Rebuilding Interior Columbia Basin Salmon and Steelhead

National Oceanographic and Atmospheric Administration

National Marine Fisheries Service

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Introduction

The Biden–Harris Administration is leading an effort to support development of a long-term, durable strategy to restore Columbia River basin salmon, steelhead, bull trout, and other listed and vulnerable species; honor long-standing commitments to tribal nations and address tribal cultural, ceremonial, and subsistence needs; balance the priorities of fishing communities; ensure a reliable, affordable, and carbon-free energy supply; and account for the other varied uses of the Columbia River, including flood risk management, water supply, navigation, and recreation. NOAA Fisheries developed this report, "Rebuilding Interior Columbia Basin Salmon and Steelhead," by drawing on existing science, our own experience and expertise with salmon and steelhead conservation, and the work of the Columbia Basin Partnership (CBP), as well as input from the United States Fish and Wildlife Service and state and tribal fisheries co-managers in the region.[1]

The CBP was a Task Force chartered by NOAA's Marine Fisheries Advisory Committee in 2017 to develop a common vision and goals for the Columbia River basin's salmon and steelhead. CBP members represented many interests, including tribes, states, watershed groups, ports, electric utilities, irrigators, agriculture, sport fishing interests, the fishing industry, and more. The CBP examined the science and history of salmon in the region and developed goals that went beyond achieving Endangered Species Act (ESA) delisting levels to rebuild healthy and harvestable runs of salmon and steelhead that would restore the economic, ecological, and cultural benefits the region wants from its fish populations. CBP members noted a strong sense of urgency for bold and immediate action.[2] The CBP also concluded that to achieve their regional vision and goals for salmon and steelhead, many aggressive actions would be needed to address the full range of threats that the species face. Furthermore, they noted that these actions would require consistent and strategic funding.

This report, "Rebuilding Interior Columbia Basin Salmon and Steelhead," outlines the actions NOAA Fisheries believes will be necessary to achieve the CBP's mid-range goals for adult salmon and steelhead abundance by 2050. These mid-range goals look beyond recovering species from the brink of extinction. They seek, for example, to return unlisted stocks to areas from which they were previously extirpated. Columbia River salmon and steelhead abundance remains far below historical levels. This report addresses the 16 interior Columbia River basin salmon and steelhead stocks that spawn above Bonneville Dam.

The report is intended to provide climate-smart, science-based information that can inform development of actions that could rebuild listed and unlisted interior Columbia River basin salmon and steelhead stocks towards healthy and harvestable levels as defined in the CBP Task Force *Phase 2 Report* (NMFS 2020a). This report does not constitute a regulatory or policy requirement and does not supersede or modify existing analyses in ESA recovery plans, viability assessments, 5-year reviews, or ESA consultation

[1] NOAA Fisheries received comments from the following tribal and state entities: Confederated Tribes and Bands of the Yakama Nation, Upper Snake River Tribes Foundation, Spokane Tribe of Indians, Coeur d'Alene Tribe, Nez Perce Tribe, Confederated Tribes of the Umatilla Indian Reservation, Confederated Tribes of the Colville Reservation, Burns Paiute Tribe, Columbia River Inter-Tribal Fish Commission, Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, and Idaho Department of Fish and Game.

[2] For example, in October 2020, the states of Oregon, Washington, Idaho, and Montana signed an agreement to work together to rebuild Columbia River salmon and steelhead stocks and to advance the goals of the Columbia Basin Partnership Task Force in a collaborative, public process to include the region's tribes, federal agencies, and stakeholders (CBC 2020).

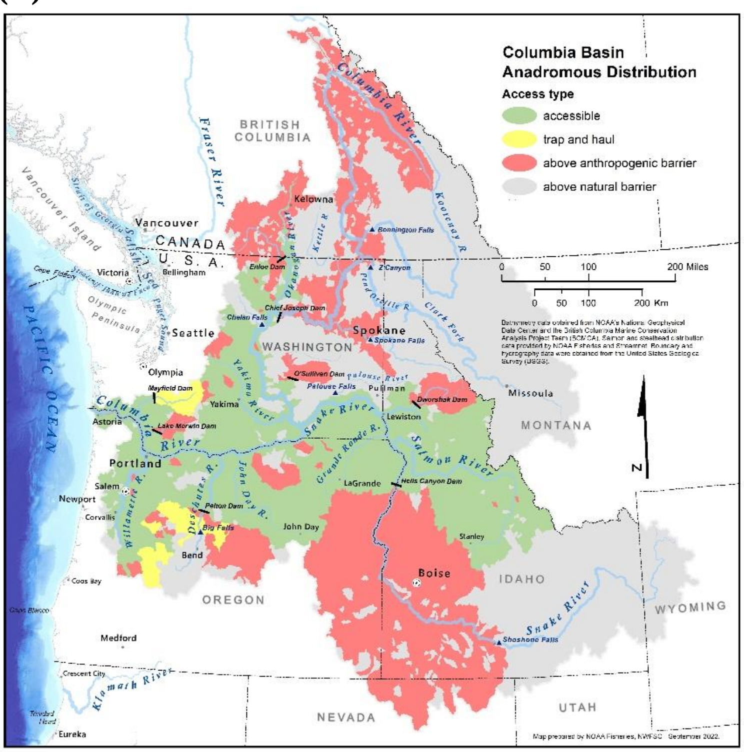
documents. The report also does not assess the impacts of implementing any rebuilding measures nor suggest funding sources, needed authorizations, or regulatory compliance measures required for implementation.

This report recognizes that a comprehensive suite of actions that address threats to salmon and steelhead across the basin, including the identified “centerpiece actions,” will provide the greatest potential to make considerable progress towards healthy and harvestable abundances. This report complements the countless ongoing actions and activities being undertaken by sovereign governments and stakeholders across the basin.

Rebuilding salmon and steelhead stocks in the Columbia River basin to levels that are healthy and harvestable requires careful consideration of the science that informs rebuilding strategies and actions. This report provides a high-level response to ten common questions about the science[3] surrounding Columbia River basin salmon and steelhead rebuilding efforts. The questions and responses are meant to inform the broader discussion around the socio-economic factors and resources necessary to help these species rebuild.

The scope of this analysis includes the clusters of populations, or stocks, of natural-origin Pacific salmon and steelhead originating above Bonneville Dam (i.e., in the interior Columbia River basin), as well as their life-cycle needs associated with freshwater, estuary, and marine habitats (**Figure 1**).

(A)



(B)

Figure 1. Maps of the Columbia River basin. **(A)** shows areas a) currently occupied by anadromous salmon and steelhead (light green), b) historically used by anadromous fish but currently inaccessible due to dams blocking fish passage (red) and c) historically inaccessible due to natural migration barriers (grey). **(B)** shows regional areas associated with stock delineations in this report (modified from NMFS 2020a).

[3] The report considers questions related to the biological effects of limiting factors and threats on the biological status of fish stocks, as well as the expected effects of actions to address those limiting factors and threats. It does not consider questions related to socio-political science evaluations of salmon and steelhead stock rebuilding strategies.

These stocks are critically important to Columbia River basin tribes, as well as to the economy and overall ecological health of the region. Despite their undisputed value, they have been negatively affected by extensive anthropogenic activity—in particular, the dams and reservoirs that form the Columbia River System[4] (CRS; NAS 1996). The CRS has been the subject of decades of litigation regarding the effects on salmon and steelhead and modifications to their stream, river, floodplain, and estuary habitats. In addition, as identified in ESA Recovery Plans (NMFS 2009, 2015, 2017a, 2017b; UCSRB & NMFS 2007), historical and ongoing degradation of stream, river, floodplain, and estuary habitats and water quality also limit the biological potential of all interior Columbia River basin stocks, as do the effects of harvest and hatchery management, predation, and ocean conditions.

The goal of this evaluation is to inform the region how to achieve the CBP's mid-range goals for naturally produced adult salmon and steelhead abundance by 2050, which would also mean making progress towards the Northwest Power and Conservation Council's (NPCC 2020) productivity goals, as measured by smolt-to adult return rates (SAR).[5] These goals are commonly understood and referenced by fish managers and the public because of the transparent public processes used to establish them; they are reasonable quantitative targets that we embrace for the purposes of this evaluation. The CBP identified low-, mid-, and high-range natural-origin abundance goals. The low-range abundance goals are generally consistent with ESA recovery thresholds for abundance, while the high-range goals represent abundances consistent with healthy and harvestable stocks. The mid-range abundance goals exceed ESA recovery thresholds for abundance, and represent considerable progress toward healthy and harvestable status of these stocks (NMFS 2020a). Rebuilding healthy and harvestable stocks is a substantially more ambitious goal than meeting ESA recovery standards, which are intended to achieve delisting, or the mandates of ESA Section 7(a)(2), which are meant to avoid jeopardizing the continued existence of ESA-listed species.

Achieving these fish-related goals would also provide the highest certainty for meeting multiple objectives, including addressing tribal inequities, securing a pathway to harvestable abundance levels, and rebuilding salmon and steelhead in the face of climate change (**Figure 2**).

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[4] Fourteen federally owned and operated hydroelectric dams (projects) on the Columbia and Snake rivers, including: Libby, Hungry Horse, Albeni Falls, Grand Coulee, Chief Joseph, Dworshak, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, The Dalles, and Bonneville.

[5] The NPCC productivity goals were not developed as part of the CBP process and do not reflect the same degree of stock specificity; nonetheless, in order to achieve marked increases in stock abundance as called for by the CBP mid-range goals, strong population growth rate increases in both the marine environment (typically indexed by SAR) and the freshwater/estuary environment (typically indexed by smolts/female) and overall habitat capacity improvements (relaxed density dependent effects at recent stock levels) would be necessary.

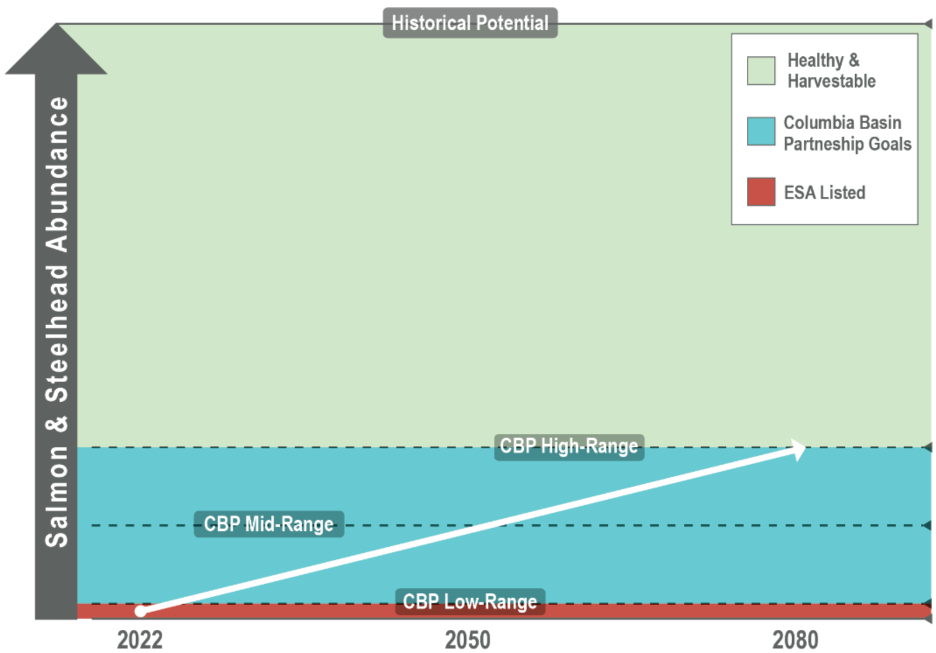

Figure 2. Conceptual abundance continuum of salmon and steelhead, aggregated across the 16 stocks (ESA listed and non listed) upstream of Bonneville dam, relative to management thresholds and goals. Mid-range goals exceed ESA recovery abundance thresholds and represent considerable progress toward high-range goals associated with healthy and harvestable status (NMFS 2020a).

Question 1: What is the **relative priority of stocks** for protection and rebuilding given the scope and criteria above?

The CBP *Phase 2 Report* describes 27 stocks of Columbia River basin salmon and steelhead, with a subset of 16 stocks[6] having populations distributed entirely upstream of Bonneville Dam (hereafter, "interior Columbia stocks;" **Table 1**). The distribution of interior Columbia stocks is further subdivided geographically into three areas: Snake, upper Columbia, and mid-Columbia (**Figure 1**). This report uses the same stock descriptions and population structure that were relied upon in the CBP *Phase 2 Report.*[7]

Overall, priority is highest for Snake River spring/summer Chinook salmon, Snake River steelhead, upper Columbia River fall Chinook, upper Columbia River spring Chinook, upper Columbia River summer Chinook, and upper Columbia steelhead (**Table 1**). With the exception of upper Columbia fall Chinook and upper Columbia summer Chinook, this approach prioritizes stocks that are at high risk of extinction. The prioritized spring Chinook stocks exhibit early return timing to the Columbia River. As such, they support important recreational fisheries in the lower Columbia River, as well as harvest for tribal ceremonial and subsistence purposes.

The upper Columbia fall Chinook and upper Columbia summer Chinook stocks are also critical to the upper river tribes, due to their importance in ceremonial and subsistence harvest needs. In the case of summer Chinook, this stock is being used in reintroduction efforts in the blocked area above Chief Joseph and Grand Coulee dams. These stocks also ensure that both lower and upper river tribes have a consistent harvest opportunity on non-ESA listed Chinook salmon, and they also support commercial and recreational fishing opportunities[8]. These stocks require protection and rebuilding efforts to maintain these purposes and to reach CBP mid-range goals. Rebuilding steelhead stocks is also important because by being intercepted as bycatch they can limit the remaining fall Chinook fishery. Steelhead also provide an important late-winter subsistence fishery for tribal members in the tributaries.

Prioritizing certain stocks for protection and rebuilding in no way indicates low priority or diminished importance for any other stocks[9]; the CBP set healthy and harvestable abundance goals for all Columbia basin stocks. However, for this evaluation, which focuses on interior Columbia basin stocks, we applied five criteria as a general context to inform the sequencing of restoration actions. The criteria for species

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[6] Nine stocks spawn primarily in the lower Columbia River, downstream of Bonneville Dam (a small number of lower Columbia River populations spawn and rear in streams just above Bonneville Dam, primarily in the White Salmon, Hood, and Wind River sub-basins). In addition, two stocks spawn and rear entirely in the Willamette River basin. Lower Columbia and Willamette River stocks are not included in this summary.

[7] Groups of similar salmon and steelhead populations are typically grouped into "stocks" for status assessment and management purposes. The CBP defined stocks based on species, region of origin, and run timing. The CBP stocks are generally the same as the ESUs or DPSs that NOAA Fisheries defines for ESA listing purposes. One exception is in cases where an ESU or DPS contained multiple run-timings. In these cases, the ESUs were split by run type into separate stocks so that abundance numbers could be more easily aggregated by run type (i.e., by stock) in a basinwide accounting and aligned more closely to fishery management units. For instance, the Upper Columbia River summer/fall Chinook ESU was separated into two stocks (UCR summer Chinook and UCR fall Chinook). Each stock (and each ESU or DPS) contains a number of independent populations. For more information on CBP stock and population structure, see Appendix A of the CBP *Phase 2 Report*.

[8] Other interior basin stocks, for example Snake River fall Chinook, also contribute to commercial fisheries.

[9] Many regional tribes have emphasized their view that restoring all populations should have the highest priority.

and area priorities are: level of extinction risk, current spatial structure and diversity, importance to tribal communities, habitats available for essential life-cycle needs, and resilience of habitat to climate change. Although they in no way reduce the importance of all extant and extirpated Columbia River basin native salmon and steelhead, the criteria provide a context for sequencing and prioritizing multifaceted, long-term, and complex rebuilding actions.

Balancing the five criteria resulted in a qualitative approach that considered the risk of extinction[10] with the potential for rebuilding in the face of climate change, and ultimately, the importance now and through rebuilding, to tribal communities. Given basinwide concerns of stock status currently, the priorities are high overall, but must be focused on a small number of stocks as a place to start. As such, all stocks were given high-, higher-, or highest-priority designations. The latter applies to Snake River spring/summer Chinook and steelhead and upper Columbia River fall Chinook, spring Chinook, summer Chinook, and steelhead. Continued development of an overall basin rebuilding strategy, as well as monitoring and analyses through rebuilding, will allow the co-manager community to reassess these designations as conditions change (Williams et al. 2009).

Table 1. Columbia River basin salmon and steelhead stocks' rebuilding priority.

Stock	Priority
Snake River Spring/Summer Chinook	Highest
Snake River Steelhead	Highest
Upper Columbia River Fall Chinook	Highest
Upper Columbia River Spring Chinook	Highest
Upper Columbia River Steelhead	Highest
Upper Columbia River Summer Chinook	Highest
Mid-Columbia River Spring Chinook	Higher
Mid-Columbia River Steelhead	Higher
Upper Columbia River Sockeye	Higher
Snake River Fall Chinook	Higher
Snake River Sockeye	Higher
Mid-Columbia River Summer/Fall Chinook	High
Mid-Columbia River Coho	High
Mid-Columbia River Sockeye	High
Upper Columbia River Coho	High
Snake River Coho	High

[10] Seven of the 16 interior stocks are listed under the ESA as threatened or endangered. Avoiding jeopardy pursuant to ESA Section 7(a)(2) and implementing existing recovery plans remains a high priority for NOAA Fisheries and is not diminished by stock priorities described in this report.

Question 2: What is the **status and outlook** for each stock?

The current abundance and productivity (viable salmonid population [VSP] parameters; McElhany et al. 2000) of naturally reproducing interior Columbia salmon and steelhead stocks are at dramatically reduced levels from our understanding of historical abundances, and harvest records show current landing levels are a fraction of the fishery size in the early 20th century.[11] Sixteen stocks historically spawned above Bonneville Dam. Of those, four are now extinct, and seven are listed under the federal ESA—including one reliant on a captive breeding program. Of the remaining five, only one approaches its historical numbers (**Table 2**).

Recent abundance trends (where data are available) are negative and productivity values are below replacement (Ford 2022). The risk of extinction from demographic collapse is moderate-to-high for all ESA-listed stocks, as is the risk of reduced adaptive capacity (Ford 2022), all resulting from small population size. For example, while there have been improvements in abundance and productivity in several populations relative to the time of listing, the majority of interior Columbia River basin populations experienced sharp declines in abundance in the recent 5-year period. Dramatic variation in productivity and run-year strength is a hallmark of salmon population biology and alone is not a reason for concern, but, in combination with low population size, can result in strong demographic risk.

Despite these concerns for the short-term survival of interior basin stocks, most are demonstrating some inherent resiliency. We have seen this in the increased survival of downstream migrants and the numbers of returning adults when environmental conditions align favorably. At the same time, the region's stream and estuary rehabilitation programs are becoming more effective at restoring the physical and biological processes necessary for salmon and steelhead to express life history diversity, as well as improving habitat for resident native fish species. Large-scale habitat access projects, such as dam removal on Washington's Elwha River, have demonstrated that they can promote dramatic abundance and productivity gains, and artificial production and reintroduction tools have proven the potential to reestablish some extirpated stocks.

However, any optimism about future stock status must be tempered by continued pressures from a changing climate and the effects of the ever-expanding human footprint. Rapid, concerted, system-wide actions that expand from existing strongholds are therefore most likely to result in durable biological benefits to interior Columbia stocks. As with all region-scale natural resource management strategies, these actions should be implemented within a framework of ongoing scientific monitoring and evaluation (see Question 10). A thoughtful, full life-cycle, quantitative decision support tool driven by an adaptive management program will allow us to detect their effects against a background of environmental conditions that are changing in an increasingly unpredictable manner (Kocik et al. 2022).

[11] Anthropogenic passage barriers prevent Interior Columbia stocks from accessing historically productive habitat in many Interior Columbia River sub-basins (e.g., Upper Columbia River, Middle Snake River, Similkameen River, Yakima River, North Fork Clearwater River, Deschutes River) (see **Figure 1a**). These barriers, that were constructed as early as 1901 and as late as the 1960s, include a substantial number of federal and privately owned hydroelectric and water storage projects in both the mainstem river reaches and in major tributaries.

Table 2. Current abundance (through return year 2019) of ESA-listed stocks from Ford (2022) and current abundance (2008-2017) of six additional stocks that are not listed under the ESA from NMFS (2020a). Table also shows current abundance as percent of CBP mid-range goal.

Stock	Number of Historical Populations	Number of Current (Extant) Populations	ESA-Listing Status	Current Blocked Areas (Yes/No)	Historical Abundance	CBP Medium Goal	Current Abundance (10yr geomean)	Current as Percent of Historic	Current as Percent of CBP Medium
Mid-Columbia River Spring Chinook	14	7	Not listed	No	246,500	40,425	11,600	4.7%	28.7%
Mid-Columbia River Summer/Fall Chinook	1	1	Not listed	No	17,000	13,000	11,500	67.6%	88.5%
Mid-Columbia River Coho	4	1	Extirpated	No	75,000	11,600	6,324	8.4%	54.5%
Mid-Columbia River Sockeye	2	0	Extirpated	Yes	230,000	45,000	1,036	0.5%	2.3%
Mid-Columbia River Steelhead	20	17	Threatened	No	132,800	43,850	18,044	13.6%	41.1%
Upper Columbia River Spring Chinook	10	3	Endangered	Yes	259,450	19,840	1,131	0.4%	5.7%
Upper Columbia River Summer Chinook	14	7	Not listed	Yes	733,500	78,350	16,920	2.3%	21.6%
Upper Columbia River Fall Chinook	5	4	Not listed	Yes	680,000	62,215	92,400	13.6%	148.5%
Upper Columbia River Coho	5	0	Extirpated	Yes	44,500	15,000	392	0.9%	2.6%
Upper Columbia River Sockeye	5	2	Not listed	Yes	1,800,000	580,000	40,850	2.3%	7.0%
Upper Columbia River Steelhead	11	4	Threatened	Yes	1,121,400	31,000	2,052	0.2%	6.6%
Snake Spring/Summer River Chinook	68	28	Threatened	Yes	1,000,000	98,750	7,013	0.7%	7.1%
Snake River Fall Chinook	2	1	Threatened	Yes	500,000	10,780[12]	9,207	1.8%	85.4%
Snake River Coho	6	2	Extirpated	Yes	200,000	26,600	100	0.1%	0.4%
Snake River Sockeye	9	1	Endangered	Yes	84,000	15,750	46	0.1%	0.3%
Snake River Steelhead	40	25	Threatened	Yes	600,000	75,000	18,689	3.1%	24.9%

[12] This estimate is based on the production potential of existing, not historically available, habitat.

Question 3: What is the **importance and context of climate change** (e.g., ocean conditions, snowpack, drought, flow, mainstem/tributary water temperature) on the life-cycle productivity, resilience, extinction risk, and recovery potential of priority stocks?

Climate change generally exacerbates threats and limiting factors, including those currently impairing salmon and steelhead survival and productivity. The growing frequency and magnitude of climate change related environmental downturns will increasingly imperil many ESA-listed stocks in the Columbia River basin and amplify their extinction risk (Crozier et al. 2019, 2020, 2021). This climate change context means that opportunities to rebuild these stocks will likely diminish over time. As such, management actions that increase resilience and adaptation to these changes should be prioritized and expedited. For example, the importance of improving the condition of and access and survival to and from the remaining functional, high-elevation spawning and nursery habitats is accentuated because these habitats are the most likely to retain remnant snowpacks under predicted climate change (Tonina et al. 2022).

Climate change is already evident. It will continue to affect air temperatures, precipitation, and wind patterns in the Pacific Northwest (ISAB 2007, Philip et al. 2021), resulting in increased droughts and wildfires and variation in river flow patterns. These conditions differ from those under which native anadromous and resident fishes evolved and will likely increase risks posed by invasive species and altered food webs. The frequency, magnitude, and duration of elevated water temperature events have increased with climate change and are exacerbated by the CRS (EPA 2020a, 2020b; Scott 2020). Thermal gradients (i.e., rapid change to elevated water temperatures) encountered while passing dams via fish ladders can slow, reduce, or altogether stop the upstream movements of migrating salmon and steelhead (e.g., Caudill et al. 2013). Additional thermal loading occurs when mainstem reservoirs act as a heat trap due to upstream inputs and solar irradiation over their increased water surface area (EPA 2020a, 2020b, 2021). Consider the example of the adult sockeye salmon, both Upper Columbia and Snake River stocks, in 2015, when high summer water temperatures contributed to extremely high losses during passage through the mainstem Columbia and Snake River (Crozier et al. 2020), and through tributaries such as the Salmon and Okanogan rivers, below their spawning areas. Some stocks are already experiencing lethal thermal barriers during a portion of their adult migration. The effects of longer or more severe thermal barriers in the future could be catastrophic. For example, Bowerman et al. (2021) concluded that climate change will likely increase the factors contributing to prespawn mortality of Chinook salmon across the entire Columbia River basin.

Columbia River basin salmon and steelhead spend a significant portion of their life-cycle in the ocean, and as such the ocean is a critically important habitat influencing their abundance and productivity. Climate change is also altering marine environments used by Columbia River basin salmon and steelhead. This includes increased frequency and magnitude of marine heatwaves, changes to the intensity and timing of coastal upwelling, increased frequency of hypoxia (low oxygen) events, and ocean acidification. These factors are already reducing, and are expected to continue reducing, ocean productivity for salmon and steelhead. This does not mean the ocean is getting worse every year, or that there will not be periods of good ocean conditions for salmon and steelhead. In fact, near-shore conditions off the Oregon and Washington coasts were considered good in 2021 (NOAA 2022). However, the magnitude, frequency, and duration of downturns in marine conditions are expected to increase over time due to climate change.

Any long-term effects of the stressors that fish experience during freshwater stages that do not manifest until the marine environment will be amplified by the less-hospitable conditions there due to climate change. Together with increased variation in freshwater conditions, these downturns will further impair the abundance, productivity, spatial structure, and diversity of the region's native salmon and steelhead stocks (ISAB 2007, Isaak et al. 2018). As such, these climate dynamics will reduce fish survival through direct and indirect impacts at all life stages (NOAA 2022, ODFW 2020).

The increasing role of deteriorating ocean or freshwater conditions from climate change on the health of salmon and steelhead stocks does not diminish the importance or necessity of taking meaningful actions in areas society has more direct influence over. In fact, the importance and necessity of meaningful actions is heightened, not diminished because of the impacts of climate change. For example, as the frequency of drought, low snowpack, elevated water temperature, and poor marine conditions increase, managers must do more, not less, to restore properly functioning tributary habitats and mainstem migration corridors currently degraded by human uses (Jordan and Fairfax 2022). These changes counteract the less-manageable deficits created by climate change in marine habitats.

All habitats used by Pacific salmon and steelhead will be affected by climate dynamics. However, the impacts and certainty of the changes will likely vary by habitat type. Some changes affect salmon at all life stages in all habitats (e.g., increasing temperature), while others are habitat-specific (e.g., stream-flow variation in freshwater, sea-level rise in estuaries, upwelling in the ocean). How climate change will affect each individual salmon or steelhead stock also varies widely, depending on the extent and rate of change and the unique life-history characteristics of different natural populations (Crozier et al. 2008). In light of this variability, habitat restoration actions should support climate resilience (Jorgensen et al. 2021) in freshwater spawning, rearing, and migratory habitats, including access to high elevation, high quality cold-water habitats, and the reconnection of floodplain habitats across the interior Columbia River basin. As all of these potential climate resilience tactics represent major long-term, large-scale restoration efforts, they should be guided by ongoing analyses of changing conditions and effectiveness in order to provide the most relevant science support for regional management action strategies.

Question 4: What are the primary ecological **threats or limiting factors**, by life stage, to achieving abundance and productivity goals? What is the relative and collective importance of addressing these threats? How much have these threats changed?

The CBP examined limiting factors[13] in its *Phase 2 Report* to identify constraints on natural production of salmon and steelhead and the potential pathways for achieving the CBP's qualitative and quantitative goals. While some factors are specific to a given life stage (e.g., fisheries largely affect adult life stages), most negatively impact multiple points in the life cycle—e.g., by reducing not only freshwater survival, but also carry over impacts on later marine life stages.

In general, the CBP found the biggest threats and limiting factors to be:

- Large-scale tributary and estuary habitat and water quality degradation.
- Hydrosystem impacts, including direct mortality, and indirect mortality, where delayed effects from transiting the hydrosystem occur during the first year of ocean residence.
- Impassable human-constructed barriers prohibiting access to much of the habitat historically accessible throughout the basin.
- Predation from pinnipeds, native and non-native fishes, and colony nesting waterbirds that are taking advantage of habitats altered by the CRS.

All priority stocks are subject to all of these major threat categories; however, the relative impacts of these limiting factors vary by stock and geography. As such, the rebuilding process will be stock and context dependent.

Table 3 shows limiting factors ranked according to their relative impacts (i.e., ranked 1 through 7 based on largest to smallest impact) for each interior Columbia River basin salmon and steelhead stock. In this framework, hydrosystem impacts are the largest threats, followed by habitat made inaccessible due to human-constructed impassable barriers and then degradation of tributary and estuary habitats.

[13] In this report, the terms limiting factors and threats are used somewhat interchangeably to indicate the human-caused impacts that have reduced and continue to reduce salmon and steelhead abundance and productivity. We use the same categories used in the CBP's *Phase 2 Report* (tributary habitat, estuary habitat, hydropower [direct and latent], blocked habitat, predation, fisheries, and hatcheries). These categories are also generally consistent with how limiting factors and threats were identified in ESA recovery plans for salmon and steelhead. The CBP did not explicitly assess ocean or climate change threats at the stock scale.

Table 3. Ranking of limiting factor impact levels (modification of CBP Phase 2 Report, Figure 13). Ranking of 1 indicates highest magnitude of impact. Shading indicates stocks from the same geographic area.[14]

Stock	Tributary Habitat	Estuary Habitat	Hydrosystem (Direct & Indirect	Blocked	Predation	Fisheries	Hatcheries
Snake River Spring/Summer Chinook	2	5	1	3	4	7	6
Snake River Steelhead	2	5	1	4	3	6	7
Upper Columbia River Fall Chinook	4	3	1	7	5	2	6
Upper Columbia River Spring Chinook	3	6	1	2	5	7	4
Upper Columbia River Steelhead	4	4	2	1	3	7	6
Upper Columbia River Summer Chinook	3	5	1	3	7	2	5
Mid-Columbia River Spring Chinook	1	6	2	3	3	7	5
Mid-Columbia River Steelhead	1	3	4	5	2	7	6
Upper Columbia River Sockeye	3	5	2	1	4	6	7
Snake River Fall Chinook	5	4	1	2	6	3	NA
Snake River Sockeye	5	4	1	2	3	6	NA
Mid-Columbia River Summer/Fall Chinook	4	2	3	6	5	1	7
Mid-Columbia River Coho	6	4	1	5	3	2	NA
Mid-Columbia River Sockeye	6	3	2	1	4	5	NA
Upper Columbia River Coho[15]	3	6	1	2	5	7	4
Snake River Coho[16]	2	5	1	3	4	7	6
Average	**3.4**	**4.4**	**1.6**	**3.1**	**4.1**	**5.1**	**5.8**

[14] **Table 3** is modified from Figure 13 in the CBP's *Phase 2 Report*. The report displayed each impact as a percentage reduction in abundance from historical conditions as a result of that limiting factor. Here, **Table 3** displays only the relative impacts. In addition, the report displayed impacts for direct (mainstem) and indirect (latent) hydrosystem mortality separately, while in **Table 3** they are combined. The CBP separated direct and indirect hydrosystem mortality because one is estimated directly and the other inferred based on trends in time series. The CBP identified a range of values for indirect hydrosystem mortality that was generally consistent with existing information, and **Table 3** combines the direct mainstem mortality and the mid-point of the range identified by the CBP for indirect mortality. This table, as with Figure 13 in the CBP's *Phase 2 Report*, provides an appropriate basis for exploring the relative magnitude of key limiting factors at the stock scale, but additional evaluation will be needed in some cases to refine understanding of these impacts.

[15] The CBP did not evaluate limiting factors for this stock due to lack of data; for purposes of this report, metrics for spring/summer Chinook were applied as surrogates.

[16] The CBP did not evaluate limiting factors for this stock due to lack of data; for purposes of this report, metrics for spring/summer Chinook were applied as surrogates.

The CBP *Phase 2 Report* does not quantify impacts of ocean and climate conditions on each stock, nor does it identify potential for management actions for the marine environment. Human impacts have reduced ocean productivity for salmon and steelhead stocks, and the Northern California Current is one of the more highly impacted regions from land activities along the west coast (Halpern et al. 2009). Widespread loss and degradation of estuary habitat (Greene et al. 2015, Toft et al. 2018), fishing that disrupts seafloor communities (Teck et al. 2010), high nutrient inputs to the coastal zone in runoff, removal of forage fishes, and aquaculture practices (Andrews et al. 2015) have widespread cumulative impacts on salmon and ecosystem capacity. The manageable components of the marine environment could have a substantial impact on the restoration and recovery of interior Columbia River basin salmon and steelhead stocks. Salmon population dynamics are highly sensitive to mortality rates in the marine environment, often swamping effects from other life stages (Kareiva 2000; Crozier 2021). Yet, management of these components is rarely considered a viable option. To identify management actions, we must first acknowledge that salmon in the ocean are part of a complex ecosystem. Components of the ocean ecosystem that impact salmon population processes include the habitat (e.g., freshwater plumes, water buoyancy fronts, eddies, water temperatures, upwelling intensity and frequency), "bottom-up" productivity in time and space (phytoplankton, zooplankton, larval and juvenile fishes), particularly in the spring, and "top-down" predator population controls (birds, mammals, fish, and fishing).

The most devastating impacts of climate change are not uniform across life stages in all stocks. In some cases, the worst threats could be addressed with targeted water protection and restoration actions, and these should be a high priority. For example, low flow and high temperature in the free-flowing lower Salmon River is projected to pose the greatest threat to endangered Snake River sockeye salmon under climate change scenarios, and this threat could be mitigated by restoring flows and natural river processes to the mainstem Salmon River. In other cases, such as Snake River spring Chinook, the marine stage is the most threatened, and actions to improve marine survival need to be identified (Crozier et al. 2019). If carryover effects from early life stages are lowering marine survival, as suggested by the strong impacts of density dependence in freshwater habitat, then these impacts must be prioritized in the rebuilding strategy.

As described in the CBP *Phase 2 Report*, including estimates of direct and indirect mortality, the broad range of ecological and physical impacts of hydrosystem-related limiting factors have the largest collective impacts on survival for the most interior stocks, including all four extant Snake River basin stocks, and four of the six upper Columbia River stocks. Dams in the Columbia River and its tributaries (storage, irrigation, hydro) have altered flow regimes that have dramatically degraded water quantity and quality, reduced fish passage success, decreased sediment movement, and created conditions for native and non-native predator and competitor (e.g., shad) species to thrive.

Blocked access to historical habitats was the highest limiting factor for the remaining two upper Columbia stocks. For mid-Columbia stocks, the primary limiting factors were mixed, with no single factor emerging as the largest across most stocks.

Stream, river, and estuary habitat degradation is a major limiting factor and continued threat to the rebuilding success of all interior Columbia River basin stocks. The quality of salmon and steelhead habitats (freshwater and estuarine) is determined by physical, biological, and chemical processes. Physical and biological factors determining habitat quality and quantity are understood, and suites of action strategies are continually improving in their capacity to address the needed ecological uplift.

However, the chemical, or “water quality” component is a major, and often overlooked, factor shaping the environmental health of individual salmon. With nuanced effects on survival, reproduction, and other life history traits that map directly to population growth and abundance, poor water quality cuts across all aspects of the “clean, cool water” habitat requirements for salmonids. However, the linkages between physical (high stream temperatures, excess sediments), biological (invasion of pollution-tolerant taxa), and chemical (toxic contaminants) aspects of water quality also make it particularly challenging. For example, the degree of management uncertainty around physical and biological processes (e.g. surface water temperatures, invasive pikeminnow predation) is dwarfed by the poorly understood impacts of toxics from agriculture, mining, municipal wastewater treatment discharges, historical industrial pollution, and urban/suburban stormwater runoff. Therefore, expanding the scale and pace of habitat restoration must also include integrating physical, biological, and chemical process impairments into the riverscape restoration strategies implemented.

Fisheries and hatcheries also impact interior Columbia salmon and steelhead stocks, and can have demographic impacts. Natural-origin salmon and steelhead across the Columbia River basin share their environmental space with hatchery-origin salmon. Hatchery-origin salmon represent the majority of fish returning to the region above Bonneville Dam and are produced at dozens of facilities distributed throughout the Columbia and Snake rivers and their tributaries. One of the primary purposes for these facilities is the production of fish to support harvest in both ocean and in-river fisheries, benefiting cultural, sport, and commercial fishing sectors.

Natural-origin and hatchery-origin fish are isolated from each other for much of their early rearing, from spawning through release as yearling smolts, making it easy to assume there is no interaction between these fish. However, interactions occur between natural- and hatchery-origin juvenile salmon after release in the riverine migration corridor, in the Columbia River estuary, and subsequently in the Columbia River plume and coastal ocean. Competition may occur between juvenile fish, especially if migration by hatchery fish is slow or delayed. Moreover, large numbers of hatchery-origin juveniles may attract predators, increasing mortality of co-migrating natural-origin juveniles. This underscores the importance of continued hatchery risk management and reform and maintaining harvest regimes that are responsive to stock status and run size.

Each sector of threats, mainstem river conditions, tributary and estuary habitat quality and quantity, ocean conditions, climate impacts, and fishery management, contributes to a decrement in life-stage specific survival, or the capacity of the environment to support these life-stages. Survival and capacity impact population processes differentially - as a rate versus a ceiling—but they also interact within a life-stage and can carry over between life-stages. Therefore, any rebuilding strategy must recognize the need to comprehensively address survival and capacity limits, and do so in a manner that leverages the opportunities and challenges presented by the interactions.

For example, in order to reach abundance goals approaching the mid-range CBP goals, it is critical to increase freshwater carrying capacity and juvenile condition in the tributaries. Parr rearing and overwintering conditions affect juvenile survival in both their tributary and marine stages. In Salmon River spring Chinook populations, marine survival is inversely proportional to the number of spawners that produced that cohort, but also depends on ocean conditions. Because reduced marine survival can be a carryover effect from early life stages via fish size or condition, addressing these problems in freshwater could improve the ability of populations to rebound during good ocean years and reduce the impacts of worsening ocean conditions.

Although the CBP assessment is several years old (NMFS 2020a) and efforts to understand and improve fish conditions are ongoing, we believe its general approach for ranking manageable limiting factors and threats is still both relevant and accurate for current (2022) conditions. It is important to recognize that the backdrop of climate change (see Question 3) will exacerbate these identified manageable threats, while also magnifying less-manageable threats such as deteriorating ocean conditions, reduced snowpack, and increased drought.

Some of these threats have been recognized far longer than others and some have only recently emerged as primary limiting factors. For example, some of the worst degradation of tributary habitats occurred more than 100 years ago, whereas pinniped predation was recognized and addressed only recently. Caspian terns began nesting on dredge material islands in the lower river in the 1980s, but recognition that bird predation affects salmon and steelhead survival basin-wide is relatively recent. Fish passage routes at Bonneville Dam became focused foraging areas for sea lions and colony nesting water birds forage in tailraces, fish ladders, and reservoirs. Although harvest was historically a significant threat to some stocks, fisheries are currently managed more conservatively and are the only threat category responsively managed to run size, with fewer impacts allowed as runs diminish. The scope of tributary habitat threats remains large and is not just limited to habitats degraded anthropogenically, but more broadly across remote, wilderness-designated watersheds vulnerable to climate change and ongoing deficits of marine-derived nutrients from collapsed anadromous fish runs.

Taken together with the widely recognized, pervasive impacts of predator communities and other survival threats resulting from altered mainstem habitats, the main limiting factors present in the Columbia River basin dramatically impact all interior Columbia salmon and steelhead stocks. They require a comprehensive suite of actions, coupled with robust scientific monitoring to continually evaluate and adjust its implementation (Williams et al. 2009).

Question 5: Which **actions** have the highest likelihood of helping by avoiding additional abundance and productivity downturns and providing reasonable certainty of achieving the mid-range CBP goals by addressing primary life-cycle threats and bottlenecks to survival and distribution in the face of climate change?

No single action is enough, given the abundance and survival goals for rebuilding, the stock priorities, the stocks' current status, and the primary threats within the context of climate change. To make progress towards healthy and harvestable stocks it is essential that the comprehensive suite of management actions includes:

- Significant reductions in direct and indirect mortality from mainstem dams, including restoration of the lower Snake River through dam breaching.
- Management of predator and competitor numbers and feeding opportunities.
- Focused tributary and estuarine habitat and water quality restoration and protection.
- Passage and reintroduction into priority blocked areas, including the upper Columbia River (and, potentially, the Middle Snake River and Yakima River).
- Focused hatchery and harvest reform.

It will be essential that we implement *all* these actions, and that we do so at a large scale. While efforts in all these areas have been underway, there is a need in most cases to substantially enhance and focus implementation, and to incorporate new and emerging knowledge about effective implementation. These actions are needed to provide the highest likelihood of reversing near-term productivity declines and rebuilding towards healthy and harvestable runs in the face of climate change.

Primary life-cycle threats to survival and distribution vary across and even within stocks (NMFS 2020a). Thus, the successful rebuilding of interior Columbia stocks will require a diverse suite of actions. Generally, actions that benefit multiple stocks, and multiple populations within a stock, will have the greatest impact on overall adult returns. Similarly, identification of carry-over and interacting impacts across life-stages allows the opportunity to amplify benefits of actions. Likewise, actions that provide more immediate effects, rather than actions with longer time-lagged benefits, are necessary to help avoid near-term productivity declines and help reduce extinction risk while providing an additional buffer to climate change effects. However, long-term planning horizons for large actions cannot be a rationale to continually focus on small, fast-acting projects—sequencing and prioritizing will be needed over all action types across all sectors of priority stocks.

It is also important to recognize that, within the comprehensive suite of actions listed above, several centerpiece actions are paramount for specific stocks. Implementing this comprehensive suite of actions that address threats to salmon and steelhead across the basin, including the identified centerpiece actions, will provide the greatest potential to make progress towards healthy and harvestable abundances.

- **For Snake River stocks, the centerpiece action is restoring the lower Snake River via dam breaching.**[17] Restoring more normalized reach-scale hydrology and hydraulics, and thus river conditions and function in the lower Snake River, requires dam breaching. Breaching can address the hydrosystem threat by decreasing travel time for water and juvenile fish, reducing powerhouse encounters, reducing stress on juvenile fish associated with their hydrosystem experience that may contribute to delayed mortality after reaching the ocean, and providing additional rearing and spawning habitat.

- **For upper Columbia River stocks, the centerpiece action is reintroducing fish into blocked areas.**[18] Establishing adult and juvenile passage to and from areas of the upper Columbia River blocked by high-head dams provides the highest likelihood for achieving mid-range CBP goals. This action addresses the blocked area threat by providing access to additional and more productive spawning and nursery areas, indirectly benefits other species through ecosystem impacts, and buffers populations against climate change effects.

- **For mid-Columbia stocks, in addition to improved passage through lower mainstem dams, it is important to improve water quality and quantity and passage survival in focused areas of low- to mid-elevation tributary habitats**. Maximizing functional tributary habitats (primarily instream flows, water quality, and fish passage improvements) and improving passage in the lower mainstem Columbia River is necessary to provide the highest likelihood for achieving mid-range CBP goals. For example, for high-risk Yakima basin stocks, smolt survival through the Yakima River should be significantly increased by increasing spring flows, implementing structural and operations improvements at federal diversion dams, and targeting specific habitat improvements. These actions address habitat threats in tributaries and help reduce direct and indirect effects of the hydrosystem threat in the mainstem.

The urgency of the comprehensive suite of actions is accentuated by ongoing climate change. Actions that have the highest likelihood to **buffer climate change** impacts and support restoration fit into three categories:

> *Maintaining suitable water temperatures and flows in mainstem and tributary habitats.* Juvenile and adult salmon and steelhead use migration corridors in the mainstem Columbia and Snake Rivers to move between their spawning and rearing areas and the ocean. These corridors suffer from rising water temperatures and reduced flows. Increased temperature and reduced flow in

[17] Breaching the four lower Snake River dams specifically refers to removing the earthen portion of each dam, and allowing a naturalized river channel to be established around the concrete spillway and powerhouse structures.
[18] Passage into blocked areas specifically recommended for high-head dams that lack fish ladders and/or juvenile bypass facilities (e.g., upper Columbia and, potentially, North Fork Clearwater, Middle Snake, and Yakima Rivers). Restoring adult and/or juvenile passage within tributaries (e.g., culverts, irrigation diversions) is covered under tributary habitat restoration.

adult holding and spawning areas and juvenile rearing areas is also becoming a concern. Some examples of actions necessary to provide reasonable confidence in addressing this need include:

- Normalizing reach-scale hydrology and hydraulics in the mainstem Columbia and Snake Rivers.
- Attaining EPA Clean Water Act water quality standards and associated TMDLs for temperature, turbidity, toxics, and nutrient loading.
- Maintaining and enhancing flow augmentation from Columbia River Treaty and U.S. storage projects for spring and summer juvenile migration.
- Systematically and extensively restoring tributary habitat, especially at the riverscape scale. Restoring natural rates and dynamics of biological and physical processes that create and maintain healthy functioning riparian and floodplain habitats.
- Durable, targeted agreements to accomplish increased instream flow volumes through water acquisitions, irrigation system conversions, conservation, and land-use modification.

Maximizing survival and production from freshwater habitats (including migration corridors). This will help reduce productivity declines during periods of poor ocean conditions, and increase rebuilding during periods of good ocean conditions. Some examples of actions necessary to provide reasonable confidence in addressing this need include:

- Maintain and enhance fish passage structures and operations at remaining mainstem dams and reservoirs. This will increase juvenile survival, decrease indirect mortality, and increase adult returns.
- Minimizing predation on juveniles as they migrate to the ocean.
- Minimizing predation on adults as they return to their spawning grounds.
- Minimizing passage delays and removing passage barriers to adults returning to spawning grounds.
- Increasing tributary habitat quality and quantity through focused actions that support sustained productivity[19] across much broader return rates.
- Increasing the quantity and quality of and access to estuary habitat that provides migration corridor refugia and highly productive juvenile rearing environments.

Maintaining and restoring access to climate resilient habitats for spawning and rearing (e.g., high-elevation spawning and rearing habitats with snowpack-driven hydrology, or extensive connected floodplain habitats). Some examples of actions necessary to provide reasonable confidence in addressing this need include:

- Restoring or improving adult and juvenile passage to and from high elevation upper Columbia and upper Snake historical production areas and reintroduction and passage into currently blocked tributary (e.g., above Enloe Dam on the Similkameen River or Yakima basin reservoirs) and mainstem (e.g., Grand Coulee) areas.

[19] Freshwater productivity of at least 100 smolts per female across broad return rates is a generally accepted rule of thumb for robust freshwater productivity of stream-type salmonids. Stock specific freshwater productivity goals have not been uniformly established across the interior Columbia River basin.

- Protecting and restoring cold-water refugia in tributary adult holding areas and in spawning and nursery areas.
- Maintaining and maximizing thermal refugia within the mainstem migration corridor.
- Restoring connected floodplain habitat across all ecoregions of the interior Columbia River basin.

Building off the CBP effort, **Table 4a** generally assesses action urgency and priority based on stock status and limiting factor impact level. From there, further refinement helps provide stock-specific priority actions. **Table 4b** identifies the most common actions in the high priority categories: hydro (11 stocks), tributary habitat (10 stocks), blocked habitat (10 stocks), and predation (7 stocks). As action implementation planning moves to finer scales, there will be a need for additional consideration of how to sequence management actions. For example, as the CBP acknowledged, the goal is to align harvest and fishing with the need to restore natural production (consistent with the CBP's vision for thriving future salmon and steelhead populations). Similarly, artificial production is an important tool for supporting conservation and providing fish for harvest. There is a need to continually align hatchery and harvest with natural production.

Table 4a. Biological criteria matrix for action prioritization.[20]

Stock Status	Impact Level Low (less 20%)	Impact Level Medium (20-30%)	Impact Level High (31-50%)	Impact Level Very High (>50%)
Low (<25%)	Priority 3	Priority 2	Priority 1	Priority 1
Medium (26-50%)	Priority 4	Priority 4	Priority 2	Priority 2
High (51%-75%)	Priority 5	Priority 4	Priority 3	Priority 2
Very High (>75%)	Priority 5	Priority 5	Priority 4	Priority 4

[20] The action prioritization criteria in **Table 4a** are based on a combination of impact and stock status derived from the CBP *Phase 2 Report*. The impact level categories refer to the limiting factor impacts in the CBP *Phase 2 Report* Figure 13, that displayed, for each stock, the impact of each limiting factor as a percent reduction in productivity from historical conditions. Stock status is based on the average annual returns of natural-origin salmon and steelhead to the Columbia River, 2008–2017 (as displayed in the CBP *Phase 2 Report*, Table 8) as a percent of the CBP mid-range abundance goal (as displayed in the CBP *Phase 2 Report*, Table 8).

Table 4b. Priority actions for rebuilding each stock based on the action prioritization criteria in **Table 4a**. Shading in "stock and status" column indicates stocks from the same geographic areas.[21]

Stock and Status	Priority 1	Priority 2	Priority 3	Priority 4	Priority 5
Snake Spring /Summer Chinook **Low**	Hydro, Tributary Habitat	Predation, Blocked Habitat	Estuary Habitat, Fishery, Hatchery		
Snake Steelhead **Low**		Tributary Habitat, Hydro, Blocked Habitat, Predation		Estuary Habitat, Fishery, Hatchery	
Upper Columbia Fall Chinook **Very High**				Hydro, Fishery	Tributary Habitat, Estuary Habitat, Blocked Habitat, Predation, Hatchery
Upper Columbia Spring Chinook **Low**	Tributary Habitat, Hydro, Blocked Habitat, Hatchery	Predation	Estuary Habitat, Fishery		
Upper Columbia Steelhead **Low**	Tributary Habitat, Estuary Habitat, Hydro, Blocked Habitat, Predation	Hatchery	Fishery		
Mid-Columbia Spring Chinook **Medium**		Tributary Habitat, Hydro		Estuary Habitat, Blocked Habitat, Predation, Fishery, Hatchery	
Mid-Columbia Steelhead **Medium**		Tributary Habitat, Predation		Estuary Habitat, Hydro, Blocked Habitat, Fishery, Hatchery	
Upper Columbia Sockeye **Low**	Tributary Habitat, Hydro, Blocked Habitat	Predation	Estuary Habitat, Hatchery	Fishery	
Snake Fall Chinook **Very High**				Hydro, Blocked Habitat, Fishery	Tributary Habitat, Estuary Habitat, Predation, Hatchery
Snake Sockeye **Low**	Hydro, Blocked Habitat	Predation	Tributary Habitat, Estuary Habitat, Fishery, Hatchery		
Upper Columbia Summer Chinook **Low**	Tributary Habitat, Hydro, Blocked Habitat, Fishery	Estuary Habitat, Hatchery	Predation		
Mid-Columbia Summer/Fall Chinook **Very High**				Fishery	Tributary Habitat, Estuary Habitat, Hydro, Blocked Habitat, Predation, Hatchery
Mid-Columbia Coho **High**			Hydro	Fishery	Tributary Habitat, Estuary Habitat, Blocked Habitat, Predation, Hatchery
Mid-Columbia Sockeye **Low**	Blocked Habitat	Hydro	Tributary Habitat, Estuary Habitat, Predation, Fishery		Hatchery
Upper Columbia Coho **Low**	Tributary Habitat, Hydro, Blocked Habitat	Predation	Estuary Habitat	Fishery	Hatchery
Snake Coho **Low**	Hydro, Tributary Habitat	Blocked Habitat	Estuary Habitat, Predation	Fishery	Hatchery

[21] Stock status in **Table 4b** is based on the stock status categories defined in **Table 4a** (low, medium, high, very high), that are based on current abundance as a percent of the CBP mid-range goal (see Table 2 for current abundance and current as percent of CBP goal). Stock-specific actions in **Table 4b** are derived from the limiting factor impact levels in the *CBP Phase 2 Report*, Figure 13, and the action prioritization criteria in **Table 4a** of this report. This table provides an appropriate basis for exploring prioritization of rebuilding actions, but additional evaluation will be needed in some cases to refine understanding of action priorities.

Question 6: Given the status in Question 2 above, what is the **urgency** for implementation of actions toward the goals? What sequencing of actions achieves the highest likelihood of minimizing the potential for productivity declines and achieving the generational growth necessary to achieve goals?

Given the status of interior Columbia stocks and ongoing climate change described in Questions 2 and 3, achieving the CBP mid-range goals by 2050 requires urgent action.

Improvements in ocean conditions during 2021 provided a welcome respite, but are not expected to reverse ongoing trajectories (i.e., the increased frequency, magnitude, duration, and scope of environmental downturns) associated with a changing climate. The higher returns in 2022 have demonstrated that the salmon and steelhead populations have retained some resiliency and that aggressive large-scale actions now will be rewarded with increased abundance, in particular, those addressing density dependent limitations across the salmon life-cycle. However, 2022 has also demonstrated that despite short-term up-turns, stocks have not returned to "healthy and harvestable" levels.

All actions identified under Question 5 need to be implemented as soon as possible, but the most urgent are those that: a) provide tangible benefits shortly after implementation, b) provide the most significant survival boost for a broad range of priority populations, and c) also address habitat capacity limitations. Additional predator controls in the mainstem and expedited actions on readily accessible tributary and estuary habitat and water quality impairments address this need, but must be part of a comprehensive package that provides additional fish protections at mainstem dams, fish passage into critical blocked areas, focused habitat protection and restoration in tributaries and the estuary, and an expedited pathway to mainstem lower Snake River restoration.

Only this comprehensive package is likely to provide the productivity improvements and expanded capacity necessary to achieve the CBP abundance goals.

All but one of the interior Columbia salmon and steelhead stocks are below their CBP mid-range goals (**Table 2**). On average, stock abundance is 33% of its goal (range: 0–149%). With most stocks at extremely low abundance, achieving mid-range abundance goals requires increasing stock productivity (by, for example, reducing mortality and increasing capacity) to levels well above replacement rate, and sustaining these levels for multiple generations. Simply put, survival under the best conditions can only double or triple abundance in a single generation, and these rates are not achievable within the constraints of density dependent limitations. Generation time varies by stock, ranging from three to six years. Depending on the stock, this provides five to nine generations between 2023 and 2050 for abundance and productivity increases to reach CBP mid-range goals.

Generational productivity varies over time. A base-level positive generational growth rate (analogous to continuous interest with compounding gains over time) must be met each generation between now and 2050—the necessary average rate across stocks being 36% (range: –8% to +83%; **Figure 3**). This required productivity increases even further if crucial survival rate improvements are not realized immediately. Survival rate increases will be delayed unless the following are begun immediately: 1) actions that are likely to produce benefits relatively quickly after implementation, and 2) actions that have a lag time between implementation and environmental response.

Unfortunately, not all restoration actions will achieve their intended benefit. In addition, disturbance events are likely to occur that will reduce productivity. As such, the suite of targeted restoration actions should exceed the minimum level of necessary improvement. Otherwise, there is a potential for extreme natural events to cause localized extinctions (McElhany et al. 2000).

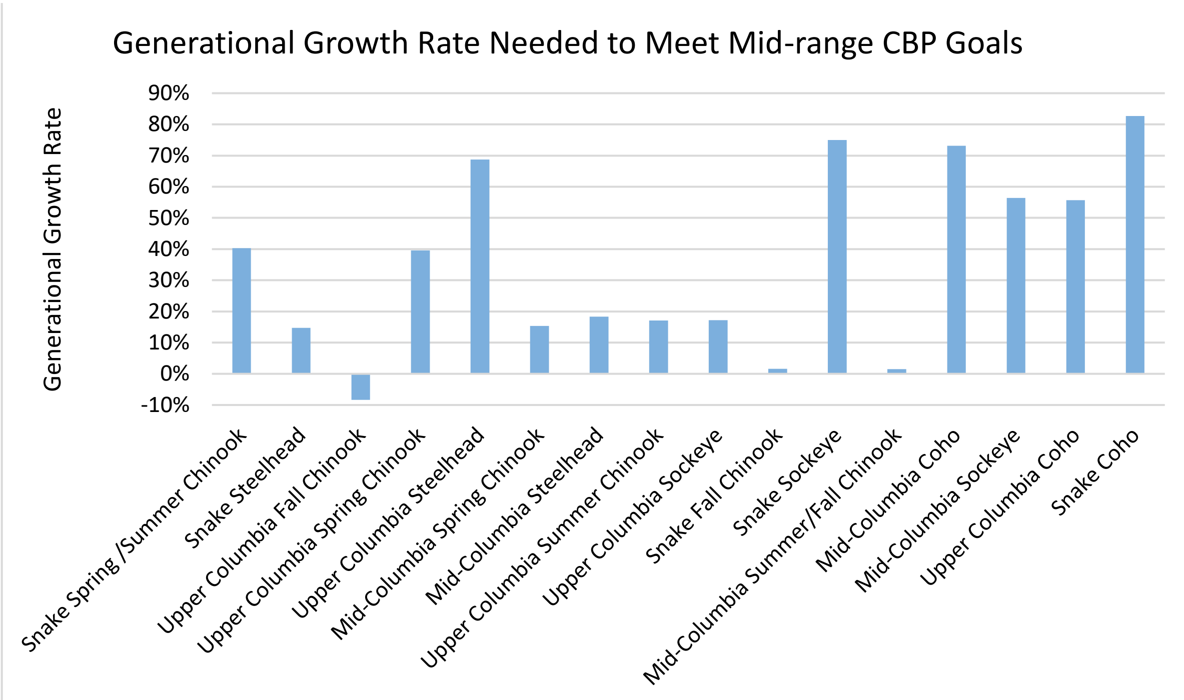

Figure 3. Stock-specific generational growth rate needed to achieve CBP mid-range goals by the year 2050.

The rebuilding plan for interior Columbia River basin steelhead and salmon must be based on quantitative evaluations and full life-cycle forecasts of expected benefits from action scenarios. The prioritization and sequencing will form the basis of an adaptively managed implementation scheme that must be responsive to short-term, interim performance metrics. For example, in the near-term, progress away from a quantifiably large risk of extinction for these stocks is paramount. Quasi-Extinction Thresholds (QETs) are a standard, commonly applied metric for evaluating population viability and the risk of extinction. QETs represent tipping points for population collapse, where the actual extinction potential may not be predictable or, in some cases, avoidable. Populations that fall below their QETs face higher genetic, demographic, and environmental risks, reducing their resilience and increasing their risk of extinction. The result can be an extinction vortex and a greatly reduced likelihood of recovery (Gilpin and Soulé 1986, Simberloff 1988, Fagan and Holmes 2006). Stock status assessments indicate numerous populations within the Columbia River basin are already at or below QET, with more likely to hit this threshold in the next five years (Storch et al. 2022). Over the coming decade, the probability of a stock hitting its QET can be a critically important programmatic performance metric, with the intention of moving all stocks out of the abundance and productivity range where QETs are relevant.

To achieve the CBP's mid-range goals, given the current stock status and demographic inertia identified above, it is imperative to start taking actions immediately. Also, given the large-scale, long-term nature of the necessary actions, it is critically important to continue and expand scientific monitoring and adaptive management to most effectively structure and guide the interior Columbia River basin salmon and steelhead rebuilding effort.

Question 7: Given the status in Question 2, what **confidence** do we have that salmon and steelhead will respond favorably if the actions identified in Question 5 are implemented comprehensively?

We are confident that extant interior Columbia stocks still retain the inherent resilience to respond favorably once the recommended actions are implemented. This confidence is informed by the strong positive responses observed in the early 2000 and mid-2010s among natural-origin Snake River spring/summer Chinook salmon and steelhead when favorable ocean and other conditions aligned to provide more productive conditions for salmon and steelhead stocks. We are also confident that the comprehensive suite of actions identified in Question 5 provides the highest and only reasonable certainty of achieving survival, productivity, and capacity improvements necessary to realize the CBP's long-term mid-range abundance goals.

Salmon life-cycle models used in previous analyses predict that breaching lower Snake River dams—in combination with other fish protection measures (e.g., enhanced spill at the four lower Columbia River dams and freshwater habitat restoration)—would have the highest increase in survival of all the alternatives considered. The range of current population projection models varies, both in the proposed mechanisms, and in the magnitude of direct and indirect mortality associated with fish passage through the mainstem hydrosystem in the Columbia River basin.[22] However, the common message is clear across all the work: salmon rebuilding depends on large-scale actions, including breaching dams, systematically restoring tributary and estuary habitats, and securing a more functional salmon ocean ecosystem.

Our certainty that actions must be large-scale, comprehensive, and begin immediately to avoid long-term declines and achieve abundance and survival goals is driven by the pace and completeness of implementation, tempered by ongoing climate change, and deteriorating environmental conditions beyond society's direct or immediate influence. Question 9 addresses the range of uncertainty relating to several important salmon and steelhead population rebuilding actions, while Question 10 addresses how a science-informed decision structure could facilitate decision-making and ensure that rebuilding actions are effective, given the uncertainties that exist.

Nonetheless, our lack of precise measures or quantitative estimates of the magnitude of biological benefit expected from large-scale management actions in no way indicates that we lack confidence in their efficacy. The science robustly supports riverscape-scale process-based stream habitat restoration, dam removal (breaching), and ecosystem-based management[23], and overwhelmingly supports acting, and

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[22] Ranges of scenarios across combinations of management sectors evaluated are presented in McCann et al. (2018), Petrosky et al. (2020), Zabel and Jordan (2020), and USACE et al. (2020).

[23] Ecosystem-based management (EBM) refers to actions that protect ecosystem structure, function and key processes. In the case of interior Columbia basin salmon and steelhead stocks, EBM could be a suite of management and mitigation options that attenuate the recent increase in predator abundance, increased consumption rates that coincide with warmer ocean conditions, and the anticipated reduction in marine survival rates due to climate change (Crozier *et al.* 2021). These include A) more active management of salmon predators such as seabirds and pinnipeds, including harvest management, B) enhanced forage fish management to provide a predator refuge for salmon, C) optimizing freshwater actions to "carryover" physiological benefits for salmon (such as increased size)

acting now. Notwithstanding uncertainty surrounding the exact magnitude of beneficial response of acting, the CBP's mid-range abundance goals will not be met unless these actions are implemented.

The fisheries management community of the Columbia River basin has identified a wide range of management actions with confidence in achieving intended physical and biological benefits. Recent, large-scale dam removal projects on the Elwha, Nooksack, Hood, Wind, White Salmon, Sandy, and Rogue rivers have all resulted in broader and quicker biological and physical benefits to local and regional riverscapes than expected. Process-based stream, river, and floodplain restoration projects in portions of many watersheds across the West (e.g., Lemhi, Pahsimeroi, John Day, McKenzie, Whychus, Fivemile, and Bell rivers) have resulted in rapid increases in abundance and productivity of resident or anadromous salmonids.[24] Ecosystem-based management actions have addressed the impacts of some natural and human-influenced activities in the mainstem and estuary of the Columbia and Snake Rivers, effectively reducing their impacts on migrating juvenile and adult salmonids.

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into the marine environment, and D) altering hatchery practices and management actions to strategically benefit other protected species in the ocean, such as southern resident killer whales.

[24] By returning some normative fluvial and biogeomorphic processes to these riverscapes.

Question 8: If the actions identified in Question 5 are implemented comprehensively for salmon and steelhead, how would they benefit or degrade conditions for **other species**?

Generally, native aquatic and terrestrial species will benefit from the actions identified above for anadromous salmon and steelhead due to the restoration of natural ecosystem structure and function (Storch et al. 2022). Breaching of the lower Snake River mainstem dams would transform the anthropogenic reservoir habitats back into a river with more functional connected floodplains, naturalized water velocity, and favorable river-channel morphological conditions. Passage improvements and reintroduction of anadromous salmon and steelhead to blocked areas would inject currently missing marine derived nutrients, benefit ecosystem function through improved primary productivity, provide aquatic and terrestrial connectivity, and increase diversification of native aquatic biota (Gende et al. 2002, Mathewson et al. 2003, Francis et al. 2006, Tonra et al. 2015, Bryson et al. 2022). Tributary water quality and quantity improvements would increase the quality of spawning and rearing habitats for both salmon and steelhead, but also for native resident species such as bull trout. These benefits would take time to fully realize, therefore accentuating the need for sequencing, prioritization, and long-term planning.

Some exceptions to the overall benefits of these actions may result due to the long-term existence of the anthropogenic function of the system that has altered historical ecosystem functions. For example, actions to intentionally reduce the abundance or distribution of native aquatic, terrestrial and avian species that feed on salmon and steelhead, e.g., lethal removal or hazing of pinnipeds, northern pikeminnows, and birds, such as gulls, terns, cormorants, and pelicans, would negatively impact their production and survival. These native species have capitalized on the hydropower system operations that result in slower transit times of migrating salmonids due to reservoir creation and island habitat formation. In the short-term, some management of these species may be necessary to support survival of salmon and steelhead recovery efforts. However, balancing multiple overlapping and interacting protected species is inherently complex and involves full consideration of both the long and short-term consequences.

The comprehensive suite of actions provides a myriad of benefits with some ramifications to native species, if fully implemented. The following sections provide a high-level review of the benefits and complicating factors for several key native species (e.g., bull trout, Pacific lamprey, white sturgeon, pikeminnow, avian and terrestrial waterfowl) for the actions identified in Question 5.

Breaching the lower Snake River dams would directly improve floodplain connectivity, natural sediment distribution and riparian habitat conditions benefiting both aquatic and terrestrial species, improve spawning habitat for species such as white sturgeon, and restore free-flowing migratory corridors for several aquatic species including bull trout, lamprey and sturgeon. Restoring and reconnecting floodplains clearly provides a myriad of benefits. A floodplain-connected valley is inherently more diverse and productive, not only for aquatic species, but across the entire floodplain (Bellmore and Baxter 2014). On the seasonally wet floodplain surface, vegetation productivity and plant and animal species richness and diversity are higher than on a disconnected, permanently dry terrace (Wohl et al. 2021). In the channels of a connected floodplain reach, primary productivity is higher, macroinvertebrate communities are richer and more productive (Nummi et al. 2021), and amphibian and fish productivity is higher (Anderson et al. 2015, Bouwes et al. 2016a) than in the simple channels of a disconnected reach. While these internal benefits are independently valuable, they are only a small fraction of the potential benefits that restored riverscapes can provide in the face of climate change (Wohl et al. 2017). When we reconnect streams and rivers to their floodplains, we perform both climate mitigation work (slowing/ stopping the trajectory of global warming impacts) and climate adaptation work (building resilience and resistance to climate-driven disturbances that are already occurring (Skidmore and Wheaton 2022).

Connectivity for migratory resident and anadromous species will directly improve with breaching of the Snake River dams. Currently fish passage facilities are designed for salmonids, however the effectiveness of the Snake River dam passage facilities at passing bull trout is unclear. Bull trout, listed as threatened under the ESA, exhibit a continuum of life histories involving lengthy migrations between spawning and rearing areas and areas of foraging and overwintering habitats. Maintaining connectivity between tributaries and within the mainstem Columbia and Snake rivers is essential for genetic exchange among core populations, supporting their resiliency against environmental and anthropogenic disturbances and ensuring a high likelihood of population viability and recovery (Barrows et al. 2016; USFWS 2015). In addition, bull trout with free-flowing, well connected habitats are larger, more fecund, and resilient to consequences of climate change and non-native species presence (i.e., brook trout). Breaching of the Snake River dams would increase access to essential foraging, migration and overwintering habitat important for bull trout throughout the Snake and Columbia Rivers (USFWS 2015, USFWS 2020a).

Current mainstem dam adult fish ladder structures preclude passage of about 50% of adult Pacific lamprey, such that fewer than 1% make it to the upper portions of the Columbia and Snake River basins. Juvenile Pacific lamprey mortality occurs when they impinge on the turbine screens designed to protect juvenile salmonids as they emigrate to the ocean. Breaching the lower Snake River dams would remove these threats to adult and juvenile Pacific lamprey in the lower Snake River reach, as well as the juvenile mortality associated with dredging navigation channels in that reach (USFWS 2020b). Substrates in the Snake River would return to more natural consistency, improving rearing conditions for juvenile Pacific lamprey.

White sturgeon migration and passage at the Snake River dams is limited. Breaching of the dams would provide free passage and access to additional spawning areas allowing for viable natural recruitment and continuous connectivity with areas upstream in the Snake and Clearwater Rivers (Storch et al. 2022). Spawning and subsequent juvenile production is currently constrained to the free- flowing reach of the Snake River between the upper end of Lower Granite Reservoir and Hells Canyon Dam. As there is currently no upstream passage for adult white sturgeon at the dams, breaching the lower Snake River dams would ultimately allow unrestricted movement of juvenile and adult white sturgeon throughout the expanded free-flowing reach from McNary Dam to Hells Canyon Dam.

Dam breaching will likely negatively impact native sedentary species such as freshwater mussels or lamprey ammocoetes in the short-term due to changes in water elevations and sediment distribution (USFWS 2020b). This effect will be particularly acute in the Lower Snake River and the McNary Reservoir (i.e., Lake Wallula). While there will likely be negative impacts on freshwater mussel habitat and other non-migratory species associated with the release of accumulated sediment, these impacts will also be short-term given the sediment transport capacity of the Lower Snake River (Grant and Lewis 2015). Over the long-term, breaching the earthen portions of the four Lower Snake River dams will likely lead to the reestablishment of natural hydrologic processes (e.g., deposition and sediment transport). Returning to a more natural flow regime would, in turn, promote island habitat and side channel sub-habitat formation, habitat that supports many aquatic species and multiple life history strategies.

In addition, the removal of reservoir habitat due to dam breach will likely decrease the abundance of northern pikeminnow as well as other non-native predatory species who have capitalized on the lowered velocities and shallow areas formed by reservoir operations. Although native to the Columbia River basin, the current abundance of northern pikeminnow is unnaturally high due to their increased productivity in reservoir habitats. Elevated pikeminnow population levels have resulted in unnaturally high predation rates on juvenile salmon and steelhead, necessitating Washington to implement a "bounty" program for northern pikeminnow within the mainstem Columbia and Snake Rivers. Restoring a more natural flow regime and riverine channel morphology in the mainstem reaches of the Columbia and Snake Rivers will dramatically reduce the abundance, distribution and encroachment of undesirable non-native species that thrive in reservoir habitats. Several of these species (walleye, smallmouth bass, and catfish) feed on native juvenile salmon, steelhead, and lamprey. Several other non-native species (e.g., carp and American shad) alter the food web and likely compete with native species for food. Native, diverse macro-invertebrate communities will improve, and while eliminating the reservoir environments will not preclude future invasion by zebra or quagga mussels, it would add approximately 140 miles of viable habitat for native mussel species and likely improve substrate conditions for native host species (e.g. sculpin).

Within the lower Snake River corridor, gulls, terns, cormorants, and pelicans congregate and feed on disoriented juvenile salmon and steelhead in dam forebays and tailraces. Avian nesting colonies are not prevalent within this reach, so breaching the lower Snake River dams would not alter nesting habitat, but it could change the distribution of avian species into the mid- and lower Columbia reservoir habitats. Restoration of natural riparian conditions along the Snake River after dam breach will increase habitat for terrestrial species (e.g., deer and waterfowl) and amphibians over time. The improved riparian conditions, combined with natural flow regimes in the Snake River are expected to increase the presence of cottonwood galleries and other riparian shrubs and vegetation, which are limited in the region. These habitats are key for ESA listed yellow-billed cuckoo and other avian species such as osprey, eagles, and herons.

While there are some uncertainties on the full extent of the benefits of dam breach for native aquatic species and short-term negative effects are expected, there is evidence from other dam removals in the region that the overall long-term benefit is high. For example, in the Elwha River, the removal of several dams has opened up habitat to anadromous salmon, steelhead, and bull trout that were historically blocked. Recent reports show that all species of salmon, steelhead and bull trout have migrated to areas above the historical dams and increased spawning has occurred (Brenkman et al 2019; Duda et al 2021). In the White Salmon River, the removal of Condit Dam resulted in new observations of bull trout above the historical dam site and evidence of migrations between the Columbia River and above the dam site (USFWS 2020).

As with breach, actions to restore access to blocked areas (e.g., above dams that provide no upstream passage) and reintroduction of anadromous salmon would benefit not only salmon and steelhead, but also resident aquatic and terrestrial species. For example, Fish and Hanavan (1948) reported the construction of Grand Coulee Dam, in the upper Columbia River, precluded anadromous fish from over 1,000 miles of spawning and rearing streams, and as a result, substantial fish production was lost (UCUT 2019). While listed in the Columbia River basin, threatened Kootenai River white sturgeon are unlikely to be impacted positively or negatively as they are geographically isolated due to natural and manmade barriers for approximately 10,000 years (Alden 1953, USFWS 1999).

Bull trout and other native resident species such as cutthroat, redband, mountain whitefish, and white sturgeon all benefit from passage improvements and reintroduction of anadromous salmon and steelhead to any of the anthropogenically blocked areas (Hardiman et al 2017). Most of these species historically coexisted with anadromous salmon populations, and the loss of marine derived nutrients has reduced nutrients and productivity in these areas. The marine-derived nutrients from spawned-out salmon carcasses fertilize low- productivity, high-elevation streams, setting the stage for the next generation of juveniles emerging from the gravel. As a result, aquatic flora and fauna will proliferate, supporting populations of resident fish species that are currently constrained or limited by low productivity. Juvenile salmonids provide high quality forage for bull trout and other native species and increased natural production over time aids in the diversification of forage base for native species. Some risks to populations in blocked areas could occur with reintroduction due to possible introduction of pathogens and increased competition in spawning and rearing areas of bull trout and other native resident species (Hardiman et al 2017).

Tributary habitat improvements for water quality and quantity are likely completely beneficial to bull trout and other native resident species. Similar to the benefits described for dam breach, bull trout and other native aquatic species will have better access to spawning and rearing areas and high-quality forage with improvements in water quality and quantity. Although native fish communities in the Columbia River basin represent a broad range of life-history strategies and have varying habitat requirements, many of the processes and mechanisms that dictate survival and productivity likely overlap. Thus, it stands to reason that actions restoring and reconnecting floodplains essential to support the life histories of salmon and steelhead would also benefit other native migratory species (e.g., Pacific lamprey) that have been imperiled by partial or complete loss of access to essential spawning and rearing habitat.

Healthy, productive salmon and steelhead populations are critical to multiple aquatic and human ecosystems in our region. Adult and juvenile salmon are the natural prey base for marine mammals. Tribal cultural and subsistence harvest opportunities have become limited, and commercial and recreational fisheries are closing. Pacific salmon and steelhead can no longer be the base for key biological and social networks across the region. Mainstem river rehabilitation, together with stream restoration across the tributary environment, is needed.

Question 9: Are there **uncertainties** associated with the efficacy of the actions identified in Question 5 and how might the region resolve these uncertainties?

NOAA Fisheries' recovery plans (NMFS 2009, 2015, 2017a, 2017b; UCSRB & NMFS 2007) and 5-Year Reviews (NMFS 2022a, b, c, d, e, f) for ESA-listed interior Columbia River basin salmon and steelhead stocks advise that many substantial actions, affecting every stage of their life-cycles, will be needed to increase the abundance and productivity of salmon and steelhead populations to achieve ESA recovery goals. Clearly, even more substantial actions will be needed to achieve the substantially higher mid-range abundance goals in the CBP *Phase 2 Report* (NMFS 2020a). It is true that despite the wealth of scientific knowledge and practical experience with salmon restoration, uncertainties regarding the efficacy of many of the actions described in response to Question 5 remain. It is equally true that these uncertainties are unlikely to be addressed unless large-scale actions are implemented and the effects of these actions on the productivity and abundance of salmon and steelhead are assessed. Adaptive management could play a central role and guide regional efforts in order to increase the likelihood of achieving the mid-range abundance goals. The following list, while by no means exhaustive, is intended to identify important factors or actions for which understanding and managing the implications of the uncertainty will be important. The sequencing and prioritization of actions during implementation should consider relevant uncertainties and make use of adaptive management approaches described under question 10.

- Climate change will continue to affect salmon and steelhead and their habitat in freshwater, estuarine, and marine environments. However, there is uncertainty about how these environments will be affected decades into the future, whether these types of effects can be mitigated, and how individual stocks and the communities they depend upon will respond to the changing conditions. Monitoring and modeling will be essential for developing actions that might be effective at lessening the impacts of climate change for individual stocks of salmon and steelhead throughout the life cycle.

- In many instances, density dependent factors are likely constraining the productivity (limiting the number of juvenile salmon and steelhead produced in freshwater spawning and rearing areas) of salmon and steelhead populations, since even under current abundance levels that are far below historical levels, life-stage specific productivity is low. Additionally, low survival rates of juvenile salmon and steelhead from tributary streams to the mainstem Columbia and Snake rivers likely constrain the productivity of the affected populations. Identifying what factors are responsible for these low survival rates will be essential for developing effective actions to reduce this constraint. Separating survival from capacity limitations, that is, understanding why density dependence is more evident than expected at low abundance, will be needed in order to develop effective actions to reduce this constraint.

- Decades of stream and river habitat restoration actions have made improvements in the quality and quantity of salmon and steelhead spawning and rearing environments, but measuring the magnitude of fish population response is challenging. Of the large-scale experimental watershed restoration projects in the Pacific Northwest (Intensively Monitored Watersheds, or IMWs), half have documented a beneficial response of restoration actions with respect to salmon and steelhead abundance or productivity metrics (Bilby et al. 2022). Importantly, this does not mean that the actions are not providing a benefit, especially when viewed in the context of long-term implementation of habitat improvement actions. Actions may be having a benefit even though the benefit cannot be detected in modeling or monitoring for various reasons, including countervailing effects such as ocean conditions or increased predation, variability in life-stage survivals, the fact that not a large enough portion of a watershed or the right factors have yet been treated, and, in the case of models, uncertainty in assumptions or parameters (Appendix A of NMFS 2020b; also see Hillman et al. 2016, Pess and Jordan eds. 2019). Given the scale of stream and river habitat restoration that will be required to achieve the CBP mid-range goals, the current model for identifying, designing, and implementing stream, river, and floodplain restoration needs to be improved. Key advances in adaptive management and program design (Bouwes et al. 2016b), understanding of bio-fluvial processes, and how to leverage this knowledge in riverscape restoration (e.g., Powers et al. 2019), provide a framework for an evolving approach to riverscape restoration that would enhance benefits to salmon and steelhead.

- Long-term, on-going field surveys have shown that all salmon and steelhead reside for some time in polluted habitats, with environmental health consequences that may be delayed in time (i.e., sick fish do not survive their first year in the ocean). Many food webs in the lower river are contaminated with PCBs, DDTs, PAHs, and other legacy pollutants. Moreover, human population growth in the greater Portland metropolitan area (as well as cities inland) remains ongoing, and is expected to increase substantially with future climate migration. This will invariably increase toxic exposure, as more people on the landscape translates to more land conversion (to impervious surfaces), more stormwater, more wastewater, etc. The relative exposure risk will also be influenced by climate change and water quantity, as lower in-river flows mean less dilution for more pollution in salmon rearing and migration corridors. These chemical habitat considerations (limiting factors) have generally not been addressed by the decision support tools currently guiding federal salmon recovery managers in the Columbia River basin. There are numerous management options that demonstrably reduce toxic loadings, with clean water outcomes that improve salmon survival. This remains a potentially highly consequential area of uncertainty for species conservation and restoration in the basin.

- Non-native invasive species, including fish species like smallmouth bass, walleye, and brook trout, are important sources of predation on juvenile salmon and steelhead stocks and have affected their productivity (Carey et al. 2012; Sanderson et al. 2009). The current combined impact of these species on salmon and steelhead is not well known and thus could not be fully assessed in the CBP *Phase 2 Report*. Exactly how these species are altering food webs and affecting salmon and steelhead stocks in response to changing climate conditions is also unknown. More non-native species are likely to be introduced into the Columbia River basin in the coming decades, but the effect of these species on extant populations of salmon and steelhead is largely speculative. For example, northern pike are of great concern, as these voracious predators have been introduced above Grand Coulee Dam and are increasing in abundance and distribution. They are expected to eventually make their way into the salmon migration corridors of the Columbia River and its tributaries. Climate change is also altering the distribution and assemblages of predator, prey, and competitor species in the marine environment. Understanding how invasive species and altered species assemblages affect salmon and steelhead stocks, both in the freshwater and marine environments, will be critical for developing effective actions to limit these impacts.

- Avian predators (e.g. gulls, cormorants, terns) annually consume large numbers of juvenile salmon and steelhead in the Columbia River basin. Predation opportunities are enhanced by human activities on the landscape (breeding habitat on islands created from dredged material and on bridges, feeding opportunities in the tailraces and reservoirs of mainstem and tributary dams). At the same time, our hatchery programs, although crucial to replace lost production, ensure that piscivorous birds have a prey base every year. That is, we have lost, or at least substantially dampened, any predator/prey cycle that may have existed in the undeveloped system. The magnitude of future losses of juvenile salmonids to avian predators, and the extent to which this will be a compensatory or additive type of mortality is uncertain—especially with respect to future geographic, seasonal, and inter-annual variability. Continuing to assess the results of our management actions will be needed to sustainably manage native, predacious bird populations to minimize their impacts on salmon and steelhead stocks.

- There is uncertainty regarding the direct productivity and survival benefits that might accrue to salmon and steelhead stocks from breaching Snake River dams. Breaching would, over time, substantially increase the amount of available spawning habitat for fall Chinook salmon in the Snake River basin, but the productivity of this habitat relative to other major spawning areas is unknown. It is also expected that juvenile survival rates would increase as they would no longer pass through dams and the associated reservoirs would no longer exist (i.e., decreased migration times, increased turbidity levels, etc.). If dams were breached, predators (birds and native and non-native fish species) would likely disperse and no longer be concentrated near the dam sites, but we assume they would continue to prey upon juvenile salmon and steelhead in other areas to some degree. Thus, while juvenile survival rates would be expected to increase, compared to the roughly 75 percent average survival rates currently observed for yearling Chinook salmon, sockeye, and steelhead smolts between Lower Granite and McNary dams, the actual survival rates that would result in the lower Snake River from dam breaching would be less than 100 percent due to continuing impacts of predators.

- Latent, or indirect, mortality is defined as mortality associated with passing dams that is not expressed until after a juvenile fish passes through the hydropower system and enters the estuary and ocean. While most researchers agree that some level of latent mortality results from an individual fish's passage experience through mainstem Columbia and Snake river hydroelectric projects, there continues to be substantial disagreement with regard to its potential magnitude, with studies supporting both high and low magnitudes. Additionally, most estimates are specific to only a few stocks of fish—primarily stream type Chinook salmon and steelhead populations. Many of the benefits associated with operational or structural actions aimed at reducing the number of juveniles passing mainstem hydroelectric projects via turbine units or bypass systems, including increased voluntary spill and dam breaching, are dependent on the magnitude of latent mortality associated with passing the dams. Dam breaching would eliminate the latent mortality associated with passing through the lower Snake River hydropower system. Given the uncertainty regarding the magnitude of latent mortality, assessing restoration actions and whether they result in predicted improvements on targeted salmon and steelhead stocks, e.g., employing a monitoring system to track the fate of individuals both before and after dam breaching, will be an important part of a comprehensive strategy to rebuild these stocks.

- The fate of hatchery-origin adults returning to the interior Columbia river basin extends beyond harvest in fisheries or return to a hatchery. Adult hatchery-origin salmon may enter and spawn within natural spawning areas, directly competing with natural-origin adults for space and spawning opportunities. These interactions are simply indexed by the pHOS measures that are represented in **Table 3**, from data reported in the CBP report. The actual quantitative effects of straying hatchery-origin adults on the productivity of natural-origin populations are not well established. Progeny produced from hatchery and natural-origin crosses may not meet conservation mandates and these juveniles may or may not match the productivity of natural-origin juveniles. Together, these issues suggest that there are trade-offs that need to be recognized and assessed with regard to increasing the productivity, abundance, and harvest opportunities associated with natural-origin stocks and also maintaining or optimizing the current harvest of hatchery-origin fish. Increasing the productivity, abundance and harvest opportunities associated with natural-origin stocks may require decreasing the release of hatchery-origin juveniles and the associated return of hatchery-origin salmon adults. The cumulative effect of potential decreases in hatchery production, designed to benefit natural-origin stocks, on total harvest opportunity for adult salmon (natural + hatchery) is an issue worthy of examination. An overall conclusion is that population trajectories for natural-origin stocks cannot be assessed or predicted without considering the effects of co-occurring hatchery-origin fish.

- Reintroduction of salmon into blocked areas above Grand Coulee Dam appears to be conceptually the only way to meet the goals identified by the CBP for the Upper Columbia. However, successful reintroduction will be challenging. Even if spawning adults can be successfully re-established above Grand Coulee, there is uncertainty regarding how to achieve juvenile passage and survival rates through the large upper reservoirs sufficient to meet the CBP goals. Current reintroduction plans by the Upper Columbia United Tribes call for a staged, carefully monitored, adaptive approach, which is sensible and appropriate given these uncertainties. Similar planning to understand the logistical considerations and manage uncertainties exist for other potential reintroductions, such as the Middle Snake. It is important to continue to support reintroductions of salmon into blocked areas with scientific studies that will allow managers to make the best informed choices in order to increase the odds of success.

Clearly, there are many factors that substantially affect the abundance and productivity of interior Columbia River basin salmon and steelhead stocks, and for which uncertainties exist. Working to resolve these uncertainties will support successfully rebuilding these fish stocks. However, any effort to resolve or reduce uncertainty will require an investment in science. While the current state of scientific understanding in the basin supports actions as described in this report, there is a strong and ongoing need to continue to reduce and resolve the uncertainties listed above and to rigorously monitor and understand change, including climate change and the impacts from management actions, throughout the rebuilding program implementation. As such, the development and use of a transparent, integrative decision support framework (see Question 10) will be critical for both assessing the relative importance of differing assumptions and for incorporating new information to adaptively manage the interior Columbia River basin salmon and steelhead rebuilding enterprise.

Question 10: What is the role of a **science-informed decision structure** in the implementation of major management actions for priority stocks?

The most appropriate decision structure to deal with the scale of the issues surrounding rebuilding salmon stocks of the Columbia River basin is the development and implementation of an adaptive management strategy. Adaptive management is defined as a structured, iterative process of decision to reduce uncertainty over time through monitoring and evaluation (Williams et al. 2009). Adaptive management has been used to guide large-scale aquatic restoration programs including programs in the Chesapeake Bay, the Florida Everglades, the Great Barrier Reef, and the Elwha River (Peters et al. 2014, Diefenderfer et al. 2021). It is important to note that many adaptive management programs have failed due to three primary reasons. First, a lack of the human and financial resources for the monitoring needed to carry out large-scale actions in the context of interim performance metrics and regular, structured adjustments. Second, the need to admit and embrace uncertainty in making policy choices. Lastly, a lack of individuals willing to do all the hard work necessary to plan and implement new and complex management programs (Walters, 2007).

Successfully implementing adaptive management would be important to inform decision making on the scale of rebuilding Columbia basin salmon and steelhead stocks. It provides the ability to incorporate all types of human impacts – climate change, habitat degradation, hydropower development, harvest, and hatcheries – and to integrate the effects of management actions using a suite of viable salmonid population metrics (VSP: abundance, productivity, spatial structure, and diversity; McElhany et al. 2000, Peters et al. 2014). Each management action can be associated, directly and indirectly, to the VSP metrics, allowing the management community to use data to guide the types and sequencing of actions needed for rebuilding. To demonstrate progress, the program must collectively establish the most relevant performance metrics around which to build the program's implementation, evaluation, and reporting structure.

For example, consider the Elwha River dam removal project, a major salmon and steelhead rebuilding effort that required considerable investment and the development of a societally accepted plan prior to implementation. The Elwha River dam removal included not only a change in habitat condition due to the reconnection of 90% of the historically available habitat, but included other management actions such as a harvest moratorium, alterations to hatchery practices, and stream restoration work in the Lower Elwha River below the dams. Managers and scientists working on the dam removal project recognized that cumulative, simultaneous restorative actions were necessary to reverse the trend of declining salmon and steelhead populations.

Before the dams were removed, a detailed adaptive management guideline document was developed by both managers and scientists working in the Elwha (Peters e al. 2014). The document focused on two of the three listed species – Chinook salmon and steelhead. It recognized that NOAA Fisheries had called for the phasing out of hatchery operations over the long term, but that those programs were needed in the short term. The group developed performance metrics for the different phases that were linked to the viable salmon population metrics. These metrics are measured and reported annually, and used by program managers to decide if hatchery or harvest management of the focal species can move to the next phase. The annual reporting, discussion, and decision making process also allows the managers and scientists to identify emerging issues and elements that are not working smoothly and the status of uncertainties in both the management actions and metrics. This structure also allows for the co-managers to lead the effort and the federal agencies to be a supporting role for the ultimate programmatic decision making.

The limiting factor and action priorities provided in this report are a basis for exploring the relative magnitude of key limiting factors and action priorities at the stock scale for the interior Columbia basin. Although some factors, such as manageable effects on ocean conditions, some manageable impacts of predators, and toxic pollutants were not integrated into the CBP limiting factors analysis, they could be integrated into implementation planning moving forward. In addition, for tributary habitat restoration, hatchery reforms, and, in some cases, opening access to blocked habitat, a population- or finer-scale analysis would be appropriate to guide sequencing watershed-scale implementation planning. For instance, to develop implementation plans for providing access to blocked areas at a stock scale, watershed-scale evaluations are needed to rank implementation order by return on investment or risk, as well as integrating secondary effects such as legacy toxic contamination, and potential for habitat improvement. Such broad-scale evaluations over the range of limiting factors across the priority stocks of the interior Columbia basin highlights the importance of a science-based decision support structure as the region moves forward with implementation planning.

In summary, adaptive management-based decision making can structure plans and actions that increase salmon populations regionally. Multiple, long-term, cumulative impacts have contributed to depleted salmon and steelhead stocks. Reversing these effects and rebuilding abundant and diverse, healthy and harvestable stocks, and high-quality freshwater, estuary, and ocean habitat will require multiple and synchronized cumulative large-scale actions through a well-designed and societally-supported adaptive management plan.

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