POTENTIAL EFFECTS OF SNAKE RIVER DAM REMOVAL ON SALMONIDS

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I. INTRODUCTION

This article focuses on the four Lower Snake River (LSR) dams and their effects on anadromous salmonids. For readers unfamiliar with regional geography, the LSR dams are located within the Snake River Basin (SRB), which is a large sub-basin within the greater Columbia River Basin; proceeding from downstream to upstream, these are Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams.[1] The intent here is not to comprehensively review ecological effects of dams and dam removal. Instead, this article discusses some of the most well-studied and most important effects of dams on the most well-studied and most important fishes, including a discussion of expected effects if the LSR dams were to be removed.

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[1] *See infra* Figure 1.

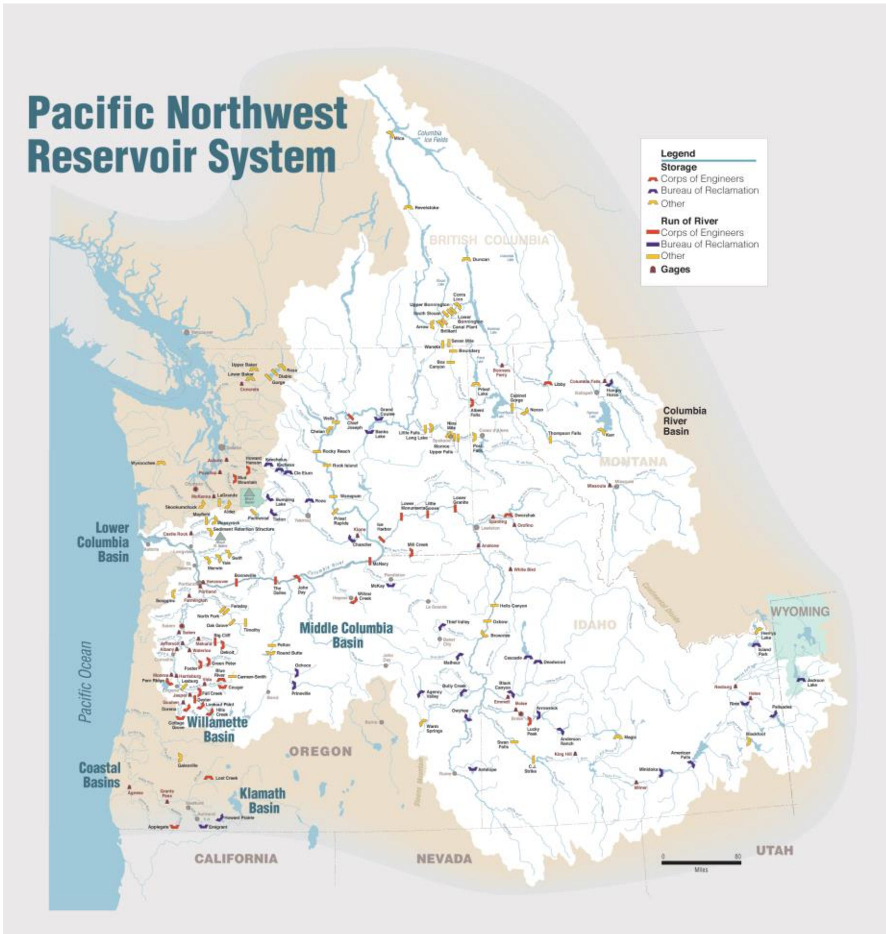

Figure 1. Major rivers and dams of the Pacific Northwest. Map drawn by U.S. Army Corps of Engineers, public domain, via Wikimedia Commons.[2]

I begin with a short primer on biological concepts relevant to the discussion of the effects of dams on fishes.[3] Next, I summarize how rivers function on the landscape by moving water and sediment downstream before discussing some of the more important physical and biological effects that dams exert. Finally, I provide examples of regional dam removals before discussing how removal of the LSR dams may affect fishes.

2. *File: Pacific Northwest River System.png*, WIKIPEDIA COMMONS, https://commons.wikimedia.org/wiki/File:Pacific_Northwest_River_System.png#filehistory (last visited Mar. 21, 2022).

3. Conventional usage holds that the word "fish" to refers to a single species, including multiple individuals of that species, while "fishes" refers to multiple species.

II. A PRIMER ON FISH BIOLOGY AND LIFE HISTORIES

For many people, defining a fish may be as simple as paraphrasing Justice Potter Stewart's, "I know it when I see it."[4] However, fishes are the most diverse group of vertebrate animals with nearly 30,000 known species, ranging in size from the nine-millimeter pygmy goby (*Pandaka pygmaea*) to the nearly nineteen-meter whale shark (*Rhincodon typus*).[5] A large range of body shapes, anatomical structures, and behavioral and physiological strategies are included among the fishes. Thus, clearly defining what a fish is can be challenging. However, one commonly accepted definition states that fishes are aquatic vertebrate animals that have gills throughout life and limbs (if they have them) that take the shape of fins but lack digits.[6]

This article focuses on fishes considered to be culturally, spiritually, ecologically, or economically important within the SRB. Undoubtedly the most important group of native species of concern within the region are the salmonid fishes: Pacific Salmon, Trout, and Charr. It is hard to overstate the effect of this group of animals on the culture of the peoples who historically and currently occupy the lands now referred to as the Pacific Northwest (PNW). Tribes and Tribal Organizations in the PNW refer to themselves as Wy-Kan-Ush-Pum, a Sahaptin term meaning Salmon People.[7] Over the past two decades, a focus of Tribal governments and natural resource agencies in the PNW has been the recovery of populations of salmon, such as the cooperative Wy-Kan-Ush-Mi Wa-Kish-Wit (Spirit of the Salmon) Columbia River Anadromous Fish Restoration Plan.[8] Consequently, the focus of this article is the salmonid fishes.

The salmonids include *resident* fishes that live entirely in freshwater and *anadromous* fishes that hatch in freshwater, migrate to saltwater as juveniles to feed and mature, then return to freshwater as mature adults to spawn.[9] Although resident fishes are affected by dams, this article focuses on the anadromous salmonids.[10] Within the SRB, this includes steelhead (*Oncorhynchus mykiss*), Chinook Salmon (*O. tshawytscha*), Coho Salmon (*O. kisutch*), and Sockeye Salmon

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4. Jacobellis v. Ohio, 378 U.S. 184, 197 (1964).

5. QUENTIN BONE & RICHARD H. MOORE, BIOLOGY OF FISHES 24, 29 (Taylor & Francis Group, 3d ed. 2008).

6. JOSEPH S. NELSON, FISHES OF THE WORLD 1–2 (John Wiley & Sons, Inc. eds., 4th ed. 2006).

7. *We Are All Salmon People*, COLUMBIA RIVER INTER-TRIBAL FISH COMMISSION, https://critfc.org/salmon-culture/we-are-all-salmon-people/ (last visited Mar. 21, 2022).

8. *Spirit of the Salmon*, COLUMBIA RIVER INTER-TRIBAL FISH COMM'N, https://plan.critfc.org/2013/spirit-of-the-salmon-plan/about-spirit-of-the-salmon/wy-kan-ush-mi-wa-kish-wit-update/ (last visited Mar. 21, 2022).

9. *See infra* Figure 2; *Conserving Salmon and Steelhead on the West Coast,* NAT'L OCEANIC & ATMOSPHERIC ADMIN. FISHERIES, https://www.fisheries.noaa.gov/west-coast/about-us/conserving-salmon-and-steelhead-west-coast (last visited Mar. 21, 2022).

10. J. MICHAEL HUDSON ET AL., LEWIS RIVER BULL TROUT SYNTHESIS OF KNOWN INFORMATION 8 (2019), https://pubs.er.usgs.gov/publication/70203784; Devon E. Pearse et al., *Over the Falls? Rapid Evolution of Ecotypic Differentiation in Steelhead/Rainbow Trout*, 100 J. HEREDITY 515, 516 (2009).

(*O. nerka*).[11] Because of their importance to so many people, the salmonid fishes are the most well-studied and reported upon in the PNW, so this article focuses primarily on this group.

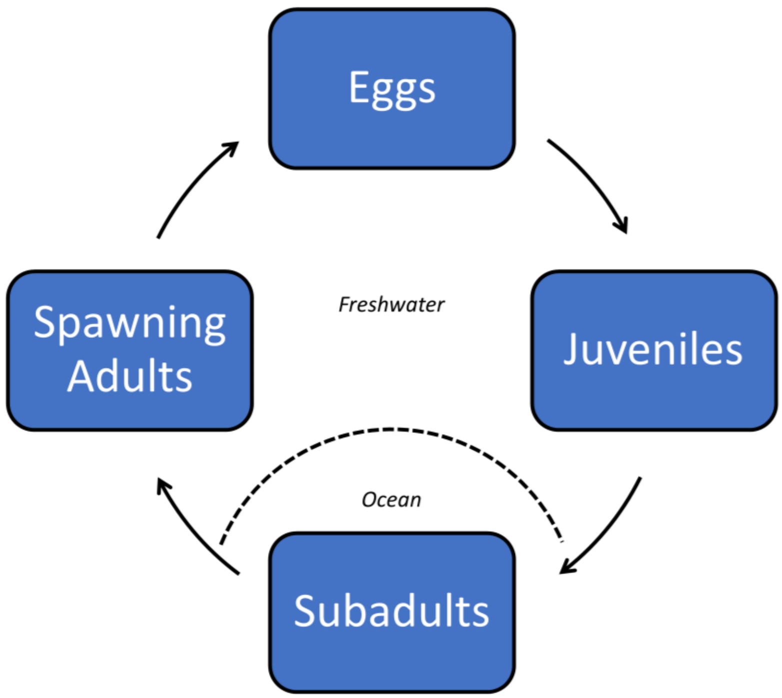

Figure 2. Simplified anadromous life cycle, indicating life stages that occur in freshwater and those that occur in the ocean.

As information allows, this article also covers additional fishes such as native White Sturgeon (*Acipenser transmontanus*) and native but problematic Northern Pikeminnow (*Ptychocheilus oregonensis*). White Sturgeon have the capacity for anadromy, but populations above Bonneville Dam, the lowest mainstem dam on the Columbia River, are landlocked because of the dams.[12]

Within the pattern of anadromy depicted in Figure 2, each phase is referred to as a *life stage*. Collectively, the duration and timing of life stages exhibited by an

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11. Peter F. Galbreath et al., *Extirpation and Tribal Reintroduction of Coho Salmon to the Interior Columbia River Basin*, 39 FISHERIES 77, 77–80 (2014); *see generally* NAT'L MARINE FISHERIES SERV., NAT'L OCEANIC & ATMOSPHERIC ADMIN., 2016 5-YEAR REVIEW: SUMMARY & EVALUATION OF SNAKE RIVER SOCKEYE SNAKE RIVER SPRING-SUMMER CHINOOK SNAKE RIVER FALL-RUN CHINOOK SNAKE RIVER BASIN STEELHEAD 4 (2016); Russel F. Thurow et al., *Distribution and Status of Seven Native Salmonids in the Interior Columbia River Basin and Portions of the Klamath River and Great Basins*, 17 N. AM. J. FISHERIES MGMT. 1094, 1103–04 (1997).

12. *See generally* John A. North et al., *Distribution and Movements of White Sturgeon in Three Lower Columbia River Reservoirs*, 67 NW. SCI. 105, 110 (1993).

individual or population is known as a *life history*.[13] Life histories represent behavioral and physiological strategies to maximize survival and reproduction opportunities. These strategies include whether a fish remains in freshwater for its entire life or migrates between fresh- and saltwater, how long fish spend in freshwater before migrating to the ocean, how long they spend in saltwater before returning to spawn, and when during the year these migrations occur. Anadromy and residency are examples of alternative life history pathways.[14] Because anadromous fish have greater feeding opportunities in the marine environment, they grow larger, and thus produce more eggs, offsetting the increased mortality risk associated with this strategy.[15] Within the salmonids, these resident and anadromous life history strategies have evolved over the last five million years, and the diversity of life history strategies that exist reflect the dynamic environments in which these animals evolved.[16]

Across the range of this diversity, many commonalities exist for anadromous salmonids. In freshwater tributaries and mainstem rivers, eggs are deposited by spawning adults into nests excavated from appropriately sized gravel, which are termed *redds*.[17] These eggs then incubate within the redds for one to three months, depending on species and ambient temperature.[18] After this incubation, embryonic fish still attached to a partially unabsorbed yolk-sac (termed *alevins*) hatch and remain within the gravel for a period of days to weeks.[19] Once the yolk-sac has been absorbed, these fish—now termed *fry*—swim up through the gravel to access the water column above and begin feeding.[20] As they continue to develop, fry increase in size, become more active, and develop further, including gaining the distinct banding along their sides that indicate they are now *parr*.[21] As parr metamorphose into *smolts*, they undergo a series of physiological changes that prepare them for life in saltwater, including a shift in how they balance their internal salt concentrations and development of a distinct silvery color.[22]

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13. Ian A. Fleming, *Reproductive Strategies of Atlantic Salmon: Ecology and Evolution*, 6 REVS. IN FISH BIOLOGY & FISHERIES 379, 381 (1996).

14. T.P. Quinn & K. W. Myers, *Anadromy and the Marine Migrations of Pacific Salmon and Trout: Rounsefell Revisited*, *in* 14 REVIEWS IN FISH BIOLOGY & FISHERIES (2004).

15. Fleming, *supra* note 13, at 404; Jeffrey A. Hutchings & Ransom A. Meyers, *The Evolution of Alternative Mating Strategies in Variable Environments*, 8 EVOLUTIONARY ECOLOGY 256, 264 (1994).

16. Robin S. Waples et al., *Evolutionary History of Pacific Salmon in Dynamic Environments*, 1 EVOLUTIONARY APPLICATIONS 189, 190, 195–97 (2008).

17. S. J. Cooke, G. T. Crossin & S. G. Hinch., *Pacific Salmon Migration: Completing the Cycle*, *in* 1945–52 ENCYCLOPEDIA OF FISH PHYSIOLOGY: FROM GENOME TO ENVIRONMENT (A.P. Farrell ed., 2011).

18. D.F. Alderdice & F. P. J. Velsen, *Relationship Between Temperature and Incubation Time for Eggs of Chinook Salmon (*Oncorhynchus Tshawytscha*)*, 35 J. FISHERIES RSCH. BD. CAN. 69, 71 (1978).

19. Cooke, Crossin & Hinch, *supra* note 17, at 1947.

20. Cooke, Crossin & Hinch, *supra* note 17, at 1947.

21. Cooke, Crossin & Hinch, *supra* note 17, at 1947–49.

22. Cooke, Crossin & Hinch, *supra* note 17, at 1947–48.

Juvenile salmonids generally begin their downstream migration to saltwater (*outmigration*) at the smolt stage.[23] However, some fish outmigrate as fry and parr, especially Coho[24] and Chinook.[25] Also, while most Coho and Chinook outmigrate within one year of hatching, some spend up to two years in freshwater,[26] and steelhead may reside within freshwater for up to three years.[27]

Anadromous salmonids generally spend one to three years in the marine environment.[28] During this marine life stage, salmonids feed on a range of prey items as they grow large and develop into sexually mature fish capable of spawning.[29] As they approach final maturation, anadromous salmonids navigate back to their *natal* river system from which they hatched, in most cases returning to spawn within the same stream, and in some cases spawning within meters from where they hatched.[30] This tendency to return to their natal stream is called *philopatry*, and the degree to which salmonids exhibit this trait is variable. Those that do not home to their natal stream are said to *stray*.[31]

Three things are important to take away from this discussion of anadromous salmonid life histories. First, juvenile anadromous salmonids hatch in freshwater and rely upon freshwater habitats to grow and develop sufficiently so that they can migrate to saltwater, where they continue to feed and mature into adults. Second, because of this strategy, the freshwater environment represents a nursery for juvenile anadromous salmonids: a place where predation risks are lower than in the

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23. Andy Noone et al., *Watershed Management for Salmon Recovery: A Reference Guide*, GOVLINK.ORG, https://www.govlink.org/watersheds/8/pdf/WRIA8-WMSR-Final.pdf (last visited Feb. 13, 2022).

24. Kim K. Jones et al., *Interannual Variability in Life-stage Specific Survival and Life History Diversity of Coho Salmon in a Coastal Oregon Basin*, 78 CAN. J. FISHERIES & AQUATIC SCIS. 1887, 1889 (2021).

25. Samuel L. Bourret et al., *Diversity of Juvenile Chinook Salmon Life History Pathways*, 26 REVS. FISH BIOLOGY & FISHERIES 375, 380, 385 (2016).

26. Kim K. Jones et al., *supra* note 24, at 1889; Bourret et al., *supra* note 25, at 380, 385.

27. Jason Hall et al., *Life History Diversity of Steelhead in Two Coastal Washington Watersheds*, 145 TRANSACTIONS AM. FISHERIES SOC'Y 990, 998 (2016); Brian W. Hodge et al., *Life History Diversity in Klamath River Steelhead*, 145 TRANSACTIONS AM. FISHERIES SOC'Y 227, 231 (2016).

28. JENNIFER POIRIER & DOUG OLSON, LITERATURE REVIEW OF SURVIVAL, AGE AT RETURN, STRAYING, LIFE HISTORY DIVERSITY AND YEARLING HATCHERY RELEASE STRATEGIES FOR FALL CHINOOK SALMON 9–10 (U.S. Fish & Wildlife Serv. ed. 2017); Thomas P. Quinn & Kurt Fresh, *Homing and Straying in Chinook Salmon (*Oncorhynchus Tshawytscha*) from Cowlitz River Hatchery, Washington*, 41 CAN. J. FISHERIES & AQUATIC SCIS. 1078, 1080 (1984).

29. Susan P. Johnson & Daniel E. Schindler, *Trophic Ecology of Pacific Salmon (*Oncorhynchus Spp.*) in the Ocean: A Synthesis of Stable Isotope Research*, 24 ECOLOGICAL RSCH. 855, 860 (2008); Marisa N.C. Litz et al., *Ontogenetic Shifts in the Diets of Juvenile Chinook Salmon: New Insight from Stable Isotopes and Fatty Acids*, 100 EVN'T BIOLOGY FISHES 337, 344 (2017).

30. *See generally* Nolan N. Bett & Scott G. Hinch, *Olfactory Navigation during Spawning Migrations: A Review and Introduction of the Hierarchical Navigation Hypothesis*, 91 BIOLOGICAL REVS. CAMBRIDGE PHIL. SOC'Y (2016); Andrew H. Dittman & Thomas P. Quinn, *Homing in Pacific Salmon: Mechanisms & Ecological Basis*, 199 J. EXPERIMENTAL BIOLOGY (1996).

31. *See generally* Matthew L. Keefer & Christopher C. Caudill, *Homing and Straying by Anadromous Salmonids: A Review of Mechanisms and Rates*, 24 REVS. FISH BIOLOGY & FISHERIES (2014).

marine environment, but food is sufficient to support their growth. The key attributes of high-quality freshwater habitat are often summed up with the phrase, "cold, clean, clear, complex, connected."[32] Third, in addition to providing a nursery, the freshwater environment also provides a migration corridor—akin to a flowing highway—by which fish access the marine environment and then return to spawn after maturing in the ocean. Impediments to these migrations can change the relative benefits and risks of the anadromous life histories, altering selection pressures that shape and maintain these behaviors.[33] Fourth, while most salmonids outmigrate as smolts, an important fraction of these populations outmigrate as very small fish (fry and parr), which are poorer swimmers that are less equipped to evade predation or otherwise fend for themselves.

III. PHYSICAL, GEOMORPHIC, AND ECOLOGICAL EFFECTS OF DAMS

Three points are important to clarify about the LSR dams. First, these four dams are "run of the river" dams, meaning they do not store appreciable amounts of water behind them, but rather continuously release flow through spill, generation (i.e., turbines), downstream passage routes, upstream passage routes, and auxiliary flow pathways.[34] Second, these dams all span the entire river width.[35] Consequently, they completely interrupt the downstream flow of the Snake River and both the downstream and upstream movement of aquatic animals. Third, as shown in Figure 1, the LSR dams exist within a broader context of hydropower projects and other dams throughout the PNW. Four mainstem Columbia River dams are in place below them, between Ice Harbor and the ocean. More than two dozen dams are in place above them in the SRB, including the Hells Canyon Complex on the Snake River and the dams within the Clearwater and Salmon Rivers sub-basins.[36] These points provide context when extrapolating the effects described for other regional dams to the LSR dams.

The effects of dams on the physical river environment and the processes that shape rivers (*fluvial geomorphology*) are documented elsewhere.[37] Three of the most important of these physical and geomorphic effects are changes in the flow

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32. Noone et al., *supra* note 23, at 18; *see generally* Jack E. Williams et al., *Cold-Water Fishes and Climate Change in North America*, REFERENCE MODULE EARTH SYS. & ENV'T SCIS. (2015).

33. *See generally* Pearse et al., *supra* note 10.

34. *Pacific Northwest River System, supra* note 2.

35. *See Lower Snake River Dams*, U.S. ARMY CORPS OF ENG'RS, https://www.nww.usace.army.mil/Missions/Lower-Snake-River-Dams (last visited Mar. 21, 2022).

36. *Pacific Northwest River System, supra note* 2.

37. *See, e.g.*, G. Mathias Kondolf, *Hungry Water: Effects of Dams and Gravel Mining on River Channels*, 24 ENV'T MGMT. 533, 537–38 (1997); G. Mathias Kondolf & Ramon J. Batalla, *Hydrological Effects of Dams and Water Diversions on Rivers of Mediterranean-Climate Regions: Examples from California, in* 7 DEVS. IN EARTH SURFACE PROCESSES, CATCHMENT DYNAMICS AND RIVER PROCESSES: MEDITERRANEAN AND OTHER CLIMATE REGIONS 197, 197–98 (Celso Garcia & Ramon J. Batalla eds., 2005).

regime, changes in the temperature regime,[38] and disruption of the downstream movement of sediment.[39]

The flow regime of a river can be visualized using a *hydrograph*, which depicts patterns in discharge (*flow*) over a period of interest.[40] Flow has been described as the "master variable" that shapes riverine ecological communities,[41] since it regulates the ultimate shape and character of a river.[42] By virtue of their purpose, dams change the flow regime of a river, although the degree to which they do so depends on specific dam design and operation.[43] Dams that are designed and operated for storage, such as Palisades Dam on the Upper Snake River in eastern Idaho, can affect the downstream flow regime for miles.[44] Nonetheless, most large dams tend to "flatten" the hydrograph of rivers by reducing the magnitude of large floods and minimizing the occurrence of very low flow events. This changes the seasonal dynamic of peak- and low-flow events and tends to reduce the frequency and intensity of interactions between the river and its floodplain.[45] This change in flow can also affect downstream temperatures and downstream sediment load, for example, by reducing floods that would otherwise recruit sediment from the banks or floodplain.

38. *See generally*, Laura E. Michie et al., *The Effect of Varied Dam Release Mechanisms and Storage Volume on Downstream River Thermal Regimes*, 81 LIMNOLOGICA (2020); JOHN G. WILLIAMS & THEODORE C. BJORNN, FALL CHINOOK SALMON SURVIVAL AND SUPPLEMENTATION STUDIES IN THE SNAKE RIVER AND LOWER SNAKE RIVER RESERVOIRS, 1996 17 (U.S. Dep't Energy 1998).

39. G. Mathias Kondolf, *supra* note 37, at 540.

40. *National Water Information System: Web Interface*, *USGS 14105700 Columbia River at the Dalles, OR*, U.S. GEOLOGICAL SURV., https://waterdata.usgs.gov/nwis/dv?referred_module=sw&site_no=14105700 (last visited Feb. 15, 2022). *See infra* Figure 3.

41. Mary E. Power et al., *Hydraulic Food-Chain Models*, 45 BIOSCIENCE 159, 166 (1995).

42. N. LeRoy Poff et al., *The Natural Flow Regime*, 47 BIOSCIENCE 769, 769 (1997).

43. *See, e.g.*, Fernando Magdaleno et al., *30-Year Response to Damming of a Mediterranean River in California, USA*, 39 PHYSICAL GEOGRAPHY 197, 201 (2018).

44. F. Richard Hauer & Mark S. Lorang, *River Regulation, Decline of Ecological Resources, and Potential for Restoration in a Semi-arid Lands Rivers in the Western USA*, 66 AQUATIC SCIS. 388, 391–93 (2004). *See infra* Figure 4.

45. Poff et al., *supra* note 42, at 772–73, 775.

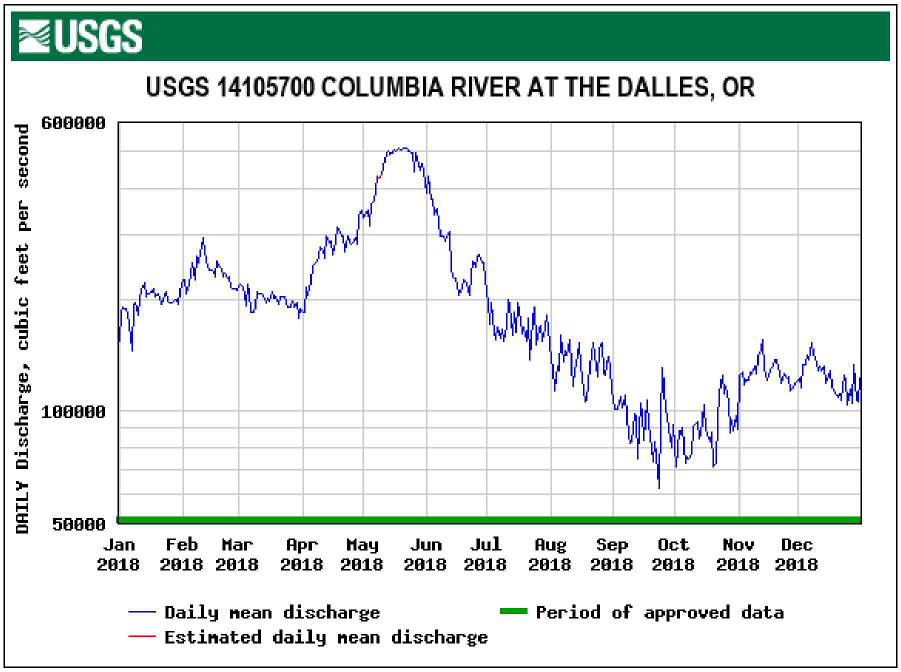

Figure 3. Annual hydrograph of daily averaged discharge, as measured near The Dalles, OR, approximately 4.6 river kilometers below The Dalles Dam.[46]

[46] *USGS 14105700 Columbia River at The Dalles, OR*, U.S. GEOLOGICAL SURV. (June 3, 2022, 2:45 PM EDT), https://waterdata.usgs.gov/nwis/dv?referred_module=sw&site_no=14105700.

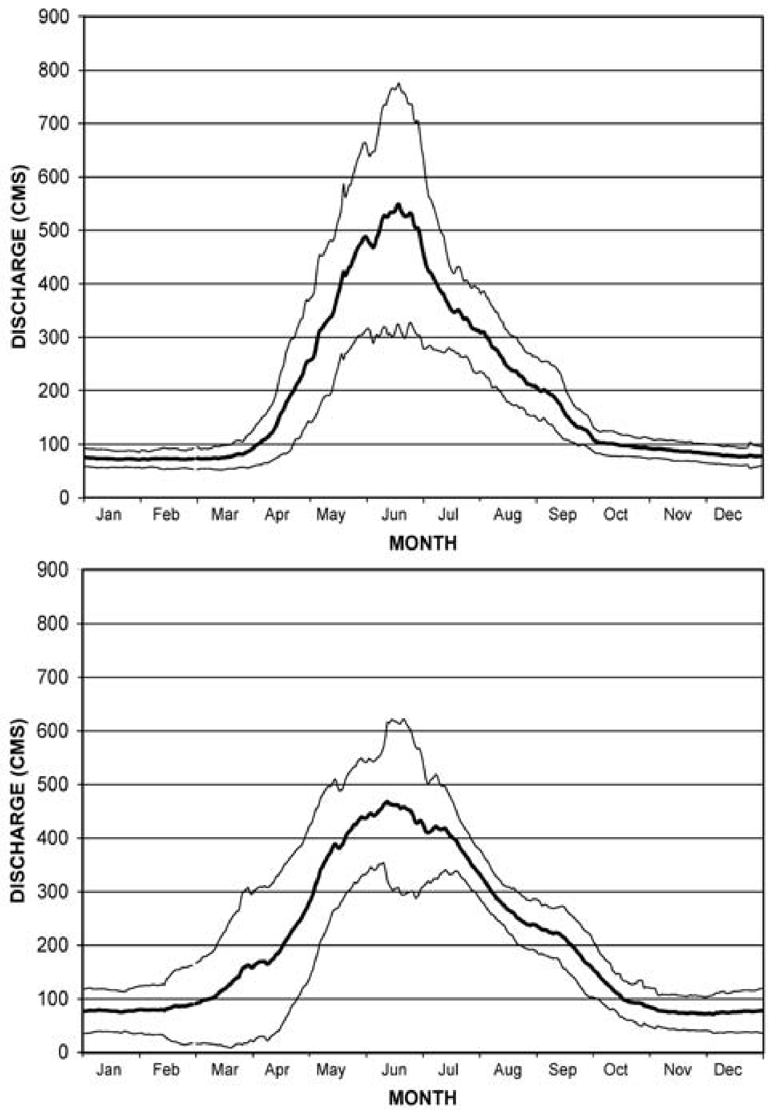

Figure 4. Upper Panel; Mean daily discharge (+1 std. dev.) in the upper Snake River at Heise USGS discharge gauge during the pre-dam period of record from 1911–1956. Lower Panel; Mean daily discharge (+ 1 std. dev.) following dam construction and during the recent period of record from 1958–2002.[47]

Changes in water temperature that result from dams include effects within impounded reservoirs upstream of the dam and those that occur in the tailrace and other reaches downstream of dams. Dam impoundments tend to cause increased

[47] Hauer & Lorang, *supra* note 44, at 391.

water temperatures during summer months, increased temperatures in fish ladders, and delayed reservoir cooling in the fall.[48] Dams with shallower impoundments tend to increase downstream water temperatures as a result of the increased warming that occurs within the impoundment.[49] Deep reservoirs that retain a large pool of cold water, like that impounded by Dworshak Dam on the Clearwater River in Idaho, can be managed to reduce downstream water temperatures.[50] However, the degree to which they can do so depends on the volume of cold water stored behind the dam, and the relative effects of these contributions may diminish in the future, under increasingly warm conditions resulting from climate change.[51]

Along with changes to the flow regime and temperature, one other major change to rivers that results from large dams, like the four LSR dams, is a disruption in the downstream movement of sediment.[52] The amount of water and sediment that a river moves is a function of geology and climate. In unaltered rivers, the amount of water and the amount of sediment dynamically interact within the context of landscape topography to define stream type and channel geometry.[53] This balance between water and sediment is referred to as a river's *sediment budget*.[54] Impounded reservoirs alter the sediment budget by trapping coarse and fine sediment behind dams,[55] "starving" rivers of the sediment load they would otherwise transport.[56] This disruption to the sediment budget causes many changes in downstream geomorphic processes and ultimately river behavior and appearance.[57] As discussed in the following subsection, these physical and geomorphic effects impact anadromous salmonids and other aquatic animals that live within such altered systems.

A. Biological/Ecological Effects

Because anadromous salmonids cue their migration behaviors in response to water temperature and changes in flow and river hydrology, when dams alter flow

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48. U.S. ENV'T PROT. AGENCY, COLUMBIA AND LOWER SNAKE RIVERS TEMPERATURE TOTAL MAXIMUM DAILY LOAD 1, 2 (2021).

49. Zaidel et al., *Impacts of Small Dams on Stream Temperature*, 120 ECOLOGICAL INDICATORS 1, 6–7 (2021).

50. U.S. ENV'T PROT. AGENCY, *supra* note 48, at 2; *see also* WILLIAMS & BJORNN, *supra* note 38, at 17.

51. U.S. ENV'T PROT. AGENCY, *supra* note 48, at 1, 35–36.

52. *See generally* Hauer & Lorang, *supra* note 44; *see also* Kondolf, *supra* note 37, at 540.

53. *See generally* B. Cluer & C. Thorne, *A Stream Evolution Model Integrating Habitat and Ecosystem Benefits*, 30 RIVER RSCH. APPLICATIONS 135 (2014).

54. *See generally* G. Mathias Kondolf & W.V. Graham Matthews, *Unmeasured Residuals in Sediment Budgets: A Cautionary Note*, 27 WATER RES. RSCH. 2483 (1991); *see generally* Magdaleno et al., *supra* note 43; Merz et al., *Sediment Budget for Salmonid Spawning Habitat Rehabiitation in a Regulated River*, 76 GEOMORPHOLOGY 207 (2006).

55. D.M. Hicks & B. Gomez, *Sediment Transport*, (2018); Magdaleno et al., *supra* note 43, at 207.

56. Kondolf, *supra* note 37, at 540.

57. Magdaleno et al., *supra* note 43, at 208.

and temperature regimes, the result can be a change in the *selection pressures* that favor particular salmonid life histories. In the Sacramento–San Joaquin River system of California, river regulation by a series of large dams has selected against juvenile Chinook salmon life histories that migrate early and late, instead favoring fish that migrate when regulated conditions are optimal.[58] In the Snake River, juvenile Chinook survival is proportional to flow, and managing the dams to increase flow likely increases survival.[59] This equates to a disruption of evolutionary processes which have led to the emergence of the historically present diversity of species and life histories. Life history strategies that were advantageous in an unaltered system may become selected against, reducing overall population diversity and thus resilience to future environmental stressors.[60]

Elevated water temperatures above and below dams affect both juvenile and adult fish, particularly during sensitive migration periods. For example, juvenile Chinook migrating down the Snake River are negatively impacted by increases in temperature that occur within and near mainstem dam impoundments, with effects seen in terms of reduced migration speed[61] and survival.[62] Similarly, adult steelhead and Chinook migrating up the Snake River frequently encounter temperatures that are known to affect migration and induce fish to seek cooler water.[63] In some cases, elevated fish ladder temperatures may lead fish to exit ladder fishways and seek refuge in cooler tailrace waters.[64] Taken together, the temperature effects associated with mainstem dams such as the LSR dams can exacerbate challenging conditions and increase mortality of both adults and juveniles during migrations through affected areas.

Dam-altered sediment transport means less gravel is present in rivers below large dams, which translates into reduced production of benthic macroinvertebrates—food for juvenile salmonids—as well as less suitable gravel with which adult salmonids can build redds.[65] These effects are also felt by other

58. Anna M. Sturrock et al., *Unnatural Selection of Salmon Life Histories in a Modified Riverscape*, GLOB. CHANGE BIOLOGY 1235, 1239, 1241 (2020).

59. William P. Conor et al., *Migrational Behavior and Seaward Movement of Wild Subyearling Fall Chinook Salmon in the Snake River*, 23 N. AM. J. FISHERIES MGMT. 414, 427–28 (2003).

60. *See generally* Jonathan W. Moore et al., *Life-History Diversity and its Importance to Population Stability and Persistence of a Migratory Fish: Steelhead in Two Large North American Watersheds*, 83 J. ANIMAL ECOLOGY 1035 (2014); Daniel E. Schindler et al., *Population Diversity and the Portfolio Effect in an Exploited Species*, 465 NATURE 609 (2010); Sturrock et al., *supra* note 58.

61. Conor et al., *supra* note 59, at 423–24.

62. William P. Connor et al., *Influence of Flow and Temperature on Survival of Wild Subyearling Fall Chinook Salmon in the Snake River*, 23 N. AM. J. FISHERIES MGMT. 362, 366–69 (2003).

63. Matthew L. Keefer & Christopher C. Caudill, *Estimating Thermal Exposure of Adult Summer Steelhead and Fall Chinook Salmon Migrating in a Warm Impounded River*, 25 ECOLOGY FRESHWATER FISH 599, 602–04 (2015).

64. Christopher C. Caudill et al., *Indirect Effects of Impoundment on Migrating Fish: Temperature Gradients in Fish Ladders Slow Dam Passage by Adult Chinook Salmon and Steelhead*, 8(12) PLOS ONE 1, 7 (2013).

65. *See generally* G. Mathias Kondolf, *The Reclamation Concept in Regulation of Gravel Mining in California*, 36 J. ENV'T PLAN. MGMT. 397 (1993); Kondolf, *supra* note 37.

fish, like sturgeon, who exhibit reduced productivity in impounded reaches of the lower Columbia River[66] and reduced spawning in the LSR compared to what likely occurred historically.[67] These changes in the composition of rocks and other sediment that form the river bottom ("benthic substrate") that result from the presence of dams thus affects juvenile salmonid growth and survival, as well as adult spawning success within mainstem reaches.

Finally, irrespective of the flow, temperature, and sediment effects from dams, their physical presence creates an impediment to upstream and downstream fish movement. For example, despite upstream and downstream passage facilities, dams tend to slow the migration of both juvenile and adult salmonids.[68] Moreover, downstream passage facilities are generally designed for juveniles, meaning that post-spawned steelhead (*kelts*)—which are capable of repeat spawning—do not fare well, and this life history tends to be selected against.[69] Repeat spawning steelhead kelts are an ecologically important life history variant whose abundance has reduced substantially in the previous century, in part because of mainstem dams.[70] This reduced migration survival can have important population level effects on abundance and diversity of sensitive anadromous salmonids.

Moreover, the effect that dams have on slowing anadromous salmonid migrations also has more complex ecological implications. For example, impounded reservoirs created by dams concentrate migrating juvenile salmonids in the forebay and in the tailrace, increasing predation by Northern Pikeminnow and other predators.[71] Northern Pikeminnow may also benefit from reduced flows below dams, as their abundance in a tailrace reach in the LSR was found to be inversely

66. Raymond C.P. Beamesderfer et al., *Differences in the Dynamics and Potential Production of Impounded and Unimpounded White Sturgeon Populations in the Lower Columbia River*, 124 TRANSACTIONS AM. FISHERIES SOC'Y 857, 864–868 (1995).

67. Michael J. Parsley & Kevin M. Kappenman, *White Sturgeon Spawning Areas in the Lower Snake River*, 74 NW. SCI. 192, 200 (2000).

68. *See generally* Christopher C. Caudill et al., *Slow Dam Passage in Adult Columbia River Salmonids Associated with Unsuccessful Migration: Delayed Negative Effects of Passage Obstacles or Condition-Dependent Mortality?*, 64 CAN. J. FISHERIES AQUATIC SCIS. 979 (2007); John R. Skalski et al., *Passage and Survival of Juvenile Salmonids Smolts Through Dams in the Columbia and Snake Rivers*, 41 N. AM. J. FISHERIES MGMT. 678 (2020). *See* SALLY T. SAUTER, ET AL., ISSUE PAPER 1 SALMONID BEHAVIOR AND WATER TEMPERATURE (Prepared as Part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project) 20 (2001).

69. *See generally* J.W. Ferguson et al., *Passage of Adult and Juvenile Salmonids Through Federal Columbia River Power System Dams*, NOAA TECH. MEMORANDUM NMFS-NWFSC-64 1 (2005).

70. *See generally* C.T. Boggs et al., *A Multi-Year Summary of Steelhead Kelt Studies in the Columbia and Snake Rivers*, TECH. REP. 2008-13 1 (2008); Nathaniel T. Fuchs et al., *Overwintering Distribution and Postspawn Survival of Steelhead in the Upper Columbia River Basin*, 41(3) N. AM. J. FISHERIES MGMT. 1 (2021); Matthew L. Keefer et al., *Iteroparity in Columbia River Summer-Run Steelhead (Oncorhynchus Mykiss): Implications for Conservation*, 65(12) CAN. J. FISHERIES AQUATIC SCIS. 2592 (2008).

correlated with discharge.[72] The resulting increase in Northern Pikeminnow abundance has contributed to their being an important predator of juvenile salmonids in some cases.[73]

IV. EFFECTS OF PREVIOUS DAM REMOVALS ELSEWHERE

Given the known negative physical and biological effects of dams, the ecological benefits of dam removal have been discussed in the literature for over two decades.[74] Proponents of dam removal point to studies that report predicted or observed improvements to physical or ecological endpoints. For example, improved water temperatures are predicted to occur following dam removal,[75] including during sensitive salmonid migratory periods after dam removal.[76] Two recent dam removal efforts in the PNW offer valuable lessons, although the transferability of these findings to predictions of the effects from LSR dam removal is not always clear.

A. White Salmon River, WA: Condit Dam

Condit Dam was constructed in 1912 on the White Salmon River, near the town of White Salmon, Washington, in the Columbia River Gorge.[77] Although originally constructed with fish ladders, these became non-functional and were not replaced. From 1917 until removal in 2011, the Condit Dam prevented anadromous salmonids from accessing habitat above the dam.[78] Removal of the dam mobilized large amounts of sediment along with flows of approximately 10,000 cubic feet per second,[79] a high-flow event approximately double the annual high flow during the

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72. D.J. Isaak & T.C. Bjornn, *Movement of Northern Squawfish in the Tailrace of a Lower Snake River Dam Relative to the Migration of Juvenile Anadromous Salmonids*, 125 TRANSACTIONS AM. FISHERIES SOC'Y 780, 780–93 (1996).

73. *See* T.D. COUNIHAN, ET AL., ASSESSING NATIVE AND INTRODUCED FISH PREDATION ON MIGRATING JUVENILE SALMON IN PRIEST RAPIDS AND WANAPUM RESIVOIRS, COLUMBIA RIVER, WASHINGTON, 2009–11 3 (2012), https://pubs.usgs.gov/of/2012/1130/pdf/ofr20121130.pdf.

74. Angela Bednarek, *Undamming Rivers: A Review of the Ecological Impacts of Dam Removal*, 27 ENV'T MGMT. 803, 803 (2001); Michael C. Blumm & Andrew Erickson, *Dam Removal in the Pacific Northwest: Lessons for the Nation*, 42 ENV'T L. 1043, 1043 (2012); David D. Hart, et al., *Dam Removal: Challenges and Opportunities for Ecological Research and River Restoration*, 52 BIOSCI. 669, 669 (2002); FRIENDS OF THE EARTH, ET AL., DAM REMOVAL SUCCESS STORIES, 3-113 (Elizabeth Maclin & Matt Sicchio eds., 1999); J.E. O'Connor, et al., *1000 Dams Down and Counting*, 348 SCIENCE 496, 496 (2015); Emily H. Stanley & Martin W. Doyle, *The Ecological Effects of Dam Removal*, 1 FRONTIERS ECOLOGY ENV'T 15, 15 (2003).

75. Peter A. Zaidel, *Impacts of Small Streams on Dam Temperature*, 120 ECOLOGICAL INDICATORS 1, 1 (2021).

76. RUSSELL W. PERRY ET AL., SIMULATING WATER TEMPERATURE OF THE KLAMATH RIVER UNDER DAM REMOVAL AND CLIMATE CHANGE SCENARIOS 2011-1243 1–2 (2011), https://pubs.usgs.gov/of/2011/1243/pdf/ofr20111243.pdf.

77. Blumm & Erickson, *supra* note 74, at 1059–60.

78. Blumm & Erickson, *supra* note 74, at 1060.

79. Blumm & Erickson, *supra* note 74,at 1065.

last decade.[80] The river quickly recovered, and recent surveys indicate substantial spawning of anadromous salmonids above the former dam site.[81]

B. Elwha

Elwha Dam was constructed in 1910, and Glines Canyon Dam in 1927, on the Elwha River, near the town of Port Angeles, Washington, on the Olympic Peninsula.[82] Neither included fish passage structures, meaning that, until removal in 2011 (Elwha) and 2014 (Glines Canyon), anadromous salmonids were blocked from upstream reaches.[83] The removal of the Elwha dams has been the subject of a substantial body of research.[84] Within days of removal of the Glines Canyon Dam, Chinook salmon were documented accessing upstream reaches.[85] Bull Trout within the Elwha resumed anadromy after decades of residence above the dams.[86] Anadromous Sockeye salmon repopulated the river as well, potentially a mix of

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80. *National Water Information System: Web Interface, White Salmon River Near Underwood, WA*, U.S. GEOLOGICAL SURV., https://waterdata.usgs.gov/nwis/dv?referred_module=sw&site_no=14123500 (last visited Feb. 11, 2022).

81. JOE ZENDT, WHITE SALMON SUBBASIN STEELHEAD SPAWNER SURVEY SUMMARY, 2012–2019 3 (2020), http://ykfp.org/klickitat/Library/pubs&presentations/YN_WhiteSalmonSubbasin_Steelhead_Spawner_Surveys_Summary_2012-2019.pdf.

82. *History of the Elwha*, NAT'L PARK SERV., https://www.nps.gov/olym/learn/nature/history-of-the-elwha.htm (last visited Feb. 11, 2022).

83. *Id.*

84. Jeffrey J. Duda et al., *Baseline Studies in the Elwha River Ecosystem Prior to Dam Removal: Introduction to the Special Issue*, 82 NW. SCI. 1, 1 (2008); Adam G. Hansen et al., *Recovery of Sockeye Salmon in the Elwha River, Washington, after Dam Removal: Dependence of Smolt Production on the Resumption of Anadromy by Landlocked Kokanee*, 145 TRANSACTIONS AM. FISHERIES SOC'Y 1303, 1303 (2016); Wendel Kane et al., *Monitoring the Return of Marine-Derived Nitrogen to Riparian Areas in Response to Dam Removal on the Elwha River, Washington*, 94 NW. SCI. 118, 118 (2020); Alexandra E. Lincoln et al., *Opportunistic Use of Estuarine Habitat by Juvenile Bull Trout, Salvelinus Confluentus, From the Elwha River Before, During, and After Dam Removal*, 101 ENV'T BIOLOGY FISHES 1559, 1559 (2018); Michael L. McHenry & George R. Pess, *An Overview of Monitoring Options for Assessing the Response of Salmonids and Their Aquatic Ecosystems in the Elwha River Following Dam Removal*, 82 NW. SCI. 29, 29 (2008); Sarah A. Morley et al., *Benthic Invertebrates and Periphyton in the Elwha River Basin: Current Conditions and Predicted Response to Dam Removal*, 82 NW. SCI. 179, 179 (2008); George R. Pess et al., *Biological Impacts of the Elwha River Dams and Potential Salmonid Responses to Dam Removal*, 82 NW. SCI. 72, 72 (2008); Thomas P. Quinn et al., *Resumption of Anadromy or Straying? Origins of Sockeye Salmon in the Elwha River*, 150 TRANSACTIONS AM. FISHERIES SOC'Y 452, 459 (2021) [hereinafter Quinn et al., *Resumption*]; Thomas P. Quinn et al., *Juvenile Chinook Salmon, Oncorhynchus Tshawytscha, Use of the Elwha River Estuary Prior to Dam Removal*, 97 ENV'T BIOLOGY FISHES 731, 731 (2014).

85. O'Connor et al., *supra* note 74 at 497.

86. Thomas P. Quinn et al., *Re-Awakening Dormant Life History Variation: Stable Isotopes Indicate Anadromy in Bull Trout Following Dam Removal on the Elwha River, Washington*, 100 ENV'T BIOLOGY FISHES 1659, 1665–66 (2017).

resumption of anadromy by previously landlocked kokanee salmon and straying of other nearby stocks of anadromous Sockeye.[87]

C. Comparability to Lower Snake River Dams

Three points are worth mentioning regarding the extension of results from elsewhere into inferred or expected benefits that may result from LSR dam removal. First, each of the four LSR dams already includes fish passage infrastructure, both adult ladders and juvenile bypass systems.[88] Although the LSR dams impede anadromous salmonid passage (as discussed in Section IIIA, above), they do not completely block it: the current fish passage infrastructure in place at the LSR dams does pass juvenile anadromous salmonids upstream[89] and downstream.[90] Because fish passage is in place at these dams, anadromous salmonids already have access to upstream habitat, as evidenced by the presence of anadromous salmonids in the Clearwater and Salmon River drainages.[91] Thus, unlike removing a dam that completely blocks anadromous salmonid passage, removing the LSR dams would not immediately provide entire species or populations of anadromous salmonids with access to previously blocked habitat.

Second, the LSR dams are not the furthest upstream impediment to fish passage within the Snake River Basin. The Hells Canyon Complex is located upstream and comprises three dams—Hells Canyon, Oxbow, and Brownlee—none of which currently have fish passage.[92] Thus, while removal of the four LSR dams would likely improve passage survival to reaches of the Clearwater and Salmon Rivers in Idaho, access to mainstem Snake River reaches above Hells Canyon would still be blocked.

Third, a controversial but vocal view championed by David Welch contends that regional declines in populations of anadromous salmonids are consistent across the Pacific West and result from a constellation of effects including poor ocean conditions and hatchery practices, but are not the result of the dams.[93] While

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87. Quinn et al., *Resumption,* supra note 84, at 459.

88. *Lower Snake River Dams*, U.S. ARMY CORPS ENG'RS, https://www.nww.usace.army.mil/Missions/Lower-Snake-River-Dams (last visited Mar. 9, 2022).

89. LISA G. CROZIER ET AL., PASSAGE AND SURVIVAL OF ADULT SNAKE RIVER SOCKEYE SALMON WITHIN AND UPSTREAM FROM THE FEDERAL COLUMBIA RIVER POWER SYSTEM 10 (2014), https://repository.library.noaa.gov/view/noaa/25639/noaa_25639_DS1.pdf; JACK TUOMIKOSKI ET AL., COMPARATIVE SURVIVAL STUDY OF PIT-TAGGED SPRING/SUMMER CHINOOK AND SUMMER STEELHEAD 2012 ANNUAL REPORT 144–65 (2012), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.423.3320&rep=rep1&type=pdf.

90. Skalski et al., *supra* note 68.

91. Steelhead Harvest Report, IDAHO FISH AND GAME, https://idfg.idaho.gov/fish/steelhead/harvest (last visited Jun. 15, 2022).

92. *Hells Canyon*, NW. POWER & CONSERVATION COUNCIL, https://www.nwcouncil.org/reports/columbia-river-history/hellscanyon (last visited Feb. 11, 2022).

93. David Warren Welch et al., *A Synthesis of the Coast-Wide Decline in Survival of West Coast Chinook Salmon (*Oncorhynchus Tshawytscha, Salmonidae*)*, 22 FISH & FISHERIES 194, 205–07 (2020).

these findings have been debated extensively,[94] if poor ocean conditions are truly the largest factor currently limiting salmon productivity and abundance, then the benefits to anadromous salmonids that result from removing the LSR dams may be less than anticipated.

V. CONCLUSION

As discussed in Section 3, above, removing the LSR dams would affect the physical river environment, including changing the downstream flow and temperature regime, rebalancing the sediment budget, and potentially reconnecting floodplain habitats within free-flowing reaches. The translation of these physical effects to benefits for aquatic ecosystems is less clear, but biological effects could include improvements to fish migration survival, increased benthic macroinvertebrate productivity, and increased mainstem salmonid spawning, as described above in Section IV. The net result of these changes would benefit fish populations that reside in or migrate through the Lower Snake River corridor. However, because the existing LSR dams already contain fish passage infrastructure, and these dams exist within a broader hydrosystem network, some of the more dramatic ecological benefits for fish that have been observed following other regional dam removals—such as immediate restoration of access to previously blocked habitat—are not anticipated.

VI. GLOSSARY

Term	Definition
alevin	Embryonic juvenile salmonid still attached to the yolk sac
anadromy	Life history strategy of migrating from freshwater to saltwater and back
fluvial geomorphology	Earth processes that shape rivers
hydrograph	Annual profile of discharge over time within a river
life stage	Distinct development phase of an organism

94. Memorandum from Michele DeHart, Fish Passage Ctr., to Brian Lipscomb, Columbia Basin Fish & Wildlife Auth., & Bill Tweit, Washington Dep't Fish & Wildlife (Nov. 13, 2008); S. Hawley, *It Doesn't Take a Degree in Marine Biology to See Dams Are Bad for Fish*, COLUMBIA BASIN BULL. (Nov. 20, 2020), https://www.cbbulletin.com/guest-column-it-doesnt-take-a-degree-in-marine-biology-to-see-dams-are-bad-for-fish/; Welch et al., *supra* note 93.

life history	Behavioral and reproductive strategy, including timing and duration of different life stages, migrations, and other key life events
natal	Relating to the place of birth or hatching
outmigration	Migration from freshwater to saltwater
parr	Juvenile salmonid life stage characterized by distinctive lateral bands
philopatry	Propensity to return to the natal stream for spawning
redd	Salmon nest, excavated by females within suitably sized gravel
resident	Life history strategy of remaining within freshwater for life
sediment budget	Balance of water and sediment moved by a river
selection pressure	Evolutionary process by which traits are favored and thus increase in frequency over time within a population, or are discouraged and thus reduce in frequency
smolt	Juvenile salmonid life stage characterized by metamorphic preparation for life in saltwater, including distinct silver appearance
stray	Adult salmonid that spawns at a distance from its natal reach