Transactions of the American Fisheries Society, 2026, **00**, 1–29
https://doi.org/10.1093/tafafs/vnag034
Published: 5 October 2026
Review

Review of reintroduction as a conservation tool for Pacific salmon in western North America

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Abstract

***Objective*: Reintroduction of Pacific salmon *Oncorhynchus* spp. into historically occupied habitat is a widely used management strategy in western North America. Since the last major review, new information on donor populations, fish passage, dam removal, ecological interactions, monitoring, and cultural and societal considerations has emerged. We conducted a comprehensive review to synthesize these advances and inform best practices.**

***Methods*: Co-authors representing federal, state, tribal, academic, and private organizations with expertise in Pacific salmon reintroductions convened to synthesize literature, evaluate case studies, and update key findings, lessons, and best practices. We developed a framework to assess program status using biological and cultural benchmarks and analyzed adult abundance trends for 26 reintroduced populations of Chinook Salmon *O. tshawytscha*, Coho Salmon *O. kisutch*, Sockeye Salmon *O. nerka*, and steelhead *O. mykiss* across 16 reintroduction sites in the Pacific Northwest, USA.**

***Results*: We reviewed 51 Pacific salmon reintroductions, along with relevant studies providing insights into reintroduction protocols and outcomes. Of the programs that have been implemented to date, 48 (94%) remain active and 27 (53%) have operated for at least 20 years. Tribal involvement has been instrumental in the initiation and advancement of many of these efforts and is focused on restoring cultural, spiritual, and ecological**

Received: February 20, 2026. **Revised:** August 6, 2026. **Accepted:** August 7, 2026
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Elements of the work have been written by employees of the US Government.

connections to salmon. Most populations (81%) evaluated in a trends analysis exhibited stable or increasing abundance, demonstrating that reintroduction is effective at reestablishing populations in historical habitats. The restoration of anadromy to these habitats has ecological benefits that are commonly recognized, such as restoring marine-derived nutrient transport, providing access to cold water in headwater tributaries, contributing to fisheries, and benefiting other species of concern (e.g., sea lions and orcas *Orcinus orca*) that rely on salmon for prey. Benefits of reintroduction also include cultural reconnections between salmon and Indigenous Peoples. Salmon are considered "relatives" and are central to the way of life in many Indigenous cultures, but this connection has been lost in places where salmon have been extirpated from their historical ranges. Such losses have resulted in great harm to Indigenous communities, and reintroduction has the potential to begin restoring what has been lost. While we acknowledge the importance of identifying and mitigating the risks associated with reintroduction, we also maintain that there are inherent risks of inaction, such as ongoing harm to communities that rely on Pacific salmon.

***Conclusions*: This synthesis updates the existing state of knowledge for Pacific salmon reintroduction. Our review indicates that reintroduction efforts are supporting many stable or increasing populations throughout western North America in addition to restoring culturally important species for Indigenous communities.**

Keywords: co-management, dam removal, fishways, trap and haul

Lay summary

Reintroduction is a management action that has been successfully used to restore Pacific salmon to historically accessible habitat and to increase population abundance. Additionally, reintroduction provides numerous ecological, cultural, and societal benefits.

Introduction

Pacific salmon *Oncorhynchus* spp. (hereafter, generally referred to as "salmon") have evolved to occupy diverse coldwater habitats from Japan and California northward to Alaska and are culturally and economically important across their native range (Quinn, 2018). Salmon were historically present in many rivers throughout western North America and served as an important nutritional source for humans and for aquatic and terrestrial ecosystems (Cederholm et al., 1999; Gende et al., 2004; Y. Zhang et al., 2003). Salmon are vitally important to Indigenous Peoples[1] in western North America, who have strong cultural and spiritual connections to these fishes (Blanchet et al., 2022) and are commonly self-described as "salmon people" (Columbia River Inter-Tribal Fish Commission, 2025; Gerwing & McDaniels, 2006; Setting Sun Circle, 2022). Salmon contribute to local economies, are an icon in contemporary Pacific Northwest (USA) society, and support one of the most valuable commercial fisheries in the United States (Quinn, 2018). Because of their importance, salmon have received intense management focus for decades (Munsch et al., 2023; National Research Council [NRC], 1996; Ruckelshaus et al., 2002), but despite these efforts, many populations are imperiled throughout their native range (Atlas et al., 2023; Ford, 2022).

Many factors have contributed to the decline of salmon in western North America since European contact, including the "four Hs" (harvest, hatcheries, hydropower, and habitat; Ruckelshaus et al., 2002) and changing climate (Crozier & Siegel, 2023). Gustafson et al. (2007) estimated that 29% of the historical populations (out of approximately 1,400) have been extirpated, and Ford (2022) reported that 18 (39%) of 46 evolutionarily significant units (or distinct population segments; Waples, 1991) are currently listed as threatened or endangered under the U.S. Endangered Species Act (ESA). Salmon migrations frequently span thousands of kilometers and cross multiple local, tribal, state, provincial, federal, and international jurisdictions. Because of this, salmon management requires complex legal and management frameworks that encompass fishing regulations, quotas, and various aspects of salmon habitat, including flow, sediment, thermal regimes, toxicant exposure, and access (Couch et al., 2026; Ulaski et al., 2025).

Dam proliferation during the 20th century is among the most prominent causes of salmon declines in western North America. The National Inventory of Dams database lists 3,656 federally owned or regulated dams in Washington, Oregon, California, and Idaho (National Inventory of Dams, 2026). Many of these dams block or restrict access to salmon habitat, reduce survival during migration, or modify flows, creating conditions that often favor nonnative predators and competitors (Nehlsen et al., 1991; NRC, 1996; U.S. Army Corps of Engineers, 2025; Waldman & Quinn, 2022). Large dams prevent salmon from accessing an estimated 42–95% of their historical spawning and rearing habitat in major rivers of the Pacific Northwest, including the Snake, Columbia, and Willamette rivers (British Columbia, Idaho, Oregon, and Washington), and in California's Central Valley (Baldwin et al., 2022; Dauble et al., 2003; National Marine Fisheries Service, 2025; Sheer & Steel, 2006).

Reintroduction is often identified as a priority for salmon recovery efforts because it can increase population spatial structure and diversity (Anderson et al., 2014; National Marine Fisheries Service, 2018) and is supported by several aspects of salmon ecology. Salmon have an innate tendency to colonize vacant, suitable habitat (Pess et al., 2014, 2024), as evidenced

[1] In this paper, we use several terms when referring to Indigenous Peoples, including tribe(s), tribal, Indian(s), and Native American(s).

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by successful introductions into diverse nonnative habitats, including the Laurentian Great Lakes (Langan et al., 2026; Quinn, 2018), and in various countries throughout the Southern Hemisphere (Correa & Gross, 2008; Quinn et al., 2001). Their diverse life history characteristics allow for local adaptation that leads to complex population structures (i.e., portfolios), which are critical for maintaining population resilience to factors such as environmental change (Griffiths et al., 2014; Hanski & Simberloff, 1997; Hilborn et al., 2003; Schtickzelle & Quinn, 2007). These factors underscore an essential principle for salmon recovery: Maintaining resilience and stability within a metapopulation requires preserving small, connected populations and diverse life history strategies (Cordoleani et al., 2021; Young, 1999). For these reasons, recovery efforts often focus on reintroducing salmon into coldwater habitats that are typically found in mountainous regions upstream of dams, where ecosystems remain less impacted by human disturbance.

A previous review of Pacific salmon reintroduction (Anderson et al., 2014) recognized the significant potential benefits of reintroduction for achieving conservation goals. In that work, the authors reviewed existing programs and provided recommendations and guidelines that have been foundational for contemporary efforts. Their review was primarily focused on ESA conservation goals (managed by the National Marine Fisheries Service) and included key elements and considerations for planning (benefits, risks, and constraints), implementation (colonization strategies and source population selection), and fish passage development (barrier removal, fishways, and active transport [trap and haul]). They also advocated for the dissemination of information and key findings to "build on lessons learned in planning future programs" (Anderson et al., 2014). Since the publication of their work more than a decade ago, significant technical, social, and institutional advances that are relevant to salmon reintroduction have occurred. Technical advances include new tools for population monitoring, modeling, habitat mapping, and fish passage, and social changes include growing recognition of multiple cultural frameworks, which has led to increased collaboration between western and Indigenous managers. Social and institutional changes have driven a shift toward co-management of salmon populations, which requires consideration of multiple goals and metrics of success when planning and implementing salmon reintroduction projects. Collectively, these technical, social, and institutional advances highlight the need to update the current state of knowledge for reintroduction planners and practitioners.

We conducted a review of salmon reintroduction that expanded on the scope of the review by Anderson et al. (2014) to include relevant cultural and societal elements. Our objectives were to (1) convene an experienced group of reintroduction practitioners and researchers representing federal, state, tribal, academic, and private entities; (2) characterize the role of tribal involvement in reintroduction efforts; (3) provide a conceptual framework that outlines progressive stages of reintroduction to articulate and assess a diverse spectrum of reintroduction goals; (4) summarize existing and planned Pacific salmon reintroductions and analyze available data from existing programs to describe adult abundance trends; and (5) provide updated information on important reintroduction planning topics using the practical experience of co-authors combined with information gleaned from literature review. Although salmon reintroduction projects exist throughout western North America, information in this review is sourced primarily from Pacific Northwest programs for Chinook Salmon *O. tshawytscha*, Coho Salmon *O. kisutch*, Sockeye Salmon *O. nerka*, and steelhead *O. mykiss* (anadromous Rainbow Trout).

Tribal leadership in Pacific salmon reintroduction

Tribal leadership has been critical for initiating and sustaining many reintroduction programs. Several key factors have contributed to the ability of tribes to successfully influence and partner with federal, state, and public or private utility companies to implement reintroduction, including:

1. Tribal governance and conservation ethics driven by spiritual and cultural connections to the land, water, and animals.
2. Legal obligations of federal and state governments established through treaties, executive orders, and court decisions.
3. Sovereignty and independent governance structures, which provide flexibility to pursue actions independent of political pendulums.
4. Funding, which in many cases is provided by dam owners and operators to support reintroduction efforts and which increases tribal capacity to implement reintroduction actions.

A strong conservation ethic has always been at the core of tribal culture and is evident in tribally led reintroductions of numerous species, including plains bison *Bison bison*, California condor *Gymnogyps californianus*, pronghorn *Antilocapra americana*, gray wolf *Canis lupus*, and Pacific salmon (Cliburn & Hoffmann, 2021; Galbreath et al., 2014; Hooton et al., 2008; Long et al., 2020; Quaempts et al., 2018; Schneider, 2023; Stumpff, 2022). Salmon have been central to the cultures, identities, and survival of Indigenous Peoples throughout western North America for millennia. Oral traditions passed down through generations emphasize the spiritual and practical importance of salmon. In the legend of the lost salmon (Yakama Nation), the creator told the people that salmon had been created especially for them. The creator cautioned the people, "Be sure that you only bring in as much salmon as you need to eat, and you will always have plenty." For many tribes, salmon were not only a staple food source and a crucial trade commodity but were also one of the "first foods," deeply embedded in cultural, ceremonial, and subsistence practices (Blanchet et al., 2022; Quaempts et al., 2018). Tribal Traditional Knowledge and cultural practices reflect the natural cycles of the Earth, teaching the people on the land to become unified with their brother salmon, which would sustain them throughout the year, particularly during harsh winters. Thus, cultural resource connections were and are the cornerstone to survival of many Indigenous Peoples and serve as the foundation of their spirituality. The impetus for Indigenous Peoples' efforts to restore altered habitats and recover imperiled native species is fundamentally rooted in the desire to revive deep spiritual and cultural connections among people, fishes, wildlife, and the land

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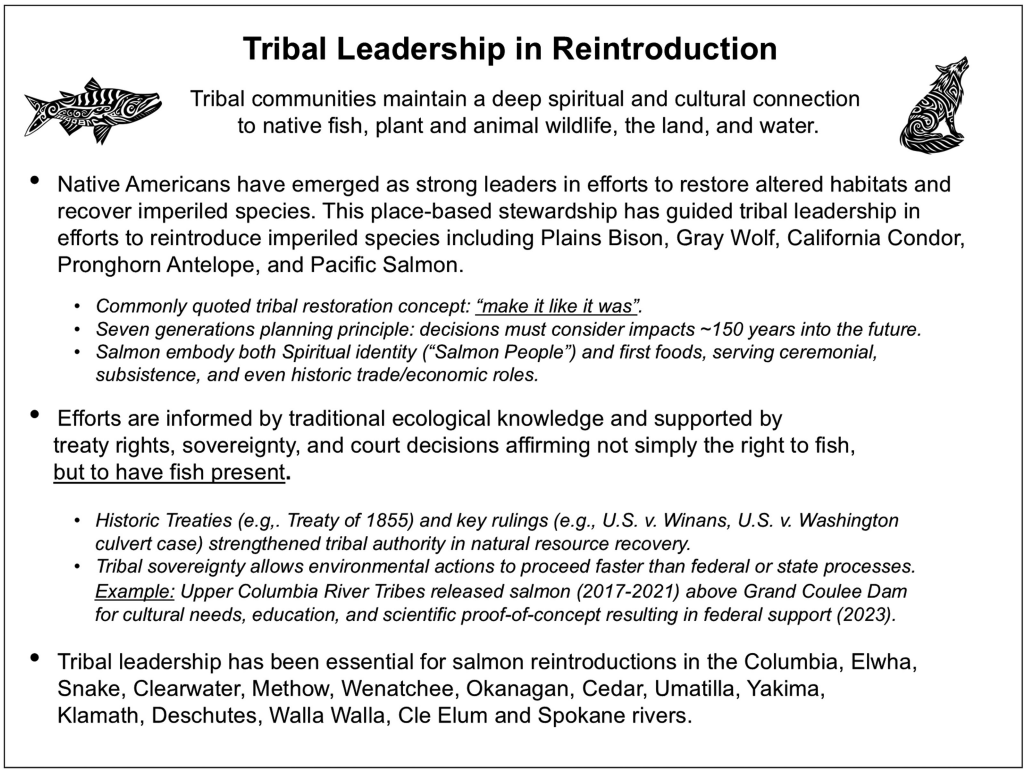


Figure 1 Examples of the importance of tribal leadership for initiation and implementation of reintroduction efforts to recover native terrestrial and aquatic species.

and water that support them (Figure 1; Long & Lake, 2018; Schneider, 2023; Stumpff, 2022). Without the historical accumulation and maintenance of tribal culture and traditions, including foundational elements such as place-based knowledge and stewardship, Indigenous Peoples remain at risk of losing their identities forever.

Extensive dam construction in the 20th century disconnected tribes from the salmon that had sustained them physically, culturally, and spiritually for thousands of years. Tribes were largely excluded from decisions affecting their natural resources. The prevailing philosophy of the era was reflected during a 1947 Columbia Basin Inter-Agency Committee meeting, where the U.S. Department of the Interior concluded that "the overall benefits are such that the present salmon run must, if necessary, be sacrificed" (Northwest Power and Conservation Council [NPCC], 2026). The construction of dams that blocked salmon migration and eliminated habitat was a violation of treaty rights articulated in the Treaty of 1855 and the Fort Bridger Treaty (NPCC, 2025b), which stipulated that Indigenous People reserved the right to fish, hunt, and gather in their "usual and accustomed places," unrestricted by reservation boundaries. In the years that followed, the resultant cultural, traditional, and subsistence injustices did not go unnoticed by tribal governments or the U.S. Government. Several key court cases have affirmed the tribes' right to fish for salmon, either due to treaty obligations (*Sohappy v. Smith*, 1969; *U.S. v. Washington*, 1974; *Herrera v. Wyoming*, 2019) or executive order (*U.S. v. Confederated Tribes of the Colville Reservation*, 2010). For example, in the Winans case (*U.S. v. Winans*, 1905), U.S. Supreme Court Justice Joseph McKenna determined that for Native Americans, salmon were "not much less necessary to the existence of the Indians than the atmosphere they breathed" (Blumm & Brunberg, 2006).

Several factors make tribal entities particularly effective leaders in reintroduction efforts. Tribal sovereignty allows them to pursue long-term conservation priorities with greater flexibility and less administrative complexity than many state and federal agencies. For example, cooperators representing five tribes on the upper Columbia River (Upper Columbia United Tribes [UCUT]) were successful in implementing "cultural and educational releases" of Chinook Salmon upstream of Grand Coulee Dam several years before the U.S. Government officially supported the reintroduction (Baldwin et al., 2022). These releases occurred in the blocked area upstream of Chief Joseph and Grand Coulee dams between 2017 and 2021 to meet multiple objectives, including (1) short-term cultural and ceremonial needs of the tribes, (2) public outreach and awareness, and (3) proof of concept for future scientific projects. The initial efforts demonstrated the importance of reintroduction in the region, eventually garnering support from agencies and elected officials that ultimately led to official support by the U.S. Government in 2023 (U.S. Department of the Interior, 2023). Many tribes also embrace the principle of "Seven Generations" planning (Arden & Wall, 1990), which encourages leaders to consider how present-day decisions will affect future generations. This long-term perspective aligns closely with salmon recovery, where habitat restoration, fish passage improvements, and population recovery often require decades to achieve measurable success.

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Although tribal conservation ethics remained intact throughout the dam-building era, tribes often lacked the financial resources and institutional capacity to implement restoration at meaningful scales. Civil rights advances, treaty enforcement through the courts, and substantial increases in salmon recovery funding after ESA listings during the 1990s enabled tribal fish and wildlife programs to expand significantly. For example, Columbia River tribes went from essentially zero federal funding in the early 1980s to now receiving approximately 48% (US$122 million per year) of the contractor costs of the NPCC's Fish and Wildlife Program funding from the Bonneville Power Administration (NPCC, 2025a). Increased capacity allowed the tribes to participate fully in regional restoration programs; hold state and federal agencies accountable to treaty obligations; and, when necessary, lead restoration efforts independently. Together, enduring cultural values, treaty rights, tribal sovereignty, and expanded funding have made tribal governments the driving force behind many contemporary Pacific salmon reintroduction efforts.

Conceptual framework for stages of reintroduction

Given the diversity of stakeholders, local ecosystems, and species of interest involved in reintroduction programs, unambiguously defining the "success" of a reintroduction can be challenging. Here, we provide a flexible, staged framework for evaluating reintroduction success that can be adapted based on the unique characteristics and objectives of individual programs. Participants in reintroduction programs often operate under different priorities, objectives, and timelines, which may be related to institutional obligations, legal requirements, or social, political, and financial incentive structures. For example, federal fisheries managers may seek to meet ESA-mandated recovery or delisting goals, state managers may pursue improved fishing opportunities for residents, and dam owners may aim to reduce water restrictions or meet Federal Energy Regulatory Commission license requirements. For Indigenous Peoples, success may mean restoring culturally important traditions and practices, which in some cases can begin with the return of a single fish to a basin. This is noteworthy because a single returning fish can have a substantial effect by symbolizing an important first step along a restorative pathway and providing opportunities for public outreach about the social, ecological, and cultural benefits associated with restoring salmon to a watershed. To accommodate the wide range of priorities and objectives held by program participants, reintroduction efforts require sustained communication, collaboration, and adaptive management. Given the diversity of stakeholders involved in reintroduction, program outcomes cannot be adequately measured based on any single outcome (e.g., ESA delisting). However, developing a shared framework for program success that includes the perspectives of all participants can be valuable for promoting and sustaining collaboration.

To reflect the long-term nature of salmon reintroduction, the diversity of program participants, and the involvement of Indigenous groups, we developed a conceptual framework for defining reintroduction success based on ecological outcomes, management goals, and cultural needs (Table 1). This framework, which includes five categorical stages, shifts the focus of success away from a single metric and acknowledges that population recovery is a phased process (e.g., Hatchery Scientific Review Group, 2012) that involves biological, ecological, cultural, and societal factors. The earliest stage (stage 1: reintroduction initiation) includes initial reintroduction activities during which individuals of one life stage (juvenile or adult) are released at the reintroduction site. During this stage, fish handling and transport protocols and existing passage options

Table 1 Conceptual framework that includes five progressive stages for Pacific salmon reintroduction. The framework considers biological and cultural elements that are important in each stage.

Stage	Example outcomes	Ecological importance	Cultural importance to Indigenous communities
Stage 1: Reintroduction initiation	– Successful spawning by outplanted adults. – Juvenile outplanting (e.g., embryos, fry, parr, or smolts) results in habitat use, rearing, smolting, and out-migration.	– Demonstration of local habitat suitability and use to support specific life stages. – Demonstration of reintroduction protocol feasibility. – Partial restoration of marine-derived nutrient deposition. – Life cycle initiated through spawning, egg deposition, emergence, and fry dispersal. – Begins to restore historical ecological relationships at the reintroduction site.	– Tribal community members (re) experience the presence of *relatives* (Pacific salmon) in historical habitat. – Tribal ceremonies occur with spiritually significant animals in historically significant locations. – Inherent satisfaction that Pacific salmon have returned to ancestral habitats. – Limited fishing or harvest opportunities sometimes occur and are important contributions to outreach and education; youth participation for cultural transmission of traditional practices.

(*Continued*)

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Table 1 (*Continued*)

Stage	Example outcomes	Ecological importance	Cultural importance to Indigenous communities
Stage 2: Partial life cycle completion	– Adults return from juvenile outplanting and successfully spawn. – Juveniles are produced from spawning adults and successfully out-migrate.	– Demonstration that the reintroduction site can support multiple life stages. – May demonstrate that all stages can be supported by the reintroduction habitat(s).	– Tribal community members observe and experience life cycle transitions for Pacific salmon resulting from natural processes. – Cultural traditions expand and may include ceremonial harvest.
Stage 3: Full life cycle completion	– Return of naturally produced adults from adult outplants. – Naturally produced juvenile out-migrants are produced from successful spawning of adults that returned from juvenile outplants.	– Demonstration that local habitat and river/ocean can support the full life cycle for a population at the reintroduction site. – Demonstration that the reintroduced population is responding favorably to management actions. – Marine-derived nutrients and other ecosystem benefits build and expand.	– Ceremonies continue to expand in time, space, and complexity compared to stages 1 and 2. – Celebrating the return of naturally produced offspring takes on deeper meaning than hatchery returns.
Stage 4: Replacement	– Natural reproduction without intervention, with returning recruits per adult ≥1.0 for multiple generations.	– Demonstration that habitat, species, and management actions have resulted in a self-sustaining population with growth potential. – Marine-derived nutrients and other ecosystem benefits are significantly increased. – May indicate partial or full management goals or population recovery is achieved. – Population likely contributes as an important energy source for avian and mammal populations and to recreational, commercial, and tribal fisheries outside of the reintroduction site.	– Continued expansion in time, space, depth, and breadth of ceremonies and cultural benefits. – Subsistence fishing may become widely available to tribal community members.
Stage 5: Harvestable	– Sustained recruits per adult >1.0, and population can support managed harvest of excess adults. – Productivity gains result in subsistence, commercial, and recreational fishery opportunities.	– Full management goals (population recovery) have been achieved. – Marine-derived nutrients and other ecosystem benefits are fully realized.	– Ceremonies continue, and tribal community members expand subsistence fisheries. – Tribal communities incorporate harvest as a consistent and predictable portion of their nutritional needs. – Some tribal community members can utilize harvest as income.

can be tested, and the restoration of ecological benefits begins. Ceremonies, celebrations, and media coverage are common during this stage as salmon return to historical areas where they have typically been absent for decades. Stage 2 (partial life cycle completion) occurs when multiple life stages are present in the reintroduction site (i.e., outplanted juveniles produce returning adults, or outplanted adults produce out-migrating juveniles). This stage is important because it demonstrates that reintroduction at the site accommodates life cycle progression, and community members can observe life cycle transitions resulting from natural processes. During this stage, cultural traditions tied to salmon presence can expand and ceremonial harvest may occur. Stage 3 (full life cycle completion) is achieved when the reintroduced population

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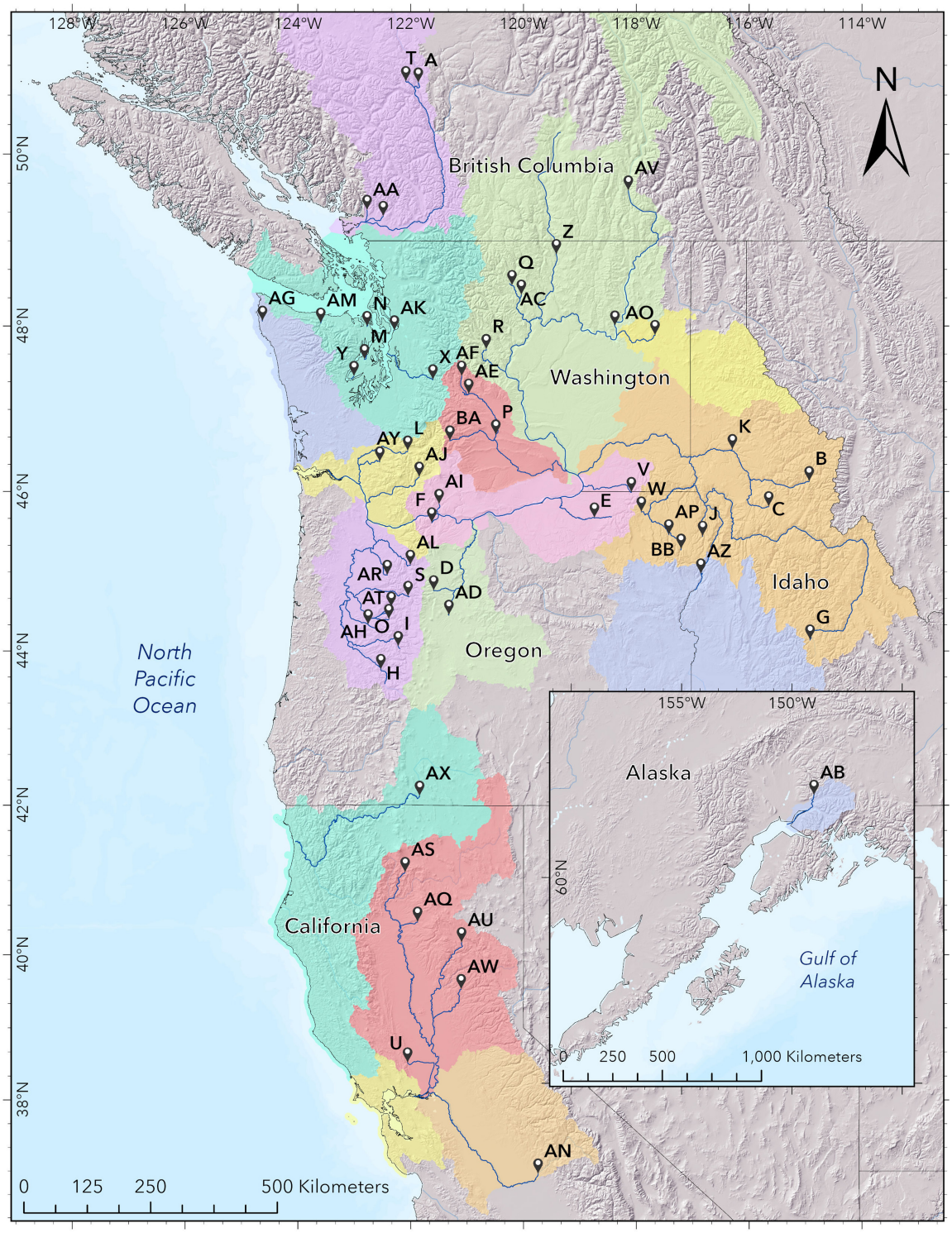


Figure 2 Map showing locations in western North America where Pacific salmon reintroductions have been implemented or are planned to be implemented. Locations in Alaska and British Columbia include Moose Creek (AB), Fraser River (A), Bridge River (T), Alouette/Coquitlam rivers (AA), and the upper Columbia River (AV). Locations in Washington include the Cowlitz River (L), Big Beef Creek (M), Chimacum Creek (N), Yakima River (P, AE), Methow River (Q), Wenatchee River (R), Walla Walla River (V), Cedar River (X), Tahuya River (Y), Okanagan River (Z), Beaver Creek (AC), Cle Elum River (AF), Umbrella Creek/Big River (AG), White Salmon River (AI), Lewis River (AJ), Japanese Gulch (AK), Elwha River (AM), upper Columbia/Spokane rivers (AO), North Fork Toutle River (AY), and Tieton River (BA). Locations in Oregon include Shitike Creek (D), Umatilla River (E), Hood River (F), Middle Fork Willamette River (H), South Fork McKenzie River (I), Big Sheep Creek (J), South Santiam River (O), North Santiam River (S), Lookingglass Creek (W), Deschutes River (AD), Calapooia River (AH), Oak Grove Fork Clackamas River (AL), Lostine River (AP), Molalla River (AR), Middle Santiam River/Quartzville Creek (AT), Klamath River (AX), Pine Creek (AZ), and Wallowa River (BB). Locations in Idaho include the Selway River (B), South Fork Clearwater River (C), Salmon River (G), and Clearwater River (K). Locations in California include Putah Creek (U), Battle Creek (AQ), McCloud River (AS), North Fork Feather River (AU), North Yuba River (AW), and San Joaquin River (AN).

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completes all life cycle transitions, and natural production of juveniles occurs. For example, outplanted adults may produce juveniles that return as adults, or outplanted juveniles may return as adults and produce a new generation of juveniles. Full life cycle completion reconnects ocean and river ecosystems, expanding the ecological benefits of anadromy. Community members experience a deeper connection with salmon that return to their natal river. Population-limiting factors are often identified during stage 3, and actions begin to be implemented to address these issues. Stage 4 (replacement) is achieved when the reintroduced population becomes self-sustaining; the population meets or exceeds replacement (i.e., cohort replacement rate ≥ 1.0; Keefer et al., 2025) during a period of several years. In stage 4, ecological benefits of reintroduction are significantly increased, management goals are at least partly achieved, and limited harvest may occur beyond ceremonial use. The final stage (stage 5: harvestable) occurs when the reintroduced population exceeds replacement and has enough returning adults to meet conservation abundance targets, allowing for sustained subsistence, commercial, and/or recreational harvest both within and outside of the reintroduction site. Ecological benefits in the reintroduction site are fully realized during this stage, and management goals and population recovery have been achieved.

Existing and future reintroductions

We identified 51 Pacific salmon reintroductions that have been implemented in western North America since 1947, with three additional efforts currently in development (Table 2; Figure 2; Supplementary Material 1). Reintroductions have occurred in Washington (37%), Oregon (31%), British Columbia (14%), California (8%), Idaho (8%), and Alaska (1%). Most programs (88%) were initiated after 1990, and only three (6%) have been discontinued; 73% have operated for at least one decade, and 53% have operated for 20 years or more (Table 2). Focal species include Chinook Salmon (67%), Coho Salmon (27%), steelhead (20%), Sockeye Salmon (18%), Chum Salmon (8%), and Pink Salmon (4%). Reintroduction efforts were initiated using the trap-and-haul approach (45%), dam removal (13%), streamflow improvement (11%), and fishway development (9%; Table 2), and most long-term programs are adaptively managed to include additional restoration activities (e.g., habitat improvement, passage development, and predator removal). Most (78%) reintroduction sites are located at least 161 km upstream from the Pacific Ocean, and 26% are at least 644 km upstream. Many (53%) of the programs have dams in their migration corridors, and 28% of the corridors are impounded by at least seven dams (maximum = nine dams). Most programs were classified as stage 2 (43%) or stage 3 (33%), followed by stage 1 (10%), stage 4 (6%), and stage 5 (2%; Table 2), using the criteria described in the preceding section and in Table 1. All stage 1 programs were implemented between 2022 and 2025, and all stage 4 and stage 5 programs were implemented before 2005 (Table 1).

Abundance trends

We analyzed adult abundance data for a subset of existing programs to describe population trends of reintroduced salmon. This analysis was modeled after recent studies (e.g., Atlas et al., 2023; Ford et al., 2025) that used adult count data to examine long-term trends in abundance for select salmon populations. Because population trends are shaped by numerous factors, including habitat restoration, predator removal, supplementation, and ocean conditions, our analysis was not intended to explicitly describe the effects of reintroduction on population trends—rather, results from this analysis described changes in population sizes of reintroduced salmon due to a combination of ecological factors and management actions. The goal was to provide complementary insights regarding the status and potential long-term sustainability of reintroduction programs when considered alongside our conceptual framework for the stages of reintroduction (Table 2).

For our analysis, data were acquired from reintroduction programs on 16 rivers (Supplementary Material 2). Some programs had data available for a single species, while others had data for multiple species, including Chinook Salmon, Coho Salmon, Sockeye Salmon, and steelhead. The time series of adult returns ranged from 12 to 32 years and were collected between 1993 and 2025. Population trends were analyzed using first-order autoregressive models implemented in the package forecast version 8.24.0 (Hyndman & Khandakar, 2008; Hyndman et al., 2025) in R version 4.5.1 (R Core Team, 2025). Similar autoregression approaches have been widely used to model and forecast Pacific salmon count data (Hare & Francis, 1995; Noakes et al., 1990; Saila et al., 1980). Because only adult count (census) data were available for our populations of interest, more complex models (e.g., stock–recruitment models and state-space models; Atlas et al., 2023; Ford et al., 2025) were not appropriate for our data set. For the analysis, count data were log transformed, and separate first-order autoregressive models with linear time trends for calendar year were fitted for each population. Coefficients and 95% CIs for the linear time trends from each model were used to evaluate mean annual percent change in escapement for each population.

We evaluated 26 site × species populations from 16 reintroduction locations, including 11 populations of Chinook Salmon, 7 populations of Coho Salmon, 4 populations of Sockeye Salmon, and 4 populations of steelhead (Figure 3). Most (81%) populations exhibited increasing abundance trends (Figure 3; Supplementary Material 3). None of the steelhead populations and only one of the Coho Salmon populations had trend estimates that were less than zero (Figure 3). Nine populations, five of which were Coho Salmon populations, had positive trend estimates, with 95% CIs that did not overlap zero. A single population (South Fork McKenzie River Chinook Salmon) had a negative trend estimate, with a 95% CI that did not overlap zero. These results indicate that most populations with available adult return data are stable or increasing.

Okanagan River Sockeye Salmon

To demonstrate the significant potential of reintroduction to contribute to salmon recovery, we present the case study of Sockeye Salmon in the Okanagan River, a major tributary of the Columbia River (Figure 4). Historically, Sockeye Salmon used three headwater nursery lakes (Osoyoos, Skaha, and

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Table 2 Fifty-one implemented Pacific salmonid reintroductions and three planned reintroductions in western North America. Letters within parentheses in the "Location" column refer to the locations shown on the map in Figure 2. Stage definitions are provided in Table 1 (T = program terminated). Asterisks (*) in the Location column indicate that data from the program were used in the population trends analysis. The dagger (†) in the "Passage provision" column indicates a barrier created from river channelization. State and provincial abbreviations are as follows: BC = British Columbia, CA = California, ID = Idaho, OR = Oregon, and WA = Washington. Species abbreviations are as follows: CK = Chinook Salmon, CO = Coho Salmon, CM = Chum Salmon *Oncorhynchus keta*, PK = Pink Salmon *O. gorbuscha*, SK = Sockeye Salmon, and ST = steelhead.

Location (Figure 2 map code)	Initial year	Species	Initial reintroduction strategy	Passage provision	Stage
Fraser River, BC (A)	1947	PK	Natural adults	Fishway	4
Selway River, ID (B)	1961	CK	Outplanted juveniles	Trap and haul	2
South Fork Clearwater River, ID (C)	1963	CK	Natural adults	Dam removal	2
Shitike Creek, OR (D)	1983	CK	Natural adults	Dam removal; trap and haul	T
Umatilla River, OR (E)	1986	CK, CO	Outplanted juveniles	Streamflow modification; trap and haul	3
Hood River, OR (F)	1988	CK	Outplanted juveniles	Dam removal	2
Salmon River, ID* (G)	1993	SK	Outplanted juveniles	None	3
Middle Fork Willamette River, OR* (H)	1993	CK	Outplanted adults	Trap and haul	2
South Fork McKenzie River, OR* (I)	1993	CK	Outplanted adults	Trap and haul	2
Big Sheep Creek, OR (J)	1993	CK	Outplanted adults	Trap and haul	2
Clearwater River, ID* (K)	1994	CO	Outplanted juveniles	None	3
Cowlitz River, WA* (L)	1994	CK, CO, ST	Outplanted adults; outplanted juveniles	Trap and haul	3
Big Beef Creek, WA (M)	1996	CM	Outplanted juveniles	None	T
Chimacum Creek, WA (N)	1996	CM	Outplanted juveniles	None	4
South Santiam River, OR* (O)	1996	CK	Outplanted adults	Trap and haul	2
Yakima River, WA* (P)	1996	CO	Outplanted juveniles/ adults	None	3
Methow River, WA* (Q)	1997	CO	Outplanted juveniles	None	3
Wenatchee River, WA* (R)	1999	CO	Outplanted juveniles	None	3
North Santiam River, OR* (S)	2000	CK	Outplanted adults	Trap and haul	2
Bridge River, BC (T)	2000	CK, CO, ST	Natural adults	Streamflow modification	2
Putah Creek, CA (U)	2000	CK	Natural adults	Streamflow modification	2
Walla Walla River, WA (V)	2000	CK, ST	Outplanted adults	Trap and haul	3
Lookingglass Creek, OR* (W)	2001	CK	Outplanted juveniles; outplanted adults	Trap and haul	3
Cedar River, WA* (X)	2003	CK, CO	Natural adults	Fishway/dam modifications	3[a]; 2[b]

(*Continued*)

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Table 2 (*Continued*)

Location (Figure 2 map code)	Initial year	Species	Initial reintroduction strategy	Passage provision	Stage
Tahuya River, WA (Y)	2003	CM	Outplanted juveniles	None	4
Okanagan River, WA* (Z)	2004	SK	Outplanted juveniles/ natural adults	Fishway	5
Alouette River/Coquitlam River, BC (AA)	2005	SK	Natural adults	Increased streamflow	2
Moose Creek near Palmer, Alaska (AB)	2005	CK, CO	Natural adults	Barrier removal[†]	3
Beaver Creek, WA (AC)	2005	CK, ST	Natural adults	Fishway	2
Deschutes River, OR* (AD)	2007	CK, SK, ST	Outplanted juveniles	Trap and haul	2
Yakima River, WA* (AE)	2009	CK	Outplanted juveniles	None	2
Cle Elum River, WA* (AF)	2009	SK	Outplanted adults	Trap and haul	3
Umbrella Creek/Big River, WA (AG)	2009	SK	Outplanted juveniles	None	3
Calapooia River, OR (AH)	2011	CK, ST	Natural adults	Dam removal	3[c]; T[d]
White Salmon River, WA (AI)	2011	CK, CO, ST	Natural adults	Dam removal	2
Lewis River, WA* (AJ)	2012	CK, CO, ST	Outplanted adults	Trap and haul	3
Japanese Gulch, WA (AK)	2012	CO	Natural adults	Fishway	2
Oak Grove Fork Clackamas River, OR (AL)	2013	CK	Natural adults	Streamflow increase	3
Elwha River, WA (AM)	2014	CK, CM, CO, PK, SK, ST	Natural adults	Dam removal	3
San Joaquin River, CA (AN)	2014	CK	Outplanted juveniles	Trap and haul	2
Upper Columbia River/Spokane River, WA (AO)	2017	CK	Outplanted juveniles	Trap and haul	2
Lostine River, OR (AP)	2017	CO	Outplanted juveniles	Trap and haul	2
Battle Creek, CA (AQ)	2018	CK	Outplanted juveniles	Dam removal	3
Molalla River, OR (AR)	2020	CK	Outplanted juveniles	None	2
McCloud River, CA (AS)	2022	CK	Outplanted juveniles	Trap and haul	2
Middle Santiam River/Quartzville Creek, OR (AT)	2022	CK	Outplanted adults	Trap and haul	1
North Fork Feather River, CA (AU)	2023	CK	Outplanted juveniles	Trap and haul	1
Upper Columbia River, BC (AV)	2023	SK	Outplanted juveniles	Trap and haul	1
North Yuba River, CA (AW)	2024	CK	Outplanted juveniles; outplanted adults	Trap and haul	1
Klamath River, CA/OR (AX)	2024	CK, CO, ST	Natural adults	Dam removal	1
North Fork Toutle River, WA (AY)	2025	CK	Outplanted adults	Trap and haul	1

(*Continued*)

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Table 2 (*Continued*)

Location (Figure 2 map code)	Initial year	Species	Initial reintroduction strategy	Passage provision	Stage
Future reintroductions					
Pine Creek, OR (AZ)				Trap and haul	
Tieton River, WA (BA)				Trap and haul	
Wallowa River, OR (BB)				Trap and haul	

[a]Coho Salmon.
[b]Chinook Salmon.
[c]Steelhead.
[d]Chinook Salmon.

Okanagan lakes) for spawning and rearing in the Okanagan River basin (Figure 4). However, dam construction in the early 1900s eliminated access to Skaha and Okanagan lakes and confined spawning and rearing to Osoyoos Lake and a 20-km reach of the Okanagan River immediately upstream (Murauskas et al., 2021). Water management actions led to redd desiccation and scouring, and channelization and floodplain development reduced the channel length by 50% and eliminated most (96%) of the riparian habitat (Hyatt & Stockwell, 2019). These factors, along with seasonal increases in air temperature, exacerbated naturally elevated water temperatures in the lower Okanagan River, affecting adult migration and survival. During most years, river temperatures downstream of Zosel Dam exceed 20°C for several weeks during the peak adult Sockeye Salmon return, thus creating a thermal migration barrier that increases en route mortality (Hyatt & Rankin, 1999; Hyatt & Stockwell, 2019). Due to these cumulative factors, annual adult Sockeye Salmon returns declined to fewer than 2,000 fish by 1994 (Figure 4).

When Sockeye Salmon declined to critically low levels in the 1990s, the Syilx Okanagan Nation (whose homeland includes the Okanagan River) began working to prevent their extinction. Syilx leadership, through the Okanagan Nation Alliance (ONA), in collaboration with Fisheries and Oceans Canada and the British Columbia Ministry of Environment, initiated the Okanagan Basin Sockeye Salmon Reintroduction and Restoration Program in 2001 (Blanchet et al., 2022; ONA, 2014). This comprehensive and unique program enabled participating entities to identify shared interests and responsibilities for Sockeye Salmon restoration (Hyatt & Stockwell, 2019). It also integrated traditional Syilx knowledge with western science and promoted community engagement and inclusive participation in flow management decisions. Key management actions that were implemented included habitat restoration, fish passage at dams, and hatchery supplementation to augment natural production (Blanchet et al., 2022; ONA, 2014), as well as the development of the Fish and Water Management Tool (FWMT), a decision-support model funded by the Douglas County Public Utility District (Washington). The FWMT informs water management decisions aimed at restoring population productivity by minimizing losses caused by redd desiccation and scour (Correia et al., 2024; Hyatt et al., 2015), thereby maximizing fry production within given hydrological and biological constraints. Consequently, the FWMT has resulted in a twofold increase in the number of fry produced per female spawner compared to the pre-FWMT era (Bailey et al., 2025; Ng et al., 2025). As fish passage improved, ONA hatchery programs reintroduced juvenile Sockeye Salmon into Skaha and Okanagan lakes, and spawner capacity in the system was increased by the creation of spawning beds in the Penticton Channel (O'Sullivan & Alex, 2024).

Collectively, this suite of management actions produced dramatic population increases. The Osoyoos Lake component of the population has always been self-sustaining, but enhancement efforts since 2004 have contributed to its long-term sustainability (Bailey et al., 2025). Over the past 12 years, natural-origin adult returns have dominated the reintroduced Skaha Lake population, which still receives supplementation via fry outplants. Skaha Lake spawners averaged more than 21,000 individuals over the past 5 years, with the proportion of hatchery-origin spawners remaining below 0.05 (Bailey et al., 2025). Because the Okanagan Lake component is in the early stages of reintroduction, it remains the primary focus of juvenile supplementation efforts and lacks sufficient adult return data to provide meaningful insights. The overall population response to recovery efforts is noteworthy. Since 2008, the average adult returns to the Okanagan River have increased sixfold compared with the prerestoration era average (Alexander et al., 2024) and primarily comprise naturally produced fish (Bailey et al., 2025). Total adult counts exceeded 250,000 individuals in 8 years during 2008–2024, including a high of 609,940 fish in 2024 (Figure 4). During that period, Okanagan River Sockeye Salmon comprised more than 80% of the total Sockeye Salmon returns to the Columbia River basin and supported substantial recreational, commercial, and tribal harvest in both the United States and Canada. It is worth noting that this occurred during the same period when Sockeye Salmon in the Fraser River (one of the largest Sockeye Salmon-producing rivers in the world; Wong et al., 2026) experienced serious declines (Peterman & Dorner, 2012). The Okanagan River case study demonstrates the

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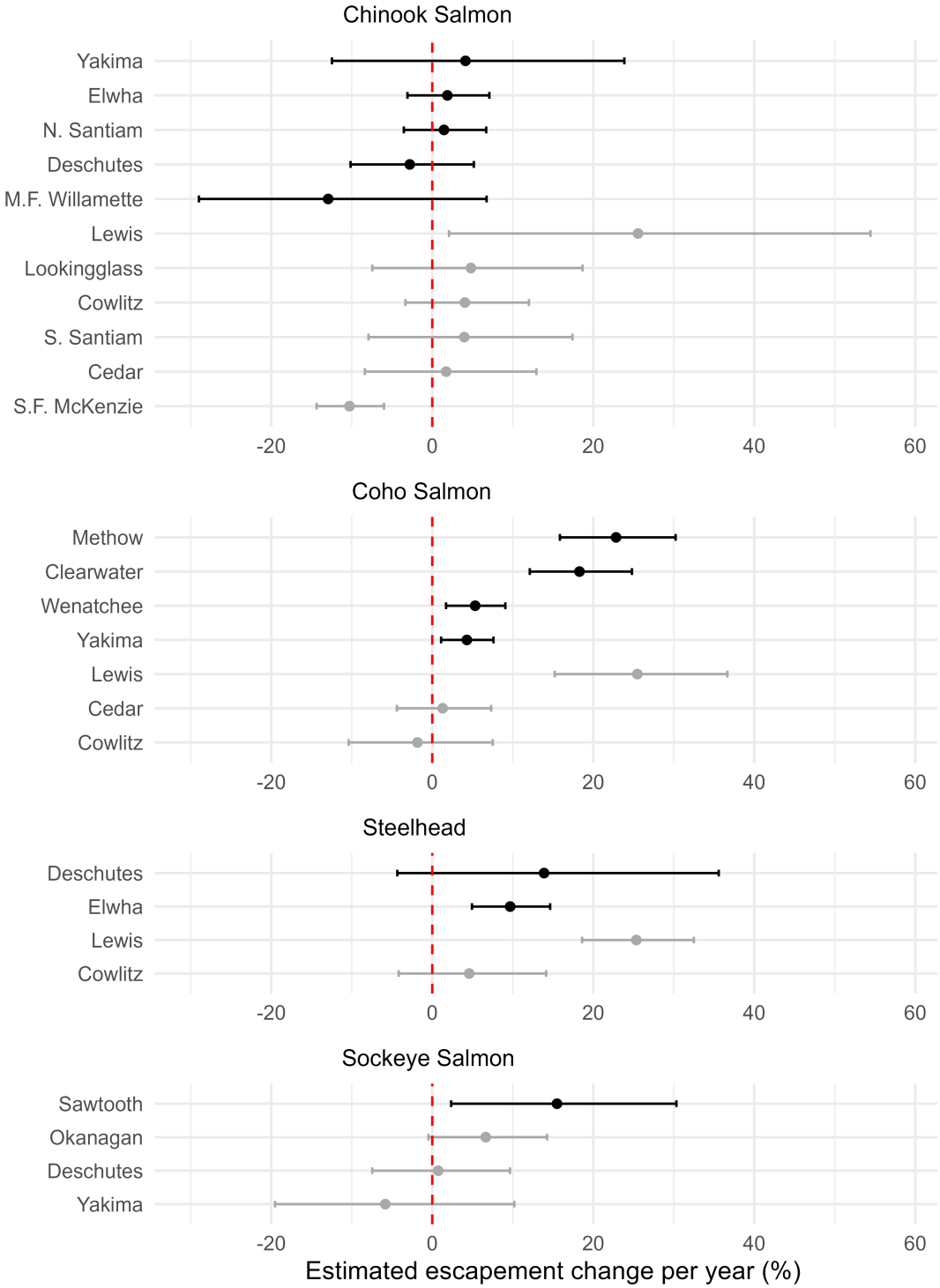


Figure 3 Estimated percent escapement change per year (with 95% CIs) for 26 reintroduced Pacific salmonid populations (refer to Figure 2 for locations); values were generated from first-order autoregressive models with linear time trends, applied to log-transformed count data for adult returns. Abbreviations are as follows: N. = North; M.F. = Middle Fork; S. = South; S.F. = South Fork.

potential for salmon reintroduction to contribute significantly to population recovery and highlights the importance of tribal reintroduction initiatives.

Critical elements of reintroduction planning

Reintroduction requires long-term commitment, sustained funding, and effective collaboration. Therefore, careful planning is required to engage stakeholders, define clear goals, and initiate community outreach. Initial planning steps may also include evaluation of benefits, risks, and costs to guide informed decisions on whether to proceed with reintroduction. In this section, we outline important components of reintroduction planning and build on the foundational topics identified by Anderson et al. (2014). Our objective is to advance current knowledge by integrating relevant research

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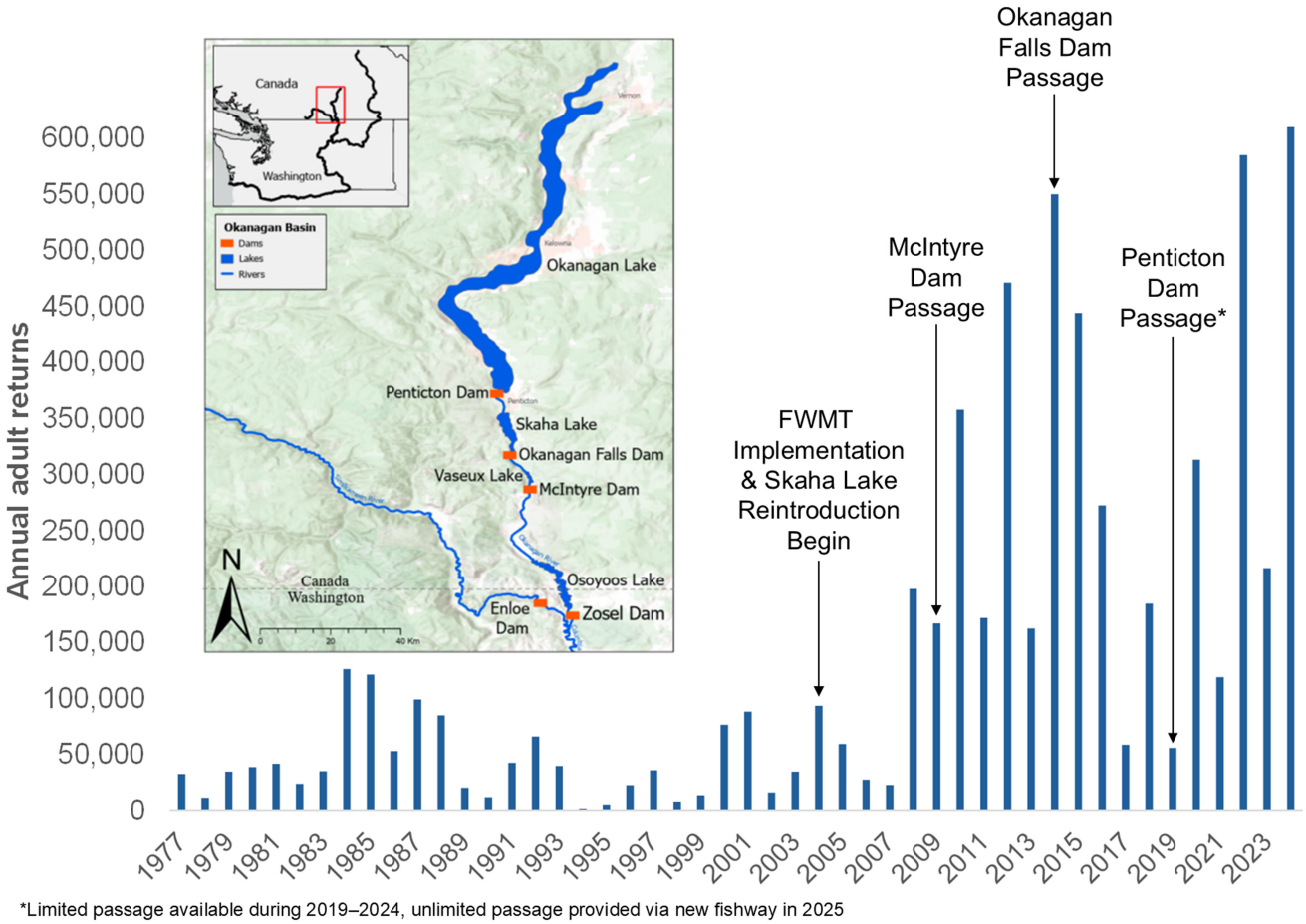


Figure 4 Number of Okanagan River-origin adult Sockeye Salmon returning to Bonneville Dam (near the Columbia River mouth) during 1977–2024 and key management milestones for reintroduction and recovery actions, including the implementation of the Fish and Water Management Tool (FWMT) and fish passage development at McIntyre, Okanagan Falls, and Penticton dams. Data used in this figure are available in Bailey et al. (2025; their Table 2).

published since the Anderson et al. (2014) review and the extensive experience of reintroduction practitioners on our author team.

Benefits, risks, and constraints

Benefits

Salmon reintroduction can provide a broad range of biological benefits, summarized by Anderson et al. (2014), in addition to many cultural and social benefits. The biological benefits of reintroducing salmon include increased spatial diversity of sensitive populations (National Marine Fisheries Service, 2022) and expanded access to coldwater habitat to provide refuge against long-term environmental change (National Marine Fisheries Service, 2018, 2025). Reintroduction can also provide genetic rescue by enhancing the diversity of sensitive populations—if a suitable source population is used (Feuerstein et al., 2024; Whiteley et al., 2015). Research has shown that an influx of diverse genetic material can improve population health and sustainability (Bell et al., 2026; Frankham, 2016; Hufbauer et al., 2015), particularly for small, isolated populations that may be targeted for reintroduction. Reintroduction within a portion of a larger metapopulation can provide spillover effects that improve overall stability and resilience of the metapopulation (Schindler et al., 2010), highlighting the importance of contributions that can accumulate even from small populations. Benefits to local ecosystems include the restoration of marine-derived nutrients and contributions to the prey base for native species that reside within (e.g., Bull Trout *Salvelinus confluentus*; Beauchamp & Van Tassell, 2001; R. C. Johnson, Jensen, et al., 2024; Lowery & Beauchamp, 2015) and outside of (e.g., marine mammals; Bailey et al., 2025; Ng et al., 2025; UCUT, 2022; Figure 4) the reintroduction site.

Beyond the measurable biological benefits, reintroduction can also provide significant cultural and social benefits that are not easily quantified. As a result of the deep cultural and spiritual connections between Indigenous Peoples and Pacific salmon that have existed since time immemorial (Atlas et al., 2021), local extirpations have resulted in a profound sense of loss for Indigenous Peoples that have been physically separated from salmon for decades. Salmon are also widely viewed as an iconic cultural symbol to the broader human population in the Pacific Northwest (Lackey, 2000; NRC, 1996); they support economically important fisheries (Criddle & Shimizu, 2014; Noakes, 2014) and receive large investments to aid recovery (Holland & Fonner, 2026; Lewis et al., 2019; Naylor et al., 2003). Thus, reintroduction can reestablish cultural and spiritual relationships, foster connections with both tribal

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and nontribal communities, and contribute to important recreational and commercial fisheries.

Risks

Reintroduction can be associated with risks that should be carefully identified and mitigated, particularly when the reintroduction site supports other native species that are threatened, culturally significant, or economically valuable and that could be affected by competition, predation, or disease transmission from reintroduced species. Ecological risk assessments incorporating expert knowledge and published information from the ecosystems of interest have been conducted for several salmon reintroductions and supplementation programs (Hardiman et al., 2017, 2022; Pearsons et al., 2012). These efforts identified site-specific risk factors, including potential pathogens that could be transmitted from donor populations, sensitive species in the reintroduction site, and ecotypes that could genetically mix with the reintroduced population. This type of risk identification process has been used to develop implementation strategies and postreintroduction monitoring priorities aimed at increasing the likelihood of reintroduction success while reducing the risks of negative outcomes (Temple & Pearsons, 2012). To date, the number of empirical evaluations conducted to evaluate the ecological effects of salmon reintroduction on native species in reintroduction sites has been limited (Fast et al., 2015; Temple & Pearsons, 2012; Temple et al., 2017), so this topic remains a critical uncertainty in many reintroduction programs and for future projects.

Constraints

The success of reintroduction efforts can be constrained by the quality and quantity of available habitat within a potential reintroduction site, as a lack of suitable habitat has the potential to negatively affect growth, survival, and reproductive success (Jensen et al., 2023; Thompson & Beauchamp, 2016). Even if salmon were historically present at a site, a variety of natural (e.g., fires and floods) and anthropogenic (e.g., mining and logging; Bubac et al., 2019; Cochran-Biederman et al., 2014; Fullerton et al., 2011; Lamothe & Drake, 2019) effects may have reduced or eliminated available habitat in the intervening period. Habitat capable of supporting reintroduction must accommodate multiple juvenile stages (i.e., embryos, fry, parr, and subyearlings) as well as adult holding and spawning. Habitat suitability assessments have been conducted prior to some reintroductions to evaluate current conditions at the reintroduction site and to estimate the numbers of each life stage that could potentially be supported (Dunham et al., 2011; McClure et al., 2018; UCUT, 2019). Assessing the thermal suitability of reintroduction habitat may be especially important in watersheds that have undergone significant changes in land use, that have experienced severe effects of climate warming (e.g., wildland fires; Isaak et al., 2010), or where the underlying geology creates stressfully warm conditions (e.g., Boughton et al., 2022).

Mortality of juvenile and adult salmon that occurs within the reintroduction site has been shown to significantly affect reintroduced populations. Predation on juvenile salmon by nonnative fishes has been documented in numerous locations (e.g., Murphy et al., 2021; Pope et al., 2024), and predation risk from piscivorous salmonids and native fishes (e.g., resident Rainbow Trout, Brown Trout *Salmo trutta*, and Northern Pikeminnow *Ptychocheilus oregonensis*) poses a chronic threat because these species share similar thermal niches with juvenile salmon (Hansen et al., 2021; R. C. Johnson, Hoy, et al., 2024; R. C. Johnson, Jensen, et al., 2024; R. C. Johnson et al., 2026; Sorel, Hansen, Connelly, Wilson, et al., 2016). Adult mortality that occurs within the reintroduction site (prespawn mortality) has been reported in some reintroduced populations, most notably for spring Chinook Salmon that are trapped and hauled above high-head dams in the Willamette River basin (Carey et al., 2024; Naughton et al., 2023). Elevated prespawn mortality has also been observed in other areas with active reintroduction programs, including Sockeye Salmon in the Cedar River, Washington (Barnett et al., 2020), and spring Chinook Salmon in Lookingglass Creek, Oregon (Crump et al., 2023). While monitoring efforts in many reintroduction programs are insufficient to fully quantify the effects of prespawn mortality on population dynamics, this source of mortality will remain a research priority because of established relationships with thermally stressful conditions and predictions of continued river warming.

For reintroductions that occur upstream of major river impoundments, juveniles may need to traverse large reservoirs during downstream migration, which introduces several constraints on survival and migration success. For example, reservoir size and complexity, thermal conditions, geomorphic characteristics, biological community composition, and dam operating protocols can all influence survival and behavior. Reservoirs have been shown to function as ecological traps owing to migration delay, ineffective dam passage, and increased mortality (Coutant, 2023; Keefer et al., 2012, 2013; Ohms et al., 2022; J. Plumb et al., 2019; Pope et al., 2024; Stockwell et al., 2026; Tiffan, Kock, Haskell, et al., 2009). Additionally, thermal reservoir stratification influences the depth distribution and migration rate of juvenile salmon (Beeman et al., 2016; Sutton & Soto, 2012; Tiffan, Kock, Connor, et al., 2009) and often provides suitable conditions for nonnative warmwater piscivores, including black bass *Micropterus* spp., Walleye *Sander vitreus*, catfish *Ictalurus* spp., and crappies *Pomoxis* spp. (Erhardt et al., 2018; Murphy et al., 2021). Similarly, environmental conditions in reservoirs may lead to elevated rates of parasite infection in juvenile salmon (Baldwin et al., 2003; Larson et al., 2024; Monzyk et al., 2015). For example, the parasitic gill copepod *Salmincola californiensis* is common in reservoirs in the Pacific Northwest (Antonelli et al., 2025; Lepak et al., 2022) and causes high infection rates in reservoir-rearing juvenile Chinook Salmon (Monzyk et al., 2015). Studies have shown that *S. californiensis* infection results in gill damage and high mortality even in the absence of macroscopically visible infections (Gardner, 2022; T. Neal et al., 2021; W. T. Neal, 2020). Other parasites, such as anchor worms *Lernaea cyprinacea* and parasitic nematodes (e.g., *Philonema* spp.; Larson et al., 2024), may also be common in reservoir environments.

Finally, juvenile growth potential may be constrained by the availability of zooplankton and benthic prey within accessible depths of the reservoir (Hansen et al., 2016; R. C. Johnson, Code, et al., 2024; R. C. Johnson, Hoy, et al., 2024;

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Sorel, Hansen, Connelly, & Beauchamp, 2016). In places where reservoir constraints jeopardize reintroduction success, efforts are focused on developing fish collection systems in upstream reaches to prevent juvenile salmon from entering reservoirs (Clancey et al., 2017; Kock, Evans, et al., 2021; Stockwell et al., 2026).

Dam removal, fish passage, and trap and haul

Dam removal

Dam removal projects in the United States have primarily focused on small structures (90% < 3 m in height; Bellmore et al., 2017), but removals of large dams (i.e., >10 m; McCaffery et al., 2024) have recently occurred in rivers that support Pacific salmon, including the Elwha River (Washington) and the Klamath River (Oregon; Figure 2; Arnett et al., 2025; Duda, Torgersen, et al., 2021; Pess et al., 2024). Dam removal is often more cost-effective than upgrading aging infrastructure to modern safety standards. It permanently eliminates migration barriers and avoids the financial burden of constructing, operating, and maintaining facilities (Born et al., 1998), including fish passage infrastructure. Furthermore, dam removal restores ecological connectivity for a broader range of species compared with engineered fish passage solutions, which are often designed only for strong swimmers like salmon (Birnie-Gauvin et al., 2019). As information on dam removal accumulates, decision makers increasingly seek to couple the cost-saving effects of dam removal projects with opportunities to restore river connectivity and promote reintroduction of native aquatic species (Duda et al., 2023; Jumani et al., 2023; Kemp & O'Hanley, 2010). Several salmon reintroductions identified in this review were implemented via dam removal (Table 2), including programs on the Hood, White Salmon, Elwha, and Klamath rivers.

Migratory fish species respond quickly to dam removal and benefit from restored access to main-stem, tributary, and side-channel habitats (Allen et al., 2016; Brewitt, 2016; Hess et al., 2021; Izzo et al., 2016; Pess et al., 2024; Waldman & Quinn, 2022). For example, in the Klamath River, where four large dams were recently removed, Coho and Chinook salmons were documented upstream in the main-stem river and in several tributaries within months of removal (Aquatic Resources Group, 2025; Arnett et al., 2025). Removing dams can restore access to diverse habitats, fostering greater life history diversity in salmonids. For example, Munsch et al. (2023) documented increased life history diversity in out-migrating Chinook Salmon, Coho Salmon, and steelhead in the Elwha River. This diversity was attributed to juveniles using tributaries with distinct hydrological and geomorphic conditions, resulting in varied abundance, age structures, and size ranges. Dam removal also led to significant increases in the population size and spatial distribution of summer steelhead, which were rarely observed in the watershed prior to removal (Duda, Torgersen, et al., 2021; Pess et al., 2024). Most major reintroduction efforts using dam removal have occurred since 2011 (Table 2); therefore, valuable insights will continue to accumulate as new generations of salmon adapt to these ecosystems.

Fish passage

In systems where dam removal is not feasible, scientific and practical advances in fish passage are facilitating reintroduction at increasingly large scales. Thanks to these advances, passage development is being considered in large, complex systems with high-head dams, including Grand Coulee and Chief Joseph dams on the Columbia River, Washington (Baldwin et al., 2022; Bellgraph et al., 2020; Hardiman et al., 2017), and Shasta Dam on the Sacramento River, California (Clancey et al., 2017; Houck, 2019; J. Plumb et al., 2019). Progress toward implementing these large-scale projects has been facilitated by numerous factors, including knowledge accumulated from long-term efforts to improve upstream and downstream fish passage (Silva et al., 2018; Skalski et al., 2016; Williams et al., 2012), insights from comprehensive topical reviews (Harris et al., 2016; Kock, Ferguson, et al., 2021; Kock, Verretto, et al., 2019; Panagiotopoulos et al., 2024), and innovations in fish passage technologies (Harris et al., 2019; Kammerlander et al., 2020; Martino et al., 2025; Moser et al., 2019). Recent examples of passage innovations that have been developed include two devices at Cle Elum Dam on the Yakima River, Washington: an upstream fish passage system (Whooshh transport device; Mesa et al., 2013) that was tested in 2017 (Kock, Evans, et al., 2018) and a new helical downstream passage device that will become fully operational in 2027 (Bureau of Reclamation, 2016). Another large downstream passage system was recently designed at Howard A. Hanson Dam on the Green River, Washington (U.S. Army Corps of Engineers, 2024). These new devices and others (e.g., Harris et al., 2019; Kammerlander et al., 2020; Martino et al., 2025; Moser et al., 2019; Zielinski et al., 2020) provide promising options for current and future salmon reintroductions upstream of high-head dams where dam removal is unfeasible (e.g., Kock et al., 2025).

Trap and haul

Dam removal and volitional passage often provide biologically superior outcomes relative to trap-and-haul programs. However, the trap-and-haul method is the most used reintroduction approach (47%; Table 2) and has contributed to population increases for several reintroductions. Dam removal and volitional passage provide options that allow fish to move freely within a watershed, whereas the trap-and-haul approach constrains movements due to transport timing (i.e., fish hauling can occur daily, weekly, or biweekly) and in some cases is associated with significant transport-related and postrelease mortality (e.g., Willamette River tributaries; Bowerman et al., 2018; Colvin et al., 2018; Keefer et al., 2010). However, in many locations, the trap-and-haul method provides the only feasible means for reintroduction when dam removal is not an option and when the scale and complexity of dams and reservoirs in a watershed make volitional passage either too expensive or unlikely to succeed. Two recent reviews (Kock, Ferguson, et al., 2021; Lusardi & Moyle, 2017) discuss many of the salient aspects of trap and haul, so we refer readers to those documents for comprehensive information about this reintroduction technique.

Donor sources

Selecting appropriate donor sources is a critical component of reintroduction planning. Ideally, a robust population of in-basin, natural-origin fish would serve as the donor source, but such populations are rarely available. In many cases, donor source options are limited to natural-origin fish from other

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basins or fish sourced from hatchery programs. Although concerns exist regarding the fitness limitations of hatchery fish (Araki et al., 2008; Chilcote et al., 2011; Williamson et al., 2010), particularly those from mixed-lineage stocks (Anderson et al., 2014; Busby et al., 1996), they have been successfully used in many existing reintroductions (Table 2). This section distills key takeaways from several reintroductions that have used various life stages (embryos, fry, parr, smolts, and adults) of hatchery- or natural-origin fish.

Several tribally led reintroductions in the Columbia River basin have used hatchery-produced juvenile Coho Salmon to initiate reintroduction, and these programs are now contributing significantly to overall production in the basin (Bosch et al., 2007, 2025; Galbreath et al., 2014). By the 1940s, annual adult returns of Coho Salmon to the interior Columbia River basin had declined to about 4,000 fish (compared with hundreds of thousands historically), and these were assumed to be primarily strays from hatcheries located downstream of Bonneville Dam (Galbreath et al., 2014; Mullan, 1983). In the mid-1990s, tribes in the Columbia River basin initiated reintroduction efforts to recover Coho Salmon in the Yakima, Wenatchee, Methow, and Clearwater rivers (Bosch et al., 2007, 2025; Galbreath et al., 2014). For those efforts, juvenile Coho Salmon from hatcheries in the lower Columbia River were acclimated and released into each river. Fish that survived, moved downstream to the ocean, and then returned as first-generation natural-origin spawners were either allowed to spawn naturally or were collected and used as hatchery broodstock to produce additional juveniles for supplementing reintroduction efforts (Galbreath et al., 2014). This process successfully established locally adapted stocks that originated from hatchery outplants. Those fish contributed to increased numbers of returning adults, expanded redd distributions within each watershed, and led to naturally producing populations within two to five generations of initial outplanting efforts (Bosch et al., 2007; Galbreath et al., 2014). Adult returns to these programs now collectively exceed, on average, 40,000 fish each year (2010–2024) and comprise approximately one-third of the total number of adult Coho Salmon that return to the interior Columbia River basin (based on counts at Bonneville Dam; Fish Passage Center, 2026).

Research has shown that juvenile life stage at release and local environmental conditions influence survival and smolt-to-adult return rates. In the Yakima River basin, Coho Salmon that were outplanted as parr (i.e., were released during fall, overwintered, and out-migrated the following spring) out-migrated faster and later than juveniles that were outplanted as smolts (i.e., were released during spring and out-migrated during spring), and survival and adult return rates differed for these groups between subbasins (Bosch et al., 2025). In the Snake River basin, Sockeye Salmon smolt releases were 3.6–9.7 times more likely to survive than releases of eyed eggs or presmolts (E. L. Johnson et al., 2020), which suffered from posthatch survival bottlenecks in nursery lakes and had lower reserves of the lipid needed for a grueling 1,450-km migration that includes eight dams (Powell et al., 2010; Waples, 1991). Ultimately, utilizing a diverse "portfolio" of multiple life stage release strategies appears to spread environmental risk, thereby optimizing success across varied habitats and environmental conditions (Bosch et al., 2025; Cordoleani et al., 2021).

Several reintroduction programs that rely on adult outplanting have demonstrated how fish origin and release site location can affect behavior and distribution, which subsequently influence the likelihood of successful reproduction. In the upper Cowlitz River, Washington, natural-origin steelhead, Chinook Salmon, and Coho Salmon migrated upstream to spawning tributaries more quickly than hatchery-origin fish during a multiyear study (2005–2012; Kock et al., 2016; Kock, Perry, et al., 2018). Hatchery-origin fish were also more likely than natural-origin fish to remain in a reservoir, which lacks spawning substrate, or to fall back downstream past a dam. These behaviors reduced their potential contribution to the spawning population. However, releasing hatchery-origin adults directly into spawning rivers rather than into the reservoir substantially increased their retention in spawning habitat (Kock et al., 2016; Kock, Ekstrom, et al., 2019). In contrast, spring Chinook Salmon that were reintroduced above Swift Dam in the Lewis River, Washington, dispersed broadly and spawned successfully across extensive habitat even though most (>80%) transported adults were of hatchery origin (Carpenter & Shappart, 2026). Researchers also observed that spawning distributions appeared to be primarily affected by streamflow, with increased occupancy of spawning habitat occurring during years when August and September flow was elevated (Shappart, 2026). A Chinook Salmon study in the South Santiam River suggested potential benefits to releasing naturally produced adults directly into a reservoir, as these fish held in the hypolimnion and had lower thermal exposure (~3–6°C cooler per day) compared with adults that were released in tributaries above the reservoir (Naughton et al., 2018). However, the rate of fallback downstream of the dam was higher for reservoir-released fish (14%) compared with river-released fish (1%). Naughton et al. (2018) concluded that despite increased fallback rates, reservoir releases provided an overall benefit to the population by reducing the risk of prespawn mortality in a system with challenging thermal conditions. Collectively, these findings show that fish origin and release site location may be influential in adult reproductive success, but they highlight the importance of monitoring to understand site-specific responses of salmon for a given reintroduction program.

The adult outplanting strategy for Sockeye Salmon reintroduction in the Cle Elum River relies on two naturally produced populations, providing a rare opportunity to assess how different donor stocks interact and perform. Cle Elum Lake is a historically important Sockeye Salmon nursery lake in the Yakima River basin, Washington. A dam constructed on the outlet river of the lake led to the extirpation of all anadromous species by the early 1900s (Matala et al., 2019). The Confederated Tribes and Bands of the Yakama Nation began implementing Sockeye Salmon reintroduction in 2009 under agreements among tribal, state, and federal agencies. The reintroduction source populations are a mix of natural-origin adult Sockeye Salmon from Lake Wenatchee, Washington (Wenatchee River basin), and Osoyoos/Okanagan lakes, Washington–British Columbia (Okanagan River basin).

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Translocation of these exogenous stocks for the Cle Elum River reintroduction was intended to be a short-term solution, with an overarching objective of establishing a self-sustaining, naturally spawning population. Managers assumed that the use of two donor stocks would maximize genetic diversity and life history variability in the naturalized population, thus boosting adaptive potential (Braun & Reynolds, 2014; Burger et al., 2000; Fraser et al., 2007). The Wenatchee and Okanagan stocks are genetically and phenotypically distinct, differing in age structure, spawn timing, and spawning distribution. Wenatchee Sockeye Salmon spawn primarily in mid-September and higher in the river system, whereas Okanagan fish spawn about 1 month later, primarily in the river near the exposed lake bed and along the lakeshore (Kock, Evans, et al., 2021; Matala et al., 2019). These stock-specific traits have persisted after several generations of natural spawning in the Cle Elum River system. Limited overlap in spawn timing results in low levels of admixture, with admixed adults comprising less than 5% of natural-origin returns, although the fitness of these individuals remains unknown (Matala et al., 2019). Additional time will be needed to better understand how these two stocks acclimate to the Cle Elum River watershed, but the approach appears to have resulted in increased spatial and temporal distribution patterns for Sockeye Salmon.

Monitoring and adaptive management

Reintroduction requires long-term commitment, active monitoring, and adaptive management to ensure that populations persist and reintroduction goals are achieved. Once implementation begins, monitoring is essential to track dispersal, evaluate survival, and measure reproductive success. Monitoring also assesses whether life cycle progression is occurring relative to program goals (e.g., out-migrating smolts from outplanted adults, or returning adults from outplanted juveniles; Table 1). The resultant data allow managers to adjust strategies and improve outcomes for juvenile and adult life stages. Although a comprehensive review of monitoring and decision-support tools is beyond the scope of this article, a general overview of these topics is provided here.

A suite of tools has been applied to monitor existing reintroduction programs, including various approaches for collecting count data (e.g., trap catches and sonar), fish tagging studies (e.g., PIT tagging and radiotelemetry/acoustic telemetry), and genetic monitoring approaches (e.g., parentage-based tagging, close-kin mark–recapture, and environmental DNA). In programs using trap-and-haul methods, trap count data for juveniles and adults provide information that can be used to evaluate population trends, and sonar has been invaluable for collecting adult return data in rivers where dam removal was implemented (Aquatic Resources Group, 2025; Pess et al., 2024). Fish tagging studies continue to provide valuable information on fish movements and survival at multiple time scales, and the capabilities of these techniques continue to expand as the technologies are refined (e.g., Hansen et al., 2021; Phillips et al., 2026; Sandford et al., 2024). Advanced genetic monitoring approaches provide the ability to evaluate reintroduction outcomes in new ways. As examples, researchers have calculated the number of breeders (Luikart et al., 2021), tracked genetic diversity and evaluated inbreeding depression over time (Waters et al., 2020), identified admixture with other populations (Chang et al., 2022), and detected the development of local adaptation (Campbell et al., 2017; Horn et al., 2020, 2025; Matala et al., 2019). Additionally, parentage-based tagging has been used to extensively evaluate reintroduction of threatened spring Chinook Salmon and steelhead above dams in Oregon's upper Willamette River basin (e.g., Evans et al., 2016; O'Malley, Dayan, Fitzpatrick, Bohn, & Grenbemer, 2023; O'Malley, Dayan, Fitzpatrick, & Couture, 2023; Weigel et al., 2019) and is one of the key monitoring tools planned for use in reintroduction within the upper Columbia River (UCUT, 2022). This pedigree-based monitoring method has also enabled the estimation of survival in out-migrating juvenile salmon that are too small for conventional tagging (Pope et al., 2024) and the estimation of adult-to-adult survival (i.e., total lifetime fitness) and cohort replacement rate (Dayan et al., 2024; Evans et al., 2016; O'Malley, Dayan, Fitzpatrick, Bohn, & Grenbemer, 2023; O'Malley, Dayan, Fitzpatrick, & Couture, 2023; Sard et al., 2016). Noninvasive methods, such as environmental DNA sampling, provide powerful ways to monitor waters for postrelease persistence, dispersal, and distributional shifts across a river system without direct handling or observation of individual fish (Duda, Hoy, et al., 2021; Hempel et al., 2020; Riaz et al., 2019), which can be particularly useful in the early stages of a reintroduction effort, when abundances are low (Brys et al., 2020; Jerde et al., 2011; Nordstrom et al., 2023).

Life cycle modeling can be used to identify critical life stages and key parameters influencing salmon population dynamics and is a useful tool for evaluating salmon reintroductions (Benjamin et al., 2024; Crozier et al., 2021; Jacobs et al., 2024). This approach can help to identify key limiting factors for population performance, thus contributing to informed decision making. Life cycle models can be used in a prospective fashion to evaluate potential outcomes of a future reintroduction effort, or they can be used retrospectively to evaluate ongoing programs. In planning stages, a detailed analysis of watershed characteristics can be used to parameterize potential productivity and capacity (Anderson et al., 2014; Honea et al., 2009; UCUT, 2019). After initiation of a reintroduction program, life cycle models can be fitted to population data to evaluate trends in productivity and capacity parameters, which can inform management actions. Life cycle models can be an important tool for adaptive management of salmon reintroduction and have been used in existing programs on the upper Columbia River (UCUT, 2022), Cowlitz and Lewis River (J. M. Plumb & Perry, 2020, 2025), Yakima River, and North Santiam River (Keefer et al., 2025) basins.

Conclusions

Salmon reintroduction has emerged as an important management tool and population recovery strategy, as evidenced by the implementation of at least 51 individual programs throughout western North America since 1947. In this review, we found that most reintroduction programs remain active, have operated for at least a decade, and support functional to increasing populations (stages 2–5) despite challenges that include long migration distances, passage at multiple dams, a

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warming climate, and changing ocean conditions. Based on the conceptual stages for reintroduction developed in this work, we found that individual programs tend to progress quickly through the initiation stage (stage 1) because all programs implemented prior to 2022 have progressed to at least stage 2 (Table 2). Conversely, it may take many years for reintroduced populations to reach population replacement; all stage 4 and stage 5 populations are from programs that have operated for at least two decades (Table 2). Results from our population trends analysis are noteworthy given recent widespread decreasing trends in abundance and ESA listing status for many (nonreintroduced) populations (Atlas et al., 2023; Ford, 2022). Although it is difficult to attribute salmon population trends to a single management action, the increasing trends in some reintroduced populations may be due in part to expanded access to historical habitat and resultant increases in productivity. We recognize that restoration to historical abundance levels in some systems may not be possible given past and ongoing changes to watersheds, migration corridors, and ocean conditions (Boughton et al., 2022; Crozier et al., 2021; Peterman & Dorner, 2012; Ulaski et al., 2025; Wilson et al., 2023). However, the presence of even small populations of salmon on the landscape can have important cultural value for stakeholder groups beyond the potential benefits for ecosystems and fisheries.

Reintroduction is a long-term, learn-by-doing process, and the ability to efficiently implement and adaptively manage individual programs largely depends on effective stakeholder relationships and consistent funding. Because priorities and objectives are likely to vary among stakeholder groups, it is important for participants to be transparent about their objectives and to acknowledge that difficult decisions and tradeoffs may be necessary during reintroduction planning and implementation. At the same time, the many shared benefits of reintroduction may serve as a foundation for establishing and maintaining productive relationships focused on common goals. The decision to proceed with implementation can be a catalyst that galvanizes stakeholder relationships while simultaneously initiating biological and societal benefits and providing key opportunities for data collection. Although risk assessment is an essential component of feasibility evaluations, the inherent risks of inaction must also be considered, and excessive delays to accommodate research timelines can erode momentum. While we acknowledge that risks to sensitive native species must be considered, we also note that reintroduction ultimately seeks to restore ecological interactions that existed for millennia prior to human intervention. The initiation of pilot-level reintroduction efforts can provide both key scientific information and institutional momentum toward achieving long-term goals. Pilot programs are often a logical step once the risks associated with disease transfer and potential population sinks have been identified and mitigated. For example, prior to establishing a reintroduction plan, the Yakama Nation began outplanting hatchery adult Chinook Salmon into the Cle Elum River to reestablish marine-derived nutrient transport upstream of Cle Elum Dam and to allow fish to begin cleaning spawning gravel during spawning. Similarly, ceremonial releases on the upper Columbia River (Baldwin et al., 2022) were useful for creating momentum, securing future funding, addressing short-term cultural objectives, and demonstrating proof of concept for full reintroduction implementation.

The reintroduction of Pacific salmon to their historical headwater habitats provides a critical climate buffer by restoring access to coldwater refuges that may mitigate the effects of future rising temperatures. Numerous studies have considered how environmental change will affect habitat and the resulting distributions of Pacific salmon (e.g., FitzGerald et al., 2021; Mantua et al., 2010; Mote et al., 2003; X. Zhang et al., 2019), highlighting the importance of high-elevation tributaries that are expected to remain suitable in the coming decades. As climate change continues to exert stronger and more unpredictable effects on Pacific salmon across freshwater and marine life stages (Caudill et al., 2021; Fullerton et al., 2018; Martins et al., 2012; Taylor, 2008; Wilson et al., 2023; X. Zhang et al., 2019), access to refuge habitat may help to buffer some of these effects.

Findings from this review emphasize the importance of reintroduction as a long-term strategy to protect Pacific salmon, but it is important to note that a suite of other management actions (e.g., habitat restoration, predator removal, and ongoing supplementation) may be needed to achieve program goals and support populations in historical habitat. Ongoing monitoring and adaptive management of reintroduced populations are critical for identifying limiting factors and informing decision making and resource allocation for reintroduction practitioners. We echo the conclusion of Anderson et al. (2014) by emphasizing that salmon reintroduction will benefit greatly if rigorous monitoring and dissemination of results are adopted as routine practice. As highlighted throughout this work, numerous technical, cultural, and institutional advances have the potential to accelerate and improve reintroduction efforts over the coming decades, and the benefits of these advances will be greatest if the community of reintroduction practitioners and researchers engage in information sharing via systematic data collection, timely dissemination, and collaborative research.

Supplementary material

Supplementary material is available at *Transactions of the American Fisheries Society* online.

Data availability

Data used in the population trends analysis are available in Supplementary Material 2.

Ethics statement

This study did not require fieldwork, so ethical guidelines associated with animal welfare were not a factor.

Funding

This research was conducted using funding provided by the California Department of Fish and Wildlife to the U.S. Geological Survey (grant agreement number Q2396042).

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Conflicts of interest

Mariah Meek holds the position of associate editor for *Transactions of the American Fisheries Society* and has not peer reviewed or made any editorial decisions for this paper.

Acknowledgments

We thank Joe Blodgett (Yakama Nation Fisheries), Conor Giorgi (Spokane Tribe of Indians), and Tom Biladeau (Coeur d'Alene Tribe) for participating in several planning meetings associated with this review. Dennis Daw (Upper Snake River Tribes), and three anonymous reviewers provided recommendations that improved this document. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Alexander, C. A., Alameddine, I., Machin, D., & Alex, K. (2024). A weight-of-evidence approach for understanding the recovery of Okanagan Sockeye Salmon. *Environmental Management*, *74*, 1063–1085. https://doi.org/10.1007/s00267-024-02031-y

Allen, M. B., Engle, R. O., Zendt, J. S., Shrier, F. C., Wilson, J. T., & Connolly, P. J. (2016). Salmon and steelhead in the White Salmon River after the removal of Condit Dam—Planning efforts and recolonization results. *Fisheries*, *41*, 190–203. https://doi.org/10.1080/03632415.2016.1150839

Anderson, J. H., Pess, G. R., Carmichael, R. W., Ford, M. J., Cooney, T. D., Baldwin, C. M., & McClure, M. M. (2014). Planning Pacific salmon and steelhead reintroductions aimed at long-term viability and recovery. *North American Journal of Fisheries Management*, *34*, 72–93. https://doi.org/10.1080/02755947.2013.847875

Antonelli, K., Murphy, C., Pollock, A., & Arismendi, I. (2025). Environmental conditions influencing the abundance of the salmonid ectoparasite *Salmincola californiensis* across upper Willamette River reservoirs, Oregon. *PeerJ*, *13*, Article e19228. https://doi.org/10.7717/peerj.19228

Aquatic Resources Group. (2025). *Fish presence monitoring in the Lower Klamath Project*. https://klamath-data-management-platform-klamath.hub.arcgis.com/pages/aquatic-resources-group

Araki, H., Berejikian, B. A., Ford, M. J., & Blouin, M. S. (2008). Fitness of hatchery-reared salmonids in the wild. *Evolutionary Applications*, *1*, 342–355. https://doi.org/10.1111/j.1752-4571.2008.00026.x

Arden, H., & Wall, S. (1990). *Wisdomkeepers: Meetings with Native American spiritual elders*. Beyond Words Publishing.

Arnett, V. R., Giudice, D., & Kang, J. (2025). *Fall Creek adult salmonid annual report Siskiyou County, CA* (Technical Report). California Department of Fish and Game.

Atlas, W. I., Ban, N. C., Moore, J. W., Tuohy, A. M., Greening, S., Reid, A. J., Morven, N., White, E., Housty, W. G., Housty, J. A., & Service, C. N. (2021). Indigenous systems of management for culturally and ecologically resilient Pacific salmon (*Oncorhynchus* spp.) fisheries. *BioScience*, *71*, 186–204. https://doi.org/10.1093/biosci/biaa144

Atlas, W. I., Sloat, M. R., Satterthwaite, W. H., Buehrens, T. W., Parken, C. K., Moore, J. W., Mantua, N. J., Hart, J., & Potapova, A. (2023). Trends in Chinook Salmon spawner abundance and total run size highlight linkages between life history, geography and decline. *Fish and Fisheries*, *24*, 595–617. https://doi.org/10.1111/faf.12750

Bailey, C. J., Stiff, H. W., Thompson, P. L., Judson, B., & Ogden, A. D. (2025). *Osoyoos Lake Sockeye Salmon* (Oncorhynchus nerka) *return abundance (1977–2023), adult age composition (1985–2023), and marine survival (1998–2021)* (Canadian Manuscript Report of Fisheries and Aquatic Sciences 3282). Fisheries and Oceans Canada. https://doi.org/10.60825/v3g8-jw96

Baldwin, C. M., Giorgi, C., & Biladeau, T. (2022). Cultural and educational releases of salmon in areas blocked by major hydroelectric projects on the Columbia River. *Journal of Aquatic Ecosystem Health and Management*, *25*, 16–26. https://doi.org/10.14321/aehm.025.01.16

Baldwin, C. M., McLellan, J. G., Polacek, M. C., & Underwood, K. (2003). Walleye predation on hatchery releases of kokanees and Rainbow Trout in Lake Roosevelt, Washington. *North American Journal of Fisheries Management*, *23*, 660–676. https://doi.org/10.1577/M02-021

Barnett, H. K., Quinn, T. P., Bhuthimethee, M., & Winton, J. R. (2020). Increased prespawning mortality threatens an integrated natural- and hatchery-origin Sockeye Salmon population in the Lake Washington basin. *Fisheries Research*, *227*, Article 105527. https://doi.org/10.1016/j.fishres.2020.105527

Beauchamp, D. A., & Van Tassell, J. J. (2001). Modeling trophic interactions of Bull Trout in Lake Billy Chinook, Oregon. *Transactions of the American Fisheries Society*, *130*, 204–216. https://doi.org/10.1577/1548-8659(2001)130%3C0204:MSTIOA%3E2.0.CO;2

Beeman, J. W., Evans, S. D., Haner, P. V., Hansel, H. C., Hansen, A. C., Hansen, G. S., Hatton, T. W., Kofoot, E. E., & Sprando, J. M. (2016). *Evaluation of the biological and hydraulic performance of the portable floating fish collector at Cougar Reservoir and Dam, Oregon, September 2015–January 2016* (Open-File Report 2016-1197). U.S. Geological Survey. https://doi.org/10.3133/ofr20161197

Bell, D. A., Kovach, R. P., Robinson, Z., Dangora, A., Mullen, J., Poole, A., Olsen, J., Spoon, R., Pipinich, C., Nelson, L., & Whiteley, A. R. (2026). Inbred source populations result in genetic rescue of imperiled trout populations. *Biological Conservation*, *314*, Article 111677. https://doi.org/10.1016/j.biocon.2025.111677

Bellgraph, B. J., Baldwin, C., Garavelli, L., Hague, Z., Perkins, W., Richmond, M., Howell, M., & McClellan, J. (2020). Estimates of Chinook Salmon spawning habitat in a blocked reach of the Columbia River upstream of Grand Coulee Dam. *Northwest Science*, *94*, 99–110. https://doi.org/10.3955/046.094.0201

Bellmore, J. R., Duda, J. J., Craig, L. S., Greene, S. L., Torgersen, C. E., Collins, M. J., & Vittum, K. (2017). Status and trends of dam removal research in the United States. *WIREs: Water*, *4*, Article e1164. https://doi.org/10.1002/wat2.1164

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Benjamin, J. R., Dunham, J. B., Scheidt, N., Rothenbuecher, C., & Sipher, C. (2024). Assisted migration of Coho Salmon: Influences of passage and habitat availability on population dynamics. *River Research and Applications*, *40*, 2009–2021. https://doi.org/10.1002/rra.4355

Birnie-Gauvin, K., Franklin, P., Wilkes, M., & Aarestrup, K. (2019). Moving beyond fitting fish into equations: Progressing the fish passage debate in the Anthropocene. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*, 1095–1105. https://doi.org/10.1002/aqc.2946

Blanchet, R., Willows, N., Johnson, S., Okanagan Nation Salmon Reintroduction Initiatives, & Batal, M. (2022). Enhancing cultural food security among the Syilx Okanagan adults with the reintroduction of Okanagan Sockeye Salmon. *Applied Physiology, Nutrition, and Metabolism*, *47*, 124–133. https://doi.org/10.1139/apnm-2021-0321

Blumm, M. C., & Brunberg, J. (2006). "Not much less necessary… than the atmosphere they breathed": Salmon, Indian treaties, and the Supreme Court—A centennial remembrance of United States v. Winans and its enduring significance. *Natural Resources Journal*, *46*, 489–546. https://www.jstor.org/stable/24889047

Born, S. M., Genskow, K. D., Filbert, T. L., Hernandez-Mora, N., Keefer, M. L., & White, K. A. (1998). Socioeconomic and institutional dimensions of dam removals: The Wisconsin experience. *Environmental Management*, *22*, 359–370. https://doi.org/10.1007/s002679900111

Bosch, W. J., Newsome, T. H., Dunnigan, J. L., Hubble, J. D., Neeley, D., Lind, D. T., Fast, D. E., Lamebull, L. L., & Blodgett, J. W. (2007). Evaluating the feasibility of reestablishing a Coho Salmon population in the Yakima River, Washington. *North American Journal of Fisheries Management*, *27*, 198–214. https://doi.org/10.1577/M05-044.1

Bosch, W. J., Pandit, S. N., Newsome, T., Matala, A. P., Frederiksen, C., Mays, Z., Lind, D., Johnston, M. V., & Blodgett, J. (2025). Emigration and survival of hatchery-reared Coho Salmon released as parr and smolts in a reintroduction program. *River Research and Applications*, *41*, 1104–1118. https://doi.org/10.1002/rra.4416

Boughton, D. A., Harrison, L. R., John, S. N., Bond, R. M., Nicol, C. L., Legleiter, C. J., & Richardson, R. T. (2022). Capacity of two Sierra Nevada rivers for reintroduction of anadromous salmonids: Insights from a high-resolution view. *Transactions of the American Fisheries Society*, *151*, 13–41. https://doi.org/10.1002/tafs.10334

Bowerman, T., Roumasset, A., Keefer, M. L., Sharpe, C. S., & Caudill, C. C. (2018). Prespawn mortality of female Chinook Salmon increases with water temperature and percent hatchery origin. *Transactions of the American Fisheries Society*, *147*, 31–42. https://doi.org/10.1002/tafs.10022

Braun, D. C., & Reynolds, J. D. (2014). Life history and environmental influences on population dynamics in Sockeye Salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*, 1198–1208. https://doi.org/10.1139/cjfas-2013-0326

Brewitt, P. K. (2016). Do the fish return? A qualitative assessment of anadromous Pacific salmonids' upstream movement after dam removal. *Northwest Science*, *90*, 433–449. https://doi.org/10.3955/046.090.0405

Brys, R., Haegeman, A., Halfmaerten, D., Neyrinck, S., Staelens, A., Auwerx, J., & Ruttink, T. (2020). Monitoring of spatiotemporal occupancy patterns of fish and amphibian species in a lentic aquatic system using environmental DNA. *Molecular Ecology*, *30*, 3097–3110. https://doi.org/10.1111/mec.15742

Bubac, C. M., Johnson, A. C., Fox, J. A., & Cullingham, C. I. (2019). Conservation translocations and post-release monitoring: Identifying trends in failures, biases, and challenges from around the world. *Biological Conservation*, *238*, Article 108239. https://doi.org/10.1016/j.biocon.2019.108239

Bureau of Reclamation. (2016). *Helix design for downstream fish passage at Cle Elum Dam* (Hydraulic Laboratory Report HL-2015-01). https://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/HL/HL-2015-01.pdf

Burger, C. V., Scribner, K. T., Spearman, W. J., Swanton, C. O., & Campton, D. E. (2000). Genetic contribution of three introduced life history forms of Sockeye Salmon to colonization of Frazer Lake, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences*, *57*, 2096–2111. https://doi.org/10.1139/f00-200

Busby, P. J., Wainwright, T. C., Bryant, G. J., Lierheimer, L. J., Waples, R. S., Waknitz, F. W. & Lagomarsino, I. V. (1996). *Status review of West Coast steelhead from Washington, Idaho, Oregon, and California* (NOAA Technical Memorandum NMFS-NWFSC-27). National Oceanic and Atmospheric Administration. https://repository.library.noaa.gov/view/noaa/2986

Campbell, N. R., Kamphaus, C., Murdoch, K., & Narum, S. R. (2017). Patterns of genomic variation in Coho Salmon following reintroduction to the interior Columbia River. *Ecology and Evolution*, *7*, 10350–10360. https://doi.org/10.1002/ece3.3492

Carey, K. C., Kent, M., Schreck, C. B., Couch, C. E., Whitman, L., & Peterson, J. T. (2024). Influence of stream temperature and human disturbance on prespawn mortality of Chinook Salmon in the Willamette River basin. *North American Journal of Fisheries Management*, *44*, 1147–1164. https://doi.org/10.1002/nafm.11035

Carpenter, P., & Shappart, J. (2026). Memorandum: Final 2025 salmon spawning survey results upstream of Swift Dam. In Pacificorp & Public Utility District No.1 of Cowlitz County (Ed.), *Lewis River fish passage program 2025 annual report—final* (Appendix D). Pacificorp. https://www.pacificorp.com/energy/hydro/lewis-river/acc-tcc.html

Caudill, C., Masingale, J., Seaborn, T., Hora, D., & Isaak, D. (2021). *Sensitivity of Idaho fishes to climate change* (Idaho Climate–Economy Impacts Assessment). James A. & Louise McClure Center for Public Policy Research, University of Idaho.

Cederholm, C. J., Kunze, M. D., Murota, T., & Sibatani, A. (1999). Pacific salmon carcasses: Essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. *Fisheries*, *24*, 6–15. https://doi.org/10.1577/1548-8446(1999)024<0006:PSC>2.0.CO;2

Chang, S. L., Ward, H. G., Elliott, L. D., & Russello, M. A. (2022). Genotyping-in-thousands by sequencing panel

Downloaded from academic.oup.com/tafs/advance-article/doi/10.1093/tafs/vnag034/8863164 by guest on 05 October 2026

development and application for high-resolution monitoring of introgressive hybridization within Sockeye Salmon. *Scientific Reports*, *12*, Article 3441. https://doi.org/10.1038/s41598-022-07309-x

Chilcote, M. W., Goodson, K. W., & Falcy, M. R. (2011). Reduced recruitment performance in natural populations of anadromous salmonids associated with hatchery-reared fish. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*, 511–522. https://doi.org/10.1139/F10-168

Clancey, K., Saito, L., Hellmann, K., Svoboda, C., Hannon, J., & Beckwith, R. (2017). Evaluating head-of-reservoir water temperature for juvenile Chinook Salmon and steelhead at Shasta Lake with modeled temperature curtains. *North American Journal of Fisheries Management*, *37*, 1161–1175. https://doi.org/10.1080/02755947.2017.1350223

Cliburn, A. D., & Hoffmann, H. M. (2021). Coming home again: Tribal sovereignty, the Tribal Wildlife Grant Program, and their potential for endemic wildlife reintroduction. *Arizona Journal of Environmental Law & Policy*, *12*, 1–39. https://heinonline.org/HOL/Page?handle=hein.journals/arijel12&div=3&g_sent=1&casa_token=&collection=journals

Cochran-Biederman, J. L., Wyman, K. E., French, W. E., & Loppnow, G. L. (2014). Identifying correlates of success and failure of native freshwater fish reintroductions. *Conservation Biology*, *29*, 175–186. https://doi.org/10.1111/cobi.12374

Columbia River Inter-Tribal Fish Commission. (2025). *We are all salmon people*. https://critfc.org/salmon-culture/we-are-all-salmon-people

Colvin, M. E., Peterson, J. T., Sharpe, C., Kent, M. L., & Schreck, C. B. (2018). Identifying optimal hauling densities for adult Chinook Salmon trap-and-haul operations. *River Research and Applications*, *34*, 1158–1167. https://doi.org/10.1002/rra.3348

Cordoleani, F., Phillips, C. C., Sturrock, A. M., FitzGerald, A. M., Malkassian, A., Whitman, G. E., Weber, P. K., & Johnson, R. C. (2021). Threatened salmon rely on a rare life history strategy in a warming landscape. *Nature Climate Change*, *11*, 982–988. https://doi.org/10.1038/s41558-021-01186-4

Correa, C., & Gross, M. R. (2008). Chinook Salmon invade southern South America. *Biological Invasions*, *10*, 615–639. https://doi.org/10.1007/S10530-007-9157-2

Correia, M., Alexis, S., & Dulic, A. (2024). Bringing the salmon home: A study of cross-cultural collaboration in the Syilx Okanagan Territory of British Columbia. *Ecology and Society*, *29*, Article 15. https://doi.org/10.5751/ES-14831-290115

Couch, C. E., Wallick, J. R., Peterson, J. T., Morgan, B. A., Keefer, M. L., Caudill, C. C., O'Malley, K. G., Murphy, C. A., White, J. S., Kelley, J. R., Hance, D. J., Hansen, G. S., & Kock, T. J. (2026). Navigating uncertainty and competing objectives: Spring Chinook Salmon recovery in the upper Willamette River. *Reviews in Fish Biology and Fisheries*, *36*, Article 76. https://doi.org/10.1007/s11160-026-10070-3

Coutant, C. C. (2023). Hydropower peaking and stalled salmon migration are linked by altered reservoir hydraulics: A multidisciplinary synthesis and hypothesis. *River Research and Applications*, *39*, 1439–1456. https://doi.org/10.1002/rra.4146

Criddle, K. R., & Shimizu, I. (2014). The economic importance of wild Pacific salmon. In P. T. K. Woo & D. J. Noakes (Eds.), *Salmon: Biology, ecological impacts and economic importance* (pp. 269–306). Nova Science Publishers.

Crozier, L. G., Burke, B. J., Chasco, B. E., Widener, D. L., & Zabel, R. W. (2021). Climate change threatens Chinook Salmon throughout their life cycle. *Communications Biology*, *4*, Article 222. https://doi.org/10.1038/s42003-021-01734-w

Crozier, L. G., & Siegel, J. E. (2023). A comprehensive review of the impacts of climate change on salmon: Strengths and weaknesses of the literature by life stage. *Fishes*, *8*, Article 319. https://doi.org/10.3390/fishes8060319

Crump, C. A., Naylor, L. M., VanSickle, A., Kennedy, J., Cottingham, M., Shippentower, G., & Les Naylor, C. P. (2023). *Evaluation of reestablishing natural production of spring Chinook Salmon in Lookingglass Creek, Oregon using a local stock (Catherine Creek)*. Confederated Tribes of the Umatilla Indian Reservation, Department of Natural Resources.

Dauble, D. D., Hanrahan, T. P., Geist, D. R., & Parsley, M. J. (2003). Impacts of the Columbia River hydroelectric system on main-stem habitats of fall Chinook Salmon. *North American Journal of Fisheries Management*, *23*, 641–659. https://doi.org/10.1577/M02-013

Dayan, D. I., Sard, N. M., Johnson, M. A., Fitzpatrick, C. K., Couture, R., & O'Malley, K. G. (2024). A single generation in the wild increases fitness for descendants of hatchery-origin Chinook Salmon (*Oncorhynchus tshawytscha*). *Evolutionary Applications*, *17*, Article e13678. https://doi.org/10.1111/eva.13678

Duda, J. J., Hoy, M. S., Chase, D. M., Pess, G. R., Brenkman, S. J., McHenry, M. M., & Ostberg, C. O. (2021). Environmental DNA is an effective tool to track recolonizing migratory fish following large-scale dam removal. *Environmental DNA*, *3*, 121–141. https://doi.org/10.1002/edn3.134

Duda, J. J., Jumani, S., Wieferich, D. J., Tullos, D., McKay, S. K., Randle, T. J., Jansen, A., Bailey, S., Jensen, B. L., Johnson, R. C., & Wagner, E. (2023). Patterns, drivers, and a predictive model of dam removal cost in the United States. *Frontiers in Ecology and Evolution*, *11*, Article 1215471. https://doi.org/10.3389/fevo.2023.1215471

Duda, J. J., Torgersen, C. E., Brenkman, S. J., Peters, R. J., Sutton, K. T., Connor, H. A., Kennedy, P., Corbett, S. C., Welty, E. Z., Geffre, A., & Geffre, J. (2021). Reconnecting the Elwha River: Spatial patterns of fish response to dam removal. *Frontiers in Ecology and Evolution*, *9*, Article 765488. https://doi.org/10.3389/fevo.2021.765488

Dunham, J., Gallo, K., Shively, D., Allen, C., & Goehring, B. (2011). Assessing the feasibility of native fish reintroductions: A framework applied to threatened Bull Trout. *North American Journal of Fisheries Management*, *31*, 106–115. https://doi.org/10.1080/02755947.2011.559830

Erhardt, J. M., Tiffan, K. F., & Connor, W. P. (2018). Juvenile Chinook Salmon mortality in a Snake River reservoir: Smallmouth Bass predation revisited. *Transactions of the American Fisheries Society*, *147*, 316–328. https://doi.org/10.1002/tafs.10026

Evans, M. L., Johnson, M. A., Jacobson, D., Wang, J., Hogansen, M., & O'Malley, K. G. (2016). Evaluating a multi-generational reintroduction program for threatened salmon using genetic parentage analysis. *Canadian Journal of Fisheries*

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and Aquatic Sciences, *73*, 844–852. https://doi.org/10.1139/cjfas-2015-0317

Fast, D. E., Bosch, W. J., Johnston, M. V., Strom, C. R., Knudsen, C. M., Fritts, A. L., Temple, G. M., Pearsons, T. N., Larsen, D. A., Dittman, A. H., & May, D. (2015). A synthesis of findings from an integrated hatchery program after three generations of spawning in the natural environment. *North American Journal of Aquaculture*, *77*, 377–395. https://doi.org/10.1080/15222055.2015.1024360

Feuerstein, C. A., Kovach, R. P., Kruse, C. G., Jaeger, M. E., Bell, D. A., Robinson, Z. L., & Whiteley, A. R. (2024). Genetic variation and hybridization determine the outcomes of conservation reintroductions. *Conservation Letters*, *17*, Article e13049. https://doi.org/10.1111/conl.13049

Fish Passage Center. (2026). *FPC homepage*. Retrieved June 2026, from https://www.fpc.org/fpc_homepage.php

FitzGerald, A. M., John, S. N., Apgar, T. M., Mantua, N. J., & Martin, B. T. (2021). Quantifying thermal exposure for migratory riverine species: Phenology of Chinook Salmon populations predicts thermal stress. *Global Change Biology*, *27*, 536–549. https://doi.org/10.1111/gcb.15450

Ford, M. J., Lindley, S. T., Barnas, K. A., Shelton, A. O., Spence, B. C., Weitkamp, L. A., Holzer, D. M., Boughton, D. A., Holmes, E. E., Myers, J. M., & Jordan, C. E. (2025). Abundance trends of Pacific salmon during a quarter century of ESA protection. *Fish and Fisheries*, *26*, 1087–1106. https://doi.org/10.1111/faf.70019

Ford, M. J. (Ed.). (2022). *Biological viability assessment update for Pacific salmon and steelhead listed under the Endangered Species Act: Pacific Northwest* (NOAA Technical Memorandum NMFS-NWFSC-171). National Oceanic and Atmospheric Administration. https://repository.library.noaa.gov/view/noaa/34363

Frankham, R. (2016). Genetic rescue benefits persist to at least the F_3 generation, based on a meta-analysis. *Biological Conservation*, *195*, 33–36. https://doi.org/10.1016/j.biocon.2015.12.038

Fraser, D. J., Jones, M. W., McParland, T. L., & Hutchings, J. A. (2007). Loss of historical immigration and the unsuccessful rehabilitation of extirpated salmon populations. *Conservation Genetics*, *8*, 527–546. https://doi.org/10.1007/s00442-007-0763-6

Fullerton, A. H., Lindley, S. T., Pess, G. R., Feist, B. E., Steel, E. A., & McElhany, P. (2011). Human influence on the spatial structure of threatened Pacific salmon metapopulations. *Conservation Biology*, *25*, 932–944. https://doi.org/10.1111/j.1523-1739.2011.01718.x

Fullerton, A. H., Torgersen, C. E., Lawler, J. J., Steel, E. A., Ebersole, J. L., & Lee, S. Y. (2018). Longitudinal thermal heterogeneity in rivers and refugia for cold water species: Effects of scale and climate change. *Aquatic Sciences*, *80*, Article 3. https://doi.org/10.1007/s00027-017-0557-9

Galbreath, P. F., Bisbee, M. A., Jr., Dompier, D. W., Kamphaus, C. M., & Newsome, T. H. (2014). Extirpation and Tribal reintroduction of Coho Salmon to the interior Columbia River basin. *Fisheries*, *39*, 77–87. https://doi.org/10.1080/03632415.2013.874526

Gardner, E. N. (2022). *An evaluation of the effects of the parasite* Salmincola californiensis *on at-risk Chinook Salmon populations* [Master's thesis, Oregon State University]. Graduate Thesis Or Dissertation. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/0g354p19h

Gende, S. M., Quinn, T. P., Willson, M. F., Heintz, R., & Scott, T. M. (2004). Magnitude and fate of salmon-derived nutrients and energy in a coastal stream ecosystem. *Journal of Freshwater Ecology*, *19*, 149–160. https://doi.org/10.1080/02705060.2004.9664522

Gerwing, K., & McDaniels, T. (2006). Listening to the salmon people: Coastal First Nations' objectives regarding salmon aquaculture in British Columbia. *Society and Natural Resources*, *19*, 259–273. https://doi.org/10.1080/08941920500460864

Griffiths, J. R., Schindler, D. E., Armstrong, J. B., Scheuerell, M. D., Whited, D. C., Clark, R. A., Hilborn, R., Holt, C. A., Lindley, S. T., Stanford, J. A., & Volk, E. C. (2014). Performance of salmon fishery portfolios across western North America. *Journal of Applied Ecology*, *51*, 1554–1563. https://doi.org/10.1111/1365-2664.12341

Gustafson, R. G., Waples, R. S., Myers, J. M., Weitkamp, L. A., Bryant, G. J., Johnson, O. W., & Hard, J. J. (2007). Pacific salmon extinctions: Quantifying lost and remaining diversity. *Conservation Biology*, *21*, 1009–1020. https://doi.org/10.1111/j.1523-1739.2007.00693.x

Hansen, A. G., Gardner, J. R., Beauchamp, D. A., Paradis, R., & Quinn, T. P. (2016). Recovery of Sockeye Salmon in the Elwha River, Washington, after dam removal: Dependence of smolt production on the resumption of anadromy by landlocked kokanee. *Transactions of the American Fisheries Society*, *145*, 1303–1317. https://doi.org/10.1080/00028487.2016.1223752

Hansen, A. G., Gardner, J. R., Connelly, K. A., Polacek, M., & Beauchamp, D. A. (2021). Resource use among top-level piscivores in a temperate reservoir: Implications for a threatened cold water specialist. *Ecology of Freshwater Fish*, *31*, 469–491. https://doi.org/10.1111/eff.12644

Hanski, I., & Simberloff, D. (1997). The metapopulation approach, its history, conceptual domain, and application to conservation. In I. Hanski & D. Simberloff (Eds.), *Metapopulation biology: Ecology, genetics, and evolution* (pp. 5–26). Academic Press. https://doi.org/10.1016/B978-012323445-2/50003-1

Hardiman, J. M., Breyta, R. B., Haskell, C. A., Ostberg, C. O., Hatten, J. R., & Connolly, P. J. (2017). *Risk assessment for the reintroduction of anadromous salmonids upstream of Chief Joseph and Grand Coulee dams, northeastern Washington* (Open-File Report 2017-1113). U.S. Geological Survey.

Hardiman, J. M., Breyta, R. B., & Ostberg, C. O. (2022). *Risk assessment for Bull Trout introduction into Sullivan Lake and Harvey Creek, northeastern Washington* (Open-File Report 2022-1032). U.S. Geological Survey. https://doi.org/10.3133/ofr20221032

Hare, S. R., & Francis, R. C. (1995). Climate change and salmon production in the northeast Pacific Ocean. In R. J. Beamish (Ed.), *Climate change and northern fish populations* (Canadian Special Publication of Fisheries and Aquatic Sciences 121, pp. 357–372). National Research Council of Canada.

Downloaded from academic.oup.com/tafs/advance-article/doi/10.1093/tafs/vnag034/8863164 by guest on 05 October 2026

Harris, J. H., Kingsford, R. T., Peirson, W., & Baumgartner, L. J. (2016). Mitigating the effects of barriers to freshwater fish migrations: The Australian experience. *Marine and Freshwater Research*, *68*, 614–628. https://doi.org/10.1071/MF15284

Harris, J. H., Roberts, D. T., O'Brien, S., Mefford, B., & Pitman, K. S. (2019). A trap-and-haul fishway for upstream transfers of migrating fish at a challenging dam site. *Journal of Ecohydraulics*, *4*, 56–70. https://doi.org/10.1080/24705357.2019.1669080

Hatchery Scientific Review Group. (2012). *Review of the Elwha River fish restoration plan and accompanying HGMPs*. https://www.streamnet.org/app/hsrg/docs/Review-of-Elwha-River-Fish-Restoration-Plan-and-HGMPs[1].pdf

Hempel, C. A., Peinert, B., Beermann, A. J., Elbrecht, V., Macher, J., Macher, T., Jacobs, G., & Leese, F. (2020). Using environmental DNA to monitor the reintroduction success of the Rhine Sculpin (*Cottus rhenanus*) in a restored stream. *Frontiers in Ecology and Evolution*, *8*, Article 81. https://doi.org/10.3389/fevo.2020.00081

Herrera v. Wyoming, 587 U.S. __. (2019).

Hess, J. E., Paradis, R. L., Moser, M. L., Weitkamp, L. A., Delomas, T. A., & Narum, S. R. (2021). Robust recolonization of Pacific Lamprey following dam removals. *Transactions of the American Fisheries Society*, *150*, 56–74. https://doi.org/10.1002/tafs.10273

Hilborn, R., Quinn, T. P., Schindler, D. E., & Rogers, D. E. (2003). Biocomplexity and fisheries sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, *100*, 6564–6568. https://doi.org/10.1073/pnas.1037274100

Holland, D. S., & Fonner, R. (2026). Econometric models for estimating costs of salmon habitat restoration in the Northwest USA. *Biological Conservation*, *320*, Article 111912. https://doi.org/10.1016/j.biocon.2026.111912

Honea, J. M., Jorgensen, J. C., McClure, M. M., Cooney, T. D., Engie, K., Holzer, D. M., & Hilborn, R. (2009). Evaluating habitat effects on population status: Influence of habitat restoration on spring-run Chinook Salmon (*Oncorhynchus tshawytscha*). *Canadian Journal of Fisheries and Aquatic Sciences*, *66*, 386–403. https://doi.org/10.1139/F09-007

Hooton, B., Smith, R., & District, K. W. (2008). *A plan for the reintroduction of anadromous fish in the Upper Klamath Basin*. Oregon Department of Fish and Wildlife.

Horn, R. L., Caisman, J., Kamphaus, C., & Narum, S. R. (2025). Genomic insights into local adaptation and migration success in reintroduced Coho Salmon of the Wenatchee River basin. *Transactions of the American Fisheries Society*, *154*, 414–423. https://doi.org/10.1093/tafafs/vnaf019

Horn, R. L., Kamphaus, C., Murdoch, K., & Narum, S. R. (2020). Detecting genomic variation underlying phenotypic characteristics of reintroduced Coho Salmon (*Oncorhynchus kisutch*). *Conservation Genetics*, *21*, 1011–1021. https://doi.org/10.1007/s10592-020-01307-0

Houck, D. L. (2019). Salmon repatriation: One tribe's battle to maintain its culture and spiritual connection to place. *Natural Resources & Environment*, *34*, 23–27.

Hufbauer, R. A., Szűcs, M., Kasyon, E., Youngberg, C., Koontz, M. J., Richards, C., Tuff, T. Y., & Melbourne, B. A. (2015). Three types of rescue can avert extinction in a changing environment. *Proceedings of the National Academy of Sciences*, *112*, 10557–10562. https://doi.org/10.1073/pnas.1504732112

Hyatt, K. D., Alexander, C. A., & Stockwell, M. M. (2015). A decision support system for improving "fish friendly" flow compliance in the regulated Okanagan Lake and River system of British Columbia. *Canadian Water Resources Journal/Revue Canadienne des Ressources Hydriques*, *40*, 87–110. https://doi.org/10.1080/07011784.2014.985510

Hyatt, K. D., & Rankin, D. P. (1999). *A habitat based evaluation of Okanagan Sockeye Salmon escapement objectives*. Fisheries and Oceans Canada, Canadian Stock Assessment Secretariat.

Hyatt, K. D., & Stockwell, M. M. (2019). Chasing an illusion? Successful restoration of Okanagan Sockeye Salmon in a sea of uncertainty. In C. C. Krueger, W. W. Taylor, and S. J. Youn (Eds.), *From catastrophe to recovery: Stories of fishery management success* (pp. 65–100). American Fisheries Society. https://doi.org/10.47886/9781934874554.ch4

Hyndman, R., Athanasopoulos, G., Bergmeir, C., Caceres, G., Chhay, L., O'Hara-Wild, M., Petropoulos, F., Razbash, S., Wang, E., & Yasmeen, F. (2025). *Forecast: Forecasting functions for time series and linear models* (R package version 8.24.0) [Computer software]. https://pkg.robjhyndman.com/forecast/

Hyndman, R. J., & Khandakar, Y. (2008). Automatic time series forecasting: The forecast package for R. *Journal of Statistical Software*, *27*, 1–22. https://doi.org/10.18637/jss.v027.i03

Isaak, D. J., Luce, C. H., Rieman, B. E., Nagel, D. E., Peterson, E. E., Horan, D. L., Parkes, S., & Chandler, G. L. (2010). Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. *Ecological Applications*, *20*, 1350–1371. https://doi.org/10.1890/09-0822.1

Izzo, L. K., Maynard, G. A., & Zydlewski, J. (2016). Upstream movements of Atlantic Salmon in the lower Penobscot River, Maine, following two dam removals and fish passage modifications. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, *8*, 448–461. https://doi.org/10.1080/19425120.2016.1185063

Jacobs, G. R., Thurow, R. F., Petrosky, C. E., Osenberg, C. W., & Wenger, S. J. (2024). Life-cycle modeling reveals high recovery potential of at-risk wild Chinook Salmon via improved migrant survival. *Canadian Journal of Fisheries and Aquatic Sciences*, *81*, 297–310. https://doi.org/10.1139/cjfas-2023-0167

Jensen, B. L., Johnson, R. C., Duda, J. J., Ostberg, C. O., Code, T. J., Mclean, J. H., Stenberg, K. D., Larsen, K. A., Hoy, M. S., & Beauchamp, D. A. (2023). Growth performance of Rainbow Trout in reservoir tributaries and implications for steelhead growth potential above Skagit River dams. *North American Journal of Fisheries Management*, *43*, 1427–1446. https://doi.org/10.1002/nafm.10944

Jerde, C. L., Mahon, A. R., Chadderton, W. L., & Lodge, D. M. (2011). "Sight-unseen" detection of rare aquatic species

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using environmental DNA. *Conservation Letters*, *4*, 150–157. https://doi.org/10.1111/j.1755-263x.2010.00158.x

Johnson, E. L., Kozfkay, C. C., Powell, J. H., Peterson, M. P., Baker, D. J., Heindel, J. A., Plaster, K. E., McCormick, J. L., & Kline, P. A. (2020). Evaluating artificial propagation release strategies for recovering endangered Snake River Sockeye Salmon. *North American Journal of Aquaculture*, *82*, 331–344. https://doi.org/10.1002/naaq.10148

Johnson, R. C., Code, T. J., Stenberg, K. D., Mclean, J. H., Jensen, B. L., Hoy, M. S., & Beauchamp, D. A. (2024). Change in growth and prey utilization for a native salmonid following invasion by an omnivorous minnow in an oligotrophic reservoir. *Hydrobiologia*, *851*, 3767–3785. https://doi.org/10.1007/s10750-024-05540-3

Johnson, R. C., Couch, C. E., Barsky, R. E., Powers, C. R., Pak, C. E., Stenberg, K. D., Diallo, J. O., Larsen, K. A., Hoy, M. S., Beauchamp, D. A., & Kock, T. J. (2026). Seasonal trophic dynamics drive growth potential and predation risk for reintroduced Chinook Salmon in Shasta Reservoir. *Frontiers in Ecology and Evolution*, *14*, Article 1843449. https://doi.org/10.3389/fevo.2026.1843449

Johnson, R. C., Hoy, M. S., Stenberg, K. D., Mclean, J. H., Jensen, B. L., Code, T. J., Ostberg, C. O., & Beauchamp, D. A. (2024). Shift in piscivory by salmonids following invasion of a minnow in an oligotrophic reservoir. *Ecology of Freshwater Fish*, *33*, Article e12778. https://doi.org/10.1111/eff.12778

Johnson, R. C., Jensen, B. L., Code, T. J., Duda, J. J., & Beauchamp, D. A. (2024). Prey supply and predation as potential limitations to feasibility of anadromous salmonid introductions in a reservoir. *Water*, *16*, Article 1157. https://doi.org/10.3390/w16081157

Jumani, S., Andrews, L., Grantham, T. E., McKay, S. K., Duda, J., & Howard, J. (2023). A decision-support framework for dam removal planning and its application in northern California. *Environmental Challenges*, *12*, Article 100731. https://doi.org/10.1016/j.envc.2023.100731

Kammerlander, H., Schlosser, L., Zeiringer, B., Unfer, G., Zeileis, A., & Aufleger, M. (2020). Downstream passage behavior of potamodromous fishes at the fish protection and guidance system "flexible fish fence." *Ecological Engineering*, *143*, Article 105698. https://doi.org/10.1016/j.ecoleng.2019.105698

Keefer, M. L., Taylor, G. A., Garletts, D. F., Gauthier, G. A., Pierce, T. M., & Caudill, C. C. (2010). Prespawn mortality in adult spring Chinook Salmon outplanted above barrier dams. *Ecology of Freshwater Fish*, *19*, 361–372. https://doi.org/10.1371/journal.pone.0204274

Keefer, M. L., Taylor, G. A., Garletts, D. F., Helms, C. K., Gauthier, G. A., Pierce, T. M., & Caudill, C. C. (2012). Reservoir entrapment and dam passage mortality of juvenile Chinook Salmon in the Middle Fork Willamette River. *Ecology of Freshwater Fish*, *21*, 222–234. https://doi.org/10.1111/j.1600-0633.2011.00540.x

Keefer, M. L., Taylor, G. A., Garletts, D. F., Helms, C. K., Gauthier, G. A., Pierce, T. M., & Caudill, C. C. (2013). High-head dams affect downstream fish passage timing and survival in the Middle Fork Willamette River. *River Research and Applications*, *29*, 483–492. https://doi.org/10.1002/rra.1613

Keefer, M. L., Yuksel, M. K., & Caudill, C. C. (2025). Assessing the role of juvenile life history and adult translocation on cohort productivity in a Chinook Salmon population. *Fisheries*, *51*, 284–297. https://doi.org/10.1093/fishmag/vuaf110

Kemp, P. S., & O'Hanley, J. R. (2010). Procedures for evaluating and prioritising the removal of fish passage barriers: A synthesis. *Fisheries Management and Ecology*, *17*, 297–322. https://doi.org/10.1111/j.1365-2400.2010.00751.x

Kock, T. J., Ekstrom, B. K., & Liedtke, T. L. (2019). *Distribution of adult Chinook Salmon (*Oncorhynchus tshawytscha*) in relation to water temperatures, Lake Scanewa, Cowlitz River, Washington, 2012* (Open-File Report 2019-1055). U.S. Geological Survey.

Kock, T. J., Ekstrom, B. K., Liedtke, T. L., Serl, J. D., & Kohn, M. (2016). *Behavior patterns and fates of adult steelhead, Chinook Salmon, and Coho Salmon released into the upper Cowlitz River basin, 2005–09 and 2012, Washington* (Open-File Report 2016-1144). U.S. Geological Survey.

Kock, T. J., Evans, S. D., Hansen, A. C., Perry, R. W., Hansel, H. C., Haner, P. V., & Tomka, R. G. (2018). *Evaluation of Sockeye Salmon after passage through an innovative upstream fish-passage system at Cle Elum Dam, Washington, 2017* (Open-File Report 2018-1116). U.S. Geological Survey.

Kock, T. J., Evans, S. D., Saluskin, B. P., Matala, A. P., Visser, R., Johnston, M. V., Galbreath, P. F., & Pope, A. C. (2021). Adult Sockeye Salmon responses to transplanting upstream of an impassable dam. *North American Journal of Fisheries Management*, *41*, 1640–1651. https://doi.org/10.1002/nafm.10675

Kock, T. J., Ferguson, J. W., Keefer, M. L., & Schreck, C. B. (2021). Review of trap-and-haul for managing Pacific salmonids (*Oncorhynchus* spp.) in impounded river systems. *Reviews in Fish Biology and Fisheries*, *31*, 53–94. https://doi.org/10.1007/s11160-020-09627-7

Kock, T. J., Morse, J. M., Stockwell, C. L., & Hansen, A. C. (2025). Evaluation of juvenile salmon behavior to inform downstream fish passage development at a high head dam. *River Research and Applications*, *42*, 30–39. https://doi.org/10.1002/rra.70047

Kock, T. J., Perry, R. W., Pope, A. C., Serl, J. D., Kohn, M., & Liedtke, T. L. (2018). Responses of hatchery- and natural-origin adult spring Chinook Salmon to a trap-and-haul reintroduction program. *North American Journal of Fisheries Management*, *38*, 1004–1016. https://doi.org/10.1002/nafm.10199

Kock, T. J., Verretto, N. E., Ackerman, N. K., Perry, R. W., Beeman, J. W., Garello, M. C., & Fielding, S. D. (2019). Assessment of operational and structural factors influencing performance of fish collectors in forebays of high-head dams. *Transactions of the American Fisheries Society*, *148*, 464–479. https://doi.org/10.1002/tafs.10146

Lackey, R. T. (2000). Restoring wild salmon to the Pacific Northwest: Chasing an illusion? In P. Koss & M. Katz (Eds.), *What we don't know about Pacific Northwest fish runs—An inquiry into decision-making under uncertainty* (pp. 91–143). Portland State University. https://www.bluefish.org/chasing.htm

Downloaded from academic.oup.com/tafs/advance-article/doi/10.1093/tafs/vnag034/8863164 by guest on 05 October 2026

Lamothe, K. A., & Drake, D. A. R. (2019). Moving repatriation efforts forward for imperilled Canadian freshwater fishes. *Canadian Journal of Fisheries and Aquatic Sciences*, *76*, 1914–1921. https://doi.org/10.1139/cjfas-2018-0295

Langan, J. A., Alsip, P. J., Abdelhady, H. U., Bronte, C. R., Goldsworthy, C. A., Kornis, M. S., Oke, K. B., Thorstad, E. B., & Turschak, B. A. (2026). The forgotten Pink Salmon in the Laurentian Great Lakes: An unexpected invasion with insights for three oceans. *Fish and Fisheries*, *27*, 813–830. https://doi.org/10.1111/faf.70084

Larson, M. S., Choudhury, A., Gardner, E. N., Konstantinidis, P., Murphy, C. A., Kent, M. L., Peterson, J. T., & Couch, C. E. (2024). Unique diet and *Philonema* sp. infections in reservoir-rearing juvenile Chinook Salmon. *Transactions of the American Fisheries Society*, *153*, 312–325. https://doi.org/10.1002/tafs.10462

Lepak, J. M., Hansen, A. G., Hooten, M. B., Brauch, D., & Vigil, E. M. (2022). Rapid proliferation of the parasitic copepod, *Salmincola californiensis* (Dana), on kokanee salmon, *Oncorhynchus nerka* (Walbaum), in a large Colorado reservoir. *Journal of Fish Diseases*, *45*, 89–98. https://doi.org/10.1111/jfd.13539

Lewis, D. J., Dundas, S. J., Kling, D. M., Lew, D. K., & Hacker, S. D. (2019). The non-market benefits of early and partial gains in managing threatened salmon. *PLoS One*, *14*, Article e0220260. https://doi.org/10.1371/journal.pone.0220260

Long, J. W., & Lake, F. K. (2018). Escaping social-ecological traps through Tribal stewardship on national forest lands in the Pacific Northwest, United States of America. *Ecology and Society*, *23*, Article 10. https://www.jstor.org/stable/26799109

Long, J. W., Lake, F. K., Goode, R. W., & Burnette, B. M. (2020). How traditional tribal perspectives influence ecosystem restoration. *Ecopsychology*, *12*, 71–82. https://doi.org/10.1089/eco.2019.0055

Lowery, E. D., & Beauchamp, D. A. (2015). Trophic ontogeny of fluvial Bull Trout and seasonal predation on Pacific salmon in a riverine food web. *Transactions of the American Fisheries Society*, *144*, 724–741. https://doi.org/10.1080/00028487.2015.1035452

Luikart, G., Antao, T., Hand, B. K., Muhlfeld, C. C., Boyer, M. C., Cosart, T., Trethewey, B., Al-Chokhachy, R., & Waples, R. S. (2021). Detecting population declines via monitoring the effective number of breeders (N_b). *Molecular Ecology Resources*, *21*, 379–393. https://doi.org/10.1111/1755-0998.13251

Lusardi, R. A., & Moyle, P. B. (2017). Two-way trap-and-haul as a conservation strategy for anadromous salmonids. *Fisheries*, *42*, 478–487. https://doi.org/10.1080/03632415.2017.1356124

Mantua, N., Tohver, I., & Hamlet, A. (2010). Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Climatic Change*, *102*, 187–223. https://doi.org/10.1007/s10584-010-9845-2

Martino, J. C., Suthers, I. M., Kingsford, R. T., Doyle, K. E., Baumgartner, L. J., & Felder, S. (2025). Pipe fishways: Opportunities and challenges for effective fish passage. *Environmental Technology Reviews*, *14*, 471–487. https://doi.org/10.1080/21622515.2025.2505246

Martins, E. G., Hinch, S. G., Cooke, S. J., & Patterson, D. A. (2012). Climate effects on growth, phenology, and survival of Sockeye Salmon (*Oncorhynchus nerka*): A synthesis of the current state of knowledge and future research directions. *Reviews in Fish Biology and Fisheries*, *22*, 887–914. https://doi.org/10.1007/s11160-012-9271-9

Matala, A. P., Narum, S. R., Saluskin, B. P., Johnston, M. V., Newell, J. E., Fast, D. E., & Galbreath, P. F. (2019). Early observations from monitoring a reintroduction program: Return of Sockeye Salmon to a nursery lake of historical importance. *Transactions of the American Fisheries Society*, *148*, 271–288. https://doi.org/10.1002/tafs.10133

McCaffery, R., Duda, J. J., Soissons, L., & Roussel, J.-M. (2024). Editorial: Large-scale dam removal and ecosystem restoration. *Frontiers in Ecology and Evolution*, *12*, Article 1471146. https://doi.org/10.3389/fevo.2024.1471146

McClure, M. M., Anderson, J. H., Pess, G. R., Cooney, T. D., Carmichael, R. W., Baldwin, C. M., Hesse, J. A., Weitkamp, L. A., Holzer, D. M., Sheer, M. B., & Lindley, S. T. (2018). *Anadromous salmonid reintroductions: General planning principles for long-term viability and recovery* (NOAA Technical Memorandum NMFS-NWFSC-141). National Oceanic and Atmospheric Administration. https://repository.library.noaa.gov/view/noaa/17732

Mesa, M. G., Gee, L. P., Weiland, L. K., & Christiansen, H. E. (2013). Physiological responses of adult Rainbow Trout experimentally released through a unique fish conveyance device. *North American Journal of Fisheries Management*, *33*, 1179–1183. https://doi.org/10.1080/02755947.2013.833560

Monzyk, F. R., Friesen, T. A., & Romer, J. D. (2015). Infection of juvenile salmonids by *Salmincola californiensis* (Copepoda: Lernaeopodidae) in reservoirs and streams of the Willamette River basin, Oregon. *Transactions of the American Fisheries Society*, *144*, 891–902. https://doi.org/10.1080/00028487.2015.1052558

Moser, M. L., Corbett, S. C., Keefer, M. L., Frick, K. E., Lopez-Johnston, S., & Caudill, C. C. (2019). Novel fishway entrance modifications for Pacific Lamprey. *Journal of Ecohydraulics*, *4*, 71–84. https://doi.org/10.1080/24705357.2019.1604090

Mote, P. W., Parson, E. A., Hamlet, A. F., Keeton, W. S., Lettenmaier, D., Mantua, N., Miles, E. L., Peterson, D. W., Peterson, D. L., Slaughter, R., & Snover, A. K. (2003). Preparing for climatic change: The water, salmon, and forests of the Pacific Northwest. *Climatic Change*, *61*, 45–88. https://doi.org/10.1023/A:1026302914358

Mullan, J. W. (1983). *Overview of artificial and natural propagation of Coho Salmon on the mid-Columbia River* (Report FRI/FAO-84-4). U.S. Fish and Wildlife Service, Fisheries Assistance Office.

Munsch, S. H., McHenry, M., Liermann, M. C., Bennett, T. R., McMillan, J., Moses, R., & Pess, G. R. (2023). Dam removal enables diverse juvenile life histories to emerge in threatened salmonids repopulating a heterogeneous landscape. *Frontiers in Ecology and Evolution*, *11*, Article 1188921. https://doi.org/10.3389/fevo.2023.1188921

Murauskas, J., Hyatt, K., Fryer, J., Koontz, E., Folks, S., Bussanich, R., & Shelby, K. (2021). Migration and survival of Okanagan River Sockeye Salmon *Oncorhynchus nerka*,

Downloaded from academic.oup.com/tafs/advance-article/doi/10.1093/tafs/vnag034/8863164 by guest on 05 October 2026

2012–2019. *Animal Biotelemetry*, *9*, Article 37. https://doi.org/10.1186/s40317-021-00262-y

Murphy, C. A., Romer, J. D., Stertz, K., Arismendi, I., Emig, R., Monzyk, F., & Johnson, S. L. (2021). Damming salmon fry: Evidence for predation by non-native warmwater fishes in reservoirs. *Ecosphere*, *12*, Article e03757. https://doi.org/10.1002/ecs2.3757

National Marine Fisheries Service. (2018). *Anadromous salmonid reintroductions: General planning principles for long-term viability and recovery* (NOAA Technical Memorandum NMFS-NWFSC-141). National Oceanic and Atmospheric Administration.

National Marine Fisheries Service. (2022). *Rebuilding interior Columbia Basin salmon and steelhead*. National Oceanic and Atmospheric Administration. https://repository.library.noaa.gov/view/noaa/46461

National Marine Fisheries Service. (2025). *Recovery through reintroductions for California's Central Valley salmon*. National Oceanic and Atmospheric Administration. https://www.fisheries.noaa.gov/west-coast/endangered-species-conservation/recovery-through-reintroductions-californias-central-valley-salmon

National Research Council. (1996). *Upstream: Salmon and society in the Pacific Northwest*. The National Academies Press.

Naughton, G. P., Keefer, M. L., Clabough, T. S., Knoff, M. J., Blubaugh, T. J., Morasch, M. R., Sharpe, C. S., & Caudill, C. C. (2023). Prespawn mortality of spring Chinook Salmon in three Willamette River populations. *North American Journal of Fisheries Management*, *43*, 715–729. https://doi.org/10.1002/nafm.10887

Naughton, G. P., Keefer, M. L., Clabough, T. S., Knoff, M. J., Blubaugh, T. J., Sharpe, C., & Caudill, C. C. (2018). Reservoir provides cool-water refuge for adult Chinook Salmon in a trap-and-haul reintroduction program. *Marine and Freshwater Research*, *69*, 1995–2007. https://doi.org/10.1071/MF18124

Naylor, R. L., Eagle, J., & Smith, W. L. (2003). Salmon aquaculture in the Pacific Northwest a global industry with local impacts. *Environment: Science and Policy for Sustainable Development*, *45*, 18–39. https://doi.org/10.1080/00139150309604562

Neal, T., Kent, M. L., Sanders, J., Schreck, C. B., & Peterson, J. T. (2021). Laboratory infection rates and associated mortality of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) from parasitic copepod (*Salmincola californiensis*). *Journal of Fish Diseases*, *44*, 1423–1434. https://doi.org/10.1111/jfd.13450

Neal, W. T. (2020). *Evaluating the effects of a parasitic copepod (*Salmincola californiensis*) on the performance of juvenile Chinook Salmon (*Oncorhynchus tshawytscha*)* [Master's thesis, Oregon State University]. Graduate Thesis Or Dissertation. https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/r781wp234

Nehlsen, W., Williams, J. E., & Lichatowich, J. A. (1991). Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries*, *16*, 4–21. https://doi.org/10.1577/1548-8446(1991)016%3C0004:PSATCS%3E2.0.CO;2

Ng, E., Alex, K., Hyatt, K., Machin, D., Gardner, E., Murauskas, J., & Stockwell, M. (2025). Managing flows for Sockeye Salmon emergence using the Fish Water Management Tool. *Canadian Water Resources Journal/Revue Canadienne des Ressources Hydriques*, *50*, 61–78. https://doi.org/10.1080/07011784.2025.2459421

Noakes, D. J. (2014). Overview of salmon and their ecological and economic importance. In P. T. K. Woo & D. J. Noakes (Eds.), *Salmon: Biology, ecological impacts and economic importance* (Chapter 1). Nova Science Publishers.

Noakes, D. J., Welch, D. W., Henderson, M., & Mansfield, E. (1990). A comparison of preseason forecasting methods for returns of two British Columbia Sockeye Salmon stocks. *North American Journal of Fisheries Management*, *10*, 46–57. https://doi.org/10.1577/1548-8675(1990)010%3C0046:acopfm%3E2.3.co;2

Nordstrom, B., Budd, A. M., Mitchell, N. J., Cornish, C., Byrne, M., Kuchling, G., & Jarman, S. (2023). Environmental DNA reflects spatial distribution of a rare turtle in a lentic wetland assisted colonization site. *Environmental DNA*, *6*, Article e507. https://doi.org/10.1002/edn3.507

Northwest Power and Conservation Council. (2025a). *2024 report on Bonneville Power Administration's fish and wildlife expenditures*. https://www.nwcouncil.org/fs/19438/2025-4.pdf

Northwest Power and Conservation Council. (2025b). *Indian treaties*. https://www.nwcouncil.org/reports/columbia-river-history/indiantreaties/

Northwest Power and Conservation Council. (2026). *Dams: Impacts on salmon and steelhead*. https://www.nwcouncil.org/reports/columbia-river-history/damsimpacts/

Ohms, H. A., Chargualaf, D. N., Brooks, G., Hamilton, C., Palkovacs, E. P., & Boughton, D. A. (2022). Poor downstream passage at a dam creates an ecological trap for migratory fish. *Canadian Journal of Fisheries and Aquatic Sciences*, *79*, 2204–2215. https://doi.org/10.1098/rspb.2015.2647

Okanagan Nation Alliance. (2014). *Syilx Okanagan Nation Alliance annual report 2014–2015*. https://syilx.org/about/annual-reports/

O'Malley, K. G., Dayan, D. I., Fitzpatrick, C. K., Bohn, S., & Grenbemer, G. A. (2023). *Evaluating spring Chinook Salmon releases above Detroit Dam and below Big Cliff Dam, on the North Santiam River, using genetic parentage analysis*. U.S. Army Corps of Engineers. https://usace.contentdm.oclc.org/digital/collection/p16021coll3/id/1317

O'Malley, K. G., Dayan, D. I., Fitzpatrick, C. K., & Couture, R. (2023). *Evaluating spring Chinook Salmon releases above Cougar Dam, on the South Fork McKenzie River, using genetic parentage analysis*. U.S. Army Corps of Engineers. https://usace.contentdm.oclc.org/digital/collection/p16021coll3/id/1190/rec/14

O'Sullivan, A. M., & Alex, K. I. (2024). Establishing present-day Sockeye Salmon (*Oncorhynchus nerka* | sćwin) spawning capacity in the highly impacted sq'awsitk^{w} | Okanagan River to guide population conservation and restoration. *River Research and Applications*, *40*, 1195–1204. https://doi.org/10.1002/rra.4293

Panagiotopoulos, P., Buijse, A. D., Winter, H. V., & Nagelkerke, L. A. (2024). A large-scale passage evaluation for multiple fish species: Lessons from 82 fishways in lowland rivers

Downloaded from academic.oup.com/tafs/advance-article/doi/10.1093/tafs/vnag034/8863164 by guest on 05 October 2026

and brooks. *Ecological Engineering*, *199*, Article 107158. https://doi.org/10.1016/j.ecoleng.2023.107158

Pearsons, T. N., Murdoch, A. R., Mackey, G., Murdoch, K. G., Hillman, T. W., Cooper, M. R., & Miller, J. L. (2012). Ecological risk assessment of multiple hatchery programs in the upper Columbia watershed using Delphi and modeling approaches. *Environmental Biology of Fishes*, *94*, 87–100. https://doi.org/10.1007/s10641-011-9884-1

Pess, G. R., McHenry, M. L., Denton, K., Anderson, J. H., Liermann, M. C., Peters, R. J., McMillan, J. R., Brenkman, S. J., Bennett, T. R., Duda, J. J., & Hanson, K. M. (2024). Initial responses of Chinook Salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) to removal of two dams on the Elwha River, Washington State, USA. *Frontiers in Ecology and Evolution*, *12*, Article 1241028. https://doi.org/10.3389/fevo.2024.1241028

Pess, G. R., Quinn, T. P., Gephard, S. R., & Saunders, R. (2014). Re-colonization of Atlantic and Pacific rivers by anadromous fishes: Linkages between life history and the benefits of barrier removal. *Reviews in Fish Biology and Fisheries*, *24*, 881–900. https://doi.org/10.3389/fevo.2024.1241028

Peterman, R. M., & Dorner, B. (2012). A widespread decrease in productivity of Sockeye Salmon (*Oncorhynchus nerka*) populations in western North America. *Canadian Journal of Fisheries and Aquatic Sciences*, *69*, 1255–1260. https://doi.org/10.1139/f2012-063

Phillips, K. A., Tung, A. M., Platzer, E., O'Rear, T. A., Lawler, S. P., & Durand, J. R. (2026). Pulsed zooplankton production in seasonally managed wetlands could supplement food availability for a threatened fishery in the San Francisco Estuary. *Estuaries and Coasts*, *49*, Article 69. https://doi.org/10.1007/s12237-026-01686-6

Plumb, J., Hansen, A., Adams, N., Evans, S., & Hannon, J. (2019). Movement and apparent survival of acoustically tagged juvenile late-fall run Chinook Salmon released upstream of Shasta Reservoir, California. *San Francisco Estuary and Watershed Science*, *17*, Article 4. https://doi.org/10.15447/sfews.2019v17iss3art4

Plumb, J. M., & Perry, R. W. (2020). *Development of a two-stage life cycle model for* Oncorhynchus kisutch *(Coho Salmon) in the upper Cowlitz River basin, Washington* (Open-File Report 2020-1068). U.S. Geological Survey. https://doi.org/10.3133/ofr20201068.

Plumb, J. M., & Perry, R. W. (2025). *Development of a two-stage life cycle model to inform the trap-and-haul program for Coho Salmon in the Lewis River, Washington*. bioRxiv. https://doi.org/10.1101/2025.04.30.651546, preprint: not peer reviewed.

Pope, A. C., Kock, T. J., Perry, R. W., Cogliati, K. M., O'Malley, K. G., Murphy, C. A., Hance, D. J., & Fielding, S. D. (2024). Using parentage-based tagging to estimate survival of Chinook Salmon fry in a large storage reservoir. *Environmental Biology of Fishes*, *107*, 735–754. https://doi.org/10.1007/s10641-024-01564-9

Powell, M. S., Hardy, R. W., Flagg, T. A., & Kline, P. A. (2010). Proximate composition and fatty acid differences in hatchery-reared and wild Snake River Sockeye Salmon overwintering in nursery lakes. *North American Journal of Fisheries Management*, *30*, 530–537. https://doi.org/10.1577/M09-002.1

Quaempts, E. J., Jones, K. L., O'Daniel, S. J., Beechie, T. J., & Poole, G. C. (2018). Aligning environmental management with ecosystem resilience: A First Foods example from the Confederated Tribes of the Umatilla Indian Reservation, Oregon, USA. *Ecology and Society*, *23*, Article 29. https://doi.org/10.5751/ES-10080-230229

Quinn, T. P. (2018). *The behavior and ecology of Pacific salmon and trout* (2nd ed.). University of Washington Press; American Fisheries Society.

Quinn, T. P., Kinnison, M. T., & Unwin, M. J. (2001). Evolution of Chinook Salmon (*Oncorhynchus tshawytscha*) populations in New Zealand: Pattern, rate, and process. *Genetica*, *112*, 493–513. https://doi.org/10.1023/A:1013348024063

R Core Team. (2025). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Riaz, M., Kuemmerlen, M., Wittwer, C., Cocchiararo, B., Khaliq, I., Pfenninger, M., & Nowak, C. (2019). Combining environmental DNA and species distribution modeling to evaluate reintroduction success of a freshwater fish. *Ecological Applications*, *30*, Article e02034. https://doi.org/10.1002/eap.2034

Ruckelshaus, M. H., Levin, P., Johnson, J. B., & Kareiva, P. M. (2002). The Pacific salmon wars: What science brings to the challenge of recovering species. *Annual Review of Ecology and Systematics*, *33*, 665–706. https://doi.org/10.1146/annurev.ecolsys.33.010802.150504

Saila, S. B., Wigbout, M., & Lermit, R. J. (1980). Comparison of some time series models for the analysis of fisheries data. *ICES Journal of Marine Science*, *39*, 44–52. https://doi.org/10.1093/icesjms/39.1.44

Sandford, B., Widener, D., Axel, G., Nesbit, M., & Smith, S. (2024). *Post-construction assessment of passive integrated transponder detection efficiencies in Spillbay 1 at Lower Granite Dam* (NOAA Contract Report NMFS-NWFSC-CR-2024-04). National Oceanic and Atmospheric Administration.

Sard, N. M., Johnson, M. A., Jacobson, D. P., Hogansen, M. J., O'Malley, K. G., & Banks, M. A. (2016). Genetic monitoring guides adaptive management of a migratory fish reintroduction program. *Animal Conservation*, *19*, 570–577. https://doi.org/10.1111/acv.12278

Schindler, D. E., Hilborn, R., Chasco, B., Boatright, C. P., Quinn, T. P., Rogers, L. A., & Webster, M. S. (2010). Population diversity and the portfolio effect in an exploited species. *Nature*, *465*, 609–612. https://doi.org/10.1038/nature09060

Schneider, L. (2023). Decolonizing conservation? Indigenous resurgence and Buffalo restoration in the American West. *Environment and Planning E: Nature and Space*, *6*, 801–821. https://doi.org/10.1177/25148486221119158

Schtickzelle, N., & Quinn, T. P. (2007). A metapopulation perspective for salmon and other anadromous fish. *Fish and Fisheries*, *8*, 297–314. https://doi.org/10.1111/j.1467-2979.2007.00256.x

Setting Sun Circle. (2022, April 14). *Salmon people*. https://www.youtube.com/watch?v=RHdpzOyzJPo

Shappart, J. (2026). Retrospective analysis of anadromous fish seed planting upstream of Swift Reservoir. In *Appendix B: Analysis of Coho monitoring data upstream of Swift Dam*

Downloaded from academic.oup.com/tafs/advance-article/doi/10.1093/tafs/vnag034/8863164 by guest on 05 October 2026

in relation to the changes in release location in 2025. Lewis River 2026 Hatchery and Supplementation Annual Operating Plan. PacifiCorp. https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/hydro/lewis-river/license-implementation/reports/Lewis_River_2026_H-S_Annl_Op_Plan.pdf

Sheer, M. B., & Steel, E. A. (2006). Lost watersheds: Barriers, aquatic habitat connectivity, and salmon persistence in the Willamette and lower Columbia River basins. *Transactions of the American Fisheries Society*, *135*, 1654–1669. https://doi.org/10.1577/T05-221.1

Silva, A. T., Lucas, M. C., Castro-Santos, T., Katopodis, C., Baumgartner, L. J., Thiem, J. D., Aarestrup, K., Pompeu, P. S., O'Brien, G. C., Braun, D. C., & Burnett, N. J. (2018). The future of fish passage science, engineering, and practice. *Fish and Fisheries*, *19*, 340–362. https://doi.org/10.1111/faf.12258

Skalski, J. R., Weiland, M. A., Ham, K. D., Ploskey, G. R., McMichael, G. A., Colotelo, A. H., Carlson, T. J., Woodley, C. M., Eppard, M. B., & Hockersmith, E. E. (2016). Status after 5 years of survival compliance testing in the Federal Columbia River Power System (FCRPS). *North American Journal of Fisheries Management*, *36*, 720–730. https://doi.org/10.1080/02755947.2016.1165775

Sohappy v. Smith, 302 F. Supp. 899 (1969).

Sorel, M. H., Hansen, A. G., Connelly, K. A., & Beauchamp, D. A. (2016). Trophic feasibility of reintroducing anadromous salmonids in three reservoirs on the North Fork Lewis River, Washington: Prey supply and consumption demand of resident fishes. *Transactions of the American Fisheries Society*, *145*, 1331–1347. https://doi.org/10.1080/00028487.2016.1219678

Sorel, M. H., Hansen, A. G., Connelly, K. A., Wilson, A. C., Lowery, E. D., & Beauchamp, D. A. (2016). Predation by Northern Pikeminnow and tiger muskellunge on juvenile salmonids in a high-head reservoir: Implications for anadromous fish reintroductions. *Transactions of the American Fisheries Society*, *145*, 521–536. https://doi.org/10.1080/00028487.2015.1131746

Stockwell, C. L., Morse, J. M., Dirling, M. E., Couch, C. E., Michel, C. J., Notch, J. J., & Kock, T. J. (2026). Evaluating reservoir passage and survival of juvenile Chinook Salmon to support reintroduction upstream of Shasta Dam, California. *Transactions of the American Fisheries Society*, *155*, 471–483. https://doi.org/10.1093/tafafs/vnag016

Stumpff, L. M. (2022). Through the Taos lens: Underlying values and emerging tribal strategies for protecting wilderness and wild lands. In T. P. Holmes (Ed.), *A perpetual flow of benefits: Wilderness economic values in an evolving, multicultural society* (General Technical Report WO-101, pp. 171–187). U.S. Forest Service. https://doi.org/10.22004/ag.econ.347459

Sutton, R., & Soto, T. (2012). Juvenile Coho Salmon behavioural characteristics in Klamath River summer thermal refugia. *River Research and Applications*, *28*, 338–346. https://doi.org/10.1002/rra.1459

Taylor, S. G. (2008). Climate warming causes phenological shift in Pink Salmon, *Oncorhynchus gorbuscha*, behavior at Auke Creek, Alaska. *Global Change Biology*, *14*, 229–235. https://doi.org/10.1111/j.1365-2486.2007.01494.x

Temple, G. M., Newsome, T., Webster, T. D., & Coil, S. W. (2017). Evaluation of Rainbow Trout abundance, biomass, and condition following Coho Salmon reintroduction in Taneum Creek, Washington. *Northwest Science*, *91*, 54–68. https://doi.org/10.3955/046.091.0107

Temple, G. M., & Pearsons, T. N. (2012). Risk management of non-target fish taxa in the Yakima River watershed associated with hatchery salmon supplementation. *Environmental Biology of Fishes*, *94*, 67–86. https://doi.org/10.1007/s10641-011-9811-5

Thompson, J. N., & Beauchamp, D. A. (2016). Growth of juvenile steelhead under size-selective pressure limited by seasonal bioenergetic and environmental constraints. *Journal of Fish Biology*, *89*, 1720–1739. https://doi.org/10.1111/jfb.13078

Tiffan, K. F., Kock, T. J., Connor, W. P., Steinhorst, R. K., & Rondorf, D. W. (2009). Behavioural thermoregulation by subyearling fall (autumn) Chinook Salmon *Oncorhynchus tshawytscha* in a reservoir. *Journal of Fish Biology*, *74*, 1562–1579. https://doi.org/10.1111/j.1095-8649.2009.02228.x

Tiffan, K. F., Kock, T. J., Haskell, C. A., Connor, W. P., & Steinhorst, R. K. (2009). Water velocity, turbulence, and migration rate of subyearling fall Chinook Salmon in the free-flowing and impounded Snake River. *Transactions of the American Fisheries Society*, *138*, 373–384. https://doi.org/10.1577/T08-051.1

Ulaski, M. E., Moore, J. W., Carlson, D., Taddei, K. F., Kriese, K., Griggs, J., Murray, C. C., Adams, M., Wilson, K. L., Reid, A., & Sainsbury, N. (2025). Barriers and opportunities for the effective management of cumulative effects in salmon ecosystems in British Columbia, Canada. *Facets*, *10*, 1–25. https://doi.org/10.1139/facets-2024-0348

United States v. Confederated Tribes of the Colville Indian Reservation, 606 F.3d 698 (9th Cir. 2010).

United States v. Washington, 384 F. Supp. 312 (W.D. Wash. 1974).

United States v. Winans, 198 U.S. 371 (1905).

Upper Columbia United Tribes. (2019). *Fish passage and reintroduction phase 1 report: Investigations upstream of Chief Joseph and Grand Coulee dams*. https://ucut.org/habitat/fish-passage-and-reintroduction-phase-1-report/

Upper Columbia United Tribes. (2022). *The phase 2 implementation plan: Testing feasibility of reintroduced salmon in the upper Columbia River basin*. https://ucut.org/project/phase-2-implementation-plan-p2ip-testing-feasibility-of-reintroduced-salmon-in-the-upper-columbia-river-basin/

U.S. Army Corps of Engineers. (2024). *USACE awards Howard A. Hanson Dam fish passage contract*. https://www.nws.usace.army.mil/Media/News-Releases/Article/3940011/usace-awards-howard-a-hanson-dam-fish-passage-contract/

U.S. Army Corps of Engineers. (2025). *National inventory of dams* [Online database]. Retrieved September 23, 2025, from https://nid.sec.usace.army.mil/nid/#/

U.S. Army Corps of Engineers. (2026). *National inventory of dams* [Online database]. Retrieved January 15, 2026, from https://nid.sec.usace.army.mil/

U.S. Department of the Interior. (2023). *Biden–Harris Administration, Tribes reach historic agreement supporting efforts to restore healthy and abundant salmon population to*

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upper Columbia River basin. https://www.doi.gov/pressreleases/biden-harris-administration-tribes-reach-historic-agreement-supporting-efforts-restore

Waldman, J. R., & Quinn, T. P. (2022). North American diadromous fishes: Drivers of decline and potential for recovery in the Anthropocene. *Science Advances*, *8*, Article eabl5486. https://doi.org/10.1126/sciadv.abl5486

Waples, R. S. (1991). Genetic interactions between hatchery and wild salmonids: Lessons from the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences*, *48*, 124–133. https://doi.org/10.1139/f91-311

Waters, C. D., Hard, J. J., Fast, D. E., Knudsen, C. M., Bosch, W. J., & Naish, K. A. (2020). Genomic and phenotypic effects of inbreeding across two different hatchery management regimes in Chinook Salmon. *Molecular Ecology*, *29*, 658–672. https://doi.org/10.1111/mec.15356

Weigel, D. E., Adams, J. R., Jepson, M. A., Waits, L. P., & Caudill, C. C. (2019). Introgressive hybridization between native and non-local steelhead (*Oncorhynchus mykiss*) of hatchery origin. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *29*, 292–302. https://doi.org/10.1002/aqc.3028

Whiteley, A. R., Fitzpatrick, S. W., Funk, W. C., & Tallmon, D. A. (2015). Genetic rescue to the rescue. *Trends in Ecology and Evolution*, *30*, 42–49. https://doi.org/10.1016/j.tree.2014.10.009

Williams, J. G., Armstrong, G., Katopodis, C., Larinier, M., & Travade, F. (2012). Thinking like a fish: A key ingredient for development of effective fish passage facilities at river obstructions. *River Research and Applications*, *28*, 407–417. https://doi.org/10.1002/rra.1551

Williamson, K. S., Murdoch, A. R., Pearsons, T. N., Ward, E. J., & Ford, M. J. (2010). Factors influencing the relative fitness of hatchery and wild spring Chinook Salmon (*Oncorhynchus tshawytscha*) in the Wenatchee River, Washington, USA. *Canadian Journal of Fisheries and Aquatic Sciences*, *67*, 1840–1851. https://doi.org/10.1139/F10-099

Wilson, S. M., Moore, J. W., Ward, E. J., Kinsel, C. W., Anderson, J. H., Buehrens, T. W., Carr-Harris, C. N., Cochran, P. C., Davies, T. D., Downen, M. R., & Godbout, L. (2023). Phenological shifts and mismatch with marine productivity vary among Pacific salmon species and populations. *Nature Ecology & Evolution*, *7*, 852–861. https://doi.org/10.1038/s41559-023-02057-1

Wong, S., Hague, M. J., Phung, A., & Michielsens, C. G. (2026). Discerning Fraser River Sockeye Salmon migration patterns for mixed-stock management. *North American Journal of Fisheries Management*, *46*, 463–477. https://doi.org/10.1093/najfmt/vqag004

Young, K. A. (1999). Managing the decline of Pacific salmon: Metapopulation theory and artificial recolonization as ecological mitigation. *Canadian Journal of Fisheries and Aquatic Sciences*, *56*, 1700–1706. https://doi.org/10.1139/f99-113

Zhang, X., Li, H. Y., Deng, Z. D., Leung, L. R., Skalski, J. R., & Cooke, S. J. (2019). On the variable effects of climate change on Pacific salmon. *Ecological Modelling*, *397*, 95–106. https://doi.org/10.1016/j.ecolmodel.2019.02.002

Zhang, Y., Negishi, J. N., Richardson, J. S., & Kolodziejczyk, R. (2003). Impacts of marine-derived nutrients on stream ecosystem functioning. *Proceedings of the Royal Society of London Series B: Biological Sciences*, *270*, 2117–2123. https://doi.org/10.1098/rspb.2003.2478

Zielinski, D. P., McLaughlin, R. L., Pratt, T. C., Goodwin, R. A., & Muir, A. M. (2020). Single-stream recycling inspires selective fish passage solutions for the connectivity conundrum in aquatic ecosystems. *Bioscience*, *70*, 871–886. https://doi.org/10.1093/biosci/biaa090

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