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Environmental Evidence

SYSTEMATIC REVIEW PROTOCOL

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The effectiveness of spawning habitat creation or enhancement for substrate spawning temperate fish: a systematic review protocol

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Abstract

Background: Habitat is the foundation for healthy and productive fisheries. For substrate spawning fish, lack of appropriate spawning substrate is inherently limiting and a lack of access to suitable spawning habitat will lead to population collapse. When specific properties of a habitat (e.g., temperature, depth, vegetation composition) are matched to the species' ecological niche, a spawning habitat can be created or enhanced as a means of mitigating or offsetting the harmful effects of human development. Given the acceleration of habitat degradation in aquatic systems as a result of human activity and resultant loss of biodiversity, it is becoming ever more important to consider the effectiveness of the techniques being used to enhance or create habitat, to ensure management resources are being allocated wisely. The primary aim of this systematic review will be to assess the effectiveness of techniques currently being used to create or enhance spawning habitat for substrate spawning fish in temperate climate regions.

Methods: This review will examine studies on the effectiveness of habitat creation or enhancement for substrate spawning fish. We will consider studies in either the North or South temperate climate regions, and include freshwater, estuarine, coastal, or marine environments. Relevant outcomes will include a range of measures used by authors to define effectiveness, including but not limited to the presence of eggs, successful emergence, or improved recruitment. This review will obtain relevant studies from online publication databases, specialist websites, and grey literature using a range of search engines and networking tools. Additional searches will be conducted using the bibliographies of relevant review publications. Study data will be extracted and appraised for quality, including study design, confounding factors, and statistical analysis. A narrative synthesis will be compiled and a meta-analysis will be completed should the data availability and quality allow for it.

Keywords: Aquatic, Compensate, Evidence-based policy, In-stream structures, Lithophil, Mitigation, Offset, Reproduction, Restoration, Phytophil

Background

Habitat is the foundation for healthy and productive fisheries [1]. When critical habitats are degraded or altered, their ability to function (e.g., for reproduction, rearing) may be compromised [2]. In an effort to ensure that fish habitats are appropriately managed, many jurisdictions require some form of offsetting (also known as compensation) for degraded habitats. For substrate spawning fish [3, 4], lack of appropriate spawning substrate is inherently limiting and a lack of access to suitable spawning habitat may lead to population collapse. Spawning habitat can be created and thus this method is often used to mitigate or offset for human developments affecting aquatic habitat. However, to be suitable for a target species, spawning habitat must have specific properties matched

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to the species' ecological niche. As such, there is much interest in identifying the extent to which spawning habitat creation or enhancement for substrate spawning fish are effective. This is particularly the case in temperate regions with well-developed regulatory frameworks for habitat protection, as in Canada, and where substrate spawning species such as salmonids, centrarchids, percids, and ictalurids are especially common.

Several methods of habitat creation or enhancement exist that have the potential to increase fish productivity (i.e. production rates of fish species of interest, biomass), many of which have been reviewed [5]. Some of these methods can be used to create viable spawning habitat. The addition of in-stream structures, including large woody debris, boulders/cobbles, log jams, and brush bundles are some of the most common restoration techniques for spawning and nursery habitat [6]. These structures not only provide favourable habitat for juveniles [5, 7], but can also recruit and store gravel [8] which is of particular benefit to substrate spawners. For example in salmonids, enhanced gravel beds provide suitable spawning habitat [9, 10] and have resulted in higher survival rates to swim-up stage [11].

To effectively create or enhance spawning habitat, it is important to identify habitat that is conducive to productivity given the species and environment. The spawning habitats used by fishes are quite varied and factors such as temperature, depth, wave exposure, water quality, water velocity, and vegetation composition must all be considered when attempting to design a successful habitat [12, 13]. Species often have specific substrate requirements [3], and spawning behaviour including nest building and guarding [3, 14]. In examining the relationship between groundwater and selection of spawning sites in brook trout (*Salvelinus fontinalis*), Curry and Noakes [15] demonstrated the complexity of the importance of groundwater. Relationships between groundwater and spawning success were highly variable among populations across geologic regions. Other species, such as Chinook salmon (*Oncorhynchus tshawytscha*), spawn in sites with both downwelling and upwelling depending on the population. These behaviours inspired further investigation into the importance of water quality characteristics such as dissolved oxygen and temperature [12]. Although information on the necessary physical and chemical attributes for spawning habitat exists for some species [16], it remains difficult to recreate these attributes in the wild [17].

Given the acceleration of habitat degradation in aquatic systems as a result of human activity [18] and resultant loss of biodiversity [19], it is becoming ever more important to consider the effectiveness of the techniques being used to enhance or create habitat. Spawning habitats are critical to the success and productivity of a fishery [2] and are often created to compensate for the destruction of habitat. The evidence-based nature of meta-analyses and systematic reviews makes them increasingly valuable tools for making informed environmental policy decisions, in this case to assess the effectiveness of techniques currently being used to create or enhance spawning habitat for substrate spawning fish.

Topic identification and stakeholder input

In 2012, amendments to Canada's *Fisheries Act* were made to update the ability of Fisheries and Oceans Canada (DFO) to manage threats to fisheries created by development projects. The new amendments put responsibility on developers to avoid and mitigate any "serious harm to fish" resulting from projects affecting aquatic habitat [20–22]. In the event that serious harm cannot be completely avoided or mitigated during all stages of development, proponents must request authorization and develop a plan to counterbalance this harm using offsetting measures. Offsetting measures differ on a case-by-case basis; however, all must support fisheries management and local objectives, balance project impacts, and provide additional benefits, such as generating long-term, self-sustaining benefits for the fishery [20]. For this reason, creation of spawning habitats (regarded as critical to ongoing productivity of a fishery) is often used as an offsetting measure. It is therefore important to determine if spawning habitat is a limiting factor of productivity and ensure that resources spent on offsets are being used wisely.

During the formulation of the question for this review, an Advisory Team made up of stakeholders and experts was established and consulted. This team included academics, staff from the Canadian Wildlife Federation (CWF), and staff from DFO, specifically the Fisheries Protection Program (FPP), and DFO Science Branch. The Advisory Team guided the focus of this review to ensure the primary and secondary questions were both answerable and relevant, and suggested search terms to capture the relevant literature. An ongoing systematic review (see protocol: Macura et al. [23]) is currently synthesizing evidence on the impact of anthropogenic activities in shallow water nurseries and/or spawning grounds on fish recruitment. Our systematic review is complementary to this work, and broader in scope. While methods of habitat creation or enhancement have been studied, to our knowledge no synthesis of evidence has been undertaken to compare the effectiveness of all relevant creation or enhancement methods on substrate spawning fish. Discussions with our Advisory Team confirmed the value of systematically reviewing available literature to examine how and when habitat creation or enhancement can benefit populations of substrate spawning fish.

Objective of the review

The objective of this systematic review is to evaluate the existing literature to assess the effectiveness of spawning habitat creation or enhancement for substrate spawning fish.

Primary question

What is the effectiveness of spawning habitat creation or enhancement for substrate spawning fish?

Components of the primary question

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

Subject (population): Substrate spawning fish in temperate regions (covering a variety of substrate types as per Balon [3, 4])

Intervention: Habitat creation or enhancement

Comparator: No intervention or alternative levels of intervention

Outcome: Use of habitat and the presence of eggs, successful emergence, or improved recruitment

Secondary questions

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. Under what circumstances (e.g. species, substrate type, location) is spawning habitat creation or enhancement effective?
b. What role does the time since habitat creation or enhancement play in determining effectiveness?

Methods

Searches

Search terms

A list of relevant search terms was generated by the Advisory Team, and divided into three components: the population, intervention and outcome and will be combined using Boolean operators "AND" and/or "OR" (Table 1).

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 focusing efforts equally on each article type, and all articles will be equally critically appraised to ensure validity.

Article/file formats

The search will not have any article type restrictions (e.g., PDF vs. 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. The Review Team will use interlibrary loans or

Table 1 Proposed search string for the execution of the searches

	Search string
Population terms	((Fish* OR Substrate Spawn* OR Substratum OR Benth* OR Lithophil* OR Phytophil* OR Salmo* OR Centrarchid* OR Catostomid* OR Acipenserid* OR Percid* OR Ictalurid* OR Trout OR Sturgeon OR Char* OR Esocid*) AND (Marine OR "Fresh water" OR Freshwater OR Stream* OR Creek* OR Water* OR River* OR Lake* OR Reservoir* OR Pond* OR Canal* OR Wetland* OR Channel* OR Aquatic))
	AND
Intervention terms	(Restor* OR Rehabilitat* OR Offset* OR Transplant* OR Enhance* OR Excavat* OR Augment* OR Compensat* OR Improve* OR Mitigat* OR Creat* or Modif*) AND (Gravel OR Sand OR Cobble OR Boulder OR Substrate OR Vegetation OR Wood$ OR Structur* OR Flow* OR Plant* OR Artificial* OR Riffle$ AND Habitat*)
	AND
Outcome terms	((Abundan* OR Biomass OR Productiv* OR Fertiliz* OR Densit* OR Surviv* OR Rear* OR Spawning Rate*) AND (Hatch* OR Spawn* OR Nest* OR Juvenile* OR Redd$ OR Embryo* OR Egg* OR Roe* OR Fry))

The asterisk (*) is a wildcard and represents any characters (e.g., restor* includes restore, restores, restoring, restoration) while the dollar sign ($) includes zero or one character (e.g., boulder$ includes boulder and boulders). Broad search terms such as "fish", "substrate spawn", as well as spawning strategies, were included in an attempt to capture studies of every relevant species. Since it was not feasible to include every possible relevant species name, based on the recommendations of the Advisory Team, some family names and genera of species commonly targeted for restoration studies were included. Based on preliminary scoping exercises, search results were found to be more inclusive when including these family and genera names given that these specific names were combined with "fish" using the operator "OR"

contact authors of unobtainable articles in an attempt to gain access to every article in full form.

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. ISI Web of Science core collection—Multidisciplinary research topics including journals, books, proceedings, published data sets, and patents
2. Scopus—Abstract and citation database of peer-reviewed literature including journals, books, and conference proceedings
3. ProQuest Dissertations and Theses Global—International depository of graduate dissertations and theses
4. Waves (Fisheries and Oceans Canada)—Canadian government books, reports, government documents, theses, conference proceedings and journal titles
5. Science.gov—US Federal Science

Search engines

Search terms will be entered into Google Scholar and the first 500 hits (sorted by relevance) will be screened for the appropriate fit for the review questions.

Specialist websites

Specialist organization websites listed below will be searched using connectors created in Import.io and abbreviated search terms (e.g. substrate spawning, habitat restoration, spawning habitat). Page data from the first 50 search results will be extracted, screened for relevance, and searched for links or references to relevant publications and data and grey literature. The list of websites was narrowed to the following 31 organizations after consulting with our Advisory Team for relevance. These have been restricted to English websites, primarily in North America, due to the scope of our review question.

1. Atlantic Salmon Federation
2. British Columbia Hydro
3. Centre for Ecology and Hydrology
4. Centre for Environment, Fisheries and Aquaculture Science
5. Commonwealth Scientific and Industrial Research Organisation
6. Department of the Environment, Food and Rural Affairs
7. Fisheries and Oceans Canada
8. Fisheries Research Service
9. Food and Agriculture Organization of the United Nations
10. Hydro-Québec
11. Joint Nature Conservation Committee
12. Manitoba Hydro
13. Ministry of Natural Resources and Environment of the Russian Federation
14. National Institute of Water and Atmospheric Research
15. Natural England
16. Natural Resources Canada
17. Natural Resources Wales
18. Newfoundland and Labrador Hydro
19. Northern Ireland Environment Agency
20. Ontario Ministry of Natural Resources
21. Ontario Power Generation
22. Pacific Salmon Foundation
23. Parks Canada
24. Salmon Enhancement Foundation
25. Trout Unlimited
26. The Nature Conservancy
27. United Nations Environment Programme
28. US Department of Energy—Office of Scientific and Technical Information
29. US Fish and Wildlife Service
30. Western Native Trout Initiative
31. World Wildlife Fund

Other literature searches

Reference sections of accepted articles and relevant reviews 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.

We will also use social media and email 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. The Advisory Team will be consulted for insight and advice for new sources of information. 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 ensure it is comprehensive

and inclusive. Any changes made to the search strategy will be justified and documented in the final review.

Search record database

All articles generated by each of the search strategies will be exported into separate Zotero databases. After all searches have been completed and references found using each different strategy have been compiled, the individual databases will be exported into EPPI-reviewer as one database. Duplicates will be identified and merged. 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 imported into EPPI reviewer and screened at title, abstract and full text, and included/excluded based on criteria outlined below.

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 are screened out and which go on in the process for further review. 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 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 and reach a decision as a group. If there are any further disagreements on inclusion of articles based on the outline criteria, the Advisory Team will be consulted. Any articles that do not have abstracts (as is the case for some grey literature), will automatically be screened at the full text level. Justification of the reason for inclusion or exclusion of an article will be recorded using EPPI reviewer, and all articles excluded at the full text level will be included with the review, in compliance with Collaboration for Environmental Evidence (CEE) guidelines. Only English-language literature will be included during the screening stage.

Articles will be included based on the following predefined inclusion criteria developed in consultation with the Advisory Team:

Relevant subjects

Any population of substrate spawning fish in North (23.5°N to 66.5°N) or South (23.5°S to 66.5°S) temperate regions. Spawning strategy will include lithophils and phytophils as defined by the reproductive guilds described in Balon [3].

Relevant interventions

Any creation or enhancement of spawning habitat

Relevant comparators

Non-intervention or alternate intervention.

Relevant outcomes

Only direct outcomes in the form of a quantitative or qualitative measured effect of intervention will be included. Outcomes should indicate if there was a change in the presence of eggs, successful emergence or improved recruitment relative to control, reference, and/or pre-treatment. Estimates using survival rate calculations, and changes in spawning area are not eligible outcomes and will be excluded.

Relevant types of study design

Study designs with appropriate comparators including Before/After (BA), Control/Impact (CI), as well as studies combining these types of comparisons, Before/After/Control/Impact (BACI) and Randomized Controlled Trials (RCT) will be included. Simulation studies, review papers, and policy discussions will be excluded.

Study quality assessment

Each of the studies that pass 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 (e.g., stocking, chemical modifications)
- Use of (and number of) control and/or reference sites
- Statistical methods used in assessment

- Accounting for and/or identifying potential effect modifiers (see list in following sections).

Bilotta et al. [24] 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 [25] for use in the field of environmental science. The assessment criteria include assessing selection bias, attrition bias, reporting bias, as well as criteria relevant to our study (e.g. duration of monitoring, endpoints). The criteria outlined in Bilotta et al. [24] will be used 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 study, and to provide insight into any potential risk of bias present in each of the studies. Studies that include confounding factors will be assessed separately than those focusing on exclusively habitat creation/enhancement, but will be subject to the same assessment of validity as all other studies. As the review proceeds, additional or more specific criteria will be developed through consultation with the Advisory Team. 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 method.

Data extraction strategy

Meta-data 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, as additional supporting files. The extracted information will be used to assess the overall effectiveness of each intervention strategy, and when sufficient, good quality data exist, 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 are 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 are provided in the article, the Review Team will calculate summary statistics. In those instances, we will record how the calculations were conducted and with what information. To ensure that data are being extracted in a consistent and repeatable manner, two reviewers will extract information from ten 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 from articles that are included at the full-text level of screening. All information will be recorded in the database. Potential effect modifiers that will be recorded for all included studies, given the data is available, include but are not limited to:

- Study location (including geographical coordinates)
- Climate region
- Waterbody (freshwater/marine, lake/stream/river, etc.)
- Substrate type
- Fish species data (including spawning strategy)
- Intervention type and study information
- Confounding factors at study site (stocking, chemical modifications)
- Outcome data (magnitude of change compared to control/reference site)
- Post-monitoring effort and time-scale

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 the different methods of creating and enhancing habitat to identify the factors that influence success to better inform management decisions. 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. Where studies report similar outcomes, meta-analysis will be performed. In these cases, effect sizes will be standardized and weighted appropriately. If meta-analysis is possible, it will take the form of random-effects models. Depending on the availability of the data, meta-regressions or subgroup analyses of categories of studies will also be performed. Sufficient evidence may exist for some common target species (i.e. salmonids) but not for all regionally-specific species, in which case subgroup analysis based on species may be possible. Special efforts will be made to analyze the influence of intervention type (i.e., woody structures, addition of gravel, boulders) and time since habitat creation on the effectiveness

of spawning habitat creation/enhancement for substrate spawning fish. Publication-bias and sensitivity analysis will be carried out where possible. Overall management effects will be presented visually in plots of mean effect sizes and variance.

Authors' contributions
The manuscript was drafted by JJT. TR, KS, JRB, and SJC provided comments and revisions. All authors read and approved the final manuscript.

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Competing interests
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