Widespread human alteration of natural barriers threatens Pacific salmon biodiversity

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Abstract

Anthropogenic barriers such as dams are a pervasive threat to freshwater diversity, yet human-mediated increases in aquatic connectivity can also have unintended consequences. Natural, flow-dependent barriers such as waterfalls structure the upstream limits of Pacific salmon and steelhead by completely or partially obstructing passage. Across the Pacific Northwest, natural barriers were modified to improve passage for adult salmonids, yet this history is poorly recognized. Here we document natural barrier modifications from California to British Columbia. We present case studies that highlight unintended impacts of natural barrier modification to early-migrating runs, whose persistence is contingent on exclusive habitat access facilitated by natural barriers, and we discuss strategies for mitigating biodiversity impacts in modified systems. This study suggests that management and policy can more

effectively conserve biodiversity by recognizing natural barrier modifications and the linkages between landscape features and salmon biodiversity.

Background

Habitat fragmentation and loss of connectivity along movement corridors are primary factors contributing to biodiversity decline across the globe (Rybicki and Hanski 2013, Haddad et al. 2015, Horváth et al. 2019, Brauer and Beheregaray 2020). This recognition has motivated decades of conservation action to protect corridors for terrestrial wildlife, restore landscape connectivity, and remove passage barriers, including the Yellowstone to Yukon Conservation Initiative (Chester 2015) and wildlife crossing structures (Smith et al. 2015). Within river systems, habitat fragmentation from dams and other anthropogenic barriers is also a pervasive threat to aquatic species (Fuller et al. 2015, Reid et al. 2019, Zarfl et al. 2019). The artificial fragmentation of river networks has severed migration routes and driven the declines of fish populations, negatively impacting adjacent human communities (Richter et al. 2010, Beck et al. 2012, Liermann et al. 2012). The removal of dams to restore riverine connectivity has become a key conservation strategy (Foley et al. 2017), with remarkable success in restoring salmon distribution, abundance, and diversity (Pess et al. 2024, Goodman et al. 2026). However, natural features such as cascades and waterfalls (hereafter falls) also fragment river systems, and they can play an important role in mediating eco-evolutionary processes, as they may limit the upstream distribution of some species or populations but not others. Thus, the modification of natural barriers to enhance aquatic connectivity may have unintended consequences within ecosystems.

Increased connectivity between naturally fragmented aquatic systems can lead to cascading ecological impacts that are costly and difficult (if not impossible) to remedy, as shown by large-scale, high-profile examples. For example, the construction of shipping channels and water conveyance infrastructure has inadvertently created passage opportunities for economically damaging aquatic species into habitats outside of their historical range (e.g., the Great Lakes-St. Lawrence Seaway, Alexander 2009). Rahel (2013) describes specific instances from across the globe where natural barriers such as falls support (or are/were essential to) the persistence of native species. These include falls in Australia and New Zealand that separate native galaxiids from nonnative trout (Crowl et al. 1992) and the Sete Quedas Falls on the Paraná River between Brazil and Paraguay, which prevented homogenization among distinct fish assemblages prior to its inundation by Itaipu Reservoir (Vitule et al. 2012). Such natural barriers can provide ecological benefits by increasing primary productivity or species diversity, or by reducing dispersal of pathogens and nonnative taxa (Marks et al. 2006, Rahel 2007, Dias et al. 2013, Rahel 2013). Natural fragmentation in river systems may be especially important as a diversifying force when it selects for species and life histories that might not otherwise persist. For example, features like cascades and falls abound in Pacific salmon watersheds because of the geologic legacy of landscape evolution around the Pacific Rim (Montgomery 2000, Waples et al. 2008). These features have shaped the radiation of Pacific salmon species and life histories by limiting upstream access to a subset of species and life histories whose seasonal migration timing aligns with flows that enable passage (Withler 1966, Smith 1969). Yet, managers have often viewed natural barriers as limiting factors to salmon abundance and have promoted their

removal or modification, with uncertain consequences for salmon population structure, diversity, and resilience.

Pacific salmon and steelhead (encompassing anadromous forms of the genus *Oncorhynchus*) are an ideal system for exploring the impacts of anthropogenically increased connectivity in river systems because of the strong coupling between life history diversity and landscape features (Kannry et al. 2020, Pepping et al. 2026). Many such features do not completely obstruct migration, but rather are partial barriers that may be passable for some species or populations at certain times of year. Modification of natural barriers to increase connectivity for Pacific salmon and steelhead is a widespread though poorly recognized practice, but there is growing awareness that cascades and falls were modified with little consideration of potential trade-offs (e.g., McMillan 2024). The goals of our study are to (1) document the frequency and spatial extent of natural barrier modification within river networks of the Pacific Northwest, including both partial and complete barriers to migration; and (2) highlight, with examples from data-rich case studies, the unintended consequences of natural barrier modification for early-migrating runs of Pacific salmon and steelhead. We focus on impacts to diversity of adult migration timing among Pacific salmon and steelhead, although we recognize that natural barrier modification may have broader ecological outcomes (e.g., to resident fishes and non-fish species). We begin by introducing and synthesizing linkages between the evolution of the Pacific Rim and Pacific salmon life histories. Next, we summarize the prevalence of natural barrier modification and provide context for how and why such barriers were modified. We conclude by examining the implications of our study for watershed management, biodiversity policy, and climate

change adaptation (including management of flow-phenology mismatches), and consider solutions to address the unintended (and largely unstudied) consequences of natural barrier modifications.

The role of natural barriers in Pacific salmon watersheds and life history diversity

Pacific salmon and steelhead occupy dynamic, disturbance-prone landscapes that have shaped their evolutionary history (Waples et al. 2008). Landscape features like cascades and falls are a key but underappreciated diversifying force that, by influencing the freshwater migration extent and timing of adults, affect the spatiotemporal distribution of their progeny and the environments and organisms to which they are exposed. During coastal mountain formation, uplift of the land relative to sea level results in deeper downcutting of stream networks into the landscape, a process starting at river mouths and moving upstream. The upstream progression of river incision is halted (or slowed) when it meets erosion-resistant bedrock, leading to the formation of cascades and falls (i.e., geologic knickpoints; Seidl and Dietrich 1992, May et al. 2017). The ability of salmon to migrate past these knickpoints is limited by structural elements such as knickpoint height and the depth of the water below the knickpoint (Powers and Orsborn 1985), as well as species-specific leaping ability (Reiser et al. 2006). However, the relative passability of barriers is often flow dependent and temporally variable, with extremes of flow (low or high) enhancing or reducing passage at particular times of year, e.g., during summer baseflow or spring runoff (Reiser et al. 2006, Kelson et al. 2020, Wright et al. 2025). Notably, geologic knickpoints can create stable, high-quality fish habitat by limiting channel incision, thereby creating

lower channel slopes, wider valleys, and connected floodplains upstream of the knickpoint (May et al. 2017). Opportunities for surmounting barriers to access optimal upstream habitats can therefore be a strong selective force on adult migration timing.

Pacific salmon and steelhead run types are often grouped for the season when adults enter fresh water to begin their upstream migration in preparation for spawning (e.g., “spring-run Chinook,” “winter-run steelhead”). These migrations are also described as “early,” for runs that enter fresh water in a relatively immature state months before spawning (spring, summer), or “late,” for runs that enter fresh water in a relatively mature state immediately before spawning. Across their range, Pacific salmon and steelhead return to their natal rivers during all months of the year (Snyder 1931, Rich 1943, Hallock et al. 1957, Busby et al. 1996, Potapova et al. 2026) but specific species, life-histories, and populations migrate at different times and thus encounter barriers under different flow conditions that influence their passability. In the Willamette River, Oregon, for example, Willamette Falls was historically impassable at lower flows during summer and fall, blocking passage by fall-migrating salmonids including fall-run Chinook (*O. tshawytscha*) and coho (*O. kisutch*) (Reisenbichler et al. 1992, McElhany et al. 2007). Conversely, in the North Umpqua River, Oregon, natural falls and cascades function as high-flow barriers, impeding seasonal passage by winter-run steelhead (*O. mykiss*) (Loomis et al. 2003, Pepping et al. 2026). At a cascade in California’s Elder Creek, upstream steelhead migration was observed only during passage windows when flows were neither too high nor too low to ascend falls and elevational steps (Trush 1989, Kelson et al. 2020), resulting in highly variable year-to-year passage success. In many river systems, such flow-phenology matches and mismatches (*sensu* Carlson et

147 al. 2025) hold considerable potential for determining upstream distributional limits and
148 structuring salmon diversity across the landscape, and are responsible for the
149 persistence of early runs (Box 1).

Box 1. Early migrators: a significant and formerly abundant life history type

It has long been observed by some biologists, though not widely recognized, that early-migrating runs occur in streams with flow-dependent natural barriers that allow passage only during flow windows when those runs are present (see Withler 1966, Smith 1969, McMillan 1985). In fact, evidence from coastal watersheds in western North America suggests that falls and other flow-dependent barriers are essential for the persistence of early-migrating runs of steelhead, Chinook, and coho, which are otherwise at a disadvantage when they directly compete with late migrators (Withler 1966, Marshall 1973, Sandercock 1991, Busby et al. 1996, Quinn et al. 2016, Waples et al. 2022). Early river entry may offer advantages by facilitating access to high-quality habitats above barriers that are inaccessible to later runs migrating during different flows. Greater fat reserves upon river entry facilitate extended holding in fresh water (Hearsey and Kinziger 2015), but early migrators have smaller average body mass at spawning and undergo energetically costly gonadal development in a fasted state, both of which negatively impact fecundity (Healey 2001, Hearsey and Kinziger 2015, Lamperth et al. 2017). Other disadvantages include reduced opportunities for marine feeding and longer periods of exposure to thermal stress, flow extremes, and disease during prolonged freshwater holding (Quinn et al. 2016, Waples et al. 2022).

The unique characteristics of early migrators give them distinct importance that is irreplaceable by later-migrating salmonids. Their early-season availability in fisheries, higher fat content at river entry, and distinct taste provide unique cultural, caloric, and culinary value (Neuner and Tucker 2023; Box 2). Diverse migration timing extends fishing opportunities and supports food security, particularly among Indigenous communities (Nesbitt and Moore 2016), and extends foraging opportunities for mobile consumers (Schindler et al. 2013). Additionally, early migrators enhance salmonid life history diversity, buffering the response of metapopulations to changing environmental conditions and promoting stability and resilience (Schindler et al. 2010, Braun et al. 2016).

Early runs were historically more abundant than late runs in some systems, including in the Columbia, Klamath, and San Joaquin rivers (Snyder 1931**,** Chapman 1986, Yoshiyama et al. 2001)**,** although they have experienced dramatic declines across their range. Early migrators have been adversely affected by the same factors that depressed other runs of Pacific salmon, including habitat degradation and overfishing (Nehlsen et al. 1991), but particularly by dams and water diversions that have severed access to oversummer habitats (McClure et al. 2008, Quinn et al. 2016). Recent research suggests that when early runs are lost, they may not quickly reestablish. In both Chinook and steelhead, early run timing (i.e., spring-run Chinook, summer-run steelhead) is controlled by a large-effect locus that arose through a single mutation in the evolutionary history of each species and subsequently spread by straying (Prince et al. 2017, Thompson et al. 2019, Waples et al. 2022). This rare evolutionary event suggests that when the early-run phenotype is lost from a system,

it is unlikely to reevolve on human timescales, if at all, even when habitat or other limiting factors are remedied (Thompson et al. 2019).

Improved understanding of the genetic basis of run timing underscores the gravity of the widespread decline and loss of early migrators. Genetic tools have made it possible to distinguish runs rather than relying on run-type assumptions based on phenotype alone (Thompson et al. 2019, Kannry et al. 2020, Waples et al. 2022, Pepping et al. 2026). These recent genetic advances enable monitoring of run-type status, trends, and response to conservation strategies, including the management of seasonal barriers, as demonstrated in the case studies below.

Natural barrier modification is widespread but poorly documented

We compiled instances of natural barrier modification from British Columbia to central California through an email survey and literature search (Supplemental 1). We found that across coastal watersheds of western North America, humans modified natural landscape features such as falls, chutes, rapids, cascades, roughs and other gradient barriers primarily to increase passage by upstream-migrating adult salmonids. We documented 170 instances of barriers or barrier complexes (e.g., a series of falls in close spatial proximity) that were modified by dynamite blasting and/or by construction of a fishway; in many locations, bedrock was blasted to create a fishway (e.g., step pools), or more than one type of modification occurred across time (Table S2). These modifications are distributed across the west coast of the United States and Canada, with most modifications occurring in the Columbia River basin (56), the Klamath River basin (33), Oregon coastal rivers (26), and on Vancouver Island (21) (Figure 1).

Importantly, we found that many barrier modifications were poorly documented. Some reports indicated that specific modification projects were proposed, planned, and/or funded, but we could not find confirmation of implementation, including projects in Mendocino (Sommarstrom 1984) and Trinity (Trinity River Basin Fish and Wildlife Task Force 1980) counties in California. Many documents underscore the prevalence of natural barrier modification. Referring primarily to natural barriers, a fishery biologist wrote in 1980 that “Most fish migration barriers on major spawning and rearing streams in Trinity County [California] have been modified to pass fish” (Trinity River Basin Fish and Wildlife Task Force 1981). Similarly, a project description for a rock barrier removal initiative states that “Between 1976 and 1982, work crews have opened or improved access to nearly 200 miles of spawning nursery habitat on 65 streams in Mendocino County [California] alone” (Sommarstrom 1984). We conclude that the 170 barrier modifications documented here greatly underestimate the actual number of modifications undertaken throughout this region.

Documented natural barrier modifications occurred between the 1880s and the present day, peaking in the 1950s and 1980s (Figure 1). Modification via fishway was more common overall, especially throughout Washington and Oregon, whereas blasting was the primary method in California. Natural barriers were modified primarily by agencies, including state fish and wildlife departments and the federal United States Forest Service (USFS), United States Bureau of Land Management, and Fisheries and Oceans Canada (DFO). In California, where some state staff biologists were recognized explosives experts and state-licensed blasters, state and federal agencies often cooperated to remove natural barriers (“Bombs away for fish” 1974, Trinity River Basin

187 Fish and Wildlife Task Force 1980, Sommarstrom 1984). In the Rogue River, USFS
188 furnished legendary river guide Glen Wooldridge with blasting powder for channel
189 modifications, up to a thousand pounds at one time (Arman and Wooldridge 1982).
190 Modifications in the 21st century have often been led by or have involved the
191 participation of non-governmental organizations (NGOs) as well as Native American
192 Tribes and First Nations.

193 Natural barriers were modified to make barriers passable over a wider range of
194 flows (partial barriers) or to provide passage where none previously existed (complete
195 barriers). Many natural barriers were modified to mitigate habitat loss caused by dams,
196 with the goal of creating or improving access into or within downstream tributary habitat.
197 The Oregon State Fisheries Director wrote in 1952: “The construction of permanent and
198 insurmountable barriers in the upper [Columbia] R]iver has resulted in the confinement
199 of existing runs to a fraction of their former freshwater habitat. In order to maintain this
200 natural resource it is, therefore, necessary to develop fully tributaries that can offer
201 potential spawning and rearing areas” (Fish Commission of the State of Oregon 1953).
202 Natural barrier modifications in Columbia River tributaries included fishway construction
203 at Punchbowl Falls in the West Fork Hood River, Bonnie Falls in North Fork Scappoose
204 Creek, and Clatskanie Falls in the Clatskanie River (Fish Commission of the State of
205 Oregon 1953). In the Snake River, Idaho, the rearing potential of newly accessible
206 habitats following natural barrier removal in Johnson and Boulder creeks produced
207 “mitigation credit” for the Bonneville Power Administration, the federal agency that
208 markets electricity from dams on the Columbia River and tributaries (Holubetz and
209 Petrosky 1988a, Holubetz and Petrosky 1988b). Similarly, a fishway in Deer Creek

(Sacramento River tributary) was built as part of the Shasta Fish Salvage Plan, a mitigation effort for the construction of Shasta Dam (Yoshiyama et al. 2001).

In some watersheds, human alterations made natural features more of a passage barrier than they were previously, which motivated subsequent modifications to those barriers. In Ames Creek (Columbia River watershed), dam construction on the South Santiam River reduced backflooding into the tributary, impairing creek access and prompting modification at the mouth (Morgan 2012). In the Umatilla River, Oregon, irrigation-induced low flows motivated excavation of a shallow bedrock reach to improve fish passage (Sanguine 1985). Similarly, in the Puntledge River (Vancouver Island), reductions in flow from hydropower operations made passage over Stotan and Nib falls more difficult for summer-run Chinook, and the falls were subsequently modified to improve passage, incidentally improving passage for fall-run Chinook (Marshall 1973, Withler et al. 2012).

Our intention was to document natural barrier modifications that were undertaken to improve fish passage; however, we encountered striking examples of the modification of natural barriers for other purposes. Specifically, we found that large boulders and bedrock features were extensively blasted to ease log transport and boat navigability. In some rivers, natural barrier modification for these purposes was so pervasive that it fundamentally altered channel morphology. In the Cowichan River (Vancouver Island), blasting to facilitate timber rafting eliminated 29 falls and reduced the number of rapids from 130 to approximately five (Pike et al. 2017). An 80-kilometer stretch of the Rogue River (Oregon) was extensively blasted to improve navigability by boat, including half a dozen times at Rainie Falls alone (Arman and Wooldridge 1982). We included these

examples in our database (Table S2), but we recognize in particular that many (or most) watersheds included in our study were heavily logged and subject to timber rafting prior to agency records (Wohl 2014), and boulders and other obstructions were commonly blasted to transport logs down rivers during low flows (Brown 1936). The legacy impacts of logging-related blasting on fish passage in watersheds of the Pacific Northwest are likely substantial and warrant further characterization.

Among the documentation of natural barrier modifications we encountered (Table S2), there was little recognition of the role barriers play in maintaining diverse life histories and populations, or of there being potential trade-offs associated with natural barrier modification. In fact, among all documents reviewed, we encountered only a handful of examples. One fact sheet on fishways at natural barriers mentions "intermingling of stocks" as a factor that could reduce production potential (Fisheries and Environment Canada 1977). Similarly, a DFO manual acknowledges that providing anadromous access above a natural barrier may negatively impact an existing resident population (Adams and Whyte 1990), as does the California Salmonid Stream Habitat Restoration Manual (which also provides guidance on blasting falls and chutes to provide fish passage; Flosi et al. 2010). However, these and other biological impacts were not explicitly recognized in project-specific documents. Rather, natural barrier modification has generally been viewed as a cost-effective method to increase salmon and steelhead production potential (Trinity River Basin Fish and Wildlife Task Force 1980, Holubetz and Petrosky 1988a, 1988b). Nevertheless, detailed histories and contemporary data from three watersheds, described in the following case studies, suggest that natural barrier modification has likely contributed to reduced intraspecific

diversity within Pacific salmon and steelhead, with particular impacts to early-migrating runs.

Natural barrier modification can erode salmonid biodiversity, but data-informed management can mitigate impacts

Case study 1: Kalama River, Washington, USA

The Kalama River (Figure 2) enters the Columbia River below the lowermost hydroelectric dam (Bonneville Dam) and supports populations of wild and hatchery summer- and winter-run steelhead, spring- and fall-run Chinook, and coho, as well as wild chum (*O. keta*) and cutthroat trout (*O. clarkii*). Kalama Falls, a series of high-velocity stepped cascades and pools at river kilometer (rkm) 17, is thought to have historically blocked upstream passage for coho and chum, and seasonally limited passage for steelhead and Chinook. Based on the distribution of summer-run steelhead above partial migration barriers throughout their range, it is expected that summer-run steelhead would be more likely to successfully ascend the falls than winter-run steelhead (Withler 1966, Quinn et al. 2016, Kannry et al. 2020, Waples et al. 2022, Pepping et al. 2026).

Infrastructure was built at Kalama Falls beginning in the early 1900s with construction of a hydropower generation facility and undescribed modification to the natural falls, followed by a fishway in 1936 (Bradford et al. 1996, Lower Columbia Fish Recovery Board 2004). The facility was replaced with a fish hatchery that began operation in the late 1950s. Kalama Falls Hatchery includes a concrete and steel cap that increased the height of the falls to 3-4 meters as well as an adjacent fishway to

279 divert adult migrants for either broodstock collection or upstream passage (Bradford et
280 al. 1996, Skalicky 2022). Initially, all salmonid species and origins, excluding chum,
281 were passed upstream through hatchery operations based on the presumption that
282 providing access to more and higher-quality habitat would increase population sizes and
283 recreational fishing opportunities. Since 2015, only natural-origin winter- and summer-
284 run steelhead and spring-run Chinook have been passed upstream.

285 Biologists observed as early as the 1990s that the natural-origin summer-run
286 steelhead population in the Kalama River was depressed relative to the winter-run
287 steelhead population (Lower Columbia Fish Recovery Board 2004). Subsequently,
288 research commenced to understand the role of the modified falls and fishway in
289 spatially partitioning the two runs, from which the historical role of the original falls could
290 be extrapolated. Steelhead were found to have great difficulty ascending the modified
291 falls during periods of higher streamflow (> 30 m^3/s) and cooler water temperatures (<
292 10 °C) that typically occur in winter (Bradford et al. 1996). The number of successful
293 jump attempts was estimated to be highest in July, June, and August, respectively,
294 whereas no steelhead were estimated to have passed the modified falls prior to May or
295 after September in any study year (1988-1991; Bradford et al. 1996). This suggests that
296 the original falls would have historically selected for summer-run steelhead, which
297 migrate upstream during periods of lower flows and warmer water temperatures, with
298 most winter migrants spawning below the falls (Bradford et al. 1996; Lamperth et al.
299 2017).

300 Today, the natural-origin Kalama River summer-run steelhead population
301 remains smaller than other natural-origin summer-run steelhead populations in the

Lower Columbia Distinct Population Segment, despite comparable quantities of available above-barrier habitat. Recent genetic work indicates that among juvenile steelhead rearing upstream of the modified falls and hatchery, 54.6% are homozygous winter run, 25.1% are homozygous summer run, and 20.3% are heterozygotes (i.e., they have one copy of the allele for summer run timing and one for winter run timing; WDFW, unpublished data). In contrast, in the nearby East Fork Lewis River, Horseshoe Falls is an unmodified and more complete barrier to passage by winter-run steelhead. In that system, juvenile steelhead found upstream of the falls are nearly all homozygous summer run (WDFW, unpublished data). Although it is unknown if the falls on the Kalama River were historically as complete a barrier as the falls on the East Fork Lewis River, the current operation of the Kalama Falls fishway allows more winter-run steelhead to access upstream habitat than would occur naturally. Bradford et al. (1996) speculated that the fishway may allow mixing of previously segregated populations and create genetic risks, so winter-run passage has likely resulted in increased hybridization and competition between runs, and may be contributing to the ongoing depressed status of summer-run steelhead. Ultimately, operating the fishway in a manner that more closely mimics the segregating role of the original falls would likely promote the viability of summer-run steelhead by reducing interactions with winter-run steelhead.

Case study 2: Salmon River, California, USA

The Salmon River (Figure 2) is a major tributary to the Klamath River, which straddles the California-Oregon border and is the second-largest watershed in California. Spring-run Chinook were the most abundant salmon run in the Klamath River historically

(Snyder 1931), with the population totaling over 100,000 fish (Moyle 2002). Today, the Salmon River hosts the last viable population of wild spring-run Chinook in the Klamath Basin, making it a high priority for efforts to conserve Klamath River Chinook salmon biodiversity and repopulate newly accessible habitat above the removed Klamath River dams. However, annual escapement of Salmon River spring-run Chinook averaged only 227 fish from 2015-2026, and without significant human intervention, the run is at risk of extirpation (Moyle et al. 2017). The Salmon River also hosts wild populations of fall-run Chinook, coho, and summer- and winter-run steelhead; hatchery fish of any species are rarely encountered. Temporary dams associated with mining and logging were historically found throughout the watershed, but presently there are no human-made barriers to anadromous fish migration in the mainstem Salmon River and its forks.

Several natural barriers occur in the Salmon River and were historically primarily passable by spring-run Chinook, which migrate during higher-flow periods than their fall-run counterparts. Upriver migration in the spring and early summer gave spring-run Chinook exclusive (or near-exclusive) access to upstream habitat. However, at least four natural, low-flow migration barriers in the Salmon River watershed are known to have been modified by dynamite blasting, all in the early 1980s, by the California Department of Fish and Game and USFS. On the mainstem Salmon River, Bloomer Falls (rkm 21.7) was modified by dynamite in 1983 to improve boater safety, with a secondary aim of improving fish passage (Olson and Dix 1993; Toz Soto, Karuk Tribe, Orleans, CA, personal communication, 6 July 2026). On the South Fork Salmon River, the falls at Methodist Roughs (10.5 km from the confluence of the forks; Figure 3) and upstream of Matthews Creek (16.4 km) were modified by explosives in 1984 to enhance

fish passage (Olson and Dix 1993). The purpose of the Methodist Roughs modification was to “provide easier access for anadromous fish to upstream spawning areas…While fish do get past this area, they are at times held up when certain flow conditions prevent passage. This is particularly true for King [Chinook] salmon in the low flow late-summer and fall months” (Kesner 1979), the time of year during which fall-run Chinook migrate upstream to spawn.

In Wooley Creek, the largest tributary to the Salmon River and important cold-water spawning and rearing habitat for spring-run Chinook, bedrock at the confluence of Deadhorse Creek prohibited fish passage to upper Wooley Creek during low flows, but was similarly modified by explosives (Neuner and Tucker 2023). This site was a primary spearfishery location for the Karuk Tribe, with traditional harvest targeting only the fish that failed to ascend the bedrock, thereby selecting for the strongest fish over thousands of years (Neuner and Tucker 2023). Additionally, a fishway was constructed around a falls in Nordheimer Creek, another important tributary for both Chinook runs. The impact of this fishway, which is sporadically maintained for fish passage, is unknown.

Today, fall-run Chinook now regularly spawn upstream of dynamited barriers on the Salmon River mainstem and forks, despite migrating in the season when river flows are at their lowest levels (Thompson et al. 2020, Fingerle et al., in prep.), directly competing with spring-run Chinook and increasing the likelihood of redd superimposition. Heterozygote Chinook now far outnumber spring-run Chinook, likely due to interbreeding facilitated by low-flow barrier modification (Fingerle et al., in prep.). Further, run-type genotyping of fin clips from juvenile Chinook captured throughout the

371 watershed revealed a three- to four-fold increase in both spring-run genotype frequency
372 and spring-run allele frequency in years (2023, 2025) when extreme low river flows
373 during the fall-run Chinook spawning migration limited access to upstream habitat,
374 compared to a year (2024) when flows were higher (Fingerle et al., in prep.). This
375 suggests that, in the Salmon River, spring-run Chinook production is strongly driven by
376 the ability of spring-run Chinook to access habitat inaccessible to fall-run Chinook.
377 Addressing the effects of anthropogenically modified barriers is likely necessary
378 to conserve and restore the full breadth of genetic variation within and among salmon
379 populations in the Salmon River (and wider Klamath Basin). Discussions are in progress
380 with the Salmon River community to consider strategies for recovering spring-run
381 Chinook, including the possibility of reestablishing a low-flow barrier by operating a
382 seasonal weir to manage upriver habitat for spring-run Chinook. This proposed
383 intervention holds promise for restoring habitat exclusivity as a recovery strategy and is
384 consistent with Indigenous salmon stewardship in the Klamath Basin (Box 2).
385
386 *Case study 3: Siletz River, Oregon, USA*
387 The Siletz River (Figure 2) is an Oregon coastal river that supports summer- and
388 winter-run steelhead, spring- and fall-run Chinook, and coho salmon. Summer-run
389 steelhead are currently found in only three rivers on the Oregon Coast, and the Siletz
390 represents the only population in a coastal river that drains entirely from the Oregon
391 Coast Range (Kostow 2012, Hemstrom et al. 2018). The only other two populations
392 occupy the much larger Umpqua and Rogue rivers that originate in the Cascade
393 Mountains and transect the Coast Range to reach the Pacific Ocean.

394 Siletz Falls, a 9 meter-high boulder cascade at rkm 104, creates a natural
395 velocity barrier during high flows that historically blocked passage of most winter-run
396 steelhead into the upper basin. Summer-run steelhead arrival at the falls during the
397 seasonal low-flow period (July-August) enabled their upstream passage. Spring-run
398 Chinook, which migrate in the spring and early summer, may also have passed the falls.
399 The presence of summer-run steelhead in the Siletz River has long been attributed to
400 Siletz Falls selecting for summer migration timing and providing exclusive habitat free
401 from competition with winter-run steelhead (Weber and Fortune Jr. 1975). Between
402 1949 and 1952, a fishway was constructed around Siletz Falls, which opened upstream
403 passage to winter-run steelhead, fall-run Chinook, and coho salmon (Weber and
404 Fortune 1975, Kostow 2012). Hatchery programs were already established in the basin
405 at the time of fishway construction, releasing coho salmon, fall-run Chinook salmon, and
406 winter-run steelhead. A summer-run steelhead hatchery program started in 1956.
407 Beginning in 1952, therefore, the fishway enabled year-round passage of all runs of
408 steelhead and salmon, of both natural and hatchery origin, eliminating the above-falls
409 habitat exclusivity for wild summer-run steelhead (Kostow 2012).
410 Systematic monitoring of fish passage at the falls was not established until 1994,
411 by which time wild summer-run steelhead accounted for only 3% of the total fish
412 counted at the fishway (Kostow 2012). Due to concerns over the critically low
413 abundance of wild summer-run steelhead and the passage of winter-run steelhead
414 above the falls, recovery actions were implemented, including the elimination of most
415 hatchery steelhead and salmon smolt releases above the falls, and conversion of the
416 fishway to a fish trap that could be used to control upstream fish passage (Kostow

2012). A short-term supplementation program for summer-run steelhead ran from 1994-1999 due to concerns that the critically low abundance of wild summer-run steelhead posed a genetic and demographic risk to the population. Beginning in 1994, the fish trap was managed to allow summer-run steelhead (natural and hatchery origin) and spring-run Chinook salmon passage and to exclude winter-run steelhead, coho, and fall-run Chinook salmon (Kostow 2012). Specifically, wild steelhead arriving at the falls between May and November are passed upstream. Wild steelhead arriving at the falls between December and April are typically not passed upstream, although a small number of individuals phenotypically identified as summer-run steelhead have been passed in some years**.** Beginning in 2000, summer-run steelhead hatchery adults (identified by lack of adipose fin) were also removed at the trap to minimize negative genetic effects from hatchery introgression (Kostow 2012). Thus, since 2000, the fish trap has been managed to select for summer-run phenotypes in wild steelhead by providing upstream habitat free from competition with winter-run steelhead, similar to the function historically provided by the natural falls.

In response to passage management favoring the summer-run life history, the abundance of wild summer-run steelhead (assumed based on timing) increased from a record low of 44 adult fish in 1997 to an average of 560 adults from 2000 to 2012, slightly below the estimated historical carrying capacity for above-falls habitat (Kostow 2012). While additional challenges to the summer-run steelhead population have resulted from prolonged marine heat waves and drought, the population averaged 359 individuals from 2014-2023 (ODFW 2025), suggesting that restoring selective passage at the falls has increased the resilience of this population relative to the period when

both summer- and winter-run steelhead were passed above the falls. Genotype data from 2022 confirm that a large majority of steelhead passed above the falls are homozygous for summer run timing, whereas only a small proportion of individuals passed (~5%) are heterozygotes (O'Malley et al. [ODFW], unpublished data). In short, genetic data from 2022 suggest that management of selective passage using arrival timing at Siletz Falls has restored habitat exclusivity for summer-run steelhead. The Siletz case study provides a powerful demonstration of how management actions focused on selective passage at a modified barrier can be used to recover summer-run steelhead by restoring exclusive access to high-quality, upriver habitats.

Discussion: **the prevalence and unintended consequences of natural barrier modification offer lessons learned for biodiversity conservation**

Our study documented widespread modifications of falls, cascades, and other high-gradient natural barriers in salmon and steelhead watersheds in northern California, Oregon, Washington, Idaho, Vancouver Island, and elsewhere in British Columbia from the late 1800s to the present day. State and federal agencies undertook most modifications, with more recent involvement of NGOs, First Nations, and Native American Tribes. Natural barriers were modified to provide passage to Pacific salmon and steelhead where none existed or to facilitate passage over a wider range of flows, ultimately to increase fish production. In other systems, blasting of natural barriers for timber rafting and boat navigation fundamentally altered channel morphology at the segment scale (Arman and Wooldridge 1982, Pike et al. 2017). Natural barrier modifications are primarily documented in 20th-century agency reports, which could

only be found through targeted internet searches and knowledge shared by agency personnel and local experts. The lack of consistent, accessible reporting suggests that substantially more natural barrier modification projects have taken place than are documented here.

Natural barriers were modified to increase the amount of habitat accessible to Pacific salmon and steelhead, with the (often implicit) goal of increasing fish production. We encountered little recognition of the potential adverse consequences of natural barrier modification: the examples we did encounter are described above, and any other explicit recognition may be lost to time. Yet, case studies from the Kalama, Salmon, and Siletz rivers reveal that modified access to high-quality, upstream habitat disproportionately impacts early-migrating forms of Pacific salmon and steelhead by compromising their exclusive (or near-exclusive) access to that habitat. These case studies also highlight that active management of modified barriers holds potential to recover early migrators and suggest that future natural barrier modifications should be approached with caution and careful evaluation of potential unintended consequences alongside potential benefits. We recognize that biodiversity conservation is not the only factor under consideration when natural barrier modifications are proposed. For example, natural barrier modification may offer certain benefits, such as increased quantity or quality of habitat.

Natural barrier modification has diminished the evolutionary advantages of early-run Chinook and steelhead life histories, which otherwise have many fitness costs relative to late-run life histories (Box 1). By providing late migrators with access to upstream habitat that was historically available (near-)exclusively to early migrators,

natural barrier modification has facilitated displacement of early runs by late runs. Ironically, the modification of many barriers to mitigate habitat lost by dam construction may have compounded the impact of dams on early migrators. Dams in large river systems, such as the Columbia, Klamath, Trinity, Sacramento, and San Joaquin, restrict access to cold headwater habitat where early migrators historically oversummered and spawned. Modifications to mitigate this impact by improving access to downstream tributaries may have increased habitat available to early migrators, but by also improving access to later-migrating runs, may have eliminated the little exclusive habitat that remained after dams were built. Many flow-dependent barriers have been made totally impassable (by dams built on top of them), have been made to be more passable (through barrier modification), or have been inundated by dam construction (e.g., Kettle Falls and Celilo Falls in the Columbia Basin), collectively resulting in reduced habitat availability and exclusivity for early migrators.

Restoring habitat exclusivity as a conservation strategy for early migrators

Recognition of natural barrier modifications draws attention to processes that maintain intraspecific life history variation, which in turn can help inform strategies to conserve biodiversity. This study suggests that the necessity of habitat exclusivity for early migrators should be recognized and considered as a key recovery action. The current operation of the Siletz Falls fishway highlights how active management of fish passage opportunities can help to maintain exclusive habitat access for early run types and conserve life history variation in Pacific salmon and steelhead. Experiences in the Salmon and Kalama rivers suggest that interventions that replicate the function of

natural barriers in segregating runs may be needed in order to maintain seasonal run-timing diversity. We can learn from efforts in watersheds where habitat exclusivity has been restored in response to different histories and contexts. For example, physical in-stream exclusion barriers, such as weirs, rock gabions, exclusion screens, and velocity barriers, have been used around the world to limit the spread of aquatic invasive animal species (Jones et al. 2021). In North America, in-stream barriers have also been used to protect native salmonids from invasion by non-native salmonids (Thompson and Rahel 1998). Changes to flow management in regulated rivers could also be considered as a strategy to restore habitat exclusivity. In dammed rivers where late summer and early fall baseflow is artificially heightened by flow releases from dams (Magilligan and Nislow 2005), natural barriers may no longer impede passage as they historically did, likely shifting the balance away from early runs and toward late runs. Overall, the potential benefits of natural barrier modification must be carefully weighed against the potential impacts (Dolan et al. 2026).

The role of natural barriers in maintaining salmon biodiversity also warrants serious consideration in large-scale watershed restoration efforts like the recent Klamath River dam removals, which demolished four of six mainstem dams and restored access to hundreds of kilometers of salmon habitat (Goodman et al. 2026). Both spring- and fall-run Chinook historically accessed the upper Klamath Basin prior to dam construction (Hamilton et al. 2016), but in at least some years passage by fall-run Chinook was likely impeded or delayed by bedrock features below Upper Klamath Lake. In particular, large numbers of (presumably fall-run) Chinook would congregate below the falls at Keno during low flows, prompting construction of a fishway there in 1910

('Fish ladder in Klamath River' 1910). Dam construction at this site, as well as at the site of the Link River Dam upstream, involved modification of the underlying bedrock and elimination of any seasonally segregating mechanism. Thus, especially since passage improvements for all salmonids are now being considered at Keno and Link River dams (which were not removed and have substandard fishways), the historical role of the falls at Keno and other bedrock features in segregating runs merits further study and may shape the outcome of spring-run Chinook restoration in the upper Klamath Basin.

Because anadromous salmonids migrate during their life cycle, restoring habitat exclusivity to a particular run or population will likely require that any such exclusion barrier be seasonal, which will minimize the potential for detrimental above-barrier isolation. Indigenous peoples have used seasonal weirs for millennia, creating opportunities for selective passage and harvest (Box 2). Seasonal weirs are also used in contemporary fisheries management to limit upstream movement of specific species or life histories. In Norway, weirs and selective passage of native fishes are implemented seasonally to limit the spread of invasive pink salmon (*O. gorbuscha*) (Thorstad et al. 2025). In Clear Creek (Sacramento River tributary), a seasonal weir has been used to restore habitat exclusivity to spring-run Chinook to mitigate the loss of exclusive habitat from mainstem dam construction (Giovannetti and Brown 2009). Given the influence of beavers on stream fish assemblage structure and habitat complexity (Snodgrass and Meffe 1998, Wathen et al. 2019), as well as the coexistence and coevolution of Pacific salmon and North American beaver (*Castor canadensis*) over millions of years, experiments to recreate exclusive habitat using beaver dam analogs could also be considered, and may provide additional ecosystem and fisheries benefits

555 (Pollock et al. 2014, Bouwes et al. 2016). Passage management can also be improved
556 by using fish morphology, run-timing phenotypes, and advances in genomics to
557 selectively pass fish across physical barriers (e.g., Case Study 3; Baerwald et al. 2023,
558 Pepping et al. 2026). Ultimately, improved understanding of specific modified natural
559 barriers can help fisheries managers and watershed stewards implement actions to
560 restore or maintain habitat exclusivity by using the historical function of natural barriers
561 as a guide.

Box 2. Indigenous stewardship in the Klamath Basin bolstered habitat exclusivity for spring-run Chinook

Although it is beyond the scope of this paper to summarize traditional stewardship practices by Indigenous peoples across the Pacific Northwest, there are clear examples of these practices in the Klamath Basin that reinforced habitat exclusivity for early-migrating salmonids. These practices include interrelated ceremonies, selective harvest, and seasonal weir operation. The Yurok, Hupa, and Karuk peoples each held an annual Spring Salmon (or First Salmon) Ceremony when the first salmon migrated upriver in spring (Waterman and Kroeber 1938, Nelson 1978, Neuner and Tucker 2023). For the Karuk, the ceremony marked the timing of an important linguistic shift from the usage of *ishyâat* (spring salmon) to *aáma* (summer and fall salmon) (Neuner and Tucker 2023). Across the basin, eating fresh fish prior to the Spring Salmon Ceremony was forbidden and considered taboo, and salmon fishing did not begin until the ceremony was completed (Harrington 1932, Bell 1991, Neuner and Tucker 2023). According to Leaf Hillman, a Karuk ceremonial leader and cultural practitioner, “The purpose…was to allow the first, the head of the run, to travel

upstream unmolested, with no fishing pressure on them" (as quoted in Neuner and Tucker 2023). The Shasta, situated immediately upstream of the Karuk, similarly believed that the first salmon should pass upstream unmolested (Swezey and Heizer 1977).

After completing the Spring Salmon Ceremony, Indigenous families and communities built weirs along the Klamath, Trinity, and Salmon rivers for selective fisheries harvest and management (Swezey and Heizer 1977, Nelson, Jr. 1978, Neuner and Tucker 2023). Weirs were built when flows receded in summer and fall, which tended to coincide with the end of the spring-run Chinook migration, and were not intended to withstand high flows following fall rains (Snyder 1931, Neuner and Tucker 2023). In this way, weirs functioned as low-flow barriers to fall-run Chinook migration and would have bolstered habitat exclusivity for spring-run Chinook. Thus, although weirs and other practices may have been intended to provide fish for harvest, they also reinforced habitat exclusivity for spring-run Chinook and supported fisheries diversity over millennia.

The Klamath Basin demonstrates the value of Indigenous leadership in recovering salmon life history diversity. Colonization violently and forcibly disrupted Indigenous stewardship and cultural practices, which developed across and provided sustainable fisheries for millennia (Atlas et al. 2021, Cannon et al. 2026), and some Western management practices (e.g., natural barrier modification) have decreased fisheries sustainability and diversity. Presently, the near loss of spring-run Chinook has prevented Klamath Basin tribes from conducting the Spring Salmon Ceremony, among other devastating impacts (Neuner and Tucker 2023). Despite this, basin

tribes have robust fisheries departments and play leading roles in Klamath Basin and spring-run Chinook recovery, including the largest dam removal project in US history. Extant practices, such as the Hoopa Valley Tribe's Trinity River weir and the Karuk Tribe's dip-net fishery, provide opportunities for selective harvest (Neuner and Tucker 2023, CDFW 2026), and cooperative efforts are being developed among basin tribes to restore spring-run Chinook to their historical habitat. Ultimately, the prevalence of First Salmon Ceremonies, weir usage, selective harvest, and other caretaking practices among Native American Tribes and First Nations across the Pacific Northwest (Gunther 1926, Swezey and Heizer 1977, Atlas et al. 2017, Morin et al. 2021, Bradford et al. 2025) underscores how Indigenous stewardship has supported salmon life history diversity, including early migrators, in more nuanced and significant ways than typically recognized by Western fisheries policy and management.

Recognition of past natural barrier modification can inform biodiversity conservation

Recognition of natural barrier modifications is an important consideration for policies that promote biodiversity, which are often based on current species distribution and may not reflect the historical distribution in systems that have been heavily modified, such as the Rogue River (Thompson et al. 2019), Salmon River (Fingerle et al., in prep.), and Siletz River (Hemstrom et al. 2018). In some regions, spring- and fall-run Chinook are managed under one Evolutionarily Significant Unit (ESU), and petitions to split early-migrating spring-run Chinook into their own ESU under the US Endangered Species Act have been denied in part because of the lack of substantial reproductive isolation between runs (e.g., Anderson et al. 2019). However, it is important to consider

how the extensive modification of natural barriers in Pacific salmon watersheds has altered patterns of reproductive exchange between run types. Data from watersheds like California's Salmon River, where natural barriers have been modified, show substantial human-mediated overlap and interbreeding between runs, with fall-run Chinook spawning above modified natural barriers and a high proportion of heterozygotes (Thompson et al. 2020, Fingerle et al. in prep). Policymaking that incorporates understanding of how landscape features shape life histories and how modification to those features can reduce diversity will more effectively support the full suite of intraspecific life history variation.

Looking to the future: natural barrier modification as a climate change adaptation tool

Climate change is one of the gravest challenges facing freshwater fishes, with coldwater-adapted salmonids expected to be particularly impacted (Williams et al. 2015, Reid et al. 2019). In the Pacific Northwest, reduced snowpack and earlier snowmelt are expected to lead to reduced streamflow and warmer water temperatures (Stewart et al. 2005, Fullerton et al. 2026). Climate change will increase flow-phenology mismatches for migratory salmonids (Carlson et al. 2025), and we hypothesize that these mismatches will often manifest themselves at flow-dependent natural barriers. Specifically, with reduced flows, flow-dependent barriers may no longer provide passage opportunities that they did historically. In systems where early migrators have disappeared, prolonged fall drought and more extreme migration conditions may limit the upstream extent of spawning by anadromous fishes. Thus, modification of natural barriers may be considered as a management tool for climate change adaptation.

Fisheries managers might consider modification of additional natural barriers to provide passage to previously inaccessible cold headwater habitat, or to restore access to historical habitat, e.g., in cases where reduced flows restrict access over previously surmountable barriers. In these circumstances, context is important. This study suggests that watershed management would likely benefit from evaluation of multiple criteria when considering potential modifications, including what will (and will not) provide reliable, durable habitat to anadromous salmonids under climate change, the current availability of similar habitat, and trade-offs to other species that may have cascading effects across the food web. Whereas removal of dams and other artificial barriers can improve climate resilience of society and the environment (Null et al. 2026), modification of natural barriers may erode resilience inherent in Pacific salmon and steelhead. Life history diversity can be an important asset in a changing climate (Potapova et al. 2026), and the life history strategies displayed by early migrators may be advantageous under climate-induced drought conditions (Cordoleani et al. 2021). Genotypic and phenotypic diversity of salmonids improves their capacity to persist in a changing climate (Moore and Schindler 2022, Moore et al. 2025, Potapova et al. 2026), and should be considered in a climate change management framework. As with any management intervention, monitoring is needed, and in the case of natural barrier modifications has been sorely lacking to date. Robust monitoring should accompany future interventions, and genetic tools (e.g., run-type genotyping) can support more accurate and efficient monitoring.

Conclusions

Across the Pacific Northwest, natural barriers such as cascades and falls have been modified to enhance passage for Pacific salmon and steelhead. These modifications were largely intended to increase habitat access with the goal of increasing fish production, but they have had unintended impacts on specific life histories of salmon and steelhead populations. Our findings indicate that the consequences of natural barrier modification deserve more attention. They also suggest that effective salmon biodiversity conservation requires understanding of how landscape features give rise to and maintain salmon diversity. Additional studies on the impacts of barrier modification to anadromous fishes will improve understanding of historical and contemporary distributions of specific run types. This understanding has important implications for management and policy decisions that rely on assumptions regarding the contemporary spatial distribution and reproductive isolation of species and runs. Evidence from three watersheds demonstrates that natural barrier modifications can particularly impact early migrators, although management may offer opportunities to mitigate those impacts. This work emphasizes the need for caution and robust monitoring when considering additional natural barrier modifications, such as those that may be undertaken to expand the range of native species to facilitate adaptation to climate change. A more thorough accounting of the impacts of a given modification, both intended and unintended, will provide context in which values-based decisions on whether and how to proceed with future modifications can be made.

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Supplemental material

Supplemental 1 – methods & survey

Supplemental 2 – database of modifications (Table S2) & database references

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Figure 1: Distribution of natural barrier modifications across British Columbia, Washington, Oregon, California, and Idaho designated by barrier type (letter) and modification type (color). To ensure that most modifications are visible, we used a dispersal algorithm that generalizes locations in high-density areas but maintains general patterns. Pie charts show the proportion of each modification type across the region (top right) and by state. The chart in the bottom right shows barrier modification count across time, with modification type designated by color.

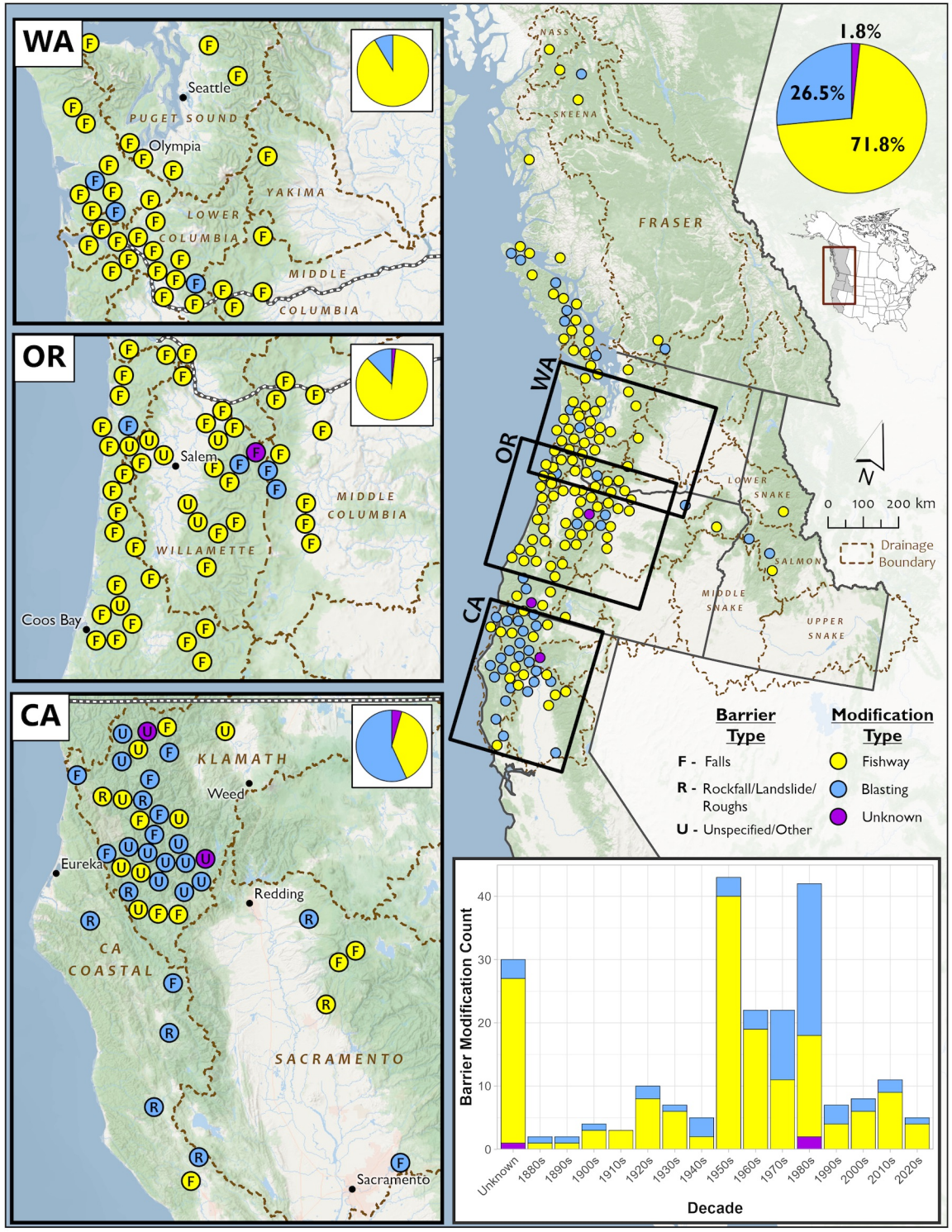
Alt text: Maps showing the locations and types of modified natural barriers across the study range, with state/province-specific and regional pie charts of the proportions of modification types, and a histogram of the count of natural barrier modifications across time.

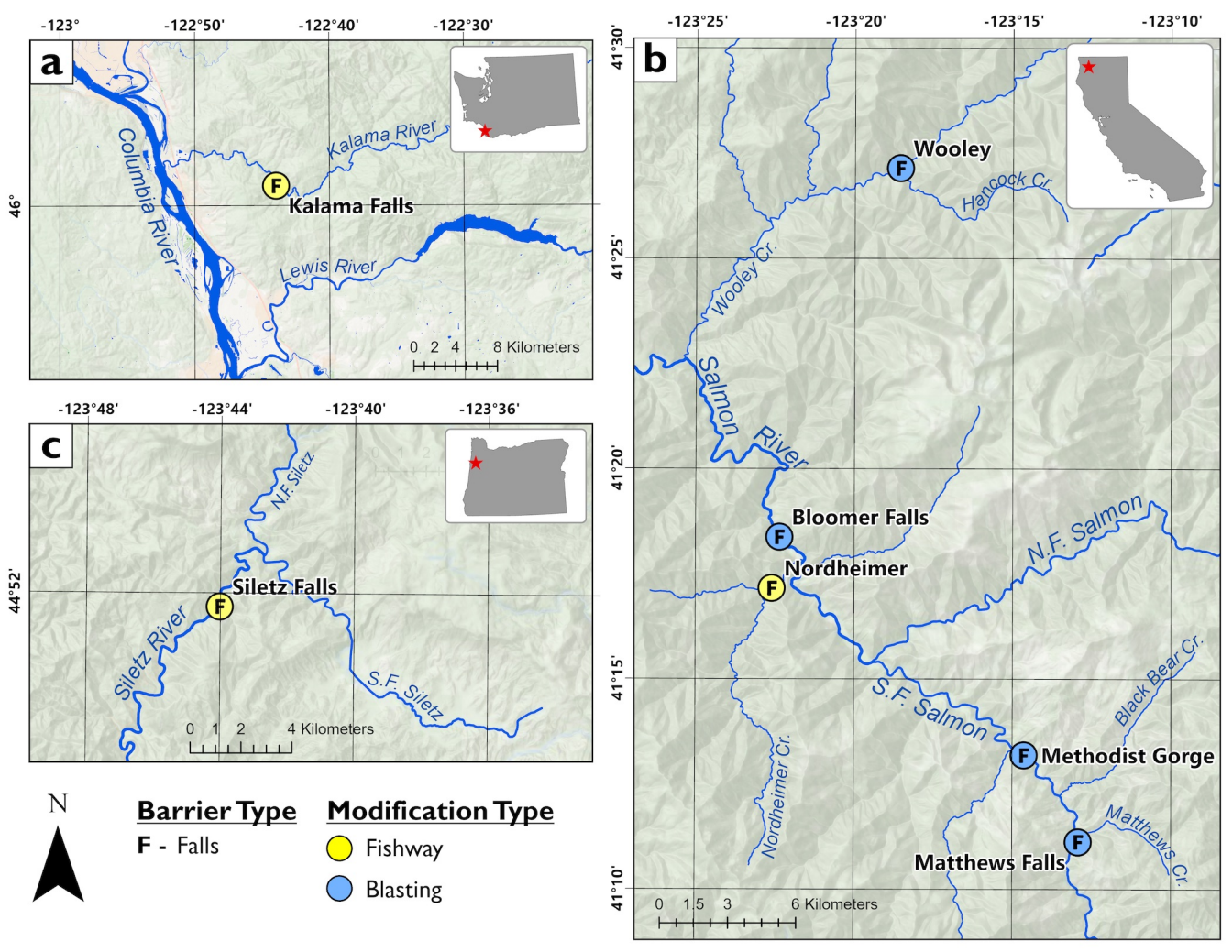
Figure 2: Locations of natural barrier modifications in the Kalama River (a), Salmon River (b), and Siletz River (c). Barrier type is designated by letter. Modification type is designated by color.

Alt text: Maps showing the locations and types of modified natural barriers in the Kalama, Salmon, and Siletz rivers.

Figure 3: Preparing to blast the Methodist Creek Gorge on the South Fork of the Salmon River, California. Prior to its modification in 1984, this bedrock gorge was a barrier to fall-run Chinook migrating during low flows in fall. Photo credit: Jeff Buchin.

Alt text: Decorative photograph of preparations for blasting of a bedrock river gorge.


WA
Seattle
PUGET SOUND
Olympia
YAKIMA
LOWER
COLUMBIA
MIDDLE
COLUMBIA
OR
Salem
MIDDLE
COLUMBIA
WILLAMETTE
Coos Bay
CA
KLAMATH
Weed
Eureka
Redding
CA
COASTAL
SACRAMENTO
Sacramento
NASS
SKEENA
FRASER
1.8%
26.5%
71.8%
WA
OR
CA
LOWER
SNAKE
SALMON
MIDDLE
SNAKE
UPPER
SNAKE
N
0 100 200 km
Drainage
Boundary
Barrier
Type
F - Falls
R - Rockfall/Landslide/
Roughs
U - Unspecified/Other
Modification
Type
Fishway
Blasting
Unknown
Barrier Modification Count
0
10
20
30
40
Unknown
1880s
1890s
1900s
1910s
1920s
1930s
1940s
1950s
1960s
1970s
1980s
1990s
2000s
2010s
2020s
Decade


a
-123°
-122°50'
-122°40'
-122°30'
46°
Columbia River
Kalama River
Kalama Falls
Lewis River
0 2 4 8 Kilometers
b
-123°25'
-123°20'
-123°15'
-123°10'
41°30'
41°25'
41°20'
41°15'
41°10'
Wooley
Hancock Cr.
Wooley Cr.
Salmon River
Bloomer Falls
Nordheimer
N.F. Salmon
S.F. Salmon
Black Bear Cr.
Methodist Gorge
Nordheimer Cr.
Matthews Cr.
Matthews Falls
0 1.5 3 6 Kilometers
c
-123°48'
-123°44'
-123°40'
-123°36'
44°52'
N.F. Siletz
Siletz Falls
Siletz River
S.F. Siletz
0 1 2 4 Kilometers
N
Barrier Type
F - Falls
Modification Type
Fishway
Blasting



Supplementary methods & Table S1

We compiled instances of natural barrier modification through an email survey and literature search. We limited our study to modifications in Pacific salmon- and steelhead-bearing watersheds ranging from British Columbia to California's Central Valley, which encompasses the greatest variation in run-timing diversity (see McMillan 2024 for a list of modifications in Alaska). We specifically focused on the modification of geomorphic barriers (such as cascades and falls), recognizing that other types of barriers (thermal, hydraulic) may also play important roles in structuring life history diversity and have their own history of modification. Although not the primary focus of our study, we included modifications to barriers created by relatively recent landslides and rockfall (such as those resulting from the historic Christmas flood of 1964 in the Pacific Northwest and northern California), recognizing that contemporary cascades may have formed from landslides and rockfall over longer geologic timelines. We excluded the extensive history of landslide modification in the mainstem Fraser River, as that history is well documented elsewhere (Evenden 2000, Pess et al. 2012). Finally, we included a particular modification only if we had reasonable certainty that the modified barrier was a naturally occurring geomorphic barrier; we did not include modifications where it was unclear whether the barrier was actually a log jam (many of which were cleared simultaneously), culvert (e.g., Table 10-1 in Pacific Watershed Associates 1994), or where the barrier type was unspecified without further identifying context (e.g., Rice 1986).

In November 2023, we emailed a Google Form survey (Table S1) to over 200 personnel from state, provincial, and federal agencies, as well as Tribal and First

Nations fisheries departments, non-governmental organizations (e.g., watershed councils), and academic institutions based in California, Oregon, Washington, Idaho, and British Columbia. The survey asked respondents if they had knowledge of human modification of natural barriers in the range of anadromous Pacific salmonids and, if so, to list the watershed(s) in which these activities occurred. We followed up as needed to gather more details about specific modifications when supporting documentation could not be found online. We received 31 survey responses as well as a few responses directly to email. Additionally, we searched peer-reviewed and gray literature through the Web of Science database and targeted searches on Google Scholar, which were aided by knowledge shared by survey respondents. We sourced additional gray literature from the archives of the National Marine Fisheries Service, focusing specifically on technical memoranda and status reviews. We also searched the Ecological Reports Catalogue (EcoCat) of the British Columbia Ministry of Environment and state fish passage databases.

Table S1. Survey questions emailed to individuals from state, provincial, and federal agencies, as well as Tribal and First Nations fisheries departments, NGOs (e.g., watershed councils), and academic institutions based in California, Oregon, Washington, Idaho, and British Columbia.

Please list your name (and employer if relevant).
What is your email?
What is your phone number?
Do you know of any instances of human modification of natural passage barriers in the range of anadromous Pacific salmonids? This includes blasting of natural features (boulders and bedrock) or building of a fish ladder around a natural feature.
If yes, please list the watershed(s) in which these activities occurred.
May we follow up with you to gather more information?
Are there other individuals or organizations that you suggest we contact to learn more about modification of natural passage barriers? If yes, please provide their name and contact information.
Any additional comments?

Supplementary methods references

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Supplemental Table 2 (Table S2). Compilation of natural barrier modifications collected through individual surveys and review of peer-reviewed literature, gray literature, and fish passage databases.

State/Province	Basin (Coastal or Major Watershed)	Subbasin(s)	Waterbody of Modification	Barrier Type	Modification Type	Modification Date(s)	Modification Description	Source(s)
British Columbia	Coastal	Khutze Inlet/Kakushdish Harbor	Kakushdish/Kadjusdis Creek	Falls	Fishway	1955	A fishway was built at a point of difficult passage.	Manzon and Marshall 1981
British Columbia	Coastal	Nass River	Cranberry River	Falls	Fishway	Unknown (blasting), Proposed as of 2018 (fishway)	Ginmiltkun Falls (or Cranberry River Falls) is a partial barrier to salmon and steelhead migration. Unsuccessful attempts have been made to remove the barrier through blasting. A fishway is proposed to increase wild salmon production and support Indigenous fisheries.	Cleveland 2018
British Columbia	Coastal	Nass River	Meziadin River	Falls	Fishway	1914, 1966	Two fishways, the latter replacing the original, were constructed at Victoria Falls to enhance passage to Meziadin Lake.	Fisheries and Environment Canada 1977, Regional District of Kitimat-Stikine 2011
British Columbia	Coastal		Kakweiken River	Falls	Fishway	1964, 1970s	Falls on the Kakweiken River blocked passage by pink salmon until fishway construction (two different styles, one replacing the other), after which runs of 100,000-230,000 pink salmon reportedly ascended the fishway to spawn.	Canada Department of Fisheries and Forestry 1970, Fisheries and Environment Canada 1977, Slaney and Milko 1982
British Columbia	Fraser River		Coquihalla River	Landslide/Rockfall/Roughs	Blasting	2017	In 2014, erosion, shifting boulders, and settling of a failed bridge foundation created a nearly impassable barrier to summer-run steelhead, reducing access to the upper 20 km of river. Blasting and high winter flows redistributed rock to create passage.	Habitat Conservation Trust Foundation 2018
British Columbia	Fraser River		Mainstem Fraser River	Falls	Fishway	1987	At Saddle Rock, a bypass channel was constructed around a velocity/gradient barrier to pink and sockeye salmon.	Adams and Whyte 1990
British Columbia	Skeena River		Babine River	Landslide/Rockfall/Roughs	Blasting	1953	During 1951-52, a rockslide ~12 km from the Skeena River confluence inhibited migration, to varying degrees, of sockeye and other salmon species. The obstruction was cleared in 1953.	Godfrey et al. 1954, Stiff et al. 2015
British Columbia	Skeena River		Bulkley River	Falls	Fishway	1951	Two fishways were constructed at Moricetown Falls.	Fisheries and Environment Canada 1977
British Columbia	Vancouver Island	Campbell River	Quinsam River	Falls	Fishway	2015	Directly below Lower Quinsam Lake, step pools and anchored logs were used to enhance passage for coho and steelhead over a range of flows.	Gale 2016; Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026
British Columbia	Vancouver Island	Campbell River	Quinsam River	Falls	Fishway	2005	In the Upper Quinsam River, fishways were built around a series of cascades that blocked passage by pink salmon at low flows.	Van Tine and Sinclair 2006
British Columbia	Vancouver Island	Courtenay River	Puntledge River	Falls	Fishway	1923 and onward (blasting), 1969 (fishway)	Concrete baffles were constructed at lower Stotan Falls (rkm 9.3) in 1969, where passage was difficult. Drilling and blasting were done the year prior to facilitate passage. Stotan Falls and Nib Falls were critical for maintaining spatial segregation between summer-run and fall-run Chinook.	Canada Department of Fisheries and Forestry 1970, Guimond 2008, Fish & Wildlife Compensation Program 2020, Wetklo et al. 2020
British Columbia	Vancouver Island	Courtenay River	Puntledge River	Falls	Blasting	1923 and onward (blasting), 1977 (fishway)	Blasting began at Nib Falls (rkm 11.3) in the 1920s, with a final modification (blasting of a fishway) in 1977. Nib Falls and Stotan Falls were critical for maintaining spatial segregation between summer-run and fall-run Chinook.	Canada Department of Fisheries and Forestry 1970, Guimond 2008, Comox Valley Regional District 2019, Fish & Wildlife Compensation Program 2020, Wetklo et al. 2020
British Columbia	Vancouver Island	Courtenay River/Puntledge River	Browns River	Falls	Fishway	Early 2000s	A fishway was built at Browns River Falls to facilitate steelhead passage in spring and coho passage in fall.	Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026
British Columbia	Vancouver Island	Cowichan River	Koksilah River	Falls	Fishway	1980	A fishway was constructed at Marble Falls (rkm 21) to enhance salmon runs by providing access to the upper watershed.	Tutty 1984
British Columbia	Vancouver Island	Cowichan River	Mainstem Cowichan River	Falls	Fishway	1921, 1931, 1956	Work to facilitate migration at Skutz Falls was undertaken in 1921, followed later by a weir fishway (1931) and a vertical slot fishway (1956).	O'Donnell 1988, Rutherford et al. 1988
British Columbia	Vancouver Island	Cowichan River	Mainstem Cowichan River	Falls	Blasting	1890s-1900s	Blasting to facilitate log driving extensively modified the channel morphology of the Cowichan River: "29 waterfalls were eliminated, leaving only one major falls (Skutz), and the number of rapids were reduced from 130 to approximately five" (Pike et al. 2017).	Pike et al. 2017
British Columbia	Vancouver Island	Somass River	Stamp River	Falls	Fishway	1927, 1955	A fishway was constructed to provide passage around Stamp Falls; a new fishway was later built next to the original.	Canada Department of Fisheries 1955, Canada Department of Fisheries and Forestry 1970, Quinn 2020
British Columbia	Vancouver Island	Somass River/Stamp River	Ash River	Falls	Blasting	Late 1970s	Dickson Falls was blasted to improve passage to anadromous salmonids.	Hatfield and Bos 2007
British Columbia	Vancouver Island	Somass River/Stamp River	Sproat River	Falls	Fishway	1903, 1927, 1951	In 1903, a channel was cut to enhance passage over Sproat Falls, but this reportedly made passage more difficult. Fishways of different styles were built later. Adult sockeye have been observed ascending the falls under low to moderate flows, bypassing the fishway.	Canada Department of Fisheries 1951; Canada Department of Fisheries 1955; Manzer et al. 1985; Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026
British Columbia	Vancouver Island		Gordon River	Falls	Fishway	1980s, 2012, 2014	A bypass channel was built at Loup Falls, which had previously been barely passable by steelhead. Additional modifications were undertaken to improve passage.	Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026
British Columbia	Vancouver Island		Marble River	Falls	Fishway	1928, 1967 (blasting); 1986 (fishway)	Bear Falls (rkm 5.2) was twice blasted to improve passage at low flows; a fishway around the falls was later constructed.	Hamilton 1980, Canada Department of Fisheries and Oceans 1990, Taylor and Dunlop 2008
British Columbia	Vancouver Island		Marble River	Falls	Blasting	1964-65, 1987	Holding pools were blasted at Lake Outlet Falls (rkm 8.3) to improve passage at low flows, followed by later enhancement.	Hamilton 1980, Canada Department of Fisheries and Oceans 1990, Taylor and Dunlop 2008
British Columbia	Vancouver Island		Marble River	Falls	Blasting	1928, 1986	The crest of Twin Falls (rkm 2.8) was lowered from 3.6 m to 2.4 m to facilitate migration by pink and chum salmon; a chute was later blasted.	Hamilton 1980, Canada Department of Fisheries and Oceans 1990, Taylor and Dunlop 2008
British Columbia	Vancouver Island		Millstone River	Falls	Fishway	1982, 2007	An 800-m long side channel was blasted to bypass a series of falls, aiding coho salmon migration. This channel replaced a damaged fishway that was built in 1982.	Northwest Hydraulic Consultants 2008
British Columbia	Vancouver Island		Millstream Creek	Falls	Fishway	1998	Beginning in 1998, five fishways were constructed in lower Millstream Creek to support passage by coho salmon. Salmon did not previously occupy the watershed due to impassable cascades near the mouth.	McCully n.d., Peninsula Streams Society n.d.
British Columbia	Vancouver Island		Nanaimo River	Falls	Unknown	1989, 1992-1993	Blasting began in 1989 at White Rapids Falls to eliminate a low-flow rock barrier and create a plunge pool at the base of the falls. A fishway was later built to ease passage for spawning Chinook.	Carter and Nagtegaal 1997; Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026

British Columbia	Vancouver Island		Nimpkish River	Falls	Fishway	1953	A fishway was blasted at Karmutsen Falls to permit salmon migration into the Schoen and Klaklakama lakes system.	Fraser et al. 1974; Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026
British Columbia	Vancouver Island		Quatse River	Falls	Fishway	Late 1970s	A fishway was built around a cascade.	Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026
British Columbia	Vancouver Island		Salmon River	Landslide/Rockfall/Roughs	Blasting	1978	Steps were blasted into falls formed by rockfall that had prevented steelhead passage.	Adams and Whyte 1990; Michael McCulloch, Ministry of Water, Land and Resource Stewardship, Nanaimo, BC, personal communication, 9 July 2026
California	Coastal	Eel River	Middle Fork Eel River	Landslide/Rockfall/Roughs	Blasting	1946, 1974, 1980, 1997, 2002, 2005	Asa Bean Roughs (approx. rkm 80), a partial barrier to steelhead, was repeatedly blasted to improve passage.	Becker and Reining 2009 (and California Department of Fish and Game references therein); Braden Herman, California Department of Fish and Wildlife, Fortuna, CA, personal communication, 7 October 2026
California	Coastal	Eel River	Middle Fork Eel River	Landslide/Rockfall/Roughs	Blasting	1960s (or earlier) to early 2000s	Large boulders comprising areas known as "roughs" (see Kannry et al. 2020) were blasted on an ongoing basis to improve passage.	Braden Herman, California Department of Fish and Wildlife, Fortuna, CA, personal communication, 7 October 2026
California	Coastal	Eel River	Van Duzen River	Landslide/Rockfall/Roughs	Blasting	1975	A seasonal barrier known as "Salmon Hole" was blasted to improve passage for winter-run steelhead.	Braden Herman, California Department of Fish and Wildlife, Fortuna, CA, personal communication, 7 October 2026
California	Coastal	Russian River	Big Sulphur Creek	Landslide/Rockfall/Roughs	Blasting	1970s, 1982	A huge rock slide that formed a narrow bottleneck was frequently blasted to widen the channel and improve passage for steelhead.	Bombs away for fish' 1974
California	Coastal	Russian River	Crane Creek	Falls	Fishway	2011	Step pools were chiseled in a bedrock outcropping to allow fish passage.	Cuneo and Manning 2020
California	Coastal	Russian River	Orrs Creek	Landslide/Rockfall/Roughs	Blasting	1970, 1987-1989	Blasting occurred at rkm 4 to improve access to the upper reaches of stream.	Klamt and Durkee 1972, California Department of Fish and Game 2002
California	Klamath River	Elk Creek	East Fork Elk Creek	Falls	Fishway	2024	Pools were chipped into bedrock to allow coho to access additional habitat.	Mid Klamath Watershed Council 2024
California	Klamath River	Salmon River	Mainstem Salmon River	Landslide/Rockfall/Roughs	Blasting	1983	Blasting occurred at Bloomer Falls (rkm 21.7) to improve recreation safety following the death of a boater and to improve anadromous fish passage during low flows. Bloomer Falls was possibly formed as a result of the 1964 flood, but topography indicates that some barrier to migration may have already existed at that time. Prior to modification, Bloomer Falls was impassable at low flows.	Olson and Dix 1993; Neuner and Tucker 2023; Toz Soto, Karuk Tribe, Orleans, CA, personal communication, 6 July 2026
California	Klamath River	Salmon River	Nordheimer Creek	Falls	Fishway	Late 1980s	A fishway was constructed around a 4.3-m falls (rkm 2.4).	Klamath River Basin Fisheries Task Force 1991
California	Klamath River	Salmon River	South Fork Salmon River	Falls	Blasting	1984	Blasting occurred at the falls at Methodist Roughs (rkm 10.5), a partial migration barrier, to provide passage during low flows.	Olson and Dix 1993
California	Klamath River	Salmon River	South Fork Salmon River	Falls	Blasting	1984	Blasting occurred at the falls upstream of Matthews Creek (rkm 16.4), a partial migration barrier, to provide passage during low flows.	Olson and Dix 1993
California	Klamath River	Salmon River	Wooley Creek	Falls	Blasting	Early 1980s	Blasting modified bedrock that was impassable at low flows. This was the site of a primary fishing ground for the Karuk, who would only spear salmon and steelhead that failed to ascend the barrier, leaving the strongest fish to continue upstream.	Neuner and Tucker 2023
California	Klamath River	Salmon River/South Fork Salmon River	Black Bear Creek	Other or unspecified gradient barrier	Fishway	1984	A fishway was built at an unspecfied barrier.	Rice 1986
California	Klamath River	Scott River	Kelsey Creek	Falls	Blasting	1987	Blasting (very likely) occurred at the mouth to provide creek access for Chinook salmon.	Klamath National Forest 1987a; Klamath National Forest 1987b; Maija Meneks, Klamath National Forest, Yreka, CA, personal communication, 26 January 2026
California	Klamath River	South Fork Trinity River	East Tule Creek	Falls	Fishway	1987	A fishway was constructed around a 7.5-m bedrock falls (rkm 0.4). As of 2020, it appeared to no longer function.	United States Forest Service 1993, Pattek and McDiffitt 2020
California	Klamath River	Trinity River	Big Bar Creek	Other or unspecified gradient barrier	Blasting	1980	The lower section of Big Bar Creek was blasted to improve access for spawning salmon and steelhead.	Trinity River Basin Fish and Wildlife Task Force 1981
California	Klamath River	Trinity River	Brown's Creek	Other or unspecified gradient barrier	Blasting	1977	The stream gradient was modified with explosives to allow fish passage.	Trinity River Basin Fish and Wildlife Task Force 1978
California	Klamath River	Trinity River	Don Juan Creek	Other or unspecified gradient barrier	Fishway	1977	An existing fishway was modified (original construction date uncertain).	Trinity River Basin Fish and Wildlife Task Force 1978
California	Klamath River	Trinity River	East Fork of North Fork	Other or unspecified gradient barrier	Blasting	1977	The stream gradient was modified with explosives to allow fish passage.	Trinity River Basin Fish and Wildlife Task Force 1978
California	Klamath River	Trinity River	Hayfork Creek	Falls	Fishway	1964, 1977	Above the East Fork, a fishway was constructed at a major falls that was recognized as a barrier to salmon and steelhead migration. Debris plugged the fishway in some years, so explosives were used to partially remove the fishway and modify the channel shape and flow velocity to aid passage. Passage is still difficult, and as of 2024, further improvement to the site was being considered to improve passage success.	Pacific Watershed Associates 1994, McCanne 2024
California	Klamath River	Trinity River	Little French Creek	Other or unspecified gradient barrier	Fishway	1977	An existing fishway was modified (original construction date uncertain).	Trinity River Basin Fish and Wildlife Task Force 1978
California	Klamath River	Trinity River	Mainstem Trinity River	Falls	Blasting	1950s	Burnt Ranch Falls was blasted over a span of years to ease salmon migration, including six weeks of "intensified blasting" in 1950 to create a new channel.	Blast channel at Burnt Ranch Falls–fish move' 1950, McDaniel 1950, McDaniel 1951, 'The news from our neighboring towns: Trinity County notes' 1956
California	Klamath River	Trinity River	New River	Other or unspecified gradient barrier	Blasting	1980	Four sections were blasted to improve access for spawning salmon and steelhead. Blasting at the site of "Barrier No. 7" created a 3.5-m wide chute.	Trinity River Basin Fish and Wildlife Task Force 1981
California	Klamath River	Trinity River	North Fork Trinity River	Other or unspecified gradient barrier	Blasting	1980	"Barrier No. 5" was blasted (location not specified, but described as 45-minute hike from the meadow at Blacks Flat).	Trinity River Basin Fish and Wildlife Task Force 1981
California	Klamath River	Trinity River	North Fork Trinity River	Other or unspecified gradient barrier	Blasting	1980	A barrier between Blacks Flat and Waldorf crossing was blasted.	Trinity River Basin Fish and Wildlife Task Force 1981
California	Klamath River	Trinity River	North Fork Trinity River	Other or unspecified gradient barrier	Blasting	1980	Blasting occurred at the mouth of Thurston Gulch.	Trinity River Basin Fish and Wildlife Task Force 1981
California	Klamath River	Trinity River	Rush Creek	Other or unspecified gradient barrier	Blasting	1980	The lower section was blasted to improve access for spawning salmon and steelhead.	Trinity River Basin Fish and Wildlife Task Force 1981

California	Klamath River	Trinity River	South Fork Trinity River	Landslide/Rockfall/Roughs	Blasting	1960s (likely)	A channel was blasted in the gorge below Hyampom to improve passage through a large boulder cascade that formed as a result of the 1964 flood.	Pacific Watershed Associates 1994
California	Klamath River	Trinity River	South Fork Trinity River	Other or unspecified gradient barrier	Fishway	Unknown	Fishways were built in many streams in the South Fork Trinity River watershed to provide passage around or through natural and human-made barriers.	Pacific Watershed Associates 1994
California	Klamath River		Bluff Creek	Landslide/Rockfall/Roughs	Fishway	~1978, early 1980s	A fishway was built to restore creek access after the 1964 flood reconfigured the channel. The fishway was damaged and blasting was undertaken in the early 1980s to further improve passage.	Klamath River Basin Fisheries Task Force 1991; LeRoy Cyr, Six Rivers National Forest, Orleans, CA, personal communication, 11 June 2026
California	Klamath River		Clear Creek	Other or unspecified gradient barrier	Blasting	Unknown	Blasting reportedly opened up almost 5 km of habitat.	Klamath River Basin Fisheries Task Force 1991
California	Klamath River		Coon Creek	Other or unspecified gradient barrier	Fishway	Unknown	A fishway was constructed that, as of 1991, functioned at some flows.	Klamath River Basin Fisheries Task Force 1991
California	Klamath River		Dillon Creek	Other or unspecified gradient barrier	Blasting	Unknown	Blasting reportedly opened up 8 km of habitat to salmon and steelhead.	Klamath River Basin Fisheries Task Force 1991
California	Klamath River		Independence Creek	Other or unspecified gradient barrier	Unknown	Unknown	The creek mouth was altered to allow passage.	Klamath River Basin Fisheries Task Force 1991
California	Klamath River		Indian Creek	Other or unspecified gradient barrier	Unknown	1985	Several migration obstructions were modified.	Rice 1986, Klamath River Basin Fisheries Task Force 1991
California	Klamath River		Mainstem Klamath River	Falls	Fishway	1910	A fishway was built at the falls at Keno to enhance passage for fall-run Chinook. Although both spring- and fall-run Chinook could historically access the upper Klamath Basin, irrigation diversions may have impacted passage over mainstem bedrock obstructions.	Fish ladder in Klamath River' 1910
California	Klamath River		Pearch Creek	Other or unspecified gradient barrier	Fishway	1996	The mouth was modified through excavation, rock movement, and the placement of five weir structures for development of step pools to improve passage for salmonids into the creek.	LeRoy Cyr, Six Rivers National Forest, Orleans, CA, personal communication, 11 June 2026
California	Klamath River		Shasta River	Other or unspecified gradient barrier	Fishway	Unknown	Four fishways were constructed on the Shasta River and in 1991 were described as functional.	Klamath River Basin Fisheries Task Force 1991
California	Klamath River		Tarup Creek	Falls	Blasting	Unknown	A falls was blasted to allow migration by Chinook salmon.	Klamath River Basin Fisheries Task Force 1991
California	Sacramento River	American River	South Fork American River	Falls	Blasting	1888-1890, 1935	Modifications at 6-m Salmon Falls began in 1888-1890, reportedly to create passage for log drives or to enhance fish passage, primarily for fall-run Chinook that were blocked from passage at low flows. The falls were again blasted in 1935 to improve passage for salmon and steelhead. Salmon Falls is now inundated by Folsom Reservoir.	Yoshiyama et al. 2001
California	Sacramento River	Battle Creek	North Fork Battle Creek	Landslide/Rockfall/Roughs	Blasting	2021	A rock barrier in Eagle Canyon that blocked passage was modified through excavation and blasting, primarily to benefit winter-run Chinook salmon.	California Trout n.d.
California	Sacramento River		Big Chico Creek	Landslide/Rockfall/Roughs	Fishway	1956, 2026	A fishway was built in Iron Canyon in 1956 where rockfall in the early 1900s blocked passage, but it ceased to function. In 2026, the fishway was removed and rockfall was reconfigured into a channel of step-pools and boulder cascades, providing access to coldwater habitat.	California Trout 2026
California	Sacramento River		Deer Creek	Falls	Fishway	Unknown	A fishway was built at Upper Deer Creek Falls, a sheer 6-m drop.	Yoshiyama et al. 2001
California	Sacramento River		Deer Creek	Falls	Fishway	1942-1943	To mitigate habitat lost by the construction of Shasta and Keswick dams, a fishway was built at 5-m high Lower Deer Creek Falls, which was reportedly impassable.	Yoshiyama et al. 2001
Idaho	Columbia River	Snake River	Selway River	Falls	Fishway	Mid- to late-1960s	A fishway tunnel was built at Selway Falls to ease passage for steelhead.	Smith and Wold 1983, Barker 2010
Idaho	Columbia River	Snake River/Little Salmon River	Boulder Creek	Falls	Blasting	1986	A falls created by a solid granite ledge was blasted to improve passage for spring-run Chinook salmon.	Holubetz and Petrosky 1988b
Idaho	Columbia River	Snake River/Salmon River	Johnson Creek	Falls	Blasting	1984-1986	Blasting occurred at five locations where boulders or bedrock blocked migration of summer-run Chinook salmon; steelhead were historically able to pass the barriers at most flows.	Holubetz and Petrosky 1988a
Idaho	Columbia River	Snake River/Salmon River	Middle Fork Salmon River	Falls	Fishway	1959-1960	A fishway was built at Dagger Falls.	Smith and Wold 1983
Oregon	Coastal	Alsea Bay	Drift Creek	Falls	Fishway	Unknown	A fishway was built at Bohannon Ranch Falls.	Schwartz 1991
Oregon	Coastal	Alsea River	Cascade Creek	Falls	Fishway	Unknown	A fishway was built at a falls (rkm 0.15) that is believed to be a complete barrier to upstream migration; passage of the falls may be possible at extremely high flows in winter.	Solazzi et. al 2000
Oregon	Coastal	Coos River/Millicoma River	West Fork Millicoma River	Falls	Fishway	1952, 2016	Stulls Falls impeded passage particularly for winter-run steelhead, coho, and Chinook. In 1952, a fishway and concrete weir were built at the lower and upper falls, respectively. In 2016, three channels were carved into bedrock to increase the range of passable flows over the upper falls.	Fish Commission of the State of Oregon 1953, Tarbox 2015
Oregon	Coastal	Coos River/South Fork Coos River	Fall Creek	Falls	Fishway	1987, 1997	A fishway was built at a falls (rkm 1) with a 12-m vertical drop that completely blocked upstream passage; the fishway was built in 1987 but steps were not added until 1997.	Solazzi et al. 2000
Oregon	Coastal	Coos River/South Fork Coos River	Tioga Creek	Falls	Fishway	1960s, 2023	In the 1960s, a fishway was built at Tioga Falls, which was historically passable at some flows, especially prior to downstream habitat alterations that reduced water levels at the base of the falls. In 2023, three channels were cut into bedrock to improve passage at a range of flows.	Oregon Fish and Wildlife Commission 2023, DeNies 2023
Oregon	Coastal	Coquille River	North Fork Coquille River	Falls	Fishway	1950-1952	A bypass channel fishway was blasted around LaVerne Park Falls.	Fish Commission of the State of Oregon 1953
Oregon	Coastal	Nehalem River	North Fork Nehalem River	Falls	Fishway	Unknown	A fishway was built at Waterhouse Falls, a partial migration barrier.	Solazzi et al. 2000
Oregon	Coastal	Nestucca River	East Creek	Falls	Blasting	1950-1952	East Creek Falls was blasted to permit easier passage.	Fish Commission of the State of Oregon 1953
Oregon	Coastal	Rogue River	Big Butte Creek	Falls	Fishway	Unknown	A fishway was built at Crowfoot Falls.	Oregon Department of Fish and Wildlife 2009
Oregon	Coastal	Rogue River	Illinois River	Falls	Fishway	1910-1912, 1930s, 1956-57	Illinois River Falls was modified throughout the 20th century, including blasting as early as 1910-1912 and construction of a fishway in 1956-57. There is uncertainty regarding historical passage at the falls and specific modifications.	Busby et al. 1993
Oregon	Coastal	Rogue River	Mainstem Rogue River	Falls	Fishway	1940s	Rainie Falls was blasted at least half a dozen times to improve passage for boats, reducing the need to portage.	Arman and Wooldridge 1982
Oregon	Coastal	Rogue River	Mainstem Rogue River	Falls, Landslide/Rockfall/Roughs	Blasting	1940s	Boulders and other natural obstructions were extensively blasted to clear a boating channel from Dunn Riffle to just above Agness, a distance of over 80 km.	Arman and Wooldridge 1982

Oregon	Coastal	Siletz River	Mainstem Siletz River	Falls	Fishway	1950-1952	A fishway was built at Valsetz Falls.	Fish Commission of the State of Oregon 1953
Oregon	Coastal	Siletz River	Mainstem Siletz River	Falls	Fishway	1949-1952	A fishway was built at Siletz Falls, which historically impeded or blocked passage for winter-run steelhead, coho salmon, and fall-run Chinook. Due to concerns over the low abundance of summer-run steelhead, in 1994 the fishway was converted to a fish trap and since then has been managed to provide passage only to summer-run steelhead and spring-run Chinook.	Kostow 2012, Hemstrom et al. 2017
Oregon	Coastal	Siletz River	Mill Creek	Falls	Fishway	Unknown	A fishway was built at a small falls (rkm 0.4) that is a partial barrier to salmon and steelhead.	Solazzi et al. 2000
Oregon	Coastal	Siuslaw River	Lake Creek	Falls	Fishway	1989	Fishways were constructed at Lake Creek Falls, formed about 10,300 years ago by a massive landslide, to allow passage by coho and other species.	Fischer et al. 2022
Oregon	Coastal	Umpqua River	Smith River	Falls	Fishway	Unknown	A fishway was constructed at Smith River Falls (rkm 47).	Oregon Department of Fish and Wildlife 2017
Oregon	Coastal	Umpqua River	South Fork Umpqua River	Falls	Fishway	1955	A fishway was built at South Umpqua Falls, primarily to ease passage by spring-run Chinook.	Pitney and Saltzman 1956
Oregon	Coastal	Umpqua River/Elk Creek/Pass Creek	Buck Creek	Other or unspecified gradient barrier	Fishway	2017	A fishway was cut into a bedrock sheet.	Lee Russell, Elk Creek Watershed Coalition, Yoncalla, OR, personal communication, 16 June 2026
Oregon	Coastal	Umpqua River/North Fork Umpqua River	Little River	Falls	Fishway	Unknown	A fishway was built at Little River Falls, an approximately 3-m step.	Loomis et. al 2003
Oregon	Coastal	Umpqua River/North Fork Umpqua River	Little Wolf Creek	Falls	Fishway	Pre-1985 (Unknown)	Little Wolf Creek Falls, reportedly a total obstruction to upstream passage, was blasted. Fish weirs were subsequently built in the blasted channel to ease passage at all flows.	Bureau of Land Management 1985
Oregon	Coastal	Umpqua River/North Fork Umpqua River	Steamboat Creek	Falls	Fishway	1959	A fishway was constructed at Steamboat Falls, a 7.6-m two-step falls, to improve passage for steelhead. Historically, the falls may have been a high-flow migration barrier.	Loomis et. al 2003
Oregon	Coastal		Little Nestucca River	Falls	Fishway	Unknown	A fishway was built at Stella Falls (rkm 7.0).	Solazzi et al. 2000
Oregon	Coastal		Little Nestucca River	Falls	Fishway	Unknown	A fishway was built at Upton Falls (rkm 6.6) where passage was judged to be "more difficult" than at Stella Falls upstream.	Solazzi et al. 2000
Oregon	Coastal		Nehalem River	Falls	Fishway	1950-1952	A fishway was constructed at Nehalem Falls.	Fish Commission of the State of Oregon 1953
Oregon	Coastal		Siuslaw River	Falls	Fishway	1972	A fishway was constructed at Siuslaw River Falls.	Hutchison 1972
Oregon	Columbia River	Clackamas River	Collawash River	Falls	Blasting	1974 (blasting), 1987 (fishway), 1989-1992 (blasting)	Collawash River Falls (rkm 12) was a partial migration barrier in a deeply incised gorge; summer-run steelhead were observed to pass the falls at an estimated 10-20% success rate. Modifications to the falls to increase passage for salmon and steelhead included excavation of a trench and substantial blasting.	Deibel 1993
Oregon	Columbia River	Clackamas River	Eagle Creek	Falls	Fishway	1930s	A fishway was built at Dwyer Falls, downstream of the confluence of the North Fork of Eagle Creek (rkm 9.7). Dwyer Falls was believed to be passable by steelhead but not salmon.	Columbia Basin Hatchery Review Team 2007
Oregon	Columbia River	Clackamas River	Eagle Creek	Falls	Fishway	1930s	A fishway was built at the middle falls of Eagle Creek (rkm 14.5).	Columbia Basin Hatchery Review Team 2007
Oregon	Columbia River	Hood River	West Fork Hood River	Falls	Fishway	1985	A fishway was built at Moving Falls.	Coccoli 1999
Oregon	Columbia River	Hood River	West Fork Hood River	Falls	Fishway	1957	A fishway was built at Punchbowl Falls, which was (and may remain, possibly due to inadequate maintenance) a partial barrier to migration. Summer-run steelhead are found above the falls. Large numbers of salmon or steelhead (runs not specified) were reportedly able to ascend the falls prior to fishway construction.	Smith and Wold 1983, Coccoli 1999, Kostow 2003
Oregon	Columbia River	Santiam River/Willamette River	Little North Fork Santiam River	Falls	Fishway	Unknown	A fishway was built at Elkhorn Falls.	Smith and Wold 1983
Oregon	Columbia River	Scappoose Creek	North Fork Scappoose Creek	Falls	Fishway	Unknown	A fishway was built at Bonnie Falls, considered to be a complete barrier to salmon and steelhead migration.	Solazzi et al. 2000
Oregon	Columbia River	Wallowa River	Minam River	Falls	Fishway	Unknown	A fishway was built at Minam Falls; blasting also occurred.	Smith and Wold 1983, Fulton 1968
Oregon	Columbia River	Willamette River	Mainstem Willamette River	Falls	Fishway	1885, 1893, 1904, 1975	A fishway was built at Willamette Falls and has been replaced multiple times to improve passage. Prior to modification, only spring-run Chinook and late winter-run steelhead could ascend the falls.	Smith and Wold 1983, Myers et al. 2006, Oregon Department of Fish and Wildlife n.d.b
Oregon	Columbia River	Willamette River	Santiam River	Other or unspecified gradient barrier	Fishway	Unknown	Rock cut fish passes were built at an unspecified natural barrier(s).	Delarm and Wold 1986
Oregon	Columbia River	Willamette River	South Santiam River	Falls	Fishway	1963	A rock cut fish pass was built at Hard (House) Rock Falls.	Delarm and Wold 1986
Oregon	Columbia River	Willamette River/Collawash River	Hot Springs Fork	Falls	Fishway	1966	A fishway was built at Pegleg Falls.	Delarm and Wold 1984, Hickman 1992
Oregon	Columbia River	Willamette River/Collawash River	Hot Springs Fork	Falls	Unknown	1986	An unnamed falls (rkm 11.4) was modified to improve passage.	Hickman 1992
Oregon	Columbia River	Willamette River/Collawash River	Hot Springs Fork/Nohorn Creek	Falls	Blasting	1985	Three jump pools and two holding pools were blasted at the uppermost (of three) waterfalls to improve access for steelhead.	Cain 1986
Oregon	Columbia River	Willamette River/Collawash River	Hot Springs Fork/Pansy Creek	Falls	Blasting	1985	Pools were blasted into bedrock to improve steelhead passage around a falls.	Cain 1986
Oregon	Columbia River	Willamette River/Luckiamute River	Coast Creek	Other or unspecified gradient barrier	Fishway	1962	A rock cut fish pass was built at an unspecfied natural barrier.	Delarm and Wold 1986
Oregon	Columbia River	Willamette River/McKenzie River	Mohawk River	Falls	Fishway	1962	A rock cut fish pass was built at Mohawk Falls.	Delarm and Wold 1986
Oregon	Columbia River	Willamette River/Milk Creek	Nate Creek	Other or unspecified gradient barrier	Fishway	1961	A rock cut fish pass was built at an unspecfied natural barrier.	Delarm and Wold 1986
Oregon	Columbia River	Willamette River/Molalla River/Pudding River	Butte Creek	Falls	Fishway	1963	Rock cut fish passes were built at "Butte Falls No. 3" and "Butte Falls No. 4."	Delarm and Wold 1986
Oregon	Columbia River	Willamette River/South Santiam River	Ames Creek	Other or unspecified gradient barrier	Fishway	2012	Step pools were excavated to facilitate passage into the creek. Foster Dam on the South Santiam River reduced the amount of backflooding into the tributary that occurred naturally, making it more difficult for fish to ascend the steep bedrock channel at the mouth.	South Santiam Watershed Council n.d., Morgan 2012
Oregon	Columbia River	Willamette River/South Santiam River	Wiley Creek	Falls	Fishway	1958, 1967	Rock cut fish passes were built at "Wiley Creek No. 3" and "Wiley Creek No. 5."	National Marine Fisheries Service 1981, Delarm and Wold 1986
Oregon	Columbia River	Willamette River/South Yamhill River	Willamina Creek	Other or unspecified gradient barrier	Fishway	Unknown	Rock cut fish passes were built at unspecified natural barriers.	Smith and Wold 1983
Oregon	Columbia River	Willamette River/Yamhill River	Agency Creek	Other or unspecified gradient barrier	Fishway	1962	Three rock cut fish passes were built at unspecfied natural barriers.	Delarm and Wold 1986
Oregon	Columbia River	Youngs River/Klaskanine River	North Fork Klaskanine River	Falls	Fishway	Unknown	A fishway was constructed at Barth Falls, which was a barrier to chum, Chinook, coho, and cutthroat trout; steelhead may have been able to pass at certain flows.	Fulton 1968, Smith and Wold 1983, Oregon Department of Fish and Wildlife 2016
Oregon	Columbia River		Clatskanie River	Falls	Fishway	Unknown	A fishway was built at Clatskanie Falls.	Smith and Wold 1983, Delarm and Wold 1986
Oregon	Columbia River		Deschutes River	Falls	Fishway	1930s	A fishway was built at Sherars Falls to enhance passage.	Oregon Department of Fish and Wildlife n.d.a

Oregon	Columbia River		Deschutes River	Falls	Fishway	1922	A fishway was built at Steelhead Falls, which was passable by steelhead in high winter or early spring flows. The fishway was purposely blocked in the 1960s to prevent upstream migration by nongame fish. By 1996, the fishway was no longer functional.	Fies et al. 1996, Davis and Kunkel 2010
Oregon	Columbia River		Deschutes River	Falls	Fishway	1920s	A fishway was built at Big Falls, which was the historic upstream limit to anadromous fish migration. By 1996, the fishway was no longer functional.	Fies et al. 1996, Davis and Kunkel 2010
Oregon	Columbia River		Deschutes River	Falls	Fishway	1920s	A fishway was built at Cline Falls to provide anadromous fish passage. By 1996, the fishway was no longer functional.	Fies et al. 1996, Davis and Kunkel 2010
Oregon	Columbia River		Fifteenmile Creek	Falls	Fishway	1960s, 1972, mid-1980s	Modifications at Seufert Falls (rkm 0.4) to improve passage (primarily for winter-run steelhead) include installation of low wooden sills across the stream (early 1960s), blasting (1972), and a fishway (mid-1980s).	Lichens 1972, Nelson 2000
Oregon	Columbia River		Goble Creek	Falls	Fishway	Unknown	A fishway was constructed at Goble Creek Falls.	Smith and Wold 1983, Delarm and Wold 1986
Oregon	Columbia River		Umatilla River	Other or unspecified gradient barrier	Blasting	1984-1986	A channel was blasted and excavated through a shallow bedrock reach downstream of Threemile Dam, where passage was difficult due to low flows from upstream irrigation diversions.	Sanguine 1985
Washington	Coastal	Chehalis River	Elk Creek	Falls	Fishway	1972	A fishway was built at a 3.7-m falls (rkm 2.4).	Phinney and Bucknell 1975
Washington	Coastal	Chehalis River	Roger Creek	Falls	Blasting	1970	Fisk Falls was blasted to improve passage by salmon; steelhead were reportedly able to ascend the falls historically.	Phinney and Bucknell 1975
Washington	Coastal	Chehalis River/Humptulips River	East Fork Humptulips Creek	Falls	Fishway	Unknown	A fishway was built at a falls below Flat Bottom Creek (rkm 27.5).	Phinney and Bucknell 1975
Washington	Coastal	Chehalis River/Newaukum River	North Fork Newaukum River	Falls	Fishway	1970, 2016	A fishway was built at a small falls where a diversion dam blocked nearly all adult fish passage. The fishway was rebuilt in 2016.	Phinney and Bucknell 1975, Washington Department of Fish and Wildlife n.d.
Washington	Coastal	Quinault River/Lake Quinault	Falls Creek	Falls	Fishway	Unknown	A fishway was built at a falls (rkm 0.3) but was (mostly) removed around 1998. The falls may also have been blasted.	Phinney and Bucknell 1975, Washington Department of Fish and Wildlife n.d.
Washington	Coastal	Willapa Bay/North River	Fall River	Falls	Fishway	1965	A fishway was built at a falls near the mouth.	Phinney and Bucknell 1975
Washington	Coastal	Willapa Bay/North River	Fall River	Falls	Blasting	1965	Blasting removed a falls approximately 1.6 km upstream from the Fall River fishway.	Phinney and Bucknell 1975
Washington	Coastal	Willapa Bay/Willapa River	South Fork Willapa River	Falls	Fishway	1950s	A fishway was built to improve passage at a 4.6-m falls downstream of the mouth of Donaldson Creek. Blasting was also conducted in the early 1950s at possibly more than one falls nearby.	Phinney and Bucknell 1975
Washington	Coastal		Salt Creek	Falls	Fishway	1951, 1961, 2000	A falls (three hydraulic jumps) at rkm 5.6 were a barrier to chum salmon and cutthroat trout at all flows, as well as coho and steelhead under low-flow conditions. In 1951, a trench was blasted between the upper and lower falls, but was unsuccessful at improving passage. Concrete weirs, which were built in 1961 and repaired in 2000, reportedly improved passage.	McHenry et al. 2004
Washington	Columbia River	Abernathy Creek	Cameron Creek	Falls	Fishway	1952	A weir-pool fishway was blasted into a bedrock falls/cascades area.	Smith and Wold 1983, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Abernathy Creek	Cameron Creek	Falls	Fishway	1952	A weir-pool fishway was built next to a bedrock cascade.	Smith and Wold 1983, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Cowlitz River	Delameter Creek	Falls	Fishway	1958	A weir-pool fishway was built at a 2-m high concrete dam on a bedrock falls.	Smith and Wold 1983, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Cowlitz River	Delameter Creek	Falls	Fishway	1956	A weir-pool fishway was built at a bedrock falls.	Smith and Wold 1983, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Cowlitz River	South Fork Ostrander Creek	Falls	Fishway	1952, 1987	A weir-pool fishway was built at a bedrock falls; streambed controls were added in 1987.	Smith and Wold 1983, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Kalama River	Little Kalama River	Falls	Blasting	1952	Fishways were blasted at three small falls.	Smith and Wold 1983, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Kalama River	Mainstem Kalama River	Falls	Fishway	Early 1900s, 1936, late 1950s	Kalama Falls was modified in the early 1900s in association with hydropower development. A fishway was built in 1936. Kalama Falls Hatchery began operation in the late 1950s, which included a concrete and steel cap that increased the height of the falls to 3-4 m as well as an adjacent fishway to divert adult migrants for either broodstock collection or upstream passage.	Bradford et al. 1996, Lower Columbia Fish Recovery Board 2004
Washington	Columbia River	Lewis River	East Fork Lewis River	Falls	Blasting	1982	A notch was blasted into Sunset Falls to reduce the height and facilitate passage by summer-run steelhead.	McMillan 1985, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Lewis River/North Fork Lewis River	Cedar Creek	Falls	Fishway	1957	Fishways were built at Cedar Creek Falls, which provided access to about 24 km of habitat for salmon.	Fulton 1968
Washington	Columbia River	Lewis River/North Fork Lewis River	Johnson Creek	Falls	Fishway	1952	A fishway was blasted into bedrock cascades (rkm 0.3) and enhanced with three channel-spanning weirs.	Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Lewis River/North Fork Lewis River	Johnson Creek	Falls	Fishway	1952	A fishway was created by blasting a series of pools throughout a bedrock cascades at rkm 0.4.	Washington Department of Fish and Wildlife n.d.
Washington	Columbia River	Yakima River/Naches River	Little Naches River	Falls	Fishway	1986-87	A fishway was constructed at Salmon Falls. The channel below the falls was also modified to permit passage to the falls during low flows.	Hoefer 1997, Muir 2003
Washington	Columbia River		Abernathy Creek	Falls	Fishway	1951	A fishway was built at a falls (rkm 6).	Fulton 1968, Washington Department of Fish and Wildlife n.d.
Washington	Columbia River		Grays River	Falls	Fishway	1952	A fishway chute was blasted in bedrock to improve passage.	Washington Department of Fish and Wildlife n.d.
Washington	Columbia River		Klickitat River	Falls	Fishway	1952, 2010	A fishway was built at Lyle Falls (rkm 3.5), a low-flow barrier, to pass adult anadromous fish at a wide range of flows. The fishway was reconstructed in 2010.	Espenson et al. 2004, Bonneville Power Administration 2008, Washington Department of Fish and Wildlife n.d., Yakima/Klickitat Fisheries Project n.d.
Washington	Columbia River		Klickitat River	Falls	Fishway	1960s, 2002-2005	A fishway complex was built at Castile Falls, a series of 11 falls in the Klickitat River Gorge. Blasting was also conducted at some of the falls to improve passage. Renovation of the fishway complex occurred in the early 2000s. Steelhead and spring-run Chinook may have been able to pass the falls historically.	Fulton 1968, National Marine Fisheries Service 1981, Espenson 2004, Galbreath et al. 2014, McMillan 2024
Washington	Columbia River		Mill Creek	Falls	Fishway	1951	A fishway was built at a 2-m falls (rkm 2) that was a low-flow barrier.	Bryant 1949, Fulton 1968
Washington	Columbia River		Washougal River	Falls	Fishway	1957	A fishway was built at 2.4-m high Salmon Falls (rkm 28), which was difficult for salmon to pass at low flows,	Bryant 1949, Fulton 1968, Washington Department of Fish and Wildlife n.d.

Washington	Columbia River		Wind River	Falls	Fishway	Unknown but likely 1950s	A weir-pool fishway was built next to a minor bedrock falls/cascade upstream of Shipherd Falls.	Washington Department of Fish and Wildlife n.d.
Washington	Columbia River		Wind River	Falls	Fishway	1956	A vertical slot fishway was built at Shipherd Falls, a series of four falls, to pass spring-run Chinook to the Carson National Fish Hatchery. Summer-run steelhead were able to pass the falls at high flows.	Fulton 1970, National Marine Fisheries Service 1981, Washington Department of Fish and Wildlife n.d.
Washington	Puget Sound	Deschutes River	Mainstem Deschutes River	Falls	Fishway	1953, 1954	Three fishways were built at lower, middle, and upper Tumwater Falls to open the upper river to anadromous fish.	Phinney and Bucknell 1975, Washington Department of Fish and Wildlife n.d.
Washington	Puget Sound	Deschutes River	Percival Creek	Falls	Fishway	1995	A fishway was built at a falls.	Washington Department of Fish and Wildlife n.d.
Washington	Puget Sound	Nisqually River	Horn Creek	Falls	Fishway	2024	Fishway chutes/pools were installed at a 1.5-m falls that partially blocked passage for salmon.	Washington State Recreation and Conservation Office 2025
Washington	Puget Sound	Samish River	Ennis Creek	Falls	Fishway	Unknown	A fishway was built at a small falls to provide passage for coho salmon.	Williams and Phinney 1975
Washington	Puget Sound	Snohomish River	South Fork Skykomish River	Falls	Fishway	1958	A fishway and trap and haul program at Sunset Falls (rkm 3) provides salmon, steelhead, and bull trout with access to 111 km of habitat upstream of three impassable barriers.	Tribble 2020, Washington Department of Fish and Wildlife n.d.
Washington	Puget Sound	Stillaguamish River	South Fork Stillaguamish River	Falls	Fishway	1954	A 50-step vertical slot fishway was constructed at Granite Falls; a tunnel was also blasted through bedrock.	Pess et al. 2002, Washington Department of Fish and Wildlife n.d.

Metadata for Table S2

Barrier Type	**Falls:** broadly defined to include high-gradient barriers such as waterfalls, cascades, chutes, and rapids. **Landslide/Rockfall/Roughs:** includes persistent natural barriers that were created by landslide or rockfall (including very large boulders), typically on more recent (rather than geologic) timescales, e.g., the Christmas flood of 1964 in the Pacific Northwest and parts of northern California. **Other or unspecified gradient barrier:** includes bedrock outcroppings and sheets, as well as instances for which the specific type of barrier is not described.
Modification Type	**Blasting:** applies to instances where explosives were used to modify or remove a barrier to enhance passage. **Fishway:** applies to instances where any variety of fishway or bypass channel was constructed to enhance passage, including instances where blasting was used to create a fishway, or where a fishway was built years to decades after blasting occurred. **Unknown:** applies to instances where a description of the type of modification could not be found.
Modification Date	Many natural barriers were modified more than once and in more than one way. Where more than one year is listed, dates reflect documentation of multiple discrete actions to modify a barrier (such as replacement of a fishway or blasting followed by fishway construction years later) or to maintain or further improve existing passage enhancements.

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