on Some Riverbottom Herbs. Journal of the Torrey Botanical Society. 1999;126(2):133–8.
23. Price EPF, Spyreas G, Matthews JW. Biotic homogenization of regional wetland plant communities within short time-scales in the presence of an aggressive invader. Journal of Ecology. 2018;106(3):1180–90.
24. Bateman HL, Chung-MacCoubrey A, Snell HL. Impact of Non-Native Plant Removal on Lizards in Riparian Habitats in the Southwestern United States. Restoration Ecology. 2008;16(1):180–90.
25. Pendleton R, Pendleton B, Finch D. Displacement of Native Riparian Shrubs by Woody Exotics: Effects on Arthropod and Pollinator Community Composition. Natural Resources and Environmental Issues. 2011;16(1).
26. Martinez AE, McDowell PF. Invasive Reed Canarygrass (Phalaris arundinacea) and Native Vegetation Channel Roughness. Invasive Plant Science and Management. 2016;9(1):12–21.
27. Simons SB, Seastedt TR. Decomposition and Nitrogen Release from Foliage of Cottonwood (Populus deltoides) and Russian-olive (Elaeagnus angustifolia) in a Riparian Ecosystem. The Southwestern Naturalist. 1999;44(3):256–60.
28. Mineau MM, Baxter CV, Marcarelli AM. A Non-Native Riparian Tree (Elaeagnus angustifolia) Changes Nutrient Dynamics in Streams. Ecosystems. 2011;14(3):353–65.

524 29. Jacinthe PA, Bills JS, Tedesco LP. Size, activity and catabolic diversity of the soil
525 microbial biomass in a wetland complex invaded by reed canary grass. Plant Soil.
526 2010;329(1):227–38.
527 30. Collier N, Austin BJ, Bradshaw CJA, McMahon CR. Turning Pests into Profits:
528 Introduced Buffalo Provide Multiple Benefits to Indigenous People of Northern Australia.
529 Hum Ecol. 2011;39(2):155–64.
530 31. Katsanevakis S, Tempera F, Teixeira H. Mapping the impact of alien species on
531 marine ecosystems: the Mediterranean Sea case study. Diversity and Distributions.
532 2016;22(6):694–707.
533 32. Blackburn TM, Essl F, Evans T, Hulme PE, Jeschke JM, Kühn I, et al. A Unified
534 Classification of Alien Species Based on the Magnitude of their Environmental Impacts.
535 PLOS Biology. 2014;12(5):e1001850.
536 33. Vimercati G, Probert AF, Volery L, Bernardo-Madrid R, Bertolino S, Céspedes V, et
537 al. The EICAT+ framework enables classification of positive impacts of alien taxa on native
538 biodiversity. PLOS Biology. 2022;20(8):e3001729.
539 34. Sax DF, Schlaepfer MA, Olden JD. Identifying key points of disagreement in non-
540 native impacts and valuations. Trends in Ecology & Evolution. 2023;
541 35. Cardou F, Vellend M. Stealth advocacy in ecology and conservation biology.
542 Biological Conservation. 2023;280:109968.
543 36. Canadian Environmental Assessment Agency, editor. Cumulative effects assessment
544 practitioners guide. Ottawa; 1999.
545 37. Council on Environmental Quality. National Environmental Policy Act - Cumulative
546 Effects.
547 38. European Environment Agency. https://www.eea.europa.eu/help/glossary/eea-
548 glossary/cumulative-impacts. Cumulative Impacts.
549 39. Spaling H, Smit B. Cumulative environmental change: Conceptual frameworks,
550 evaluation approaches, and institutional perspectives. Environmental Management.
551 1993;17(5):587–600.

552 40. Vanderhoeven S, Dassonville N, Meerts P. Increased Topsoil Mineral Nutrient
553 Concentrations Under exotic invasive plants in Belgium. Plant Soil. 2005;275(1):169–79.
554 41. Follstad Shah JJ, Harner MJ, Tibbets TM. Elaeagnus angustifolia Elevates Soil
555 Inorganic Nitrogen Pools in Riparian Ecosystems. Ecosystems. 2010;13(1):46–61.
556 42. Spyreas G, Wilm BW, Plocher AE, Ketzner DM, Matthews JW, Ellis JL, et al.
557 Biological consequences of invasion by reed canary grass (Phalaris arundinacea). Biol
558 Invasions. 2010;12(5):1253–67.
559 43. Rojas IM, Zedler JB. An invasive exotic grass reduced sedge meadow species
560 richness by half. Wetlands Ecol Manage. 2015;23(4):649–63.
561 44. Katz GL, Tuttle GM, Denslow MW, Norton AP. Legacy Effects of Russian Olive
562 (Elaeagnus angustifolia L.) in a Riparian Ecosystem Three Years Post-Removal. Wetlands.
563 2020;40(6):1897–907.
564 45. Gallego-Tévar B, Grewell BJ, Whitcraft CR, Futrell JC, Bárcenas-Moreno G, Castillo
565 JM. Contrasted Impacts of Yellow Flag Iris (Iris pseudacorus) on Plant Diversity in Tidal
566 Wetlands within Its Native and Invaded Distribution Ranges. Diversity. 2022;14(5):326.
567 46. Rodgers VL, Scanga SE, Kolozsvary MB, Garneau DE, Kilgore JS, Anderson LJ, et
568 al. Where Is Garlic Mustard? Understanding the Ecological Context for Invasions of Alliaria
569 petiolata. BioScience. 2022;72(6):521–37.
570 47. Simberloff D, Von Holle B. Positive Interactions of Nonindigenous Species:
571 Invasional Meltdown? Biological Invasions. 1999 Mar 1;1(1):21–32.
572 48. Benoit LK, Askins RA. Impact of the spread of Phragmites on the distribution of birds
573 in Connecticut tidal marshes. Wetlands. 1999;19(1):194–208.
574 49. Brooks RK, Barney JN, Salom SM. The invasive tree, Ailanthus altissima, impacts
575 understory nativity, not seedbank nativity. Forest Ecology and Management.
576 2021;489:119025.
577 50. Claeson SM, LeRoy CJ, Barry JR, Kuehn KA. Impacts of invasive riparian knotweed
578 on litter decomposition, aquatic fungi, and macroinvertebrates. Biol Invasions.
579 2014;16(7):1531–44.

580 51. Katz GL, Shafroth PB. Biology, ecology and management of Elaeagnus angustifolia
581 L. (Russian olive) in western North America. Wetlands. 2003;23(4):763–77.
582 52. Medina-Villar S, Rodríguez-Echeverría S, Lorenzo P, Alonso A, Pérez-Corona E,
583 Castro-Díez P. Impacts of the alien trees Ailanthus altissima (Mill.) Swingle and Robinia
584 pseudoacacia L. on soil nutrients and microbial communities. Soil Biology and Biochemistry.
585 2016;96:65–73.
586 53. Collaboration for Environmental Evidence. Guidelines and Standards for Evidence
587 synthesis in Environmental Management. Version 5.1 (AS Pullin, GK Frampton, B Livoreil &
588 G Petrokofsky, Eds) [Internet]. 2022. Available from:
589 https://environmentalevidence.org/information-for-authors/
590 54. Haddaway NR, Bernes C, Jonsson BG, Hedlund K. The benefits of systematic
591 mapping to evidence-based environmental management. Ambio. 2016;45(5):613–20.
592 55. Haddaway NR, Macura B, Whaley P, Pullin AS. ROSES RepOrting standards for
593 Systematic Evidence Syntheses: pro forma, flow-diagram and descriptive summary of the
594 plan and conduct of environmental systematic reviews and systematic maps. Environ Evid.
595 2018;7(1):7.
596 56. Palacio FX, Callaghan CT, Cardoso P, Hudgins EJ, Jarzyna MA, Ottaviani G, et al. A
597 protocol for reproducible functional diversity analyses. Ecography. 2022;2022(11):e06287.
598 57. Bellard C, Thuiller W, Leroy B, Genovesi P, Bakkenes M, Courchamp F. Will climate
599 change promote future invasions? Glob Chang Biol. 2013;19(12):3740–8.
600 58. Perry LG, Reynolds LV, Shafroth PB. Divergent effects of land-use, propagule
601 pressure, and climate on woody riparian invasion. Biol Invasions. 2018;20(11):3271–95.
602 59. Poland TM, Patel-Weynand T, Finch DM, Miniat CF, Hayes DC, Lopez VM, editors.
603 Invasive Species in Forests and Rangelands of the United States: A Comprehensive
604 Science Synthesis for the United States Forest Sector. Cham: Springer International
605 Publishing; 2021.
606 60. Ridley FA, McGowan PJ, Mair L. The scope and extent of literature that maps threats
607 to species: a systematic map protocol. Environmental Evidence. 2020;9(1):23.

608 61. Cohen J. A coefficient of agreement for nomimal scales. Educ Psychol Meas.
609 1960;20:2746.
610 62. Bayliss HR, Beyer FR. Information retrieval for ecological syntheses. Research
611 Synthesis Methods. 2015;6(2):136–48.
612 63. O'Dea RE, Lagisz M, Jennions MD, Koricheva J, Noble DWA, Parker TH, et al.
613 Preferred reporting items for systematic reviews and meta-analyses in ecology and
614 evolutionary biology: a PRISMA extension. Biol Rev. 2021;96(5):1695–722.
615 64. Ridley FA, Hickinbotham EJ, Suggitt AJ, McGowan PJK, Mair L. The scope and
616 extent of literature that maps threats to species globally: a systematic map. Environ Evid.
617 2022;11(1):1–26.
618