RC036

Received: 21 February 2023 | Revised: 19 June 2023 | Accepted: 26 June 2023
DOI: 10.1111/fme.12643

REVIEW

Fisheries Management and Ecology
WILEY

A global synthesis of peer-reviewed research on the effects of hatchery salmonids on wild salmonids

John R. McMillan[1] | Brian Morrison[2] | Nick Chambers[3] | Greg Ruggerone[4] | Louis Bernatchez[5] | Jack Stanford[6] | Helen Neville[1]

[1]Trout Unlimited, Arlington, Virginia, USA
[2]Brian Morrison Consulting, Peterborough, Ontario, Canada
[3]School of Aquatic & Fishery Sciences, University of Washington, Seattle, Washington, USA
[4]Natural Resources Consultants, Seattle, Washington, USA
[5]IBIS (Institut de Biologie Intégrative et des Systèmes), Université Laval, Québec City, Québec, Canada
[6]Flathead Lake Biological Station, University of Montana, Polson, Montana, USA

Correspondence
John R. McMillan, The Conservation Angler, 16430 72nd Ave W, Edmonds, WA 98026, USA.
Email: john@theconservationangler.org

Abstract

Hatcheries have long produced salmonids for fisheries and mitigation, though their widespread use is increasingly controversial because of potential impacts to wild salmonids. We conducted a global literature search of peer-reviewed publications (1970–2021) evaluating how hatchery salmonids affected wild salmonids, developed a publicly available database, and synthesized results. Two hundred six publications met our search criteria, with 83% reporting adverse/minimally adverse effects on wild salmonids. Adverse genetic effects on diversity were most common, followed by effects on productivity and abundance via ecological and genetic processes. Few publications (3%) reported beneficial hatchery effects on wild salmonids, nearly all from intensive recovery programs used to bolster highly depleted wild populations. Our review suggests hatcheries commonly have adverse impacts on wild salmonids in freshwater and marine environments. Future research on less studied effects—such as epigenetics—could improve knowledge and management of the full extent of hatchery impacts.

KEYWORDS
artificial propagation, hatchery salmonids, hatchery supplementation, salmonid captive-breeding, salmonid enhancement, salmonid stocking

1 | INTRODUCTION

For over one hundred years, hatcheries have been used to propagate and release salmonids across the globe (Jonsson, 1997; Waples, 1991; Zaporozhets & Zaporozhets, 2004), largely to subsidize fisheries, attempt to mitigate for habitat loss and overexploitation (Araki & Schmid, 2010; Hilborn, 1992; Maynard & Trial, 2014) and, more recently, to try to rebuild depleted populations of wild salmonids (Berejikian & Van Doornik, 2018; Hagen et al., 2021; Hess et al., 2012). Hatchery salmonids currently underpin many recreational, commercial, and (in the lower-48 of the United States in particular) legally obligated mitigation and tribal treaty fisheries, but the pervasive reliance on hatcheries remains contentious (Claussen & Philipp, 2022; Harrison et al., 2019; Kleiss, 2004). Although there is substantial evidence that hatchery salmonids generally have lower relative fitness than wild salmonids (Bouchard et al., 2022; Christie et al., 2014; Milot et al., 2013), continuing debate centers on the broad potential effects of releasing hatchery salmonids into nature and their potential impacts on sympatric wild salmonids (see Section 2 and Figure 1 for the definition of effect and impact), particularly when it comes to recovery of threatened and endangered populations (Araki & Schmid, 2010; Paquet et al., 2011; Young, 2013).

Evaluating and synthesizing the breadth of potential hatchery effects is complicated, however, because results may depend on

Fisheries Management and Ecology

several factors. For instance, while adverse effects on wild salmonids have been commonly reported, others have found beneficial effects (Maynard & Trial, 2014; Miller et al., 1990; Naish et al., 2007), and publications cover a range of potential effects on different "Viable Salmonid Population parameters" (VSP: McElhany et al., 2000)—distribution (Laffaille, 2011), diversity (Bernaś et al., 2014), abundance (Willmes et al., 2018), and productivity of wild salmonids (Nickelson, 2003)—that may occur through different pathways such as ecological or genetic processes (Allendorf, 1991; Flagg et al., 2000; Neff et al., 2011), disease (Lamaze et al., 2014), or fishing (Hilborn & Eggers, 2000; Naish et al., 2007). Further, responses can differ among species (Araki & Schmid, 2010); the existing body of literature encompasses numerous salmonid species, and within species, there can be very different life histories such as individuals that migrate to the ocean and back (anadromous) or remain and mature in freshwater (resident) (Gossieaux et al., 2019; Maynard & Trial, 2014; Naish et al., 2007).

The source broodstock and intent of the hatchery program could also influence the type and magnitude of effects on wild fish. Traditional "production" type hatchery programs generally breed only hatchery individuals, often from a non-local source, and stock them to provide fisheries, and consequently, their effects could differ from modern "supplementation" programs that integrate some wild fish into their broodstock (to reduce genetic impacts) and release fish to enhance fisheries and the number of naturally spawning adults (Araki & Schmid, 2010; HSRG, 2015; Naish et al., 2007, Table 1). Moreover, smaller-scale "recovery" programs, including some captive breeding efforts, that rely solely on wild fish as broodstock to provide a short-term, conservation boost to highly depleted wild populations (Berejikian & Van Doornik, 2018; Janowitz-Koch et al., 2019) may offer more conservation benefits to wild salmonids than longer running supplementation programs that try to achieve multiple goals (Bowlby & Gibson, 2011; Naish et al., 2007).

Finally, large releases of hatchery salmonids also raise the potential for ecological effects in the North Pacific Ocean (Ruggerone & Irvine, 2018). An emerging body of research suggests hatchery salmon have triggered density-dependent responses in several co-mingling populations of wild salmonids, including but not limited to, reduced survival (Fukuwaka & Suzuki, 2000; Cunningham et al., 2018), growth (Kaeriyama et al., 2011), fecundity (Shaul & Geiger, 2016), and body size and abundance (Ruggerone et al., 2012).

The immense body of literature makes it difficult to interpret the information and results succinctly (Araki & Schmid, 2010). Research on the potential effects of hatchery salmonids on wild salmonids dates to the early-1900s and spans numerous species and three continents (Jonsson, 1997; Lichatowich, 2001; Maynard & Trial, 2014; Zaporozhets & Zaporozhets, 2004). In practice, scientists, managers, and policymakers may be familiar with studies in their region and on species they are tasked with managing and conserving but may be unaware of research outside their immediate scope of focus. For example, there have been numerous hatchery studies on Atlantic salmon (*Salmo salar*) and brown trout (*Salmo trutta*) that commonly reference one another (Horreo et al., 2014; Nilsson et al., 2008) and there are several publications on brook charr (*Salvelinus fontinalis*) (Bruce et al., 2020; Létourneau et al., 2018; Marie et al., 2010), yet those results are rarely cited or utilized in research on Pacific Salmon and vice-versa (e.g., Tatara & Berejikian, 2012; Wang et al., 2002). Accordingly, while several studies have reviewed hatchery effects on wild salmonids (Fraser, 2008; Naish et al., 2007), few have covered both *Oncorhynchus* and *Salmo* spp. (e.g., Araki & Schmid, 2010; Maynard & Trial, 2014), and to our knowledge, none have attempted to account for the entire breadth of publications for all species across the globe from freshwater to the ocean.

An evaluation of the overall body of peer-reviewed literature seems particularly valuable given the ongoing debate over hatchery practices in the western United States and other regions where salmonid recovery efforts are underway. A synthesis of publications from across the globe, covering various species and spanning freshwater and saltwater ecosystems would consolidate a broad array of literature and findings, and offer comprehensive insight into the patterns and processes of how hatchery salmonids potentially affect wild salmonids (Figure 1). For example, a synthesis could help determine: (1) How many studies have been published and how is the research distributed by year, country, species, and life history? (2) What proportion of publications reported adverse or beneficial hatchery effects on wild fish and how did those results vary by year, country, species, and life history? (3) Do potential effects differ based on the type of hatchery program? (4) Which VSP parameters (abundance, productivity, diversity, spatial distribution: McElhany et al., 2000) are most affected and what are the most common pathways of hatchery influence, such as genetic or ecological processes? and, (5) How many publications have evaluated potential hatchery effects in the open ocean and what are the general results so far? In turn, such an effort would help illuminate gaps in knowledge and areas for future research, increase the breadth of information available to decision-makers, and improve opportunities for collaborative research among scientists across different regions and countries.

2 | METHODS AND SYNTHESIS

2.1 | Objective and focus

Our objective was to collate all relevant peer-reviewed publications from across the globe and synthesize the main results—as presented by the authors—to answer broad-scale questions that are important to those tasked with researching, managing, and conserving salmonids (Figure 1). We also sought to incorporate the publications into an easily accessible database that can serve as a standing resource and be updated by scientists as new information comes to light (Appendix S1). In this effort, we reviewed only publications that explicitly and quantitatively evaluated whether stocking of hatchery salmonids affected the diversity, abundance, productivity (including effects on growth and survival as components of productivity), and distribution of wild salmonids via genetics, ecology, fishing, or disease (e.g., Berejikian & Van