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Systematic Review Protocol

Title
What is the effectiveness of methods for eradicating or controlling abundance and biomass of invasive aquatic plants in Canada? A systematic review protocol

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Background
Invasion by non-native plant species can result in many adverse ecological effects (Gallardo et al., 2016) and cause billions of dollars in economic damages yearly (Hoffman & Broadhurst, 2016; Fantle-Lepczyk et al., 2022), with additional expenditures for management and control initiatives (Jardine & Sanchirico, 2018). Managing invasive aquatic plants is an important component of ecosystem management and conservation. Options include no action, controlling or suppressing the species, or complete eradication (Simberloff, 2021). Control and eradication can be extremely difficult, making it important to determine which control method(s) is most likely be effective. Complications arise when it is unclear if management activities will result in the desired effect of decreasing or eradicating the population, or if management activities could result in no change or the spread of the invasive plant species. Previous reviews on invasive plant management have been conducted to determine the use of different control methods (Hussner et al., 2017), the efficacy of control methods for a specific species (e.g., Roberts & Pullin, 2006), the influence of control methods on off-target species, environmental or ecosystem impacts (Thiemer, Schneider & Demars, 2021), and restoration initiatives (Kettenring & Reinhardt Adams, 2011). However, we know of no systematic review considering the effectiveness of invasive aquatic plant control methods, specifically for the Canadian context, that uses the Collaboration for Environmental Evidence guidelines (CEE, 2022). Where overlap does exist on specific species, our review will act as an update. A systematic review of the effectiveness of invasive plant control methods in the Canadian context, paired with the identification of gaps in available evidence, would yield valuable information to inform ecosystem management for Canadian stakeholders such as Parks Canada.

Theory of change or causal model
Selecting control methods for managing invasive aquatic plants depends on available tools, treated species, and local context. The expected direction of change in abundance and biomass, and the magnitude of change depends on the type of control method being applied. Although populations should decrease in abundance and biomass after treatment application, the amount of change in population varies widely. Some applications of control methods result in no change or spread the invasive plant species. It is unclear if there will be differences among control methods or if one broad method will be more effective. See Additional File 1.

Stakeholder engagement

A review of the effectiveness of invasive aquatic plant control methods has been identified by Parks Canada as a priority question for land managers and practitioners responsible for protecting and maintaining the natural heritage of Canadian parks. Staff from Parks Canada and the Canadian Centre for Evidence-Based Conservation (CEBC) collaborated to develop this question in the context of the non-native invasive aquatic freshwater macrophytes in Canada. During the formulation of the systematic review question, stakeholders and experts, including Canadian scientists and Parks Canada staff, were consulted to develop the plant species list, the inclusion criteria for article screening, the selection of databases and websites, identification of the benchmark list and selection of effect modifiers. Stakeholders will be consulted for additional sources of information during supplemental searches and will continue to participate in this systematic review through to completion.

Objectives and review question

What is the effectiveness of methods for eradicating or controlling abundance and biomass of invasive freshwater aquatic plants in Canada?

Definitions of the question components

Subject (population): non-native invasive aquatic macrophytes in Canada that are of concern to Canadian stakeholders such as Parks Canada. Intervention: application of control methods including biological, chemical, habitat manipulation and/or manual/mechanical. Comparators: no intervention or alternative levels of intervention, before an intervention, or lack of comparator (i.e., for studies where no temporal period or spatial control site without an intervention was included). Outcomes: measures of change in invasive aquatic plant populations (broadly defined to include measures of abundance, density, biomass, extent, cover, presence/absence).

Search strategy

Search for articles will involve sourcing both traditional academic literature and grey literature. A list of potentially relevant search terms was developed in consultation with the Advisory Team and based on previous literature and systematic reviews on the subject of invasive plant management (Rejmánek & Pitcairn, 2002; Roberts & Pullin, 2006; Kettenring & Reinhardt Adams, 2011; Hussner et al., 2017; Prior et al., 2018; Thiemer, Schneider & Demars, 2021). We conducted a scoping exercise using Web of Science Core Collections in February – June 2023 to assess search terms related to this review topic and evaluated the sensitivity of the search terms and associated wildcards. The three components of the search are population, intervention/exposure, and outcome and will be combined with Boolean operators “AND” and/or “OR”. The operator “NOT” will be used to decrease the number of non-relevant studies found by the search. The asterisk (*) is a ‘wildcard’ representing any group of characters (including no characters) and the dollar sign ($) includes zero or no character). In some databases, the dollar sign ($) may be replaced by the question mark (?) but the meaning does not differ. Quotation marks are used to search exact phrases (e.g., “control program” includes the exact phrase control program as well as the hyphenated control-program). In addition to database, search engine and website searches, the reference sections of relevant reviews identified during searching will be hand searched for articles that are within the scope of the review and not captured by the searches. We will also use social media, relevant email list serves, and professional contacts to inform the community of this ongoing systematic review. We will request submissions of potentially relevant articles, reports or grey literature. Stakeholders will be consulted for additional sources of information. No date restrictions will be applied.

Bibliographic databases

The following will be searched: 1) ISI Web of Science core collection, 2) ProQuest Dissertations and Theses Global, 3) Scopus, 4) Federal Science Library (Canada), 5) USDA National Agricultural

Library (SEARCH) which searches the Catalog and Articles Database (AGRICOLA), PubAG (USDA's public access repository) and the NAL Digital Collections (NALDC). No date or document type restrictions will be applied during the search. English search terms will be used to conduct all searches in all databases and search engines but no language restrictions will be applied during the search. All bibliographic databases will be accessed using Carleton University's institutional subscription (Supporting Information File 3) when possible or will be accessed directly through the database organization's web portal. When complex search strings are not accepted, search strings will be customized and included in the final report. Topic fields (title, abstract, keywords) will be used for Web of Science, Scopus and ProQuest, while any field (title, abstract, keywords and full-text) will be considered for USDA, and subject terms (provided by the database) will be used for searches in the Federal Science Library due to database restrictions. Please see Additional File 2 for complete search strings.

Web-based search engines

Internet searches will be performed using the search engine Google Scholar to identify additional published literature and grey literature. Due to search string limitations, two simplified search strings will be used: (1) ~Aquatic AND ~Plant AND ~Invasive AND (Biological OR Biocontrol OR Herbivory OR Physical OR Manual OR Mechanical OR Remove OR Weeding OR Rake OR Mow OR Cut OR Dredge OR Chemical OR Herbicide OR Management OR Control OR Drawdown OR Dewater OR Harvest OR Barrier) and (2) ~Aquatic AND ~Plant AND ~Invasive AND (Restore OR Remove OR Eradicate OR Control OR Reduce OR Eliminate OR Contain OR Prevent OR Exclude OR Suppress). Searches will look 'anywhere in the article' to increase the likelihood of finding relevant articles. Results will be sorted by relevance and a reasonably sized subset (i.e., the first 150 articles; see Supporting Information File 2) will be screened for appropriate fit with the review question. If the reviewer determines that the level of relevance of each article significantly declines (i.e., no new inclusions for 50 consecutive titles) before reaching that point, the reviewer will stop (Livoreil et al., 2017).

Organisational websites

Specialist organizational websites (listed below) will be searched to ensure inclusion of grey literature that might otherwise be missed by databases and search engines. Websites and portals will be searched using built-in search facilities and simplified English search terms. For each site, the top results for each search string, sorted by relevance, will be screened. In cases where built-in search facilities are not available, the sites will be searched 'by hand' (i.e., focusing on any 'Publications' pages and examining site maps where available). After consulting with the Advisory Team, a list of 22 websites and institutional databases was selected, including: • Canadian Council on Invasive Species (https://canadainvasives.ca/research/) • Conservation Evidence (https://www.conservationevidence.com/) • Ducks Unlimited - Institute of Wetland and Waterfowl Research (https://iwwr.ducks.ca/our-research/library/) • Fisheries and Oceans Canada (https://www.dfo-mpo.gc.ca/) • Great Lakes Commission • Great Lakes Phragmites Collaborative (https://www.greatlakesphragmites.net/) • Invasive Species Centre (https://www.invasivespeciescentre.ca/) • Invasive Species Council of BC (https://bcinvasives.ca/) • Midwest Invasive Plant Network (https://www.mipn.org/) • Minnesota Aquatic Invasive Species Research Centre (https://maisrc.umn.edu/) • National Park Service (https://www.nps.gov/subjects/invasive/index.htm) • North American Invasive Species Management Association • Ontario Invasive Plants Council (https://www.ontarioinvasiveplants.ca/) • Ontario Ministry of Natural Resources and Forestry (https://www.ontario.ca/page/invasive-species-ontario) • Parks Canada (https://parks.canada.ca/) • Province of British Columbia (https://www2.gov.bc.ca/gov/content/home) • Province of Manitoba (https://www.gov.mb.ca/) • Sea to Sky Invasive Species Council (https://ssisc.ca/invasives/invasive-plants/) • The Nature Conservancy of Canada (https://www.natureconservancy.ca/en/) • US Fish and Wildlife Service (https://www.fws.gov/) • US Forest Service (https://www.fs.usda.gov/) • US National Invasive Species Information Centre (https://www.invasivespeciesinfo.gov/)

Comprehensiveness of the search
To test the comprehensiveness of the search, the results of database search were checked against a benchmark list of 32 articles during scoping. The list of benchmark articles was provided by the Advisory Team. Articles were checked for indexing within the five databases, and >80% of articles indexed in the databases had to be found by the searches. New search terms were scoped into the search strings if any articles were missed before 80% were retrieved. The final list of the 32 benchmark articles can be found in Additional File 3.

Search update
N/A

Screening strategy
Results from database literature searches will be screened in EPPI-reviewer. Duplicate results will be identified and merged. Search engine, website and grey literature results will be kept separate and screened in MS-Excel with duplicates between databases and search engines removed prior to screening. Further duplicates may be removed at subsequent stages of the review. Articles will be screened at: (1) title and abstract and (2) full text. Articles from databases and search engines will be screened at title and abstract. Before screening begins, a random subset will be screened as a consistency check. Following this, each article will be screened by one reviewer. All articles included at title and abstract will be screened at full-text. An additional consistency check at that stage will be conducted in the same manner as for title and abstract screening. Articles from websites, calls for evidence or reference lists of accepted articles and relevant reviews will be screened at full-text. When uncertain, a reviewer will tend towards inclusion to the next stage. If there is further doubt, the Review Team will discuss those articles as a group and come to a decision. The random screening function will be used to allocate articles, with all articles included being screened at title and abstract. Justification of inclusion/exclusion at title and abstract will be recorded using EPPI-reviewer and a list of studies rejected at full-text will be provided in an additional file, together with reasons for exclusion, for the final report.

Eligibility criteria
See Additional File 4. Any alteration to criteria made during the review process will be recorded and included in the final report. Simplified Criteria: Populations: invasive freshwater aquatic plant species of concern to Parks Canada including those found within park lands and present in North America. Intervention: articles that describe the application of a control method or management activity on invasive aquatic plants will be included. Relevant control methods can include any biological, chemical, habitat manipulation or manual/mechanical method, or any combination of methods that are applied by land managers. Comparators: 1) invaded stands on the same waterbody with no intervention; 2) invaded separate but similar waterbodies with no intervention; 3) before intervention data within the same waterbody; 4) an alternative level of intervention on the same or different waterbody; 5) randomized control trials; or 6) time-series data within the same waterbody or spatial trends across waterbodies with different levels of the same intervention. No study will be excluded based on comparators. Outcome: Must report measured effects that indicate a change in invasive aquatic plant population size after application of a control method. The goal can be (1) complete eradication, or (2) changes in aquatic invasive plant metrics. Outcomes include those related to abundance, density, biomass, extent, cover, frequency, or presence/absence. Study design: Primary field-based, mesocosm or laboratory studies including quantification of invasive aquatic plant outcomes

Consistency checking

Articles will be screened at two stages: (1) title and abstract and (2) full text. Articles from databases, and search engines will be screened at title and abstract. Before screening begins, a random subset of 10% or 100 abstracts (whichever is larger) from database searches will be screened by two or more reviewers. This subset will be independently screened as a consistency check to ensure consistent and repeatable application of the eligibility criteria before articles are moved to the next stage of the review. The results of the consistency check will be compared between reviewers and all discrepancies will be discussed to understand why an inclusion/exclusion decision was made. Revisions to the inclusion criteria will be made as necessary to ensure consistent application of criteria. If the level of agreement is low (i.e., below 90% agreement), further consistency checking will be performed on an additional set of articles and discussed. Following consistency checking (i.e., when agreement is ≥90%), each article will be screened by one reviewer. All articles included at title and abstract will also be screened at full-text. An additional consistency check at that stage (using 10% of the articles included at title and abstract) will be conducted in the same manner as for title and abstract screening. Articles from websites, calls for evidence or reference lists of accepted articles and relevant reviews will be screened at full-text but will not be included in consistency checks

Reporting screening outcomes

The review will follow, as closely as possible, the CEE guidelines and standards for systematic reviews (CEE, 2022) and conform to ROSES reporting standards (Haddaway et al., 2018), including a ROSES diagram of included studies with reasons for inclusion/exclusion at different stages of the review. Justification of inclusion/exclusion at title and abstract will be recorded using EPPI-reviewer or MS-Excel and a list of studies rejected at full-text will be provided in an additional file, together with reasons for exclusion, for the final report.

Study validity assessment

Relevant articles will undergo study validity assessments focused on internal validity and study clarity. External validity will be captured during screening. General patterns of critical appraisal across studies will be described during narrative synthesis and will be used to assess studies during the quantitative synthesis (if performed). No studies will be excluded based on study validity assessments. Critical appraisal will incorporate FEAT (focused, extensive, applied and transparent) principles recommended by Frampton et al. (2022) and the guidelines from the CEE (2022). A modified critical appraisal tool (Additional File 5) based on the Critical Appraisal Tool version 0.3 (prototype) (Konno, Livoreil & Pullin, 2021; CEE, 2022) and previous tools (Harper et al., 2020; Birnie-Gauvin et al., 2021) will be developed to capture risk of bias unique to this topic. Articles will be assessed on seven criteria including: 1) study design and risk of 2) confounding biases prior to the occurrence of the intervention/exposure, 3) bias in post-intervention/exposure selection, 4) performance bias, 5) detection bias, 6) outcome reporting bias, 7) outcome assessment bias. If any of the seven criteria have a high risk of bias, the overall risk of bias for the study will be high. If no criteria are at high risk of bias, but at least one criterion is identified as having medium risk of bias, the overall risk of bias for the study will be medium. Studies with low risk of bias will therefore have no criteria with high or medium risk of bias (Konno, Livoreil & Pullin, 2021).

Consistency checking

Critical appraisal will be done by at least two reviewers on a subset of 10 articles to ensure consistency in assessments. When uncertainties arise, the reviewers will come together to discuss. Final decisions regarding doubtful cases will be taken by the Review Team as a whole.

Data extraction strategy

Meta-data from studies included at full-text will be extracted by the Review Team and recorded in a

MS-Excel spreadsheet that includes pre-defined coding. Meta-data from studies included at full-text will be extracted by the Review Team and recorded in a MS-Excel spreadsheet that includes pre-defined coding. When information is present in tables or graphs, all information will be extracted; if it is not possible to interpret the information from graphs, the corresponding author will be contacted (via email) if time permits, or imaging software (i.e., WebPlotDigitizer (Rohatgi, 2022)) will be used. Comparisons will only be made within individual figures/tables but not between figures/tables. Where data is presented for multiple years or sites, we will work to maximize the information extracted. When only raw data are included in the article, the Review Team will calculate summary statistics and will record how the calculations were conducted and what information was used. All extracted data will be made available with the final report.

Meta-data extraction and coding strategy
We will extract data on: 1) bibliographical information, 2) study location and characteristics (i.e., geographic location, waterbody name and type), 3) study design details (e.g., study dates, study design), 4) intervention and comparator details (i.e., control methods and intensity, comparator type and magnitude), 5) outcome (i.e., abundance, density, biomass, extent, cover, frequency, or presence/absence), 6) sampling method(s) (e.g., type, size, and number of sampling units), 7) species (e.g., species names), 8) effect modifiers, 9) study validity assessment results, 9) the goal of the methods applied (i.e., eradication or control/suppression), and 10) study findings (effectiveness) as reported by authors. Some outcome data that will be recorded include: sample size, outcome means and/or percent change and measures of variation (e.g., standard deviation, standard error, confidence intervals). This list may be expanded depending on the type and variety of included studies. Coding options within these key variables will be compiled as a partly iterative process as the range of options is encountered during extraction.

Consistency checking
Two reviewers will extract information from 10 of the same articles prior to beginning the data extraction process. This will ensure that data is extracted in a consistent and repeatable manner. Information will be compared, and any inconsistencies will be discussed. If any disagreements occur, the entire Review Team will discuss them. Modifications will be made to the extraction code book where needed to ensure that reviewers extract data and interpret studies in the same manner. Critical appraisal will be done by at least two reviewers on a subset of 10 articles to ensure consistency in assessments. When uncertainties arise, the reviewers will come together to discuss. Final decisions regarding doubtful cases will be taken by the Review Team as a whole.

Potential effect modifiers/reasons for heterogeneity
Potential reasons for heterogeneity will be identified and extracted from articles included at full-text screening if reported in primary studies or available from the authors. Effect modifiers were selected after consultation with stakeholders and will be used to test how these modifiers are expected to influence the efficacy of different control methods. The following potential effect-modifying factors will be considered and recorded: • Biological factors (i.e., plant taxa or growth patterns: floating, emergent, submerged) • Outcome metric (i.e., abundance, density, biomass, extent, cover, frequency, or presence/absence) • Stage of invasion (i.e., new, established, well established) or time since invasion recognized • Number or duration of treatments (i.e., single treatment vs multiple treatments) • Timing of treatments (i.e., season) • Spatial scale measured (i.e., stand size, aerial extent) • Herbicide formation (including surfactant type) Additional effect modifiers and reasons for heterogeneity may be identified and extracted from studies as the review proceeds. Additions will be included with stakeholder consultation.

Type of synthesis
A narrative synthesis of all eligible articles in the systematic review will be generated. The synthesis

will aim to be as visual as possible, describe the validity of results, and summarize findings in figures and tables. The goal of this review is to determine the overall effectiveness of different types of invasive plant control methods. As such, we will aim to conduct quantitative synthesis through meta-analysis. All efforts will be made to conduct formal meta-analysis of studies with comparators included in the review when study designs and evidence-base allows.

Narrative synthesis methods
A narrative synthesis of all eligible articles in the systematic review will be generated. The synthesis will aim to be as visual as possible, describe the validity of results, and summarize findings with descriptive statistics and in figures and tables.

Quantitative synthesis methods
All efforts will be made to conduct formal meta-analysis of studies with comparators included in the review when study designs and evidence-base allows. Separate subgroup analyses will be conducted for plant outcomes: (1) abundance (combining e.g., abundance, density) and 2) biomass. In the case that meta-analysis is possible (given sufficient sample size of studies), study effect sizes will be standardized and weighted appropriately, and analysis will take the form of random-effects models. Meta-regression or subgroup analysis of studies will also be performed where sufficient studies report common sources of heterogeneity. Risk of publication bias will be assessed through funnel plots and sensitivity analysis using study validity categories will be carried out when possible. We will produce forest plots to visualize effect sizes and 95% confidence intervals from individual studies. Analyses will be conducted in R (R Core Team, 2022) using the rma.mv function in the metafor package (Viechtbauer, 2010).

Qualitative synthesis methods
N/A

Other synthesis methods
N/A

Assessment of risk of publication bias
Risk of publication bias will be assessed through funnel plots.

Knowledge gap identification strategy
We will attempt to identify knowledge gaps during narrative synthesis and to summarize knowledge gaps and clusters using descriptive statistics and/or figures (such as heat maps) and tables.

Demonstrating procedural independence
Reviewers will not screen studies (at title and abstract or full-text) for which they are an author. Reviewers will not assess studies for validity for which they are an author. Reviewers will not extract data from studies for which they are an author.

Competing interests
The authors declare no competing interests.

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Author's contributions
The manuscript was drafted by MH and TR. All authors read and approved the final manuscript.

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