Collaboration for Environmental Evidence

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Systematic Review Protocol

Title
What are the impacts of salmonid fish farming on river water quality?

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Keywords
fish farming, river, water quality, biological indicator, chemical indicator

Background
Rivers are unique freshwater systems, providing essential goods (e.g. drinking water) and services (e.g. fishing for recreation) (Arthington et al., 2010, Decamps, 2011) while also supporting high levels of biodiversity (Hanna et al., 2017). However, maintaining good water quality is a major global challenge as rivers face increasing pressure from anthropogenic activity including agriculture, water abstraction, sewage pollution, and aquaculture (Arthington et al., 2010, Schwarzenbach et al., 2010). Freshwater salmonid farming is an important and growing industry dependent on good water quality (Boyd, 2017, Henriksson et al., 2021, Su et al., 2020). Apart from its economic benefits, salmonid farming also supports cultural services including recreational use of the rivers via fishing of stocked fish, as well as provisioning services through food production. However, fish farming output consisting of unconsumed feed, faecal and excretory matter can contribute to nutrient enrichment and pollute waterways, as well as affecting aquaculture products themselves (Caramel et al., 2014, Hongpin et al., 2015). Preserving fish farm services as well as river water quality requires knowledge of the effect these farming practices are having on the water. We therefore aim to carry out an evidence synthesis of the primary literature, in the form of a systematic review, on the effects of salmonid farming on river water quality. Focusing on salmonid species means that due to their 'high profile' (Worthington et al., 2020) we will expect more studies than for other farmed species (e.g., tilapia), indirectly indicating the extent of data that exists for other freshwater species. The review will use the ROSES (RepOrting standards for Systematic Evidence Syntheses) framework (Haddaway et al., 2018). The aim is to determine whether methods of water quality assessment in this context are standardised and identify the knowledge gaps in an effort to guide future related studies and stakeholder action.

Theory of change or causal model
N/A

Stakeholder engagement
N/A

Objectives and review question
The objective of this review is to reveal how freshwater salmonid fish farming affects the water

quality in rivers they are associated with. Question: What are the impacts of salmonid fish farming on river water quality?

Definitions of the question components
Population: rivers or streams across any system that supports salmonid fish farming (not brackish or marine). Exposure: freshwater salmonid fish farm presence, where the farm effluent enters a river or stream. Comparator: upstream of the fish farm/no exposure. Outcome: any water quality measures including water chemistry (e.g. nitrate concentrations), macroinvertebrate or microbial indicator species diversity, community composition, biotic indices, etc.

Search strategy
The search will cover a range of bibliographic databases, theses repositories, and specialist websites to include published scientific and grey literature. Bibliographies of included studies will also be searched ('snowballing') for relevant literature and checked against the inclusion criteria. The studies may be from any year (no cut-off point) until the present (2024). Only primary literature in English will be considered, which may bias the results, but due to limitations in resources we are unable to include other languages. The following search terms will be used for advanced searches in bibliographic databases: Population terms: river*, stream*, fresh*water, watercourse*, waterway*, tributar* Exposure terms: fish*farm*, aqua*culture, fish hatcher*, piscicultur*, fish produc*, fish rear*, trout farm*, trout produc*, trout hatcher*, salmo* farm*, salmo* produc*, salmo* hatcher* Outcome terms: water quality, water health, water condition*, pollut*, water status, sediment*, water chemistry, bio*diversity, bio* indicator*, microbi*, bacteri*, microorganism*, diatom*, bio*film*, ecology, parasit*, protozo*, nitr*, phosph*, ammonia*, *invertebrate* Wildcards (‘*’) are used to represent any number of characters, to expand search results. These search terms will be combined using the Boolean operator ‘OR’, with the categories (population, exposure, outcome) combined using the Boolean operator ‘AND’ to form search strings. The complete Boolean-style search strings formatted for each database are presented in Supplementary File 1.

Bibliographic databases
Three bibliographic databases will be searched using the University of Southampton institutional subscription: Web of Science Core Collection (WoSCC), Scopus and JSTOR. The advanced searches will involve looking at ‘Topic (i.e., title, abstract, author keywords)’, ‘Title, Abstract, Keyword’, and ‘Abstract’ for WoSCC, Scopus and JSTOR, respectively.

Web-based search engines
N/A

Organisational websites
The following specialist websites will be searched for references to publications or data, as well as grey literature, on the topic: - European Environment Agency (www.eea.europa.eu) - European Commission Joint Research Centre (joint-research-centre.ec.europa.eu) - Centre for Environment, Fisheries, and Aquaculture Science (CEFAS) (www.cefas.co.uk) - European Fisheries and Aquaculture Research Organisations (EFARO) (efaro.eu) - Food and Agriculture Organisation (FAO) Fisheries and Aquaculture Division, United Nations (www.fao.org/fishery) - United Nations Environment Programme (www.unep.org) - UK Government Research and Statistics (www.gov.uk/search/research-and-statistics) - NatureScot (Scotland’s Nature Agency) (www.nature.scot) - European Centre for River Restoration (ECRR) (www.ecrr.org) - Canal & River Trust (canalrivertrust.org.uk) - Joint Nature Conservation Committee (JNCC) (jncc.gov.uk) - UK Centre for Ecology & Hydrology (www.ceh.ac.uk) - The Rivers Trust (theriverstrust.org)

Comprehensiveness of the search

To assess the comprehensiveness of the keywords included in the search, the search string was tested in Web of Science Core Collection, against a list of 18 benchmark articles. The search string was adapted according to the search results until all benchmark articles were identified, resulting in a comprehensive search string. These benchmark articles are provided in Supplementary File 2.

Search update
N/A

Screening strategy
All titles and abstracts will be imported to CADIMA (https://www.cadima.info/index.php), which is an online evidence synthesis tool. The software automatically detects and removes duplicates, and once all potential duplicates are removed, publications will be evaluated for their relevance and eligibility at two stages: 1) title and abstract, 2) full-text. One reviewer will evaluate articles based on their titles and abstracts first, and a subset of 5% of the publications will be reviewed by a second reviewer to control for consistency. A Cohen's kappa statistic will be calculated to measure the level of agreement between reviewers. If the kappa statistic suggests inconsistency ($k < 0.5$), the discrepancies will be discussed and resolved through changing inclusion/exclusion criteria if needed. The publications that have passed this screening process will then be evaluated based on their full text by the same single reviewer. A subset of 10% of the publications will be assessed by a second reviewer. Again, the kappa statistic will be calculated and any discrepancies will be discussed and resolved. If reviewers are uncertain about whether to include a publication, it will be included, at every stage of screening. Articles excluded at the second stage will be provided in an appendix at full text, with the reasons for exclusion.

Eligibility criteria
The publications must fulfil the following criteria to be included: Relevant subjects: rivers or streams in any region. Any lakes or other lentic bodies of water will not be considered in this review. Brackish or marine waters will also be excluded. Relevant types of exposure: freshwater salmonid fish farming presence. This includes any freshwater farmed salmonid fish species (e.g., rainbow trout, brown trout, European grayling), but no other type of freshwater aquaculture (e.g., watercress farming). Relevant types of comparator: no exposure to freshwater salmonid fish farming – studies comparing water quality upstream and downstream of fish farms. Relevant types of outcome: studies that include any chemical measures or indices of water quality (e.g., nutrient concentration, dissolved oxygen concentration). Also, any measures of change to microbial (e.g., diatoms, bacteria) or invertebrate indicator species diversity, composition, abundance, or community structure. Differences in biotic indices will also be considered. Relevant types of study: All primary field studies – not theoretical, laboratory-based or modelling studies since these do not answer the question. The studies may be from any year (no cut-off point) until the present (2024). Language: full texts written in English, only.

Consistency checking
Detailed above ('Screening strategy').

Reporting screening outcomes
The ROSES flow diagram will be used to report screening outcomes. The articles meeting the inclusion criteria will be provided at the end of the review in a spreadsheet. Articles excluded at the second stage (full-text screening) will also be provided in an appendix at full text, with the reasons for exclusion.

Study validity assessment
Relevant studies that are accessible will undergo a critical appraisal. The Collaboration for

Environmental Evidence Critical Appraisal Tool prototype version 0.3 (Konno et al., 2021) will be used to assess study validity and score studies as having low, medium, or high risk of bias. This will guide exclusion of studies that have a high susceptibility to bias. The responses to the critical appraisal questions for each study will be recorded in a data sheet and presented with justifications.

Consistency checking
The studies will be critically assessed by one reviewer, but a subset of these will be appraised by an additional reviewer to ensure consistency. The studies that are rejected (low validity) and the reasons for this will be included in the appendix.

Data extraction strategy
Data will be extracted and coded from included studies and recorded in a spreadsheet. The following information will be extracted: • Study characteristics: location (including country and river), year, study duration, season(s) sampled, sample size, replication, study biases, confounding variables. • Exposure characteristics: number of farms studied, type of farming (e.g., raceway/flow-through systems, cage systems, open net pen systems, etc.), farming intensity, species farmed, other exposures (i.e., other types of aquaculture or human activities explored in the same study, if at all). • Outcome characteristics: outcome measure type (e.g., concentrations, species abundance, etc.), outcome unit (i.e., mean, median, proportion), measures of variation (standard deviation, standard error, confidence intervals). This list could include further information as the review progresses. The data will be extracted from the main text, tables, and figures where available. All extracted data will be made available at the end of the review. Plot Digitiser (https://plotdigitizer.com/app) will be used to extract data from figures. If data cannot be extracted from figures or is missing, authors of the article will be contacted to obtain the raw data if possible. Communications with authors will be recorded and shared in the systematic review. Data that cannot be obtained will be reported as ‘not stated’ in the spreadsheet.

Meta-data extraction and coding strategy
Detailed above.

Consistency checking
Most data extraction will be carried out by a single reviewer. However, a second reviewer will extract data from the same subset of included articles (5%) and will compare results, checking for disagreements. Any differences in data extraction will be discussed and changes to the data extraction strategy will be made.

Potential effect modifiers/reasons for heterogeneity
The factors that could cause variation in measured outcomes will be considered and documented. The main potential effect modifiers are listed below: • Biogeographic factors: location, climate system, altitude, river source, bedrock type. • Study characteristics: width and depth of sampled site, sampling period (i.e., length of study), year, season (time of year), sampling location (i.e., immediately downstream of effluent?). • Land use/human activity (other than fish farming) upstream or along sampling sites. • Methods for determining taxonomy (e.g., DNA sequencing, microscopy). • Methods for measuring nutrient concentrations. This is not exhaustive list; there may be further effect modifiers identified during the review, which will be recorded.

Type of synthesis
Narrative and quantitative

Narrative synthesis methods
The resulting synthesis will be narrative and will include a summary of findings for all valid studies.

The narrative synthesis will use extracted data and information on the studies' context (e.g. study location, biological indicators used) and results. These studies will be arranged according to the water quality indicators used. These data will be presented in table format. A map may also be included to display the geographical distribution of the studies.

Quantitative synthesis methods
A quantitative synthesis will be carried out, with outcome types falling in two main categories: biological (e.g., taxa richness, Shannon index, Simpson's index, abundance) and chemical (e.g., concentrations of ammonia, phosphates, dissolved oxygen, heavy metals) indicators of water quality. The log of response ratio will be used as the measure of effect and calculated using data from the included studies. Random-effects models will be applied for meta-analysis and quantitative outcomes will be presented in tables and forest plots.

Qualitative synthesis methods
N/A

Other synthesis methods
N/A

Assessment of risk of publication bias
Publication bias will be assessed graphically, using funnel plots.

Knowledge gap identification strategy
N/A

Demonstrating procedural independence
To ensure independence of the review process, if a member of the review team appears as an author in an article, they will not be involved in assessing its eligibility or validity.

Competing interests
The authors declare they have no competing interests.

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Author's contributions
AM created the search string and wrote the manuscript. KP, TS, NB, MD, GT, RH helped develop the question, search string and contributed to the manuscript.

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