Cumulative impacts of invasive plant species in British Columbia's riparian ecosystems: 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 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. 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). Riparian 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 ecosystems 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 bioaccumulate (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 to 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, while others can produce pronounced, observable effects. Impacts can be direct, but also mediated through other factors (32). Finally, while nonnative 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 (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 include also 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. 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 these are 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 propose to first devise and publish 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. We will develop and refine our systematic map protocol using an iterative approach to pilot invasive species. Next, we aim to publish the findings of our systematic map. 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.

Primary question

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

Components of the primary question

- **Population**: Riparian ecosystems in British Columbia
- **Exposure**: Impacts of a set of non-native plant species invasive to riparian 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 also studies that either use different keywords or investigate impacts in different circumstances and yet might be relevant to the target ecosystem. Using this string, we searched the literature for pilot species that aided the iterative development of the protocol. Pilot species will be included in the systematic map.

Bibliographic sources

We will conduct searches in WOS, accessing the core database. 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, 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 detail exceptions in the supplementary material. 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 (10%) will also be assessed by a second reviewer (JP). 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 meet the criteria for inclusion will be assessed by the other reviewer at every stage of the process.

We will screen published and unpublished material, but not personal communications or expert opinions. Including unpublished work 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). Currently, the time span includes all studies up to the day the search was conducted (09 January 2023), countering temporal bias (i.e. older studies might be overlooked, 46,54).

We will include studies if they (i) refer to the invasive species searched, (ii) focus on its environmental impacts and (iii) investigate such impacts in riparian ecosystems (iv) within North America (i.e. Canada & U.S.A.). 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 environmental components absent in our study system. Such cases will be excluded, and exclusions justified. Similarly, we will justify all other exceptions (63).

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 to 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.

Data coding

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

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

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

1. Bibliographic information
    1. Authors list
    2. Article title
    3. Publication year
2. Information on impacts
    c. Impact description
    c. Ecosystem component impacted (e.g. species, soil, etc.)
    c. Magnitude of impact
    c. Impact direction (negative, positive, neutral)
3. Additional information
    1. Geographic region
    2. 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.

Synthesis and presentation

For each species, we will provide a first database with all studies included at the full-text screening stage and a second database with the studies included in the review, 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 individual 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, and 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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