The status of academic research on salmon farming: a scoping review protocol

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Neal R Haddaway[1], Matthew Grainger[2], Marija Sciberras[3], Ingrid Kelling[3], Steven J Cooke[4]

1. Freelance Senior Researcher, Linhares, Portugal, neal_haddaway@hotmail.com
2. Researcher, Norwegian Institute for Nature Research (NINA), Trondheim, Norway, matthew.grainger@nina.no
3. Lyell Centre for Earth and Marine Sciences and Technology, Heriot-Watt University, Riccardton, Edinburgh, m.sciberras@hw.ac.uk; i.kelling@hw.ac.uk
4. Canadian Centre for Evidence-Informed Conservation, Department of Biology and Institute of Environmental and Interdisciplinary Science, Carleton University, Ottawa, ON, Canada, steven_cooke@carleton.ca

Abstract

Salmon aquaculture (variously Atlantic and Pacific) has rapidly expanded across Norway, Chile, Canada, and Scotland, amongst others, driven by advancements in technology and market dynamics. However, this growth has spurred debates around environmental and socio-economic sustainability, especially concerning environmental degradation and "food imperialism." The intensive industry, once purported to be essential for global protein supply, is now scrutinised for prioritising luxury markets over food security and for its high ecological and social impacts, including pollution, disease spread, feed supply chain effects, and damaging livelihoods and standards of living. Climate change intensifies these concerns, with rising sea temperatures and extreme weather exacerbating disease and infrastructure risks, for example. Furthermore, the industry's reaction to activism raises issues of transparency and public accountability. With high mortality rates and substantial welfare concerns, the sector faces ethical scrutiny as well.

This review aims to map academic research on salmon farming, analysing how studies address themes such as environmental impacts, socio-economic consequences, industrial profitability, and regulatory frameworks. We will search for relevant records from The Lens bibliographic meta-database using a tried-and-tested search strategy. We will then systematically screen records at title and abstract level and full text level according to a set of predefined inclusion criteria. Following this, we will systematically extract and code metadata, including geographical focus, study objectives and design, and funding sources. Visualisation tools, such as heat maps and interactive atlases, will illustrate research distribution and highlight gaps in the literature. The project will provide a comprehensive overview that will inform future systematic reviews and primary research, particularly in underexplored areas. This scoping review thus offers a foundation for a critical assessment of the research literature on salmon farming and its role in global food systems, social and ecological impacts, and the effectiveness of regulatory practices.

Keywords: food colonialism; food imperialism; socio-ecological impacts; intensive aquaculture; food systems; salmon aquaculture; aquaculture

Background

Wild salmon fisheries based on native species have historically supported the nutritional security and culture of Indigenous peoples and created socio-economic benefits that span the recreational and commercial fishing sectors (Mills 1991; Lackey et al. 2006). However, as a result of declining wild salmon populations (including both Atlantic salmon [Dadswell et al. 2022] and Pacific salmon [Nehlsen et al. 1991; Lackey 2003]) and immense profitability and other market forces, salmon aquaculture has emerged as a major sector of the aquaculture industry. Salmon farming has undergone rapid global expansion, with key producing regions including Norway (for Atlantic salmon), Chile (for Atlantic and Pacific salmon), Canada (for Atlantic and Pacific salmon), and Scotland (for Atlantic salmon) at the forefront (Naylor et al. 2003; Paisley et al. 2010; Lien 2015) albeit salmon are now cultured on every continent except Africa (Asche and Bjorndal 2011). This growth and intensification is indicative not only of the increasing global demand for salmon (Bostock et al. 2010) but also of the evolving practices and innovations within aquaculture (Leitritz and Lewis 1980; Pennell and Barton 1996) and the domestication of these fishes (Lein 2015). The history of salmon aquaculture is characterised by significant technological advancements and shifts in market dynamics, establishing the industry as a pivotal contributor within the global seafood sector since at least the 1980s (Muir 1985). However, the consequences of this expansion have ignited heated discussions regarding the economic and social-ecological sustainability of salmon farming, particularly in relation to environmental damage and more recent discourse around indirect social impacts - so-called ‘food imperialism’ (Feedback 2024).

The Salmon Farming Industry

When the salmon industry began to increase in scope several decades ago, it was purported that salmon farming would be vital in addressing global protein demands (Asche and Bjorndal 2011). Today, its importance is underscored by its significant economic contributions to producing regions. In Norway, salmon exports are the single greatest export by value after fossil fuels - some 17.7 billion USD in 2022 (ResourceTrade.earth 2024). In Chile, neither Atlantic nor Pacific salmon are native to their waters yet today their salmon aquaculture sector is one of the largest on the planet (Bjorndal and Aarland 1999) surpassing 1 million tonnes in 2020 (SNP 2020). The assertion that salmon farming is vital for global protein demand is complicated by the reality that salmon is predominantly consumed as a luxury product in wealthier nations (ResourceTrade.earth 2024), thereby eliciting considerable critique regarding its role in food security (Belton et al. 2020). The industry’s viability is further compromised by high mortality rates attributed to sea lice infestations, diseases, and environmental stressors (Aaunsmo et al. 2008; Overton et al. 2019; Oliveira et al. 2021), and potential impacts on native fish populations and ecosystems (Hindar et al. 2006; Quiñones et al. 2019), and the financial burden of which is then passed on to social-ecological systems involved in feed production. As the industry attempts to confront these ongoing challenges, its long-term sustainability remains a critical concern (Gudbrandsdottir et al. 2021).

Impact of Climate Change on the Industry

Climate change presents multifaceted threats to salmon farming, particularly through rising sea temperatures, which adversely affect salmon health and increase disease susceptibility (Calado et al. 2021). Additionally, the escalating frequency of extreme weather events poses risks to infrastructure and disrupts production cycles (Falconer et al. 2022), further increasing the emission of plastics into the environment (Global Ghost Gear Initiative 2021), and is associated with adverse environmental events, including marine hydrozoan blooms (Mitchell et al. 2021). Ocean acidification further exacerbates these challenges, potentially affecting salmon physiology and the availability of essential food sources (Pernet and Browman 2021). As the industry grapples with these climatic changes, it continues to attempt to develop adaptive strategies whilst maintaining production and profitability (Scholtens et al. 2023). This increasing pressure on profitability comes with indications that environmental and welfare certification schemes in some regions have failed (Environment+Energy Leader 2024).

Aggressive Behaviours in Relation to the Press and Activism

The salmon farming industry has frequently responded aggressively to scrutiny from journalists and environmental advocates, as evidenced by instances of restricted access and legal threats aimed at whistleblowers such as Don Staniford (Salmon Business 2024). This dynamic raises critical questions concerning the transparency of the industry and the freedom of the press in uncovering environmental and social issues. The capacity to scrutinise practices within salmon farming is essential for ensuring accountability and fostering public trust. This scrutiny has proven vital in recent years in identifying falsification of records relating to animal welfare and environmental impacts (Fish Farming Expert 2019; WeAreAquaculture 2023).

Environmental and Ecological Implications

Many research studies have documented the significant environmental and ecological impacts of the salmon farming industry (e.g. Quiñones et al. 2019). These impacts include: nutrient pollution from excessive food waste and excreta (Bloecher et al. 2024); escapes of farmed salmon affecting their genetics and population viability (Bradbury et al. 202); disease and pest transmission to local species (Mordecai et al. 2021); antibiotic overuse and resistance (Lozano-Munoz et al. 2021); microplastic and chemical release into the environment from pen equipment (Abihssira-García et al. 2022), and poorly maintained boats and other infrastructure (Mail Online 2024); and competition and conflict with other organisms, including pinnipeds (Heredia-Azuaje et al. 2022). Moreover, the indirect impacts of feed supply chains, especially with regard to decimation of West African fisheries through fishmeal and fish oil production (Feedback 2024) and deforestation and forest fires linked to South American soy production (Anmarkrud 2023) both used in fish feed, underscore the broader highly detrimental ecological footprint of the industry.

Social and Cultural Impacts

The repercussions of salmon farming extend to local fishing communities and traditional livelihoods, particularly among Indigenous groups (Hiedanpää et al. 2020) and artisanal fishing communities (Randin 2024). Local opposition to salmon farms is growing significantly across the world (Weitzman et al. 2022). Public attitudes towards salmon farms are influenced by perceptions of noise, odour, and disruptions to local life (Karlsen et al. 2015), further complicating the industry's social landscape. Perceived complacency over occupational health is an increasing concern following recent deaths of employees (BBC 2024).

Animal Welfare

Animal welfare issues are central to the discourse surrounding intensive salmon farming, particularly in relation to stocking densities, disease management, and mortality rates. The industry's practices raise ethical questions regarding the treatment of farmed salmon (New Scientist 2024), and in recent years mass mortality events have seen millions of animals die as a result of a range of malpractices and poor animal husbandry, including disease outbreaks (Singh et al. 2024) and climate-induced ecosystem stochasticity (Soto et al. 2019). Indeed, recent mortality rates have resulted in a significant reassessment of animal welfare certification in the UK by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) (Fish Farming Expert 2024).

Policy, Governance, and Regulatory Frameworks

The regulatory practices and governance structures governing salmon farming vary across major producing countries, reflecting differing approaches to and definitions of sustainability and accountability. A variety of international standards and certifications exist, such as the Aquaculture Stewardship Council (ASC), Royal Society for the Protection of Cruelty to Animals (RSPCA) and Marine Stewardship Council (MSC). In addition, organisations exist that claim to improve sustainability of fisheries exploitation in West Africa, where much of the salmon industry's feed is believed to be sourced (Feedback 2024). However, recent investigations suggest these are heavily affected by industry bias (DeSmog 2024). Strengthening these frameworks is seen by some as vital for enhancing the transparency and credibility of salmon farming operations (Rector et al. 2023), however the scale and complexity of indirect social-ecological impacts may make true sustainability assessment untrustworthy in practice.

The State of Academic Research

Our focus on the academic literature in this scoping review stems from a need to critically assess and mitigate potential biases in research funding and industry influence. Much of the research on salmon farming is funded by industry stakeholders with vested interests (7.4% of funding statements in a

Lens.org search included clear industry funding [90% lacked indexed funding statements] - see Additional File 1), which can shape research priorities and interpretations in ways that may favour industry perspectives. By focusing on academic sources, we aim to examine how these potential biases might influence findings both the nature of the evidence base as a whole, and also on what research is conducted and published on the environmental impacts, economic outcomes, and social ramifications of salmon farming. Additionally, the field is often highly siloed, with distinct academic subfields addressing isolated aspects—such as economic sustainability, environmental impacts, and social impacts—without sufficient cross-disciplinary integration. This review seeks to bridge these silos by mapping research from a holistic perspective, enabling a clearer understanding of the interconnected impacts of salmon farming. Furthermore, identifying gaps in the literature is essential for alleviating these biases, as it highlights areas where independent, multidisciplinary research is lacking, supporting future studies to address underrepresented issues and providing a more balanced foundation for evidence-based policy and practice.

Research Gaps and Rationale for Scoping Review

Despite the growing body of research on salmon farming (Figure 1), there has been little in the way of an overview of research on salmon farming. What reviews exist are either limited in geographical scope (e.g. Quiñones et al. 2019) or purely narrative (e.g. Chávez et al. 2019). These gaps highlight the necessity for a scoping review to comprehensively map the diverse evidence base, thereby supporting future systematic reviews and primary research in underexplored areas. It will also importantly shed light on the spread of research effort across the spectrum from industry functionality and profitability to direct and indirect social-ecological impacts.

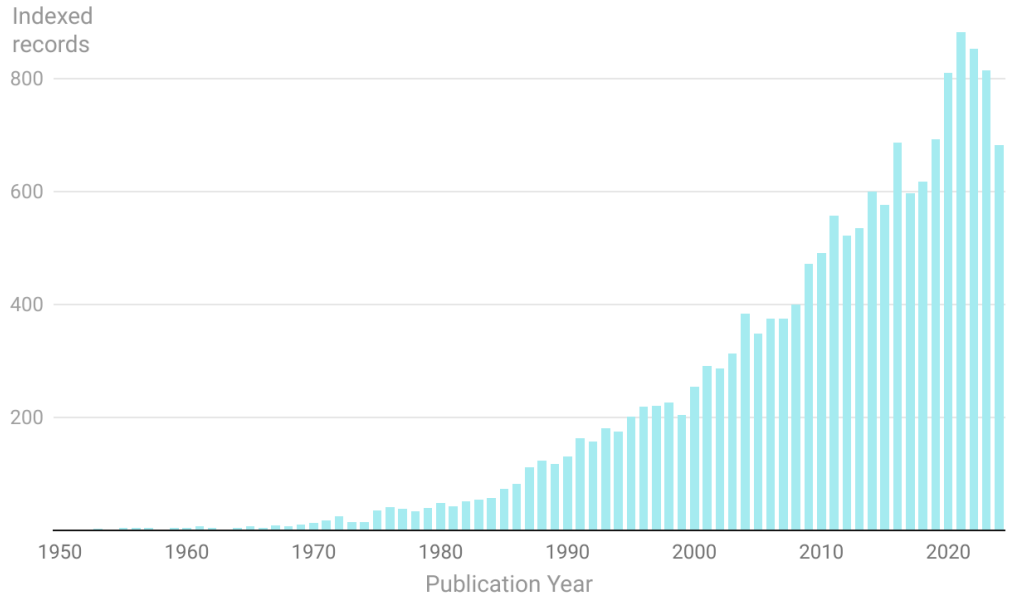

Figure 1. *Salmon farming research in Lens.org by publication year, search performed 09/11/24 explaining the lower number in 2024. See Table 1 for search strategy.*

Objectives and review question

Our review has the following primary question:

What is the nature of the academic research that has been published on the topic of salmon farms?

Our secondary questions are:

- How is research effort distributed across different subfields, e.g. from animal husbandry to indirect supply chain impacts?
- Where is the research focused?
- Who has funded this research?
- What research methods have been used in the evidence base?

Our question has the following key components:

Population: Global scope

Phenomenon: Salmon farming

Species: Atlantic and Pacific salmon (see Eligibility Criteria below for definitions)

Outcome: Any and all measured outcomes, both direct and indirect, natural and social (including economic, ecological, environmental, and social)

Study type: Empirical research (excluding commentaries, opinion pieces), including modelling research, review articles and field-, laboratory- and mesocosm- based research

Methods

The methods for this scoping review are developed from the CEE Guidelines for systematic reviews and maps (CEE 2022), and based on systematic mapping methodology (James et al. 2016). This protocol is documented in line with the ROSES standards for systematic map protocols (Haddaway et al. 2018). We modify the method here in three important ways, differentiating our methods from those of full systematic mapping for the reasons of pragmatism and resource constraints.

Firstly, we will search in a single database, rather than multiple bibliographic databases. This database is the largest meta-database available, and represents a significantly larger resource than any traditional bibliographic database (Lens.org 2024). It also indexes records through publicly available index information (titles, abstracts, keywords, etc.), corresponding to a multidisciplinary resource free from selection bias. We have chosen this database because it is free-to-use and results can be downloaded in bulk, whilst offering the same degree of precision and quality of information as traditional, expensive bibliographic databases. Secondly, we will not search for grey literature directly. By choosing to focus on traditional academic articles, we are limiting the comprehensiveness of our work, but deliberately target academic publications to demonstrate the spread of information across traditionally funded and published research work. Thirdly, we will make use of machine learning to model record relevance based on successively trained models using manual training sets, monitoring the curve of relevant records over time, and halting efforts where returns are deemed to be minimal.

By choosing these methods, we allow the possibility of upgrading the work into a full systematic map should resources and team availability allow in the future. These caveats and their limitations on our findings will be discussed in detail in our final report.

Search strategy

This scoping review will search within a single meta-database (The Lens) that aggregates bibliographic data from 4 independent databases: Microsoft Academic, CrossRef, PubMed and OpenAlex. The Lens database (www.lens.org) is an Open Access bibliographic database that contains >280 million bibliographic records across disciplines. We will use the following search string, and all search results will be extracted in bulk and deduplicated in EndNote before being screened.

Table 1. *The search string and provisional hits in Lens.org*

	Sub-string	**Hits in Lens.org 09/11/24**
#1	((title:(farm* OR cage* OR pens OR penned OR pen OR aquacultur* OR commercial*)) OR (abstract:(farm* OR cage* OR pens OR penned OR pen OR aquacultur* OR commercial*)) OR (keyword:(farm* OR cage* OR pens OR penned OR pen OR aquacultur* OR commercial*)))	4,009,081
#2	((title:(salmon OR salmonid* OR Salmo OR Oncorhynchus)) OR (abstract:(salmon OR salmonid* OR Salmo OR Oncorhynchus)) OR (keyword:(salmon OR salmonid* OR Salmo OR Oncorhynchus)))	136,559

#3	#1 AND #2	22,555
#4	#3 filtered > excl. dataset, excl. report, excl. libguide, excl. news	19,457

Searches for grey literature

Since we are interested in traditional academic research, we will not perform searches for grey literature beyond preprints and theses.

Comprehensiveness of the search

We assembled a list of 17 articles of known relevance (the *benchmark list*, see Appendix 1) that we used to verify the functionality of the above search string. The search was considered complete when all of the records indexed within the database were retrievable using the search. Where records were initially not retrieved, we examined the search string and revised it to ensure relevant synonyms were included.

Alternative search methods

We will conduct both forward citation chasing (identifying papers that cite our benchmark list) and backward citation chasing (locating references cited by these benchmark papers) using the Lens.org meta-database. These records will be incorporated into our search results before de-duplication.

Search update

As this work is planned to take place over a short period of time (c. 6-12 months), we do not plan on updating the searches before completion.

Screening strategy

Once all search results have been exported, we will deduplicate to remove unnecessary replication of records within the set. We will initially perform deduplication within EndNote following the Bramer et al. (2016) method.

We will screen records in Rayyan using the eligibility criteria listed below at two levels: title and abstract level, and full text level. Where records are deemed ineligible for inclusion at full text level, exclusion reasons will be given.

Eligibility criteria

Our review has the following inclusion criteria:

Population: Global scope

Phenomenon: All salmon farming methods, including closed land-based systems for smolts and adults and sea-based open pen systems. We exclude supplementation approaches where hatchery fish are stocked into the wild to create fishing opportunities. The study must have an explicit linkage to the salmon farming industry in its objectives.

Species: Atlantic salmon (*Salmo salar*), which forms 90% of farmed salmon across the world, as well as Pacific salmon that includes several species commonly referred to as salmon - i.e. steelhead salmon (*Oncorhynchus mykiss* - but excluding the rainbow trout which is a form that solely resides in freshwater), coho salmon (*Oncorhynchus kisutch*), chinook salmon (*Oncorhynchus tshawytscha*), pink salmon (*Oncorhynchus gorbuscha*), sockeye salmon (*Oncorhynchus nerka*), masu salmon (*Oncorhynchus masou*) and chum salmon (*Oncorhynchus keta*)

Outcome: Any and all measured outcomes, both direct and indirect, natural and social (including economic, ecological, environmental, and social)

Study type: Empirical research (excluding commentaries, opinion pieces), including modelling research, review articles and field-, laboratory- and mesocosm- based research

Consistency checking

Prior to screening the full set of records at title and abstract level, a subset of 150 records will be screened independently by each reviewer to be involved in screening. Disagreements will then be numerically estimated (McHugh 2012) and discussed in detail, with the inclusion criteria refined where necessary. When a sufficient level of inter-rater agreement is reached (i.e. kappa score > 0.6), reviewers will be assigned a share of the remaining records for independent screening. A similar approach with a subset of 10 full text records will be performed prior to screening of the full texts identified from the first round of screening.

Demonstrating procedural independence

No reviewer will be permitted to make judgements about their own work.

Reporting screening outcomes

Exclusion reasons will be reported for all records excluded after full text assessment. At least one of the following exclusion reasons must be reported:

- Incorrect phenomenon (not a fish farming method)
- Incorrect species (not Atlantic salmon)
- No relevant outcome present
- Incorrect study type (not empirical research, modelling or a review)

Machine learning screening assistance

We will make use of Rayyan's built-in machine learning screening assistance, which ranks records according to their received relevance based on continual test screening. A minimum of 100 records is needed including at least 5 includes before the model can be trained. We will manually screen an initial 150 records prior to initiating the first model run, after which point, the model will be rerun

every 150 records to improve ratings. Records are then sorted based on model relevance rating to increase efficiency. We will track the rate of relevance per 150 records after each model run, considering a stopping point where no new records are encountered in 2 subsequent sets of 150. All records not screened manually will be reported in the final review.

Data coding strategy

All included full texts will be subjected to data coding and meta-data extraction as follows.

Meta-data to be coded

All included full texts will be coded and will have the meta-data described in Table 2 extracted.

Table 2. *Meta-data that will be coded and extracted from included full texts.*

Variable	**Description**
Citation	Author / Year / Title / Source / Volume-Issue / Pages / DOI
Abstract	The given abstract provided within the citation record from The Lens
Country	Study country/ies
Primary author country	Country of the primary author
Author affiliations	Names of organisations that authors have listed as their affiliation(s)
Geographical location	Description of study location
Farm name	Name of the fish farm (where applicable)
Farm size	Operational capacity / average stocking density
Latitude	Given or imputed study latitude (decimal degrees)
Longitude	Given or imputed study longitude (decimal degrees)
Study objectives	Author-given study objectives
Farming system	Land-based Recirculating Aquaculture Systems (RAS) / Sea-based open-net pens / In-sea floating semi-closed containment system (S-CCS) / Farming in exposed facilities
Production stage	Research and development / Roe / Fry / Smolt / Adult / Processing
Measured outcome type	Productivity / Legal / Environmental / Social / Animal welfare / Human health
Measure outcome details	Inductively coded as encountered, within the above outcome type categories
Measured outcome description	Author-given description of the measured outcome
Study type	Experimental / Observational / Modelling / Review

Study design	BA / CI / BACI / Time series / RCT / Modelling / Qualitative primary / Review (Qualitative / Mixed / Quantitative / Narrative / Mapping)
Context	Model / Laboratory / Mesocosm / Farm / External
Study length	Number of years of study
Funding statement	Author-given funding statement of financial acknowledgement
Funding body	Not reported / Not funded / Industry / Government / NGO

Consistency checking

Prior to full meta-data extraction, a subset of 5 studies will be dealt with by two independent reviewers, with all disagreements discussed in detail before the remaining full texts are distributed and coded. If there is significant disagreement a further subset of 5 studies will be reviewed and discussed prior to processing the remainder.

Study validity assessment

We will not assess the validity of the included full texts within this scoping review, since the study designs will be too diverse and a large number of critical appraisal tools for assessing risk of bias would be needed. However, we will discuss several variables in our narrative synthesis that relate to risk of bias, including study length, study type, study design, and funding bias.

Synthesis

We will produce an interactive database of all research on salmon farming, including the suite of descriptive meta-data and coding described in table 2 above. In addition, we will produce maps that plot the research attention by country and latitude/longitude. We will use figures and graphics to present the remaining information individually and across multiple categorical/numerical variables in concert, for example; a choropleth of study countries; an interactive evidence atlas showing study locations; heat maps of two or more categorical variables such as the scale and measured impacts; radial heat plots showing the distribution of studies across hierarchical outcome variables.

These visualisations will help us to identify the relative spread of research effort across included studies, indicating knowledge gaps where more primary research is needed, and knowledge clusters where sufficient evidence exists to allow for meaningful systematic reviews to be undertaken.

Declarations

Competing interests

The authors declare they have no competing financial interests.

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Author's contributions

Conceptualisation - NRH;

Methodology - NRH;

Software - MG;

Validation - NRH;

Investigation - NRH;

Writing, Original Draft - NRH, SC;

Writing, Review & Editing - NRH, MG, MS, SC, IK;

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Appendix 1. Benchmark list

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