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Environmental Evidence

SYSTEMATIC REVIEW PROTOCOL

Open Access

The effectiveness of non-native fish eradication techniques in freshwater ecosystems: a systematic review protocol

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Abstract

Background: This systematic review will address the need for having a better understanding of the evidence-base for the effectiveness of different management techniques focussed on the eradication of non-native fish species in the freshwater environment. Many resource management agencies around the world attempt to eradicate non-native fish species to achieve management goals with respect to ecological integrity. There is a need to better understand the effectiveness of each management technique to provide resource managers with the information necessary to effectively manage aquatic resources, and to choose the best technique to yield desired outcomes given different ecological and biological conditions. The findings of this systematic review will inform evidence-based management and conservation activities for resource managers around the globe that deal with non-native fish eradication programs.

Methods: This systematic review will search for, compile, summarize, and synthesize evidence on the effectiveness of fisheries management techniques used for the eradication of non-native fish species in global freshwater systems. The review will use public search engines and specialist websites, and will include both primary and grey literature. All studies that assess the effectiveness of a fish eradication technique, in freshwater, will be included in the review. Potential effect modifiers will be identified to obtain a better understanding of the factors that affect the success of different eradication techniques, given different environmental conditions and biological factors. Study quality will be assessed to allow for critical evaluation, including study design, confounding factors and statistical analysis. Data will be compiled into a narrative synthesis and a meta-analysis will be conducted where data availability and quality allow.

Keywords: Alien invasive species, Removal, Restoration, Nonindigenous species, Invasive species, Invasion biology, Evidence-based policy

Background

In aquatic systems, biological invasions can result in adverse ecological effects [1, 2]. Invasive species threaten biodiversity [3–5] and impose considerable economic costs [6], placing increased demands on policy-makers, resource managers, and scientists [7]. The introduction and spread of invasive species can occur by natural or human pathways and can include: shipping networks and canals [8, 9], escapes from aquaculture, aquaria and ornamental trade [10], stocking (including authorized and unauthorized attempts), recreational boating, live food trade, as well as sport fish and baitfish introductions, which may be deliberate or accidental. Additionally, the secondary spread of introduced species poses challenges for resource managers [11–13].

Options for managing non-native fish species can include no action, control and/or containment, population extirpation, and/or species eradication [14]. Containment, such as implementing barriers, is typically the most desirable tactic to prevent the spread of non-native species into novel environments [15–18]. However, where containment is not possible or has not been

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successful, eradication has been proposed as a valid option for managing biological invasions [19, 20]. Eradication is the elimination of whole fish populations or fish species from distinct habitats or bodies of water [21]. Eradication approaches tend to be targeted, for example, by exploiting vulnerable periods in the life cycle [22, 23] or by focusing on areas of high abundance [24].

The types of fish management techniques available to resource managers to implement eradication programs can vary widely. They can include chemicals, harvest regimes, physical removal, or biological control [25]. The effectiveness of chemical eradication (e.g., rotenone, Fintrol) depends on environmental conditions (e.g., water temperature, depth, pH, discharge, target fish species, hydrology, substrate composition, areas of groundwater recharge; [26]); there are also concerns of collateral damage when non-target species are affected by chemical treatments [27]. Harvest regimes can include intentional over-fishing (e.g., gill netting, angling) of target species [28–30] or modification of angling regulations (e.g., favour overharvest of target species). Physical removal techniques can include traps, electrofishing, and/or netting programs while biological controls can include the introduction of predators, intraspecific manipulation, or targeted pathological reactions [31]. When implementing fish management programs, risk analysis is required to help decide when management strategies should be utilized, what strategy should be chosen, and what the likelihood of success of different strategies are [18]. The risk analysis includes identification and assessments of hazards, including predicting the likelihood and severity of adverse effects [32].

The success of non-native fish management approaches can vary greatly depending on the management objectives for the project: whether control, eradication, removal or containment (amongst others) was the ultimate goal of the project. As can be expected given the complexities of the natural environment, success can be difficult to quantify and some approaches can be unsuccessful despite best efforts [7, 19, 25]. Failure of non-native fish eradication techniques can occur due to a number of factors, including (but not limited to) ineffective capture techniques (e.g., size-specific efficiencies), habitat complexity (e.g., areas of refuge, plant density), species-specific factors (e.g., size, habitat preferences), and physical water properties (e.g., water chemistry, temperature, water depth; [33]). Determining the outcomes of management interventions, especially when restoration of freshwater ecosystems is a goal (i.e., to eradicate non-native target fish species from a specific waterbody), requires long-term evaluation and assessment in relation to meeting the objectives [19, 25, 34]. Post-program evaluation and assessment is required not only to determine the effectiveness of techniques but also to explore the cost-effectiveness and cost/benefit of each strategy. Narrative syntheses, meta-analyses and systematic reviews can be valuable approaches to determine broad-scale effectiveness of how management interventions can be effective and to identify future research needs.

Objective of the review

The objective of the systematic review is to evaluate the existing literature base to assess the effectiveness of different non-native fish eradication methods in global freshwater environments. The purpose of the review is not to question whether or not the eradication of a target species is an appropriate objective, but simply to evaluate the effectiveness of each technique for eradicating the target species in a desired freshwater body (including both lakes and rivers).

Primary question

What is the effectiveness of non-native fish eradication techniques in freshwater ecosystems and what effects do the various sources of potential heterogeneity have on the outcome?

Components of the primary question

The primary study question can be broken down into the study components:

Subject (population)	Non-native freshwater fish
Intervention	Fish eradication method
Comparator	No intervention or alternative method
Outcomes	Magnitude of decreased abundance relative to control or eradication of target fish species.

Secondary questions

Following the development of the primary question, secondary questions were developed to expand on relevant areas of interest to project stakeholders and user groups, including Canadian federal natural resources government agencies (e.g., Parks Canada) and members of the international scientific community specializing in invasive fish eradication science. The secondary questions are meant to help guide the overall goals of the systematic review and to ensure that areas of interest are encompassed in the methods. The secondary questions for this systematic review are:

(a) To what extent does effectiveness vary with eradication technique (e.g., electrofishing, piscicides, unlimited recreational catch limits)?

(b) What other strategies/techniques are being employed but are under-represented in the evidence and literature base?
(c) What factors (e.g., type and size of water body, species, elevation, time since invasion/introduction, ecoregion) influence the effectiveness of each type of eradication method and in what context is each technique most effective?

Methods

Details related to each step in the systematic review protocol are outlined in Fig. 1.

Search strategy

Search terms

Similar to the way that the Review Team formulated the primary and secondary questions, the Review Team

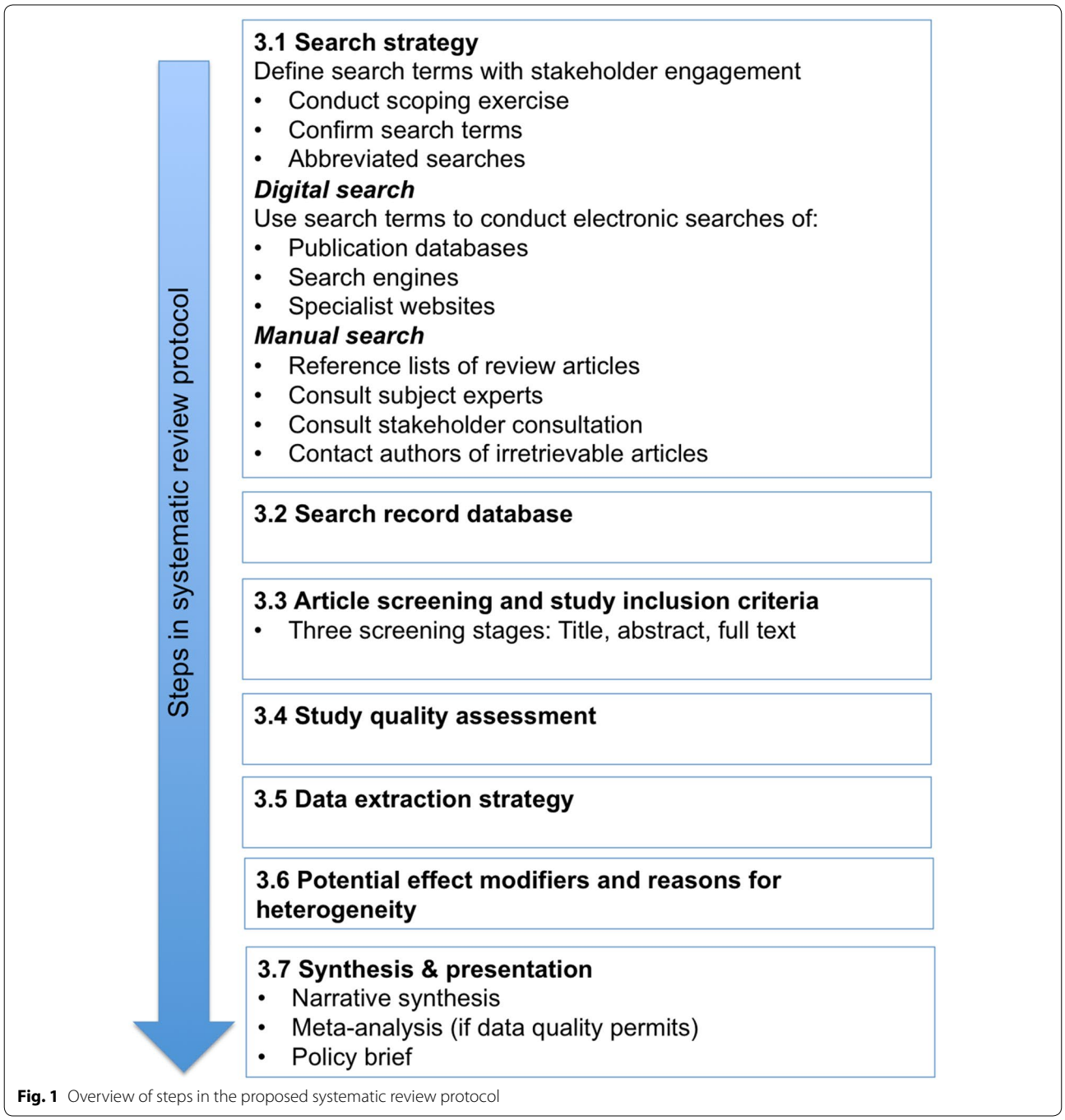

Fig. 1 Overview of steps in the proposed systematic review protocol

collaborated with project stakeholders (e.g., Parks Canada) and members of the international scientific community specializing in invasive fish eradication science to generate a list of relevant search terms (Table 1). The terms were broken into three components: population, intervention and outcome.

The terms in each of the categories of population, intervention and outcome can be combined using the Boolean operators "OR" and/or "AND", as suggested in the search string. The asterisk (*) is a wildcard and represents any characters (e.g., remov* includes remove, removal, removing, removed) while the dollar sign ($) includes zero or one character (e.g., rod$ and $reel includes rod-and-reel, rod and reel). The terms are combined in the following general format:

(Population) AND [(Intervention term) AND (Outcome term)]

Table 1 Proposed search string for the execution of the search strategy

Description	Population	Intervention	Outcome
Question elements	**Invasive fish**	**Fish eradication method**	**Eradication**
Synonyms and permutations	Fish*	Hydraulic	Restor*
	Invasive	Screen*	Rehabilitat*
	Non$native*	Weir*	Remov*
	Alien	Net*	Eradicat*
	Exotic	Gill	Control*
	Introduced	Trammel	Suppress*
	Non$indigenous	Hoop	Reduc*
	IAS	Trap	Renovat*
	Invasive$species	Cast	Exclusion
	Alien$invasive	Lift	Exclude*
	Fresh$water	Seine	
	Stream*	Trawl	
	Water*	Electrofish*	
	River*	Electric*	
	Lake*	Cull	
	Reservoir*	Piscicide*	
	Pond*	Rotenone	
	Canal*	Antimycin	
	Harbor*	Fintrol	
	Harbour*	Explosive*	
	Port*	Primacord	
	Wetland*	Biocide*	
		Angl*	
		Trotline*	
		Rodandreel	
		Limb$line*	
		De$water*	
		Draw$down	
		Pumping	

[Fish* AND (Invasive OR Non$Native OR Alien OR Exotic OR introduced OR non$indigenous OR IAS OR Invasive$species OR Alien$invasive) AND (Fresh$water OR Stream* OR Water* OR River* OR Lake* OR Reservoir* OR Pond* OR Canal* OR Harbor* OR Harbour* OR Port* OR Wetland*)] AND [(Hyraulic OR Screen* OR Weir* OR Net* OR Gill OR Trammel OR Hoop OR Trap OR Cast OR Lift OR Seine* OR Trawl* OR Electrofish* OR Electric OR Cull OR Piscicide* OR Rotenone OR Antimycin OR Fintrol OR Explosive* OR Primacord OR Biocide OR Angl* OR Trotline* OR "Rod-and-reel" OR Limb$line* OR De$water OR Drawn&down OR Pump*) AND (Restor* OR Rehabilitat* OR Remov* OR Eradicat* OR Control* or Suppress* OR Reduc* OR Renovat* OR Exclusion or Exclude*)].

Abbreviated search

When a complex search string is not accepted by the search engine, the help menu will be consulted and the search terms will be modified. The search terms will be recorded in the article databases in order to preserve all metadata associated with the search.

Article type

The search will include a variety of article types, including primary literature in peer-reviewed journals and grey literature. The search strategy will strive to minimize publication biases by focussing efforts equally on each article type and putting equal weight on the information provided in each article type.

Document/file formats

The search will not have any document type restrictions (e.g., PDF vs. MS-PowerPoint vs. MS-Word). All formats will be acquired and if specialized software is required, alternative formats will be requested for ease of file transferability. Where books are identified, digital copies will be sought (either through internet searches for availability or requests to authors) in order to ensure that all obtainable records are made available as an output from this review.

Computer settings

The browsing history and cookies will be disabled on all computers used to conduct the search. The members of the Review Team will not access any electronic accounts (e.g., email, website) during the search period and will use "private mode" (Safari) for web browsers to reduce the possibility of user-specific search results.

Language

English search terms will be used to conduct all searches in all databases. All references that are returned will be

included in the database. When articles in other languages are returned using the search strategy, those records will be reported in the database.

Publication databases

1. Waves (Fisheries and Oceans Canada)—Canadian government books, reports, government documents, theses, conference proceedings and journal titles
2. Index to Theses Online—Dissertations and theses from the UK & Ireland
3. Science.gov—U.S. Federal Science
4. ISI Web of Science core collection—Multidisciplinary research topics including journals, books, proceedings, published data sets, and patents
5. Scopus—Abstract and citation database of peer-reviewed literature including journals, books, and conference proceedings.

Search engines

The first 100 hits (based on relevance) will be examined for the appropriate fit for the review questions.

6. Google Scholar.

Specialist websites

The first 50 documents from each search will be included in the reference database and checked for relevance. Reference lists of included material will be searched and any relevant documents will be included and added to the reference database. Where links to other organisations are included on the websites, the links will be followed to try to capture any organisations that were not initially included in the website searches. All articles will be exported into EndNote prior to assessment of relevance.

7. Atlantic Salmon Federation
8. Centre for Ecology and Hydrology
9. Centre for Environment, Fisheries and Aquaculture Science
10. Commonwealth Scientific and Industrial Research Organisation
11. Convention on Biological Diversity
12. Department of the Environment, Food and Rural Affairs
13. Desert Fishes Council
14. Fisheries and Oceans Canada
15. Fisheries Research Service
16. Food and Agriculture Organization of the United Nations
17. Joint Nature Conservation Committee
18. National Institute of Water and Atmospheric Research
19. National Park Service
20. Natural England
21. Natural Resources Canada
22. Natural Resources Wales
23. Northern Ireland Environment Agency
24. Pacific Salmon Foundation
25. Parks Canada
26. Trout Unlimited
27. The Nature Conservancy
28. United Nations Environment Programme
29. US Forest Service
30. US Fish and Wildlife Service
31. Western Native Trout Initiative
32. World Wide Fund for Nature
33. World Wildlife Fund.

Other literature searches

Reference sections of accepted articles will be hand searched to evaluate relevant titles, symposium papers, and other articles that have not been found using the search strategy. Authors of any unpublished references will be contacted to request access to the full article. Stakeholders will be consulted for insight and advice for new sources of information.

The Review Team will contact authors of unobtainable articles in an attempt to gain access to the full article. We will also use social media to alert the community of this systematic review and to reach out to area experts for research articles that are difficult to obtain, or for suggestions of articles to include. Any article provided will also be used to test the comprehensiveness of our search strategy and, where appropriate, adjustments will be made to the search strategy to make sure it is comprehensive and inclusive. Any changes made to the search strategy will be justified and documented in the final review document.

Search record database

All articles generated by each of the search strategies will be exported into separate EndNote databases. After all searches have been completed and references found using each different strategy have been compiled, the individual databases will be merged into an overall EndNote database library. Duplicates will be identified. All references regardless of their perceived relevance to this systematic review will be included in the database. This database will act as the archive and will remain unchanged throughout the review process, since it is the direct product of the search strategy and will be useful in the future when updating the systematic review archive (general updating timeframe is currently every 5 years).

Article screening and study inclusion criteria

Screening process and inclusion criteria

Articles found using the search criteria will be screened in three distinct stages; title, abstract and full text.

Before the screening process begins, two reviewers using a subset of 10 % of all articles or 100 abstracts (whichever is bigger) will undertake consistency checks to ensure consistent and repeatable decisions are being made in regards to which articles get screened out and which go on in the process to be further reviewed. The two reviewers will use a Kappa test to determine consistencies in screening decisions. A Kappa score of $\geq$0.6 indicates substantial agreement between reviewers and will be required to be achieved before any further screening is conducted for the review. The results from the consistency check will be discussed and discrepancies will be reviewed by both reviewers to understand why the choice was made to include/exclude the article.

All article screening decisions will be included in the database, so it will be clear at what level any article was excluded. If the decision to include or exclude a specific article is unclear, that article will be retained and will go on to the next level of screening. If there is further doubt, the Review Team will discuss those articles as a group to come up with a decision. Any articles that do not have abstracts (as is the case for some grey literature), those articles will automatically be screened at the full text level. Justification of the reason for inclusion or exclusion of an article will be explained and recorded in the article database, and all articles excluded at the full text level will be included with the review, in compliance with CEE guidelines.

Articles will be excluded based on the following predefined inclusion criteria (Table 2).

Study quality assessment

Each of the studies that make it to the full text screening level will be classified and coded in the article database using a number of parameters including (but not limited to):

- Study setting—Lab or field
- Study design (BA/CI/BACI/RCT)
- Temporal extent of study
- Replication—Replicated or unreplicated
- Confounding factors—Present, not present, unclear, and whether they were accounted for in the study
- Clarity of objectives in relation to methods used (e.g., is the ultimate type of management intervention objective clearly identified, including eradication, controlling, containing etc.)
- Use of (and number of) control and reference sites
- Effort devoted to eradication techniques (e.g., press versus pulse, proportional area treated)
- Statistical methods used in assessment of success (e.g., were results analysed statistically?)
- Accounting for and/or identifying potential effect modifiers (see list in following sections).

Bilotta et al. [35] have outlined criteria for the assessment of the internal validity of a study. Their assessment criteria have been adapted from the Cochrane Collaboration's Risk of Bias Tool [36] for use in the field of environmental science. The assessment criteria include assessing selection bias, performance bias, attrition bias, reporting bias, as well as those biases that may only be relevant in unique situations (e.g., contamination). The criteria outlined in Bilotta et al. will be used

Table 2 Description of inclusion criteria used by the Review Team when screening articles at the title and abstract level

Type of criteria	Description of inclusion criteria
Relevant subjects	Freshwater ecosystems, including both lakes and rivers that contain non-native fish species
Relevant types of interventions	Article describes the type of eradication method used in an attempt to eradicate a fish species. Eradication method can include: mechanical, chemical, biological, environmental or other
Relevant types of comparators	An external control site: similar waterbodies with no intervention (i.e., waterbodies with non-native fish present but have not had any fish management projects conducted in them), before intervention control site within same waterbody, or an alternative intervention type conducted on the same waterbody
Relevant types of outcomes	Measured effect of treatment. Reported measured effect can be quantitative or observational and generally should indicate some change in abundance of target species relative to before treatment or control
Relevant types of study designs	Given the complexity of eradication projects, all types of study designs will be examined, including but not limited to: Before/after (BA) Comparator/intervention (CI) Before/after/comparator/intervention (BACI) Randomized controlled trial (RCT) Studies that do not do or report any before or after assessments following the implementation of an eradication effort will be excluded from the review (i.e., studies where no data is presented that would allow for any assessment of a change in abundance of the target species following eradication efforts)

by the Review Team for this review and included in the reference database. The information for each article retrieved using the search strategy will be uniquely coded based on the criteria (generally categorised as "low risk", "high risk", or "unclear risk") to help assess the quality of each article, and to provide insight into any potential risk of bias present in each of the studies. This information will be instrumental in helping to determine reliability of the evidence base available for potentially conducting a meta-analysis on the effectiveness of each eradication method.

Data extraction strategy

Metadata will be extracted from the included studies by the Review Team and will be recorded in a MS-Excel database that will be made available with the published systematic review article, as an additional supporting file. The extracted information will be used to assess the overall effectiveness of each intervention strategy, and when sufficient, good quality data exists, the information will be used in a meta-analysis. Some of the outcome data that will be recorded will include: outcome means, measures of variation (e.g., standard deviation, standard error, confidence intervals), and sample sizes. When data is presented in tables or graphs, all information will be extracted and recorded. If it is not possible to decipher information from graphs, the main contact author for the article will be contacted (via email or phone) by the Review Team to request the information. During that request, the Review Team will also solicit the author to suggest any grey literature that they may know of related to the systematic review topic. Where only raw data is provided in the article, the Review Team will calculate summary statistics. In those instances, it will be recorded in the MS-Excel database how the calculations were done and with what information. To ensure that data is being extracted in a consistent and repeatable manner, two reviewers will extract information from 10 of the same articles. Afterwards, the information will be compared. Any inconsistencies will be discussed amongst the Review Team members, and if any disagreement occurs, they will be discussed with the entire Review Team to ensure all reviewers are extracting and interpreting data in the same manner.

Potential effect modifiers and reasons for heterogeneity

The Review Team will extract data on potential effect modifiers (see Table 3) from articles that are included at the full-text level of screening. All information will be recorded in the MS-Excel database.

Table 3 presents the criteria that will be considered as potential effect modifiers and/or reasons for

Table 3 Data extraction table

Main category	Sub-category	Description
Article metadata	Study ID	Unique code given to each study (i.e., linked articles given same code)
	Paper ID	Unique code given to each manuscript
	Authors	Name of authors
	Email address	All email address of main contact
	Publication year	Year of manuscript publication
	Title	Article title
	Reference	Full reference (as extracted from relevant database)
	Publication type	Publication format (e.g., book chapter, journal paper, conference paper, thesis, organisation report)
	Abstract	Article abstract or summary (if provided)
	Keywords	Publication keywords
	Author affiliation type	Author affiliation (e.g., academic institution, government, consulting, NGO)
	Language	
	Article access notes	Any issues associated with accessing the full article (e.g., were the authors contacted?)
	Format	Article format e.g., PDF, Microsoft Word file, HTML
Location metadata	Study country	Country(ies) in which study undertaken
	Study region	Region(s) in which study undertaken
	Study type	Lab or field-based
	Study design	BA/CI/BACI/RCT
	Study waterbody	Name of waterbodies included in study
	Latitude	
	Longitude	
Location metadata	UTM zone	
	UTM coordinates	
Waterbody metadata	Waterbody type	Lake, river, reservoir, pond etc.
	Waterbody area	Record how it is reported in the article, including units
	Average depth	
	Volume	
	Area	
	Retention time	
	Secchi depth	
	Wetted width	

Table 3 continued

Main category	Sub-category	Description
	Stream order	
	Stream type	E.g., permanent, intermittent
	pH	
	Turbidity	
	Water clarity/colour	
	Conductivity	
	Discharge	
	Water temperature	
	Canopy cover (%)	
	Slope (%)	
	Substrate composition	E.g., silt, sand, gravel, cobble, rubble, bedrock
	Vectors for introduction	If discussed in article
	Open or closed system	
	Manmade or natural system	
	Waterbody accessibility	Easy (e.g., canal in city), moderate (e.g., river in national park), difficult (e.g., high alpine lake)
	History of biomanipulation?	
	Extent population is established	If discussed in article
Target species metadata	Fish species name	
	Fish species scientific name	
	Migratory or non-migratory	
	Life history strategy	E.g., anadromous, semelparous, iteroparous
	Target age class	
	Habitat preferences	
	Age at maturity	
	Fecundity	
	Relative abundance of target species (pre-intervention)	Change in abundance of target species, before intervention (e.g., CPUE)
	pH	
	DO range	
	Depth range	
	Body size	
	Habitat use	
Intervention metadata	Date: project start	dd-mmm-yy
	Date: project end	dd-mmm-yy
	Study length	Duration of study
	Study timescale	Period between intervention and study
	Pre-monitoring	Was there any pre-monitoring that occurred? If yes, describe
	Post-monitoring	Was there any post-monitoring that occurred? If yes, describe
	Study seasonality	What season did the study take place? Describe all if occurred over many seasons
	Study description	Brief description of study
	Eradication method type	Mechanical, chemical, biological, environmental, other
	Eradication method details	Mechanical method type, type of chemical used, name of introduced biological control etc.
Intervention metadata	Eradication effort	Will vary depending on method used (e.g., electrofishing time, fishing time, area treated)
	Number of fish removed	Report the total number of fish removed. Can separate number of fish removed live versus dead, depending on eradication method type
	Methodological detail	Level of methodological detail; low (very little detail, significant information missing), medium (some detail missing but generally sufficient), high (very high level of detail, no obvious information lacking)
	Methodology notes	Brief description (summary or quotation) of study methodology
	Intervention type rationale	How/why were the intervention types selected?
	Experimental design	i.e., observation, experimentation, modeled
	Study cost	If discussed in article
	Replication	Number of replicates, if applicable
	Randomization	Presence of randomization, if applicable
	Sources of potential bias	Description of other potential sources of bias
Outcome metadata	Relative abundance of target species (post-intervention), over time	Change in abundance of target species, after intervention (e.g., CPUE), over time. Report the duration that the abundance was monitored for (e.g., 1 week post intervention, 6 months, 1 year etc.)
	Eradication probability	If discussed in article
	Change in species composition	If discussed in article, the change in species composition in the waterbody

Table 3 continued

Main category	Sub-category	Description
	Change in biomass of target species	
	Change in size of target species	If discussed in article, the change in target species size over time, after eradication efforts (e.g., total length, mass, proportion of catch within a specific size range)
	Statistical results of effectiveness measure	Was the effectiveness assessed statistically? If yes, report
Social factors metadata	Social risk factors	Did project consultation occur for this project? (Y/N)
	Social risk factors—Details	If yes, describe (e.g., public meetings, media released)
Linked article metadata	Linked study	Paper ID of articles describing results of same study. This is especially important to look at overall success rates for projects that are reported over several different publications
	Additional article details	Further description of relationship with other articles

heterogeneity and will be extracted. Further factors may be identified, defined and included throughout the process, through consultation with external experts.

Data synthesis and presentation

A narrative synthesis of data from all articles included in the systematic review will be generated. The synthesis will aim to be as visual as possible, summarizing information in tables and figures. The ultimate goal of this review is to assess the effectiveness of each different eradication technique and to identify the factors that influence the overall success rate of each type of method, in order to better inform management agencies who routinely have to decide when, where and how non-native fish eradication programs should be implemented. All efforts will be made to provide quantitative assessments and meta-analysis of the articles included in this review, when the study designs and evidence-base allow. The review team has conducted some scoping exercises, particularly to help develop an efficient search strategy and to get a sense of the existing literature base. When doing so, the review team got the sense that sufficient evidence may exist to allow them to conduct a meta-analysis on some intervention types, but it is unlikely that a meta-analysis may be possible for all intervention types. It will also depend on the literature base for each target species. Sufficient evidence may exist for some more common target (problem) species but not for more regionally-relevant species.

Authors' contributions
All authors participated in the drafting, revision, and approval of the manuscript. Both authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

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