Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation

A Hatchery Program for Summer Steelhead in the Skykomish River and the Sunset Falls Trap and Haul Fishway Program in the South Fork Skykomish River

NMFS Consultation Number: *WCRO-2019-04075*

Action Agency: National Marine Fisheries Service
U.S. Fish and Wildlife Service

Affected Species and NMFS' Determinations:

ESA-Listed Species	Status	Is Action Likely to Adversely Affect Species?	Is Action Likely To Jeopardize the Species?	Is Action Likely to Adversely Affect Critical Habitat?	Is Action Likely To Destroy or Adversely Modify Critical Habitat?
Puget Sound steelhead (*Oncorhynchus mykiss*)	Threatened	Yes	No	Yes	No
Puget Sound Chinook salmon (*O. tshawytscha*)	Threatened	Yes	No	Yes	No
Hood Canal Summer Chum (*O. keta*)	Threatened	No	No	No	No
Ozette Lake Sockeye Salmon (*O. nerka*)	Threatened	No	No	No	No

Fishery Management Plan That Identifies EFH in the Project Area	Does Action Have an Adverse Effect on EFH?	Are EFH Conservation Recommendations Provided?
Pacific Coast Salmon	Yes	Yes
Pacific Coastal Pelagic Species	No	No

Consultation Conducted By: National Marine Fisheries Service, West Coast Region

Issued By: for ___________________________
Barry A. Thom, Regional Administrator
West Coast Region
National Marine Fisheries Service

Date: *April 23, 2021*

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Acronyms and Abbreviations

4(d) Rule	final rule pursuant to ESA section 4(d)
BGR	biogeographical region
CFR	Code of Federal Regulations
cfs	cubic feet per second
CWT	coded wire tag
DGF	demographic gene flow
DPS	distinct population segment
EA	environmental assessment
Ecology	Washington Department of Ecology
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
ESU	evolutionarily significant unit
fpp	fish per pound
HGMP	hatchery and genetic management plan
HSRG	Hatchery Science Review Group
NEPA	National Environmental Policy Act
NF	North Fork
NMFS	National Marine Fisheries Service (also called NOAA Fisheries)
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NWFSC	Northwest Fisheries Science Center
NWIFC	Northwest Indian Fisheries Commission
pHOS	proportion of hatchery-origin spawners
PNI	proportionate natural influence
pNOB	proportion of natural-origin adults in broodstock
PIT	passive-integrated transponder
RCW	Revised Code of Washington
RM	river mile
SF	South Fork
USFWS	U.S. Fish and Wildlife Service
WDFW	Washington Department of Fish and Wildlife

1. INTRODUCTION

The underlying activities that drive the Proposed Actions are the operation and maintenance of three programs: a hatchery program rearing and releasing summer steelhead in the Skykomish River, operation of the Sunset Falls Trap and Haul Fishway in the South Fork Skykomish River, and release of adult summer steelhead in the North Fork Skykomish River. The Snohomish basin hatchery programs are operated jointly by the Washington Department of Fish and Wildlife (WDFW) and the Tulalip Tribes, hereafter referred to as the co-managers. The summer steelhead hatchery program and the trap and haul program at Sunset Falls Trap and Haul Fishway facility are described in detail in a Hatchery and Genetic Management Plan (HGMP) and permit application, respectively (NMFS)(WDFW 2019b; WDFW and Tulalip Tribes 2019). The co-managers submitted the HGMP to the National Marine Fisheries Service (NMFS) for review under Limit 6 of the Endangered Species Act (ESA) 4(d) rule; WDFW submitted the permit application for operation of the Sunset Falls Trap and Haul Fishway under section 10(a)(1)(A) of the ESA.

1.1. Background

NMFS prepared the biological opinion (opinion) and incidental take statement (ITS) portions of this document in accordance with section 7(b) of the Endangered Species Act (ESA) of 1973 (16 USC 1531 et seq.), and implementing regulations at 50 CFR 402, as amended.

We also completed an essential fish habitat (EFH) consultation on the proposed action for three Pacific salmon species and 13 coastal pelagic species. We completed consultation in accordance with section 305(b)(2) of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) (16 U.S.C. 1801 et seq.) and implementing regulations at 50 CFR 600.

We completed pre-dissemination review of this document using standards for utility, integrity, and objectivity in compliance with applicable guidelines issued under the Data Quality Act (DQA) (section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001, Public Law 106-554). The document will be available within two weeks at the NOAA Library Institutional Repository [https://repository.library.noaa.gov/welcome]. A complete record of this consultation is on file at the Sustainable Fisheries Division (SFD) of NMFS in Portland, Oregon.

1.2. Consultation History

The first hatchery consultations in Puget Sound followed the listing of the Puget Sound Chinook Evolutionarily Significant Unit (ESU) under the ESA (64 FR 14308, March 24, 1999). In 2005, WDFW and the Puget Sound Tribes ("co-managers") completed two resource management plans (RMP) as the overarching frameworks for 114 HGMPs (Myers et al. 2015; PSTT and WDFW 2004; WDFW and PSIT 2014). The HGMPs described how each hatchery program would operate, including effects on ESA-listed fish in the Puget Sound region. In 2004, the co-managers submitted the two RMPs and 114 HGMPs to NMFS for ESA review under limit 6 of the ESA 4(d) rule (50 C.F.R. 223.203). Of the 114 HGMPs, 75 were state-operated, including 27 Chinook salmon programs, 22 coho salmon programs, 2 pink salmon programs, 4 chum salmon programs, 2 sockeye salmon programs, and 18 steelhead programs. The Puget Sound Tribes submitted 38 HGMPs, including 14 for Chinook salmon, 13 for coho salmon, 9 for chum salmon, and 2 for steelhead. USFWS submitted one HGMP for its coho salmon program at Quilcene National Fish Hatchery.

Subsequent to the submittal of these plans to NMFS, the Puget Sound Steelhead Distinct Population Segment (DPS) was listed as "threatened" (72 FR 26722, May 11, 2007). On September 25, 2008, NMFS issued a final 4(d) rule adopting protective regulations for the listed Puget Sound Steelhead DPS (73 FR 55451). In the final rule, NMFS applied the same 4(d) protections for steelhead as were already adopted for other ESA-listed Pacific salmonids in the region. Accordingly, the co-manager hatchery plans are now also subject to review for effects on ESA-listed steelhead.

When NMFS reviewed HGMPs for Puget Sound salmon and steelhead under the ESA and National Environmental Policy Act (NEPA) in 2017, NMFS informed WDFW that updated HGMPs for the Stillaguamish (White Horse Ponds) and Snohomish (Reiter Ponds) summer steelhead programs were needed, and that NMFS continued to have concerns about the use of Skamania-origin early summer steelhead broodstock in these two river basins (Thom 2017). For numerous years, WDFW released early summer steelhead into the Snohomish basin derived from Skamania stock, a hatchery stock developed from summer steelhead in the Columbia River. NMFS believes releasing early summer steelhead has negatively affected the abundance, productivity, diversity and spatial structure of natural-origin winter and summer steelhead populations in the Snohomish River basin (NMFS 2016b). This prompted WDFW to consider alternative broodstock sources for the summer steelhead program at Reiter Ponds[1]. WDFW, along with the Tulalip Tribes, submitted an HGMP for a new summer steelhead program in the Skykomish River Basin using locally adapted natural-origin fish returning to Sunset Falls Trap and Haul Fishway.

Take of listed Puget Sound Chinook salmon occurring as a result of Sunset Falls Trap and Haul Fishway operation and maintenance by the WDFW was previously authorized by the NMFS Protected Resources Division under annual 4(d) Rule limit 7 determinations effective from 2003 through 2007. Issuance of take prohibitions for Puget Sound steelhead commensurate with the ESA listing of the Distinct Population Segment (DPS) as threatened in 2007 (73 FR 555451, September 25, 2008) required additional consideration of Sunset Falls Trap and Haul Fishway effects on listed steelhead. The exemption from take prohibitions for these listed species afforded through the most recent 4(d) Rule Limit 7 determination for the Sunset Falls Trap and Haul Fishway program lapsed on December 31, 2008.

In 2009, NMFS concluded that the issuance of the ESA section 10(a)(l)(A) Permit 14433 for the operation and maintenance of the Sunset Falls Trap and Haul Fishway from 2009 to 2019 was not likely to jeopardize the continued existence of the listed ESU or DPS or to destroy or adversely modify their critical habitat (NMFS 2009a). This conclusion was based on anticipated benefits to listed species accrued through access to spawning areas upstream of several impassable barriers to fish migration afforded by the Fishway program, systematic collection of important data on the status and trends of listed populations, and application of trapping, handling, sampling, and transport protocols that reduce risks and minimize mortality of listed fish associated with collection, biological sampling, and upstream transport activities.

NMFS received an HGMP from the co-managers on April 12, 2019, which included description of a new integrated hatchery program for summer steelhead in the Skykomish River. NMFS subsequently

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[1] In this Opinion, the Skamania-origin early summer steelhead released from Reiter Ponds will be referred to as Reiter Ponds early summer steelhead. The summer steelhead from the proposed program will be referred to as Skykomish summer steelhead.

received a Section 10(a)(1)(A) permit renewal application from WDFW for the Sunset Falls Trap and Haul Fishway program on August 8, 2019. NMFS reviewed these documents and determined the information for operation of the Sunset Falls Trap and Haul Fishway facility was sufficient to satisfy the requirements of section 10(a)(1)(A) of the ESA. In reviewing the proposal for the new integrated summer steelhead hatchery program, NMFS found that several components of the described activities needed further development prior to initiating consultation and before NMFS could complete its determination of whether the hatchery program addressed criteria specified under limit 6 of the ESA 4(d) Rule. After following procedures involving analysis of the hatchery activities under the NEPA, NMFS produced a draft Environmental Assessment (EA), which was submitted for public comment on February 5, 2021. After receiving public comment on the draft EA, NMFS discussed additional information needs with the co-managers. NMFS received updated information from the co-managers on March 30, 2021. After reviewing information received on March 30, 2021, NMFS initiated consultation with itself and prepared its biological opinion on the proposed action.

1.3. Proposed Federal Action

"Action" means all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies (50 CFR 402.02). For EFH consultation, Federal action means any action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken by a Federal Agency (50 CFR 600.910).

The purpose of the proposed action is to: (1) re-issue a permit for operation and maintenance of the Sunset Falls Trap and Haul Fishway facility under section 10(a)(1)(A) of the ESA; and (2) to make an ESA 4(d) Limit 6 determination on a new summer steelhead hatchery program in the Skykomish River, jointly managed by the WDFW and Tulalip Tribes (hereafter collectively referred to as the co-managers). The hatchery program is intended to mitigate for adult fish from human developmental activities in the greater Snohomish/Skykomish Basin, reduce genetic effects from the current summer steelhead program, and provide steelhead for local and regional fisheries (WDFW and Tulalip Tribes 2019). The purpose of the Sunset Falls Trap and Haul Fishway program is to transport native species of salmon, steelhead, and trout upstream of a series of impassable barriers in the South Fork Skykomish River to areas in which these fish may spawn and rear (WDFW 2019b), which also allows for broodstock collection for hatchery programs in the Skykomish watershed.

We considered whether or not the proposed action would result in other effects as a consequence of the proposed action related to fisheries harvest. The 2020-21 marine fisheries were evaluated and authorized through a separate NMFS ESA consultation (NMFS 2020). Fisheries throughout the Puget Sound that are jointly managed by Puget Sound tribes and the Washington Department of Fish and Wildlife were determined not likely to jeopardize the continued existence of the Puget Sound Chinook Salmon ESU, the Hood Canal Summer Chum Salmon ESU, or the Puget Sound Steelhead DPS, or adversely modify designated critical habitat for these listed species (NMFS 2020). Past effects of these fisheries are described in the environmental baseline section (Section 2.4); future effects are described in the discussion of effects of the action (Section 2.5.2).

In addition, the proposed action includes funding by the U.S. Fish & Wildlife Service (USFWS) provided to WDFW through its Sportfish Restoration Act grants program. USFWS provides grants to WDFW for hatchery facility operations, which include at least a portion of the funding for operation of the Reiter Ponds and Wallace River hatchery facilities. Because the funding of the programs under consideration does not result in any actions or effects not already under consideration as part of NMFS' review of the programs themselves, this Opinion will not separately discuss the funding action other than to note its inclusion in the consultation. USFWS has no other active role in the proposed action.

1.3.1. Proposed Summer Steelhead hatchery Program

The proposed integrated South Fork Skykomish River summer steelhead program is a new hatchery program that replaces the current Reiter Ponds early summer steelhead program. The following sections summarize information from the completed HGMP (WDFW and Tulalip Tribes 2019).

Broodstock Collection and Spawning

The co-managers propose to collect broodstock for this new hatchery program by selecting natural-origin summer steelhead that return to the South Fork Skykomish River. The co-managers propose to establish the first-generation broodstock by collecting unmarked summer steelhead returning to the Sunset Falls Trap and Haul Fishway across the breadth of run timing at Sunset Falls. The co-managers propose to use no more than 30 percent of unmarked (i.e., natural-origin) adult summer steelhead returning to Sunset Falls with the maximum number of adults numbering no more than 120 fish. If the number of natural-origin fish available is insufficient to meet broodstock needs, the initial program release goals may be delayed. Once adult steelhead returns are established (3-4 years after program initiation) broodstock will continue as an integrated program with hatchery broodstock composed of a mixture of natural-origin and hatchery-origin fish (total of 120 adults); natural-origin fish will be collected at Sunset Falls, while hatchery-origin fish will be collected at the Sunset Falls Trap and Haul Fishway, Wallace River Hatchery, and Reiter Ponds. The co-managers selected these hatchery facilities because both have adult trapping facilities, which will reduce straying of adult steelhead into the natural environment. The co-managers will determine integration rates for the new program annually based on the number of hatchery-origin and natural-origin spawners.

The co-managers propose to spawn steelhead at either Reiter Ponds or Wallace River Hatchery with the potential to live-spawn natural-origin fish as necessary. The co-managers propose to select steelhead based on size and run timing to align with the natural-origin steelhead population. Hatchery staff will further select individual steelhead for spawning based on maturation and spawn fish at random on days when suitable numbers of fish are present. Hatchery staff may return natural-origin steelhead that are live-spawned fish into the river to allow for repeat spawning. If mortalities occur, hatchery staff will examine individuals to determine cause of death.

Rearing and Release

The co-managers propose to start the program by releasing 56,000 smolts to a maximum of 116,000[2] smolts as noted in Table 1. The co-managers propose to volitionally release steelhead smolts for four weeks during April-May each year at Reiter Ponds (Skykomish River RM 46), starting no earlier than April 15. The co-managers propose Reiter Ponds with potential to release steelhead at Wallace River

[2] Egg-take is carefully managed to minimize the likelihood of collecting surplus eggs or raising surplus fry. However, in years of high within-hatchery survival, juvenile production levels higher than the proposed release numbers may occur. The co-managers plan to limit production to no more than 110% of 116,000 smolts; an overage as large as 10% is anticipated to be a rare occurrence. If the running 4-year average production (beginning in the release year 2023) is more than 116,000 smolts, the co-managers will notify NMFS.

Hatchery if an alternate site is necessary. WDFW proposes to discuss alternate release sites with NMFS and tribal co-managers to reach consensus on the best course of action.

Table 1. Maximum number of steelhead smolts proposed for release beginning in from 2021.

Year	Skykomish River smolts released
2021	56,000
2022	76,000
2023 and thereafter	116,000

Hatchery personnel propose to release yearling smolts that range in size from 8–10 fish per pound (fpp). The gate for the rearing pond will be open for an extended time between April 15 through May, allowing for smolts to volitionally leave. Any fish remaining in the ponds after that time may be force released. At program startup, all of the released fish will be adipose fin-clipped and blank-wire tagged (BWT, has only an Agency code on it) or passive integrated transponder (PIT) tagged. Once hatchery returns are established, all of the released fish will be adipose fin-clipped and portions of the release may have additional BWT or PIT tags as necessary to achieve program objectives.

Adult Management

Returning hatchery-origin adults will be passed above Sunset Falls, used for hatchery-origin broodstock, or surplused as described below. During the years of abundant natural-origin returns, passage of hatchery-origin steelhead would be limited to meet gene flow needs (described in detail in Section 2.5.2.2). During the years of low natural-origin returns, hatchery-origin steelhead would be passed above Sunset Falls to allow up to 250 spawners (natural- and hatchery-origin).

The co-managers propose that returning hatchery-origin summer-run steelhead from the proposed program collected at Reiter Ponds, Wallace River Hatchery, or Sunset Falls Trap and Haul Fishway facilities in surplus of program goals (for upstream passage and broodstock needs) will be utilized for reintroduction into the North Fork Skykomish River. Up to 250 adults may be transplanted annually to the North Fork Skykomish River for up to 8 years. Food-grade quality carcasses may be distributed to the Tulalip Tribes for ceremonial and subsistence purposes or approved charitable organizations. Non food-grade carcasses will be disposed of or placed in local streams for nutrient enhancement according to Disease Control Policy guidelines. Upon agreement of the co-managers and NMFS, surplus adults may also be used to reintroduce summer steelhead into other unused or under-used habitats, to augment a mark-selective fishery upstream of Sunset Falls, or to replace Skamania-origin broodstock in the Green River or other location. At this point, the mark-selective fishery and the transport and release of integrated broodstock into the Green River have not been proposed. Therefore, these components of the proposed action are speculative and will not be considered further in this opinion. Returning hatchery-origin summer-run steelhead from the proposed program collected at Reiter Ponds, Wallace River Hatchery, or Sunset Falls Trap and Haul Fishway facilities in surplus of program goals (for upstream passage and broodstock needs) would be utilized for reintroduction into the North Fork Skykomish River. Table 2 lists the pathogens, the time period over which these were observed, and the treatment that was applied, if any, for all facilities considered in this opinion.

Table 2. Past disease occurrence at the Reiter Ponds and Wallace River hatchery facilities.

Facility	Pathogen	Occurrence	Treatment
Reiter Ponds	*Sessile ciliates*	March 2018-2019	No treatment
Wallace River Hatchery	*Ichthyobodo*	May 2019	Formalin
	Trichodina	May 2019, July 2018	Potassium permanganate, no treatment
	Flavobacterium psychrophilum	April 2019, May 2018-2019	Chloramine T, Aquaflor medicated feed
	Ichthyophthirius multifiliis	July 2017-2019, Oct 2018	Formalin, salt
	Flavobacterium columnare	Aug 2017-2019, Sept 2019	Potassium permanganate, Chloramine T, TM200 medicated feed

Research, Monitoring, and Evaluation (RM&E)

Snohomish-region hatchery programs include extensive monitoring, evaluation, and adaptive management, and many other actions to monitor and address potential risks to natural-origin juvenile and adult fish. The co-managers conduct numerous ongoing monitoring programs under existing ESA coverage[3], including catch, escapement, marking, scale sampling, genetic sampling, tagging, fish health testing and an extensive post-release juvenile monitoring program in freshwater, the estuary, and in marine areas.

RM&E activities related to the hatchery program that are not covered by existing ESA authorization include:

- Marking (adipose fin clip) and tagging (BWT, PIT tag) juvenile summer steelhead prior to release will be used to identify fish for collection in integrated broodstock.
- Examination of juvenile and adult summer steelhead (observed in snorkel surveys or collected with hook and line or electrofishing gear) for an adipose clip, and checking clipped fish for the presence of a tag (BWT, PIT tag).

The applicants will also form a work group and meet on at least a quarterly basis (and more frequently as needed) to explore the relationship between the North Fork and South Fork populations, as described in more details in Section 2.5.2.2. Outplanting of hatchery-origin adult steelhead in the North Fork Skykomish River (discussed above) would occur only if this group deems it to be consistent with viability needs.

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[3] These include the following: a) Section 7(a)(2) WCR-2019-00381 Annual, Impacts of the Role of the BIA Under its Authority to Assist with the Development of the 2019-2020 Puget Sound Chinook Harvest Plan, Salmon Fishing Activities Authorized by the U.S. Fish and Wildlife Service, and Fisheries Authorized by the U.S. Fraser Panel in 2019; b) 4(d) limit 7 authorization ("Snohomish and Stillaguamish watersheds annual salmonid biological sampling"), Annual WDFW Research and Monitoring; c) Section 10(a)(1)(A) 1345-9A, Warmwater Fish Species Monitoring; and d) limit 6 determination ("Joint Hatchery and Genetic Management Plans for Bernie Kai-Kai Gobin Salmon Hatchery "Tulalip Hatchery" Subyearling Summer Chinook Salmon, Tulalip Bay Hatchery Coho Salmon, Tulalip Bay Hatchery Chum Salmon, Wallace River Hatchery Summer Chinook Salmon, Wallace River Hatchery Coho Salmon, and Everett Bay Net-Pen Coho Salmon"), Tulalip Tribes smolt trap operations in the lower mainstem of the Skykomish River.

Facility Operation

The co-managers propose to collect, rear, and release steelhead from the following WDFW facilities in the Skykomish watershed noted below in Table 3. This includes operation of diversions, weirs, and traps to provide hatchery facilities with water and collect fish for broodstock. The operation of the trap at Sunset Falls Trap and Haul Fishway facility is discussed below.

WDFW supplies water to Reiter Ponds from Austin Creek, a nearby spring-fed tributary. The secondary source is Hogarty Creek, which WDFW uses as the primary source as necessary. Both creeks supply a combination of spring flow and natural runoff that results in similar temperature regimes from both sources that range from 35°– 65°F. Streamflow within each creek is both seasonally influenced and varies from 6.7–300.8 cubic feet per second (cfs) in Austin Creek flow to 1.3–100.3 cfs in Hogarty Creek. The distance between the intake and outfall on Austin Creek is approximately 0.75 miles and on Hogarty Creek the distance is approximately 0.55 miles. WDFW uses these water supplies at Reiter Ponds and Wallace River Hatcheries in accordance with water rights and National Pollution Discharge Elimination System (NPDES) permits, which do not allow for net removal of streamflow or dewatering to occur.

Water discharge at the Wallace River Hatchery is seasonal; during low water periods (May through October) water is discharged to May Creek. While Wallace River Hatchery is compliant with basic criteria for juvenile fish screening of water intakes (NMFS 1995; NMFS 1996), it does not meet current standards for passage of anadromous salmon (NMFS 2011a). WDFW plans to modify screening at Wallace River Hatchery to comply with NMFS screening requirements to protect natural-origin fish from entrainment and impingement that may lead to injury and mortality (WDFW 2013b). The agency has committed resources for design and permitting to bring the screens in compliance with fish passage and screening criteria(NMFS 2011a), along with the construction of a new two-bay pollution abatement pond. The improvements to water diversion screens and pollution abatement will be analyzed in a future consultation.

The co-managers propose to collect broodstock and surplus hatchery steelhead through weirs and traps. The hatchery weirs on Wallace River at RM 4.0 and near the mouth of May Creek are in place seasonally from June through October 1, and June through March 15, respectively. During these times, the weirs act as temporary barriers to upstream and downstream adult fish passage. Hatchery personnel use trapping protocols at the Wallace River weir to minimize the duration of migration delay and potential for-injury during trapping. The co-managers propose to collect adult steelhead at Reiter Ponds trap (located at the drainage channel for Reiter Ponds), which hatchery personnel operate from mid-May through March 15.

Table 3. Water usage associated with Skykomish integrated summer steelhead hatchery program and National Pollution Discharge Elimination System (NPDES) and Washington Department of Ecology (WDOE) permits for facility operation. Water discharge is measured in cubic feet per second (cfs); NA = not applicable.

Facilities	Surface Water (cfs)	Ground /Spring Water (cfs)	Water Diversion Distance	Water source	Discharge Location	Current NMFS Screening Standard	NPDES Permit Number	WDOE Water Right Certificate Number
Wallace River Hatchery	40	NA	15 feet	Wallace River	Wallace River	NMFS (1995)	WAG 13-3006	S1-00108C S1-00109C
Wallace River Hatchery	14	NA	70 feet	May Creek	May Creek	NMFS (1995)	WAG 13-0012	S1-05617C S1-23172C
Reiter Ponds	NA	10	0.75 miles	Austin Creek (spring fed)	Mainstem Skykomish	NA	WAG13-3005	S1-00667C
Reiter Ponds	NA	10	0.55 miles	Hogarty Creek (spring fed)	Mainstem Skykomish River	NA	WAG13-3005	S1-00313C
Sunset Falls Trap and Haul Fishway	180	NA	368 feet	South Fork Skykomish River	Mainstem Skykomish River	NA	NA	S1-*14279C

The co-managers operate summer steelhead hatchery facilities according to the NPDES general permit for Upland Fish-Fish Hatching and Rearing, which has established requirements for effluent monitoring and reporting overseen by the Washington Department of Ecology (WDOE). WDFW submits reports on water quality and chemicals used for disease and therapeutic treatments to the WDOE on a monthly and annual basis. Moreover, WDFW submits additional reports to WDOE on a bi-weekly to daily basis characterizing total suspended solids, settleable solids, and water temperature.

The co-managers are pursuing the option to provide additional, higher-quality water from a well to be developed at the Wallace River Hatchery. These structural improvements are currently planned, but contingent on funding allocation, permitting, and construction. The improvements are intended to supply larger volumes of cool water to support monthly fish transfers from the May Creek holding site, holding ponds, and administer chemotherapeutic treatments during and after handling as necessary. Further improvements to water supply will follow with development of an existing well planned for 2020-2021 that are contingent on permitting approval. Additional improvements scheduled for Wallace River Hatchery include installation of a water re-use and disinfection system on the Wallace River side of the hatchery that is funded and in the design development phase and may be completed in 2023.

Operation of the Sunset Falls Trap and Haul Program

The co-managers propose to continue operating the Sunset Falls Trap and Haul Fishway facility to collect and transport fish upstream of three anadromous barriers (Sunset Falls, Canyon Falls, and Eagle Falls) and to collect broodstock for the new integrated summer steelhead hatchery program. The Sunset Falls Trap and Haul Fishway is located on the South Fork Skykomish River approximately 1.9 miles upstream of the confluence of the North Fork and South Fork Skykomish River tributaries near the town of Index, Washington. WDFW supplies water to the fishway from a water intake on the South Fork Skykomish River just upstream of Sunset Falls. The total distance of the water diversion from the intake to the outlet is about 368 feet. This facility is a combination vertical slot fishway and trap-and-haul complex located at the base of Sunset Falls. The fishway begins at the base of the falls and is designed for fish to voluntarily enter through the ladder to a holding/sorting area and proceed to an overhead brail/hopper system. WDFW biologists remove fish from the sorting area and those that remain enter the brail/hopper volitionally without being handled and are then conveyed via a water to water transfer to a 1,000 gallon tanker truck. WDFW has operated the Sunset Falls Trap and Haul Fishway facility since 1958 to provide access to approximately 69 miles of habitat upstream of the natural barriers for adult Chinook salmon, coho salmon, pink salmon, chum salmon, and sockeye salmon, steelhead, bull trout, cutthroat trout, and mountain whitefish (NMFS 2017a; NMFS 2019a).

The Trap and Haul Program also provides an opportunity to conduct biological sampling important for monitoring salmon and steelhead in the Skykomish River Basin. WDFW operates the trap from July 1 through December 31 each year, weather and river flow conditions permitting. WDFW and the Puget Sound Treaty Tribes (in particular, the Tulalip Tribes) use fish species and abundance data collected each year through the Trap and Haul Program to estimate salmon and steelhead escapements and run sizes, and to develop preseason forecasts of abundance for stocks originating from the Skykomish watershed (WDFW 2019b).

The Trap and Haul Program includes:

- Operation and maintenance of the trap facility;
- Trapping migrating fish, including ESA-listed Chinook salmon and steelhead, which volitionally enter the Sunset Falls Trap and Haul Fishway from the South Fork Skykomish River;
- Enumerating these fish by species and origin (natural versus hatchery based on differential marks and/or tagging);
- Collecting biological samples and PIT tagging (or otherwise externally marking) these fish;
- Monitoring of Chinook salmon, steelhead, and other fish species as needed, as part of a basin-wide monitoring program;
- Transporting hatchery-origin[4] and natural-origin adult fish from the trap by use of a tanker truck upstream of three impassable barriers for release into suitable spawning and rearing habitat, or to other hatchery programs for use as broodstock according to prescribed limits (see bullet below);
- Collection of Chinook salmon, coho, chum, and steelhead adults for use as broodstock for annual salmon/steelhead enhancement programs;
- Removal of captured adult hatchery-origin steelhead returning from the Reiter Ponds early summer steelhead program. This will be done during the years in which adult returns from the Reiter Ponds early summer steelhead program are expected to return (2020 through 2025).

[4] Only hatchery-origin steelhead from the new Skykomish summer steelhead program will be transported above the falls. Hatchery-origin steelhead returning from the Reiter Ponds early summer steelhead program will be removed from the system.

2. ENDANGERED SPECIES ACT: BIOLOGICAL OPINION AND INCIDENTAL TAKE STATEMENT

The ESA establishes a national program for conserving threatened and endangered species of fish, wildlife, plants, and the habitat upon which they depend. As required by section 7(a)(2) of the ESA, each Federal agency must ensure that its actions are not likely to jeopardize the continued existence of endangered or threatened species, or adversely modify or destroy their designated critical habitat. Per the requirements of the ESA, Federal action agencies consult with NMFS and section 7(b)(3) requires that, at the conclusion of consultation, NMFS provide an opinion stating how the agency's actions would affect listed species and their critical habitats. If incidental take is reasonably certain to occur, section 7(b)(3) requires NMFS to provide an ITS that specifies the impact of any incidental taking and includes non-discretionary reasonable and prudent measures (RPMs) and terms and conditions to minimize such impacts. NMFS determined the proposed action is not likely to adversely affect Hood Canal Summer Chum Salmon ESU and Ozette Lake Sockeye Salmon ESU or their critical habitat. Our concurrence is documented in the "Not Likely to Adversely Affect" Determinations section (Section 2.12).

2.1. Analytical Approach

This biological opinion includes both a jeopardy analysis and an adverse modification analysis. The jeopardy analysis relies upon the regulatory definition of "jeopardize the continued existence of" a listed species, which is "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species" (50 CFR402.02). Therefore, the jeopardy analysis considers both survival and recovery of the species.

This biological opinion relies on the definition of "destruction or adverse modification," which "means a direct or indirect alteration that appreciably diminishes the value of critical habitat as a whole for the conservation of a listed species" (50 CFR 402.02).

The designation of critical habitat for Puget Sound Chinook salmon and Puget Sound steelhead uses the term primary constituent element (PCE) or essential features. The 2016 critical habitat regulations (50 CFR 424.12) replaced this term with physical or biological features (PBFs). The shift in terminology does not change the approach used in conducting a ''destruction or adverse modification'' analysis, which is the same regardless of whether the original designation identified PCEs, PBFs, or essential features. In this biological opinion, we use the term PBF to mean PCE or essential feature, as appropriate for the specific critical habitat.

The 2019 regulations define effects of the action using the term "consequences" (50 CFR 402.02). As explained in the preamble to the regulations (84 FR 44977), that definition does not change the scope of our analysis and in this opinion we use the terms "effects" and "consequences" interchangeably.

We use the following approach to determine whether a proposed action is likely to jeopardize listed species or destroy or adversely modify critical habitat:

- Evaluate the range wide status of the species and critical habitat expected to be adversely affected by the proposed action.
- Evaluate the environmental baseline of the species and critical habitat.
- Evaluate the effects of the proposed action on species and their habitat using an exposure-response approach.

- Evaluate cumulative effects.
- In the integration and synthesis, add the effects of the action and cumulative effects to the environmental baseline, and, in light of the status of the species and critical habitat, analyze whether the proposed action is likely to: (1) directly or indirectly reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species, or (2) directly or indirectly result in an alteration that appreciably diminishes the value of critical habitat as a whole for the conservation of a listed species.
- If necessary, suggest a reasonable and prudent alternative to the proposed action.

2.2. Rangewide Status of the Species and Critical Habitat

This opinion examines the status of each species that would be adversely affected by the proposed action. The status is determined by the level of extinction risk that the listed species face, based on parameters considered in documents such as recovery plans, status reviews, and listing decisions. This informs the description of the species' likelihood of both survival and recovery. The species status section also helps to inform the description of the species' "reproduction, numbers, or distribution" as described in 50 CFR 402.02. The opinion also examines the condition of critical habitat throughout the designated area, evaluates the conservation value of the various watersheds and coastal and marine environments that make up the designated area, and discusses the function of the essential PBFs that help to form that conservation value.

"Species" Definition: The ESA of 1973, as amended, 16 U.S.C. 1531 *et seq.* defines "species" to include any "distinct population segment (DPS) of any species of vertebrate fish or wildlife which interbreeds when mature." To identify DPSs of salmon species, NMFS follows the "Policy on Applying the Definition of Species under the ESA to Pacific Salmon" (56 FR 58612, November 20, 1991). Under this policy, a group of Pacific salmon is considered a DPS and hence a "species" under the ESA if it represents an evolutionarily significant unit (ESU) of the biological species. The group must satisfy two criteria to be considered an ESU: (1) It must be substantially reproductively isolated from other con-specific population units; and (2) It must represent an important component in the evolutionary legacy of the species. To identify DPSs of steelhead, NMFS applies the joint FWS-NMFS DPS policy (61 FR 4722, February 7, 1996). Under this policy, a DPS of steelhead must be discrete from other populations, and it must be significant to its taxon.

ESA-listed species in the action area

Species in the action area are described in Table 4. The effects of take associated with implementation of salmon and steelhead hatchery programs in the Hood Canal region on the Hood Canal Summer Chum Salmon ESU were previously evaluated by NMFS through a separate ESA section 7 consultation process (NMFS 2002) and were determined not likely to adversely affect either Hood Canal summer chum salmon or Lake Ozette sockeye salmon. Because the Hood Canal summer chum salmon consultation was completed nearly twenty years ago we will examine effects of the proposed action related to both Hood Canal summer chum salmon and Lake Ozette sockeye salmon in further detail in Section 2.12.

Table 4. Federal Register notices for the final rules that list species, designate critical habitat, or apply protective regulations to ESA listed species considered in this consultation.

Species	Listing Status	Critical Habitat	Protective Regulation
Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*)	Threatened, March 24, 1999; 64 FR 14508	September 2, 2005; 70 FR 52630	June 28, 2005; 70 FR 37160
Puget Sound steelhead (*O. mykiss*)	Threatened, May 11, 2007; 72 FR 26722	February 24, 2016; 81 FR 9252	September 25, 2008; 73 FR 55451
Hood Canal summer run chum salmon (*O. keta*)	Threatened, March 25, 1999; 64 FR 14508	September 2, 2005; 70 FR 52630	June 28, 2005; 70 FR 37160
Lake Ozette sockeye salmon (*O. nerka*)	Threatened, March 25, 1999; 64 FR 14528	September 2, 2005; 70 FR 52630	July 10, 2000; 65 FR 42422

In addition, NMFS has considered whether the proposed action would affect other ESA-listed species under NMFS regulatory purview, including Pacific eulachon, southern resident killer whales, or rockfish, and has determined that the proposed action is not likely to have a meaningful or measurable effect on any additional species, based on the very small proportion of hatchery-origin salmon from the Snohomish watershed produced by the proposed action in the Salish Sea and Pacific Ocean areas where these ESA-listed species occur. Pursuant to this finding, these species will not be addressed further in this opinion.

The ESA-listed threatened Coastal-Puget Sound Bull Trout (*Salvelinus confluentus*) DPS is administered by the U.S. Fish and Wildlife Service (USFWS). Effects on bull trout associated with the NMFS 4(d) rule determination for the proposed hatchery salmon programs will be addressed through a separate ESA section 7 consultation with USFWS.

Status of listed species

For Pacific salmon and steelhead, NMFS commonly uses four parameters to assess the viability of the populations that, together, constitute the species: abundance, productivity, spatial structure, and diversity (McElhany et al. 2000). These "viable salmonid population" (VSP) criteria therefore encompass the species' "reproduction, numbers, or distribution" as described in 50 CFR 402.02. When these parameters are collectively at appropriate levels, they maintain a population's capacity to adapt to various environmental conditions and allow it to sustain itself in the natural environment. These parameters or attributes are substantially influenced by habitat and other environmental conditions.

- "Abundance" generally refers to the number of naturally produced adults (i.e., the progeny of naturally spawning parents) in the natural environment.
- "Productivity," as applied to viability factors, refers to the entire life cycle; i.e., the number of naturally spawning adults (i.e., progeny) produced per naturally spawning parental pair. When progeny replace or exceed the number of parents, a population is stable or increasing. When progeny fail to replace the number of parents, the population is declining. McElhany et al. (2000) use the terms "population growth rate" and "productivity" interchangeably when referring to

production over the entire life cycle. They also refer to “trend in abundance,” which is the manifestation of long-term population growth rate.

- “Spatial structure” refers both to the spatial distributions of individuals in the population and the processes that generate that distribution. A population’s spatial structure depends fundamentally on accessibility to the habitat, on habitat quality and spatial configuration, and on the dynamics and dispersal characteristics of individuals in the population.
- “Diversity” refers to the distribution of traits within and among populations. These range in scale from DNA sequence variation at single genes to complex life history traits (McElhany et al. 2000).

In describing the range-wide status of listed species, we rely on viability assessments and criteria in NMFS Technical Recovery Team (TRT) documents and NMFS recovery plans, when available, that describe VSP parameters at the population, major population group (MPG), and species scales (i.e., salmon ESUs and steelhead DPSs). For species with multiple populations, once the biological status of a species’ populations and MPGs have been determined, NMFS assesses the status of the entire species. Considerations for species viability include having multiple populations that are viable, ensuring that populations with unique life histories and phenotypes are viable, and that some viable populations are both widespread to avoid concurrent extinctions from mass catastrophes and spatially close to allow functioning as meta-populations (McElhany et al. 2000).

2.2.1. Puget Sound Chinook Salmon ESU

Chinook salmon, *Oncorhynchus tshawytscha,* exhibit a wide variety of life history patterns that include: variation in age at seaward migration; length of freshwater, estuarine, and oceanic residence; ocean distribution; ocean migratory patterns; and age and season of spawning migration. Two distinct races of Chinook salmon are generally recognized: “stream-type” and “ocean-type” (Healey 1991; Myers et al. 1998). Ocean-type Chinook salmon reside in coastal ocean waters for three to four years, tending to not range very far northward in the Pacific Ocean prior to returning to their natal rivers. Stream-type Chinook salmon, predominantly represented by spring-run Chinook salmon populations, spend two to three years in the ocean and exhibit extensive offshore ocean migrations. Ocean-type Chinook salmon also enter freshwater later in the season upon returning to spawn than stream type fish; June through August compared to March through July (Myers et al. 1998). Ocean-type Chinook salmon use different stream areas – they primarily spawn and rear in lower elevation mainstem rivers and typically reside in fresh water for no more than three to five months compared to spring Chinook salmon, which spawn and rear high in the watershed and reside in freshwater for more than a year.

Status of the species is determined based on the abundance, productivity, spatial structure, and diversity of its constituent natural populations. Best available information indicates that the Puget Sound Chinook Salmon ESU is at high risk and is threatened with extinction (NWFSC 2015). The Puget Sound Technical Recovery Team (PSTRT) determined that 22 historical natural populations currently contain Chinook salmon and grouped them into five biogeographical regions (BGRs), based on consideration of historical distribution, geographic isolation, dispersal rates, genetic data, life history information, population dynamics, and environmental and ecological diversity. Based on genetic and historical evidence reported in the literature, the TRT also determined that there were 16 additional spawning aggregations or populations in the Puget Sound Chinook Salmon ESU that are now putatively extinct (Ruckelshaus et al. 2006). The ESU encompasses all runs of Chinook salmon from rivers and streams flowing into Puget Sound, including the Strait of Juan de Fuca from the Elwha River eastward, and rivers and streams flowing into Hood Canal, South Sound, North Sound, and the Strait of Georgia in Washington. We use the term ''Puget Sound'' to refer to this collective area of the ESU. As of 2016, there are 24 artificial propagation programs producing Chinook salmon that are included as part of the listed ESU (71 FR 20802, April 14, 2014). Indices of spatial distribution and diversity have not been developed at the population level, though diversity at the ESU level is declining (NWFSC 2015).

Table 5 summarizes the available information on current abundance and productivity and their trends for the Puget Sound Chinook salmon natural populations including NMFS' critical and rebuilding thresholds and recovery plan targets for abundance and productivity (NMFS 2004a). Most Puget Sound Chinook salmon populations are well below escapement levels and productivity goals required for recovery (Table 5). Abundance across the ESU has generally decreased since the last status review, with only five populations showing an increase in natural-origin abundance since the 2010 status review (NWFSC 2015). The remaining 17 populations showed a decline in their five-year natural-origin abundance as compared to the previous five-year period. The five-year geometric mean abundance for the entire ESU was 27,716 natural-origin adults from 2005 through 2009 and only 19,258 from 2010 through 2014, indicating an overall decline of 31% (Table 56 in (NWFSC 2015)). Natural-origin escapements for five populations are above their NMFS-derived rebuilding thresholds (Table 5), while escapements for ten populations are between their critical and rebuilding thresholds, and natural-origin escapements for seven populations are below their critical thresholds (Table 5).

Table 5. Estimates of geometric-mean escapement and productivity (1999-2014) for Puget Sound Chinook salmon.

Region	Population	Natural-origin Spawners[1]	Natural-origin Productivity[2]	Critical Escapement Threshold[3]	Rebuilding Escapement Threshold[3]	Recovery Spawner Target with High Productivity[4]	Average % hatchery fish in escapement 1999-2013 (min-max)[5]
Georgia Basin	NF Nooksack	211	0.3	200	Unknown	3,800 (3.4)	85 (63-94)
	SF Nooksack	53	1.7	200	Unknown	2,000 (3.6)	84 (62-96)
Whidbey/ Main Basin	Upper Skagit	7,748	1.8	967	7,454	5,380 (3.8)	3 (1-8)
	Lower Sauk	522	1.8	200	681	1,400 (3.0)	1 (0-10)
	Lower Skagit	1,932	1.4	251	2,182	3,900 (3.0)	4 (2-8)
	Upper Sauk	502	1.6	130	330	750 (3.0)	1 (0-5)
	Suiattle	319	1.2	170	400	160 (2.8)	2 (0-5)
	Upper Cascade	291	1.1	170	1,250	290 (3.0)	8 (0-25)
	NF Stillaguamish	582	0.9	300	552	4,000(3.4)	35 (8-62)
	SF Stillaguamish	104	0.7	200	300	3,600 (3.3)	Not Available
	Skykomish	2,052	0.9	1,650	3,500	8,700 (3.4)	30 (8-36)
	Snoqualmie	1,142	1.5	400	1250	5,500 (3.6)	19 (3-62)
Central/South Sound	Cedar	802	1.9	200	1,250	2,000 (3.1)	20 (10-36)
	Sammamish	128	0.5	200	1,250	1,000 (3.0)	86 (66-95)
	Duwamish/Green	1,179	1.1	835	5,523	Unknown	57 (33-75)
	White[6]	1,268	0.6	200	1,100	Unknown	39 (15-49)
	Puyallup[7]	655	0.8	200	522	5,300 (2.3)	53 (18-77)
	Nisqually	522	1.0	200	1,200	3,400 (3.0)	72 (53-85)
Hood Canal	Skokomish	345	0.8	452	1,160	Unknown	66 (7-95)
	Mid-Hood Canal[8]	Not available	Not available	200	1,250	1,300 (3.0)	66
Strait of Juan de Fuca	Dungeness	114	0.6	200	925	1,200 (3.0)	67 (39-96)
	Elwha[9]	117	Not available	200	1,250	6,900 (4.6)	94 (92-95)

Source: NWFSC (2015)

[1]Estimates of natural-origin escapement for Nooksack, Skagit springs, Skagit falls and Skokomish available only for 1999-2013; Snohomish for 1999-2001 and 2005-2014; Lake Washington for 2003-2014; White River 2005-2014; Puyallup for 2002-2014; Nisqually for 2005-2014; Dungeness for 2001-2014; Elwha for 2010-2014.

[2]Source is Abundance and Productivity Tables from NWFSC database; measured as the mean of observed recruits/observed spawners. Sammamish productivity estimate has not been revised to include Issaquah Creek.
[3]Thresholds under current habitat and environmental conditions (McElhany et al. 2000; NMFS 2000).
[4]Source is the final supplement to the Puget Sound Salmon Recovery Plan (NMFS 2006b); measured as recruits/spawner associated with the number of spawners at Maximum Sustained Yield under recovered conditions.
[5]Estimates of the fraction of hatchery fish in natural spawning escapements are from the Abundance and Productivity Tables and co-manager postseason reports on the Puget Sound Chinook Harvest Management Plan (PSIT and WDFW 2013; WDFW and PSTIT 2005; WDFW and PSTIT 2008; WDFW and PSTIT 2009; WDFW and PSTIT 2010; WDFW and PSTIT 2011; WDFW and PSTIT 2012) and the 2010-2014 Puget Sound Chinook Harvest Management Plan (PSIT and WDFW 2010). North Fork and South Fork Nooksack estimates are through 2011 and 2010, respectively. Skagit estimates are through 2011.
[6]Captive broodstock program for early run Chinook salmon ended in 2000; estimates of natural spawning escapement include an unknown fraction of naturally spawning hatchery-origin fish from late- and early run hatchery programs in the White and Puyallup River basins.
[7]South Prairie index area provides a more accurate trend in the escapement for the Puyallup River because it is the only area in the Puyallup River for which spawners or redds can be consistently counted (PSIT and WDFW 2010).
[8]The Puget Sound TRT considers Chinook salmon spawning in the Dosewallips, Duckabush, and Hamma Hamma Rivers to be subpopulations of the same historically independent population; annual counts in those three streams are variable due to inconsistent visibility during spawning ground surveys. Data on the contribution of hatchery fish is very limited; primarily based on returns to the Hamma Hamma River.
[9]Estimates of natural escapement do not include volitional returns to the hatchery or those fish gaffed or seined from spawning grounds for broodstock collection.

The Recovery Plan describes the ESU's population structure, identifies populations essential to recovery of the ESU, establishes recovery goals for most of the populations, and recommends habitat, hatchery, and harvest actions designed to contribute to the recovery of the ESU (NMFS 2006b; SSPS 2007) SSPS 2007). It adopts ESU and population level viability criteria recommended by the Puget Sound Technical Recovery Team (PSTRT, 2005 #7845; PSTRT, 2002 #2714) as follows:

All watersheds improve from current conditions, resulting in improved status for the species.

1. At least two to four Chinook salmon populations in each of the five biogeographical regions of Puget Sound attain a low risk status over the long-term
2. At least one or more populations from major diversity groups historically present in each of the five Puget Sound regions attain a low risk status
3. Tributaries to Puget Sound not identified as primary freshwater habitat for any of the 22 identified natural populations are functioning in a manner that is sufficient to support an ESU-wide recovery scenario
4. Production of Chinook salmon from tributaries to Puget Sound not identified as primary freshwater habitat for any of the 22 identified populations occurs in a manner consistent with ESU recovery

NMFS further classified Puget Sound Chinook salmon populations into three tiers (Figure 1. Populations delineated by NMFS for the Puget Sound Chinook salmon ESU and their assigned Population Recovery Approach tier status (NMFS 2010; SSPS 2007). Note: Dosewallips, Duckabush and Hamma Hamma River Chinook salmon are aggregated as the “Mid Hood Canal” population.) based on its draft Population Recovery Approach (PRA) using a variety of life history, production, and habitat indicators, and the Puget Sound Recovery Plan biological delisting criteria (NMFS 2010). NMFS understands that there are non-scientific factors, (e.g., the importance of a salmon or steelhead population to tribal culture and economics) that are important considerations in salmon and steelhead recovery. Tier 1 populations are of primary importance for preservation, restoration, and ESU recovery. Tier 2 populations play a secondary role in recovery of the ESU and Tier 3 populations play a tertiary role. When NMFS analyzes proposed actions, it evaluates impacts at the individual population scale in order to assess their effects on the viability of the ESU. Accordingly, impacts on Tier 1 populations would be more likely to affect the viability of the ESU as a whole than similar impacts on Tier 2 or 3 populations.

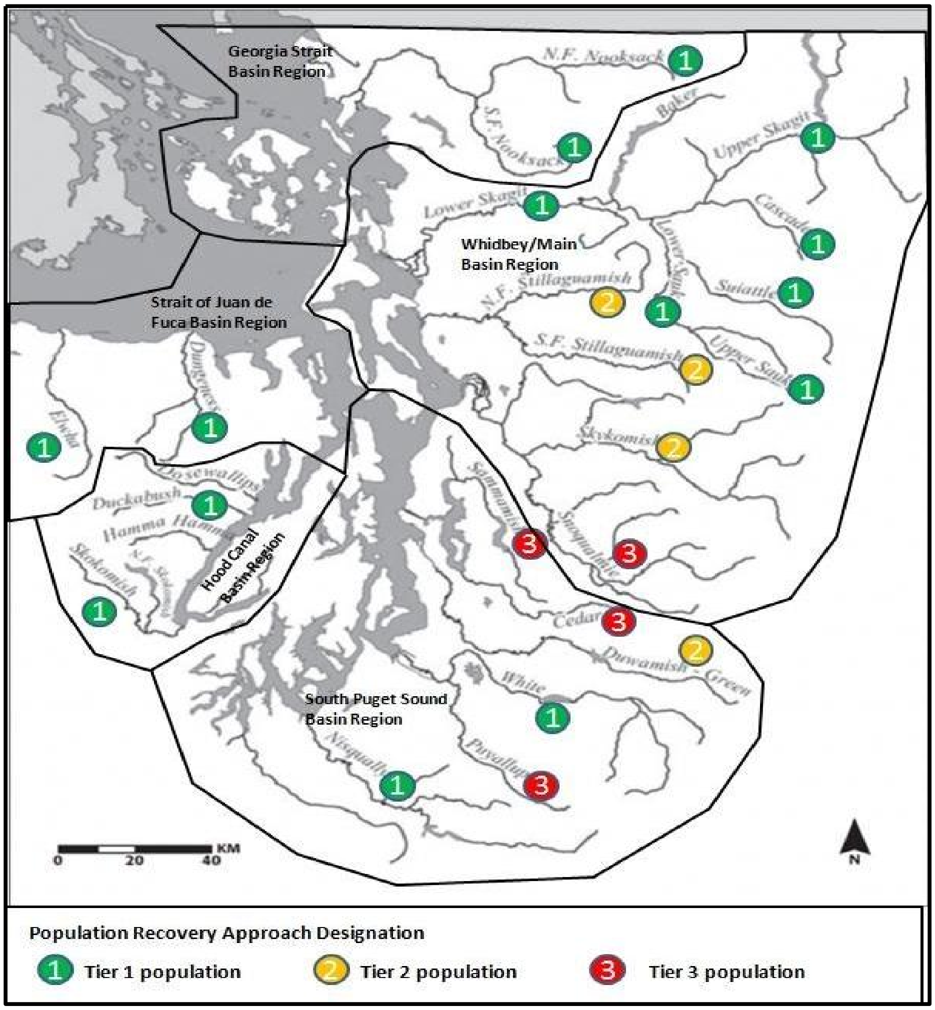

Figure 1. Populations delineated by NMFS for the Puget Sound Chinook salmon ESU and their assigned Population Recovery Approach tier status (NMFS 2010; SSPS 2007). Note: Dosewallips, Duckabush and Hamma Hamma River Chinook salmon are aggregated as the "Mid Hood Canal" population.

The limiting factors described in (SSPS 2007) and (NMFS 2006b) include:

- Degraded nearshore and estuarine habitat: Residential and commercial development has reduced the amount of functioning nearshore and estuarine habitat available for salmon rearing and migration. The loss of mudflats, eelgrass meadows, and macroalgae further limits salmon foraging and rearing opportunities in nearshore and estuarine areas.
- Degraded freshwater habitat: Floodplain connectivity and function, channel structure and complexity, riparian areas and large wood supply, stream substrate, and water quality have been degraded for adult spawning, embryo incubation, and rearing as a result of cumulative impacts of agriculture, forestry, and development.
- Anadromous salmonid hatchery programs: Salmon and steelhead released from Puget Sound hatcheries operated for harvest augmentation purposes can potentially pose ecological, genetic,

and demographic risks to natural-origin Chinook salmon populations but can also provide benefits to viability parameters such as increased abundance and preserving genetic diversity.
- Salmon harvest management: Total fishery exploitation rates have decreased 14 to 63% from rates in the 1980s, but low natural-origin Chinook salmon population abundance in Puget Sound still requires enhanced protective measures to reduce the risk of overharvest.

The severity and relative contribution of these factors varies by population. One theory for the declines in fish populations in Puget Sound in the 1980s and into the 1990s is that they may reflect broad-scale shifts in natural limiting conditions, such as increased predator abundances and decreased food resources in ocean rearing areas. These factors are discussed in more detail in the Environmental Baseline (Section 2.4).

Whidbey Basin biogeographical region

The Whidbey Basin BGR contains 10 populations including the two Snohomish populations. The Suiattle and at least one other population within the Whidbey Basin (one each of the early, moderately early and late spawn-timing) would need to be viable for recovery of the ESU. Evidence suggests that the Puget Sound Chinook Salmon ESU has lost 15 spawning aggregations that were either demographically independent historical populations or major components of the life history diversity of the remaining 22 extant independent historical populations identified (Ruckelshaus et al. 2006). Nine of the 15 putatively extinct spawning aggregations were thought to be early type Chinook salmon. The majority of extant populations with early run-timing are in this BGR and it currently accounts for about 47 percent and just under 70 percent of the all-natural spawners and natural-origin Chinook salmon escapement in the ESU, respectively (NWFSC 2015).

Considering abundance in a number of different ways, for example short-term geometric means versus long-term population growth rates, the data do not support any particular conclusion across the BGR. Abundance varies greatly among the populations (Table 5) with the Skagit populations comprising the majority (76%) of Chinook salmon in the BGR (NWFSC 2015). Based on estimates of the most recent 5-year (2010-2014) geometric mean abundances, two populations in the BGR are above their rebuilding thresholds (representing early and moderately early life histories) and the South Fork Stillaguamish is in critical status (WDFW Score Database; (NWFSC 2015)). As described above, only five populations showed an increase in abundance in the five-year geometric mean natural-origin abundance since the 2010 status review (NWFSC 2015), and three of these five are within the Whidbey Basin BGR. Long-term (1988-2019) escapement trends show the numbers of Chinook salmon returning to both the Skykomish and Snoqualmie have been highly variable but have generally declined in the most recent ten year period (Figure 2 and Figure 3). Long-term growth rates for pre-harvest abundance (return) are declining for all populations within the BGR (Haggerty 2020b; NWFSC 2015).

Snohomish River Basin Chinook salmon

The two Snohomish River basin Chinook salmon populations – Skykomish and Snoqualmie – are grouped with eight other populations in the Whidbey Basin BGR for recovery planning purposes (NMFS 2006b; SSPS 2005). Based on analyses of population and habitat status factors for Chinook salmon populations grouped within the Whidbey Basin BGR, under the NMFS PRA (NMFS 2010), the populations affected by this proposed action, the Skykomish and Snoqualmie Chinook populations, are Tier 2 and Tier 3 populations, respectfully. Within the Whidbey Basin BGR, Chinook salmon populations in the Skagit River are assigned as having primary roles for Puget Sound Chinook salmon

ESU recovery and are designated as Tier 1 (Figure 2). As described in Section 2.1, NMFS considers impacts on Tier 2 and 3 populations less likely to affect the viability of the ESU as a whole than similar impacts on Tier 1 populations, because of the primary importance of Tier 1 populations to overall ESU viability.

Both the Skykomish and Snoqualmie populations are ocean-type Chinook salmon with juveniles emigrating seaward in March through June. A substantial proportion of adult Chinook salmon in each population, averaging 24% and 22% for the Skykomish and Snoqualmie populations, respectively (1996-2011 averages from Mike Crewson, Tulalip Tribes, and Pete Verhey, WDFW, pers. comm. 2014), is composed of the yearling freshwater life-history type ("stream type"). Adults return primarily as four-year-old fish, although both populations exhibit a relatively strong age-5 component. For the period 2005 through 2013, age-5 Chinook salmon made up 20- and 17-percent of the natural-origin spawners in the Skykomish and Snoqualmie populations, respectively (Rawson and Crewson 2017).

Adult summer Chinook salmon return to the Skykomish River watershed beginning in May and extending through September (PSIT and WDFW 2010). The Skykomish natural population has a late-summer/early-fall spawn timing (early-September to early-October) with Chinook salmon spawning in the Snohomish River mainstem, the mainstem of the Skykomish, Pilchuck, Wallace, and Sultan Rivers; Woods, Elwell, Olney, Proctor, and Bridal Veil creeks; and the North and South Forks of the Skykomish River (WDFW spawning ground database). The Snoqualmie Chinook salmon population is considered a fall-run stock, migrating into the Snohomish River basin from August through October. Chinook salmon spawning occurs later than in the Snoqualmie River watershed, generally in the fall months (mid/late-September through early-November) (WDFW spawning ground database). Snoqualmie Chinook salmon spawn in the Snoqualmie River and its larger tributaries, including the Tolt and Raging rivers, and Tokul Creek (PSIT and WDFW 2010).

Abundance of Snohomish River basin Chinook salmon is a fraction of historical levels (Haggerty 2020c; SSPS 2005). The most recent estimates of escapement, hatchery contribution, and productivity for the Snohomish basin populations are summarized in Figure 2 and Figure 3 as well as Table 14 and Table 15. Naturally-produced Chinook salmon comprise a majority of natural spawners, averaging 68.7 percent for the basin in recent years (2006-2019; see Table 14). The average hatchery-origin fraction of the naturally spawning Skykomish Chinook salmon population in the last thirteen years (2006-2019; 31.3%) has decreased from the level 15 years ago (1997-2001 avg. = 49.9%). The hatchery-origin fraction of the naturally spawning Snoqualmie Chinook salmon population has varied from 11.3% in 2010 to 34.4% in 2019 largely as a result in declining returns of natural-origin adults. The actual number of hatchery-origin spawners remained relatively stable during this period with 203 HOR adults escaping in 2010 and 233 escaping in 2019 (Table 6).

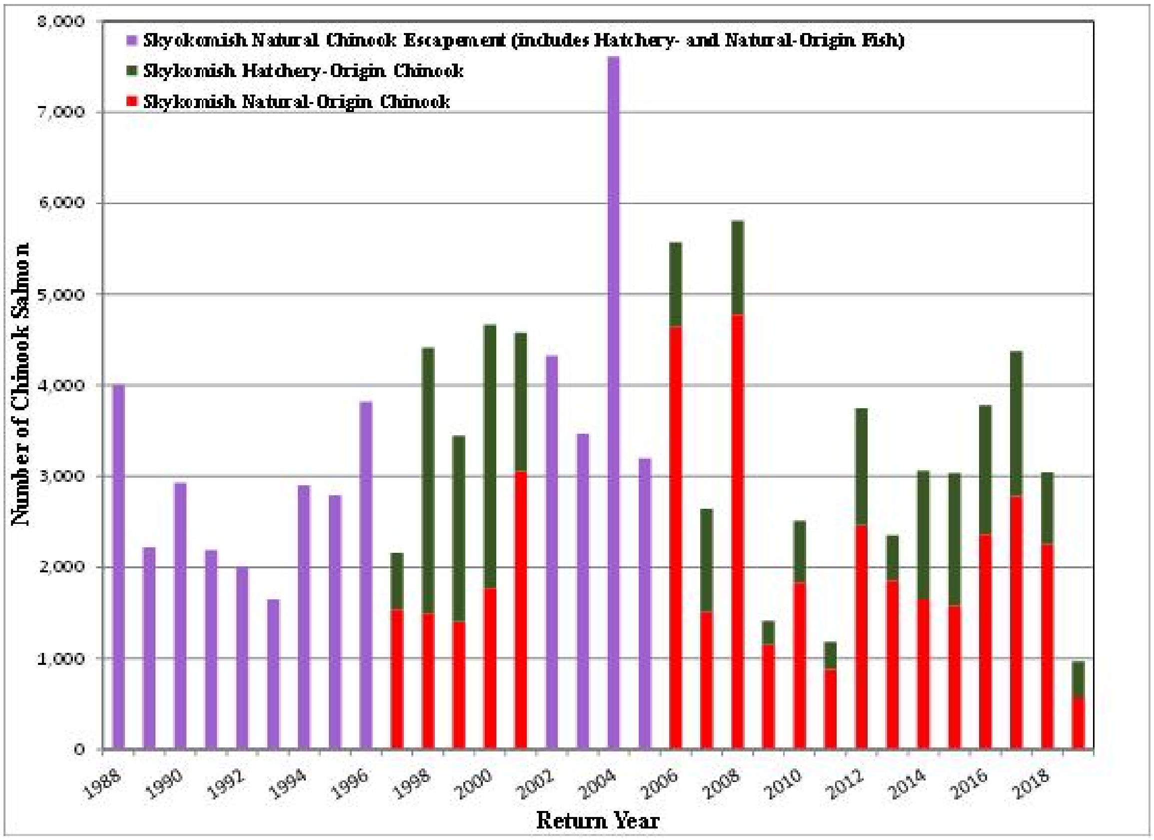

Figure 2. Estimated annual natural Chinook salmon escapement abundances in the Skykomish River for 1988 through 2019. Natural- and hatchery-origin breakouts are included for years where data are available. Source: WDFW Score database; Mike Crewson and Pete Verhey, Tulalip Tribes and WDFW unpublished escapement data 2020.

Trends in annual natural-origin spawner per natural spawner rates for the Skykomish and Snoqualmie populations indicate general declines in productivity (Table 7). For brood years 2000 through 2014, productivity of the Skykomish Chinook salmon population was less than 1:1 natural origin recruits to escapement per natural spawner in eleven of those fifteen years. For the same time period, the productivity of the Snoqualmie Chinook salmon population was less than 1:1 in ten of the years. The 2000-2010 brood year geometric mean natural origin recruit spawner per natural spawner for the Skykomish Chinook population was 0.69 and 0.65 for the Snoqualmie Chinook population (Table 7)(Haggerty 2020c).

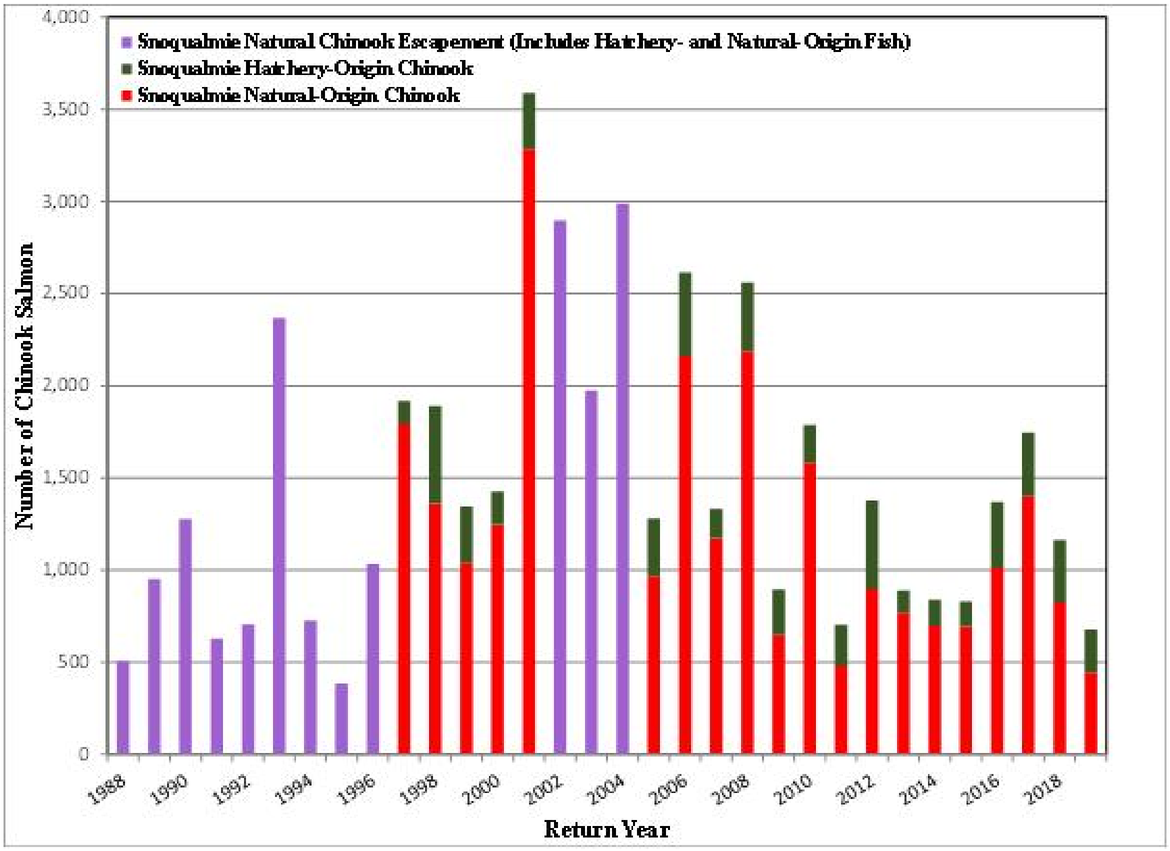

Figure 3. Estimated annual natural Chinook salmon escapement abundances in the Snoqualmie River for 1988 through 2019. Natural- and hatchery-origin breakouts are included for years where data are available. Source: WDFW Score database; Mike Crewson and Pete Verhey, Tulalip Tribes and WDFW unpublished escapement data 2020.

Table 6. Summary of Skykomish and Snoqualmie Chinook salmon populations natural escapement, natural-origin escapement, and percent of natural escapement composed of hatchery-origin spawners (pHOS) for return years 1997-2019. Source: Mike Crewson and Pete Verhey, Tulalip Tribes and WDFW unpublished escapement data 2020).

Return Year	Skykomish Total Natural Escapement	Skykomish Natural-Origin Escapement	Skykomish Percent Hatchery-Origin	Snoqualmie Total Natural Escapement	Snoqualmie Natural-Origin Escapement	Snoqualmie Percent Hatchery-Origin
1997	2,161	1,540	28.7%	1,917	1,796	6.3%
1998	4,415	1,495	66.1%	1,891	1,361	28.0%
1999	3,446	1,401	59.3%	1,345	1,040	22.7%
2000	4,668	1,775	62.0%	1,427	1,248	12.5%
2001	4,577	3,054	33.3%	3,589	3,284	8.5%
2002	4,327	NA	NA	2,896	NA	NA
2003	3,472	NA	NA	1,975	NA	NA
2004	7,614	NA	NA	2,988	NA	NA
2005	3,201	NA	NA	1,279	968	24.3%
2006	5,573	4,642	16.7%	2,615	2,161	17.4%
2007	2,648	1,510	43.0%	1,334	1,174	12.0%
2008	5,813	4,780	17.8%	2,560	2,190	14.5%
2009	1,414	1,146	19.0%	895	649	27.5%
2010	2,512	1,836	26.9%	1,788	1,585	11.3%
2011	1,181	876	25.5%	702	479	31.8%
2012	3,745	2,462	34.1%	1,379	898	34.9%
2013	2,355	1,860	21.0%	889	770	13.4%
2014	3,063	1,654	46.0%	839	698	16.8%
2015	3,034	1,585	47.8%	829	694	16.3%
2016	3,785	2,363	37.6%	1368	1013	26.0%
2017	4,374	2,783	36.4%	1745	1401	19.7%
2018	3,048	2,259	25.9%	1162	823	29.2%
2019	966	569	41.1%	678	445	34.4%
1997-2001 Skykomish pHOS			49.9%			
2006-2019 Skykomish pHOS			31.3%			
			1997-2001 Snoqualmie pHOS			15.6%
			2005-2019 Snoqualmie pHOS			22.0%
1997-2001 Basin Wide pHOS			38.9%			
2006-2019 Basin Wide pHOS			28.7%			

Table 7. Recent productivity estimates for Skykomish and Snoqualmie Chinook salmon populations as measured by the annual number of natural-origin recruits spawners (Mangel et al.) per natural spawners for the contributing brood year. (Source: Rawson and Crewson 2017; Alexandersdottir and Crewson 2019; M. Alexandersdottir personal communication November 15, 2020*)*.

Brood Year[2]	Skykomish Chinook Salmon			Snoqualmie Chinook Salmon		
	Natural Spawner Abundance	Progeny NOR Spawner Abundance[1]	Progeny NOR Spawner/Natural Spawner	Natural Spawner Abundance	Progeny NOR Spawner Abundance[1]	Progeny NOR Spawner/Natural Spawner
2000	4,668	6,274	1.34	1,427	2,361	1.65
2001	4,577	2,305	0.50	3,589	890	0.25
2002	4,327	3,760	0.87	2,896	2,209	0.76
2003	3,472	1,629	0.47	1,975	850	0.43
2004	7,614	5,568	0.73	2,988	2,244	0.75
2005	3,201	2,281	0.71	1,279	1,287	1.01
2006	5,573	1,310	0.24	2,615	1,088	0.42
2007	2,648	1,365	0.52	1,334	606	0.45
2008	5,813	2,441	0.42	2,560	744	0.29
2009	1,414	2,909	2.06	895	1,099	1.23
2010	2,511	1,060	0.42	1,788	540	0.30
2011	1,181	1,491	1.26	702	658	0.94
2012	3,744	2,216	0.59	1,379	642	0.47
2013	2,355	3,409	1.45	889	1,436	1.62
2014	3,063	1,733	0.58	838	950	1.13

[1] NOR spawner progeny of brood year natural spawners summed for all observed age classes at return.

[2]Brood year indicates the year the individual was born. This table includes data collected through 2018, which for example included 5-year-old returning adult Chinook salmon from the 2013 brood year.

The spatial structure for the Skykomish and Snoqualmie Chinook salmon natural populations has been reduced by habitat loss and degradation. Bank protection and diking of the river and major tributaries have disconnected river channels from their floodplains leading to loss of accessible river areas and habitat complexity for rearing and migrating Chinook salmon (Snohomish Basin Salmonid Recovery Technical Committee 1999). Lack of adequate in-channel large woody debris, relative to historical conditions, has decreased the amount of rearing and refuge areas available for juvenile Chinook salmon (Snohomish Basin Salmonid Recovery Technical Committee 1999). Chinook salmon habitat has been further reduced by loss of wetlands through draining and land conversion for human use (Snohomish Basin Salmonid Recovery Technical Committee 1999). Road construction, commercial and residential construction, and bank hardening for flood control have also impaired Chinook salmon habitat use and access and population spatial structure. Artificial barriers at locations throughout the basin, including dams, tide gates, water diversions, culverts, and pumping stations prevent juvenile Chinook salmon from reaching rearing habitat to the further detriment of population spatial structure (Snohomish Basin Salmon 2005). Since the 1950s, the spawning distribution of the Skykomish Chinook salmon population appears to have shifted upstream. Since that time, a much larger proportion of fish spawn higher in the drainage, between Sultan and the North and South Forks of the Skykomish River, than in previous decades (Snohomish Basin Salmonid Recovery Technical Committee 1999) .

Life history diversity of the Snohomish River basin Chinook salmon populations has been reduced by anthropogenic activities over the last century (Haring 2002), and is further threatened by on-going developmental actions in the watershed. Lost and degraded estuarine habitat has impaired the fry migrant components of the Skykomish and Snoqualmie populations, which need a properly functioning, braided lower river and brackish water environment to grow to a viable smolt size. Fry migrants represent a particularly important component of the life history diversity for both populations.

The Chinook salmon populations in the Snohomish River basin have been particularly affected by habitat loss in the estuary. The quantity and quality of salmon rearing habitat available to the two populations in the estuary is a small fraction of pre-development conditions (Snohomish County 2013). Historically, the Snohomish River estuary included a rich complex of tidal channels and productive marshes. Under current conditions, only one-sixth of the historical tidal marsh area downstream of the head of Ebey Slough remains intact and accessible to salmonids (Snohomish County 2013). The current lack of critical estuarine tidal marsh habitat is considered a limiting factor for Chinook salmon recovery (Snohomish Basin Salmon 2005). Greatly reduced ocean productivity coupled with drought, low flow and high temperatures followed by increased frequency and intensity of flooding are the main limiting factors that have increased in the last 20 years that cause the majority of the mortality (leDoux et al. 2017). These conditions compromise prospects for restoration of natural-origin Chinook salmon population viability, because ocean-type Chinook salmon stocks are extremely dependent on a properly functioning estuary due to their predominantly fry migrant life history. These factors are discussed in more detail in the Environmental Baseline (Section 2.4).

We also note here that the average number of Chinook salmon returning to Sunset Falls and transported upstream is about 380 fish (Table 8). These fish are collected by the hatchery personnel at the Sunset Falls Trap and Haul Fishway facility and transported into the upper South Fork Skykomish Basin for the purpose of conservation or used for broodstock; these effects of collecting Chinook salmon for broodstock have been evaluated and authorized in a separate biological opinion (NMFS 2017a). In this consultation, we address effects associated with transport and release of Chinook salmon into the upper South Fork Skykomish basin.

Table 8. Annual number of Chinook salmon transported upstream of Sunset Falls, 2009-2018.

Year	Chinook salmon
2009	342
2010	479
2011	493
2012	531
2013	192
2014	396
2015	591
2016	345
2017	331
2018	126
Mean	**383**

2.2.2. Status of Critical Habitat for Puget Sound Chinook Salmon

Designated critical habitat for the Puget Sound Chinook Salmon ESU includes localized estuarine areas and specific river reaches associated with the following subbasins: Strait of Georgia, Nooksack, Upper Skagit, Sauk, Lower Skagit, Stillaguamish, Skykomish, Snoqualmie, Snohomish, Lake Washington, Green, Puyallup, Nisqually, Deschutes, Skokomish, Hood Canal, Kitsap, and Dungeness/Elwha (70 FR 52630, September 2, 2005). The designation also includes some nearshore areas extending from extreme high water out to a depth of 30 meters and adjacent to watersheds occupied by the 22 extant natural populations because of their importance to rearing and migration for Chinook salmon and their prey, but does not otherwise include offshore marine areas. There are 61 watersheds (HUC5 basins) within the range of this ESU. Twelve watersheds received a low rating, nine received a medium rating, and 40 received a high rating of conservation value to the ESU (NMFS 2005a). All nineteen nearshore marine areas also received a rating of high conservation value. Of the 4,597 miles of stream and nearshore habitat eligible for designation, 3,852 miles are designated critical habitat (NMFS 2005a).

In this section NMFS describes the process for determining the range-wide status of critical habitat, which involves examining the condition of its primary constituent elements (PCEs) identified when the critical habitat was designated. These features are essential to the conservation of the listed species because they support one or more of the species' life stages (e.g., sites with conditions that support spawning, rearing, migration and foraging). PCEs for Puget Sound Chinook salmon (70 FR 52731, September 2, 2005), including the Snohomish salmon populations, include:

1. Freshwater spawning sites with water quantity and quality conditions and substrate supporting spawning, incubation and larval development.
2. Freshwater rearing sites with: (i) Water quantity and floodplain connectivity to form and maintain physical habitat conditions and support juvenile growth and mobility; (ii) Water quality and forage supporting juvenile development; and (iii) Natural cover such as shade, submerged and overhanging large wood, log jams and beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks.
3. Freshwater migration corridors free of obstruction and excessive predation with water quantity and quality conditions and natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks supporting juvenile and adult mobility and survival.
4. Estuarine areas free of obstruction and excessive predation with: (i) Water quality, water quantity, and salinity conditions supporting juvenile and adult physiological transitions between fresh- and saltwater; (ii) Natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels; and (iii) Juvenile and adult forage, including aquatic invertebrates and fishes, supporting growth and maturation.
5. Nearshore marine areas free of obstruction and excessive predation with: (i) Water quality and quantity conditions and forage, including aquatic invertebrates and fishes, supporting growth and maturation; and (ii) Natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, and side channels.
6. Offshore marine areas with water-quality conditions and forage, including aquatic invertebrates and fishes, supporting growth and maturation.

Critical habitat is designated for Puget Sound Chinook salmon within the action area. Critical habitat includes the estuarine and nearshore areas and the stream channels within the proposed stream reaches of the Snohomish sub-basin, and includes a lateral extent as defined by the ordinary high-water line (33 CFR 319.11). The Puget Sound Critical Habitat Analytical Review Team identified management activities that may affect the PCEs in the three sub-basins including agriculture, channel modifications/diking, dams, forestry, urbanization, and irrigation and water withdrawals (NMFS 2005a).

2.2.3. Puget Sound Steelhead DPS

Oncorhynchus mykiss has an anadromous form, commonly referred to as steelhead. Steelhead differ from other Pacific salmon in that they are iteroparous (capable of spawning more than once before death). Adult steelhead that have spawned and returned to the sea are referred to as kelts. Averaging across all West Coast steelhead populations, 8% of spawning adults have spawned previously, with coastal populations containing a higher incidence of repeat spawning compared to inland populations (Busby et al. 1996). Steelhead express two major life history types—summer and winter. Puget Sound steelhead are dominated by the winter life history type and typically migrate as smolts to sea at age two. Seaward emigration occurs from April to mid-May, with fish typically spending one to three years in the ocean before returning to freshwater. They migrate directly offshore during their first summer, and move southward and eastward during the fall and winter (Hartt and Dell 1986). Adults return from December to May, and peak spawning occurs from March through May. Summer steelhead adults return from May through October and peak spawning occurs the following January to May (Hard et al. 2015; Hard et al. 2007). Temporal overlap exists in spawn timing between the two life history types, particularly in northern Puget Sound where both summer and winter steelhead are present, although summer steelhead typically spawn farther upstream above obstacles that are largely impassable to winter steelhead (Behnke and American Fisheries Society 1992; Busby et al. 1996).

The Puget Sound Steelhead DPS was listed as threatened on May 11, 2007 (72 FR 26722), and the 2015 status review determined that the DPS should remain threatened (NWFSC 2015). The DPS includes all naturally spawned anadromous winter and summer steelhead populations within the river basins of the Strait of Juan de Fuca, Puget Sound, and Hood Canal, Washington, bounded to the west by the Elwha River (inclusive) and to the north by the Nooksack River and Dakota Creek (inclusive) as shown in Figure 4. Also included as part of the ESA-listed DPS are six hatchery stocks derived from local natural steelhead populations and produced for conservation purposes (FR 79 20802, April 14, 2014). Non-anadromous "resident" *O. mykiss* occur within the range of Puget Sound steelhead, but are not part of the DPS due to key differences in physical, physiological, ecological, and behavioral characteristics (Hard et al. 2007). Puget Sound steelhead populations are aggregated into three extant Major Population Groups (MPGs) containing a total of 32 Demographically Independent Populations (DIPs) based on genetic, environmental, and life history characteristics (Myers et al. 2015) (Table 9).

The 2015 status review indicated some minor increases in spawner abundance and/or improving productivity over the last few years for Puget Sound steelhead; however abundance and productivity throughout the DPS remain at levels of concern. The recent increases in abundance observed in a few populations are encouraging, but are within the range of variability observed in the past several years and overall trends in abundance of natural-origin spawners remain predominantly negative.

Currently the recovery plan for Puget Sound Steelhead is only in draft form. However, in its status review and listing documents for the Puget Sound Steelhead DPS (76 FR 1392; 71 FR 15666), NMFS noted that the factors for decline persist as limiting factors:

- Continued destruction and modification of steelhead habitat
- Widespread declines in adult abundance (total run size), despite significant reductions in harvest in recent years
- Threats to diversity from non-local hatchery steelhead stocks
- Declining diversity in the DPS
- A reduction in spatial structure for steelhead in the DPS
- Reduced habitat quality through changes in river hydrology, temperature profile, downstream gravel recruitment, and reduced movement of large woody debris
- Increased flood frequency and peak flows during storms have resulted in gravel scour, bank erosion, and sediment deposition, and reduced groundwater-driven summer flows
- Dikes, hardening of banks with riprap, and channelization have reduced river braiding and sinuosity, and increased the likelihood of gravel scour and dislocation of rearing juveniles

Table 9. Puget Sound steelhead populations and risk of extinction (Hard et al. 2015).

Major Population Groups (MPGs)	Population (Run Time)	Extinction Risk (probability of decline to an established quasi-extinction threshold (QET) for each population)	Quasi-extinction threshold (number of fish)
Northern Cascades	Drayton Harbor Tributaries (winter)	Unable to calculate	
	SF Nooksack River (summer)	Unable to calculate	
	Nooksack River (winter)	Unable to calculate	
	Samish River/Bellingham Bay (winter)	Low—about 30% within 100 years	31
	Skagit River (summer/winter)	Low—about 10% within 100 years.	157
	Baker River (summer/winter)	Unable to calculate	
	Sauk River (summer/winter)	Unable to calculate	
	Snohomish/Skykomish River (winter)	Low—about 40% within 100 years	73
	Stillaguamish River (winter)	High—about 90% within 25 years	67
	Deer Creek (summer)	Unable to calculate	
	Canyon Creek (summer)	Unable to calculate	
	Tolt River (summer)	High—about 80% within 100 years	25
	NF Skykomish River (summer)	Unable to calculate	
	Snoqualmie (winter)	High---about 70% within 100 years	58
	Nookachamps (winter)	Unable to calculate	--
	Pilchuck (winter)	Low---about 40% within 100 years	34
Central and Southern Cascades	North L. Washington/L. Sammamish (winter)	Unable to calculate	
	Cedar River (summer/winter)	High---about 90% within the next few years	36
	Green River (winter)	Moderately High—about 50% within 100 years	69
	Nisqually River (winter)	High—about 90% within 25 years	55
	Puyallup/Carbon River (winter)	High—about 90% within 25-30 years	
	White River (winter)	Low—about 40% within 100 years	64
	South Sound Tributaries (winter)	Unable to calculate percentage	--
	East Kitsap (winter)	Unable to calculate	
Hood Canal and Strait of Juan de Fuca	Elwha River (summer[5]/winter)	High— about 90% currently	41
	Dungeness River (summer/winter)	High—about 90% within 20 years	30
	South Hood Canal (winter)	High---about 90% within 20 years	30
	West Hood Canal (winter)	Low—about 20% within 100 years	32
	East Hood Canal (winter)	Low—about 40% within 100 years	27
	Skokomish River (winter)	High—about 70% within 100 years	50
	Sequim/Discovery Bay Independent Tributaries (winter)	High—about 90% within 100 years (Snow Creek)	25 (Snow Creek)
	Strait of Juan de Fuca Independent Tributaries (winter)	High—about 90% within 60 years (Morse & McDonald creeks)	26 (Morse & McDonald Ck)

[5] Native summer-run in the Elwha River basin may no longer be present. Further work is needed to distinguish whether existing feral summer-run steelhead are derived from introduced Skamania Hatchery (Columbia River) summer run.

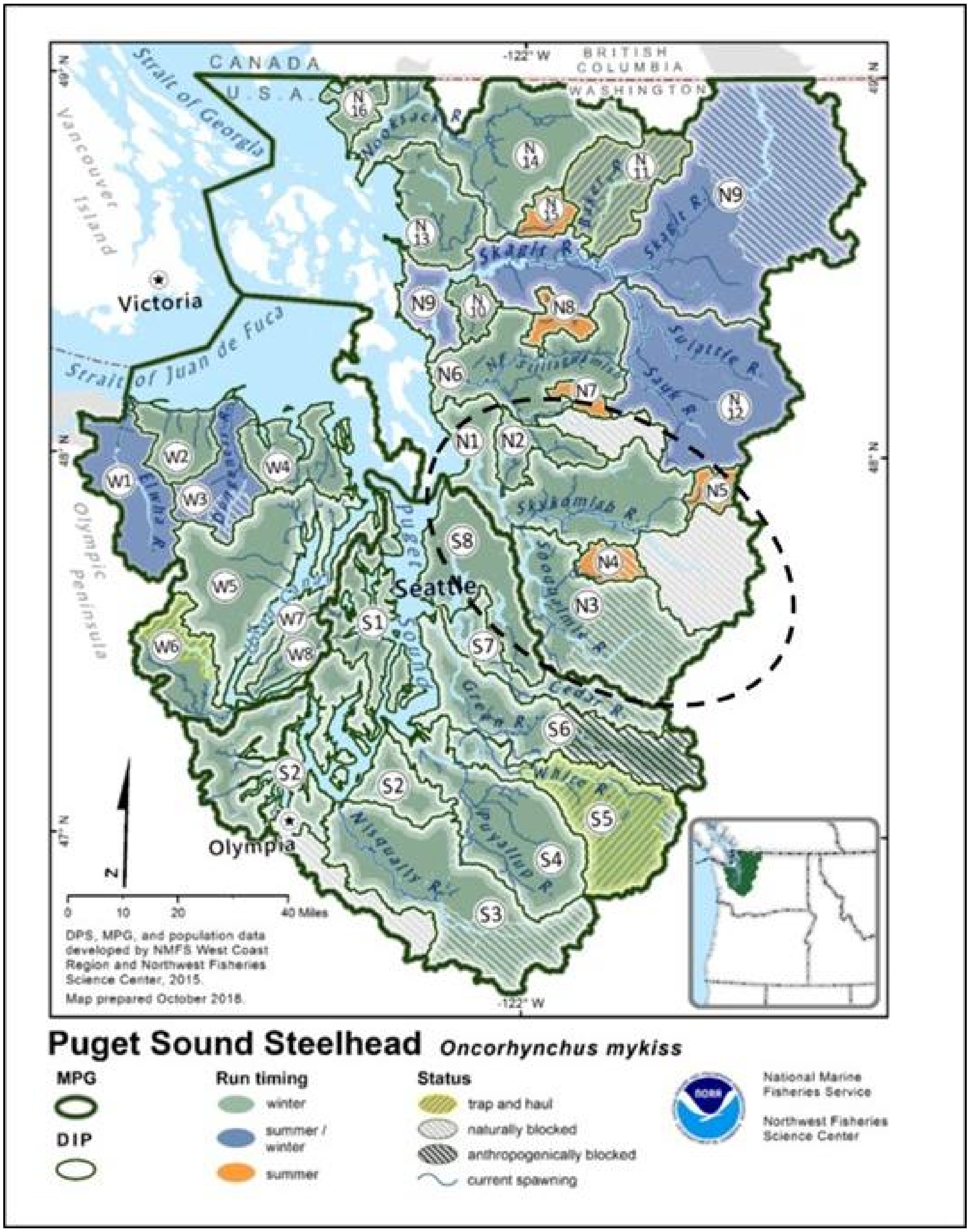

Figure 4. Location of Puget Sound steelhead populations in the Snohomish River Basin (general location indicated by the dashed black oval).

Northern Cascades MPG

The Northern Cascades MPG has 16 DIP's including eight summer or summer/winter, and eight winter DIPs (Table 10). Differences in bedrock erodibility throughout the Northern Cascades MPG create cascades and falls that may serve as isolating mechanisms for summer-and winter-run populations. This geology is likely responsible for the relatively large number of summer-run populations (PSSTRT 2013) since returning summer steelhead tend to migrate to headwater areas in the spring and early-summer when flows are higher, making possible access to upstream areas that, in other months, are impassable due to low flow related obstacles to passage that become partial or complete barriers to migration. Eight of the 10 DIPs in the DPS with extant summer run-timing or summer components are in this MPG. The Northern Cascade MPG accounts for 75 percent of the steelhead abundance in the DPS (Hard et al. 2007). Although information on the DIPs within the Northern Cascades MPG is extremely limited, abundance varies greatly among the populations (Table 10) with the Skagit and Snohomish natural populations comprising the majority of steelhead in the MPG. Mean growth rates are declining for all populations within the MPG except for the Tolt River, and abundance for this DIP is very low. Through the most recent five-year species status review, abundance trends from 1999 through 2014 for three DIPs within the MPG were evaluated (NWFSC 2015). Two of the DIPs had negative long-term trends and one had a positive long-term trend (Samish). Between the two most recent five-year periods (2004-2009 and 2010-2014), the geometric mean of estimated abundance for eight DIPs evaluated increased by an average of 3% in the North Cascades MPG (NWFSC 2015). Risk assessment by the PSSTRT indicated three populations are at high risk of extinction and four are at low risk (Table 10) with the Snohomish populations equally divided. However, more natural populations are at lower risk in this MPG than in the other MPGs in the DPS. In summary, the North Cascades steelhead MPG, relatively speaking, is at a lower extinction risk and is a stronghold in terms of life history diversity and abundance.

Snohomish Basin Populations

The Snohomish basin includes five steelhead DIPs: Snohomish/Skykomish winter-run; Pilchuck winter-run; Snoqualmie winter-run; Tolt summer-run; and North Fork Skykomish summer-run (PSSTRT 2013). The DPS viability criteria developed by NMFS (Hard et al. 2015) require that at least 40 percent of the steelhead populations within each MPG achieve viability (restored to a low extinction risk), as well as at least 40 percent of each major life history type (e.g., summer-run and winter-run) historically present within each MPG achieve viability. There are no hatchery-origin steelhead produced in basin hatcheries that are included as part of the listed DPS. The South Fork Skykomish summer steelhead population is not currently included in the listed DPS.

Winter-run steelhead in the Snohomish River basin enter freshwater as adults between mid-October and May (Myers et al. 2015). Spawning occurs from mid-March through mid-June with peak spawning in April. Most winter-run steelhead return to spawn as four-year-old (57%), and five-year-old fish (42%) ((PSSTRT 2013) citing WDFW 1994b). Juvenile out-migrant trapping data indicate that natural-origin Snohomish River basin steelhead juveniles emigrate seaward in April and May as smolts predominantly as two-year-old fish (84%) and to a lesser extent, as three-year-old smolts (15%) ((PSSTRT 2013) citing WDFW 1994b).

Table 10. Naturally spawning steelhead abundances and trends for DIPs within the North Cascades MPG for which information is available. Populations within the Snohomish basin are bolded. Populations within the Snohomish basin are bolded. WR=winter-run, SUR=summer run, and SWR=summer/winter run population.

Population (Run Timing)	2010-2014 Geometric Mean Escapement (Spawners)[1]	2015-2019 Geometric Mean Escapement (Spawners)[1]	Percent Change[1]
Nooksack R WR	1,745	1,906	9%
Pilchuck R WR	626	638	2%
Samish R WR	748	1,305	74%
Skagit R SWR[2]	6,391	7,181	12%
Snohomish/Skykomish WR	975	690	-29%
Snoqualmie R. WR	706	500	-29%
Stillaguamish R. WR[3]	386	487	26%
Tolt River SUR	108	40	-63%

1 Source: (NWFSC 2015)
2 Skagit data includes four DIPs: Skagit, Nookachamps, Baker, and Sauk.
3 Only includes the estimated number of naturally spawning steelhead in the North Fork Stillaguamish River index segments.

In the late 1950s, WDFW began releasing summer steelhead originating from Skamania Hatchery in the lower Columbia River, a stock that exhibits an early spawn timing. In its own examination of the subject, WDFW (Warheit et al. 2021) concluded that a mixing of local- and Skamania-origin steelhead likely continued from the late 1950s until brood year 1981. In subsequent years, WDFW used returning early summer steelhead from the Skamania program, and natural-origin individuals from the Skykomish Basin, as broodstock. Over the course of decades, this broodstock management produced summer steelhead that continue to exhibit an early-spawn timing life history, as well as complex ancestry.

WDFW began operating the Sunset Falls Trap and Haul Fishway facility in 1958 by transporting summer steelhead upstream into the upper South Fork Skykomish basin. WDFW managed steelhead passage in this way until recently, when it began limiting upstream transport to natural-origin steelhead. Management of the Sunset Falls Trap and Haul Fishway facility, coupled with the amalgamation of hatchery- and natural-origin summer steelhead over the course of several decades, has made it challenging to make definitive conclusions about the ancestry of summer steelhead in the Skykomish basin. These challenges were exemplified in earlier studies in which researchers used allozyme (Phelps et al. 1997) and microsatellite analyses (Kassler et al. 2008) to identify steelhead ancestry within the Skykomish basin. Results from these studies suggested a substantial genetic contribution of Skamania-stock steelhead to summer steelhead native to the North Fork and the South Fork Skykomish Rivers. However, the applicability of these analyses to the current status of summer steelhead in the South Fork Skykomish River is questionable, given changes in steelhead selected for transport upstream of Sunset Falls in subsequent years. The origin (hatchery or natural) of the adults transported upstream of Sunset Falls was not recorded until 1993. From 1993 through 2008, an average of 593 unmarked, likely natural-origin steelhead were passed upstream each year, which comprised an average of 59% of the total return to Sunset Falls. Marked hatchery-origin steelhead were generally not passed upstream beginning in 2009. From 2009 through 2018, unmarked steelhead comprised 96% of the steelhead passed upstream, which averaged 315 fish (Table 11). Subsequent to investigation by (Kassler et al. 2008), a recent, more in-depth genetic analysis by WDFW (Warheit et al. 2021) that incorporates additional samples suggests limiting passage of hatchery-origin steelhead into the upper South Fork Skykomish basin may have reduced the influence of the early summer steelhead hatchery program. This recent analysis includes genetic analysis of collections of summer steelhead from the North Fork Skykomish River, South Fork Skykomish River, and Upper SF Tolt River and has yielded a new perspective on the ancestry of the South Fork Skykomish population.

Table 11. Annual number hatchery and or natural origin steelhead transported upstream of Sunset Falls.

Year	Hatchery-origin summer steelhead	Natural-origin summer steelhead
2009	59	311
2010	0	369
2011	21	307
2012	0	592
2013	46	407
2014	0	284
2015	14	235
2016	13	261
2017	2	164
2018	0	221
Mean	**16**	**315**

WDFW's recent genetic analysis found that summer-run steelhead in the SF Skykomish River were as representative of a native summer-run steelhead in the Snohomish River basin as steelhead from the NF Skykomish River and the SF Tolt River (Figure 5; Figure 6). That is, this analysis showed that the previous assumptions to consider the SF Skykomish River summer-run steelhead as being more closely related to the out-of-basin Skamania stock than neighboring populations (Myers et al. 2015) should be re-examined. This more recent analysis, including stepwise implementation of STRUCTURE and a rooted dendrogram, illustrated the phylogeny and genetic relationships among summer steelhead in the Snohomish River basin, showing that the NF Skykomish River, SF Skykomish River, and SF Tolt River summer-run populations were genetically similar (Warheit et al. 2021). This recent analysis and a closer examination of the history of steelhead hatchery management in the Skykomish River further supports the idea that, although it is hatchery influenced, like other populations in the basin, steelhead from the South Fork Skykomish River should be considered of native Puget Sound origin rather than out-of-DPS.

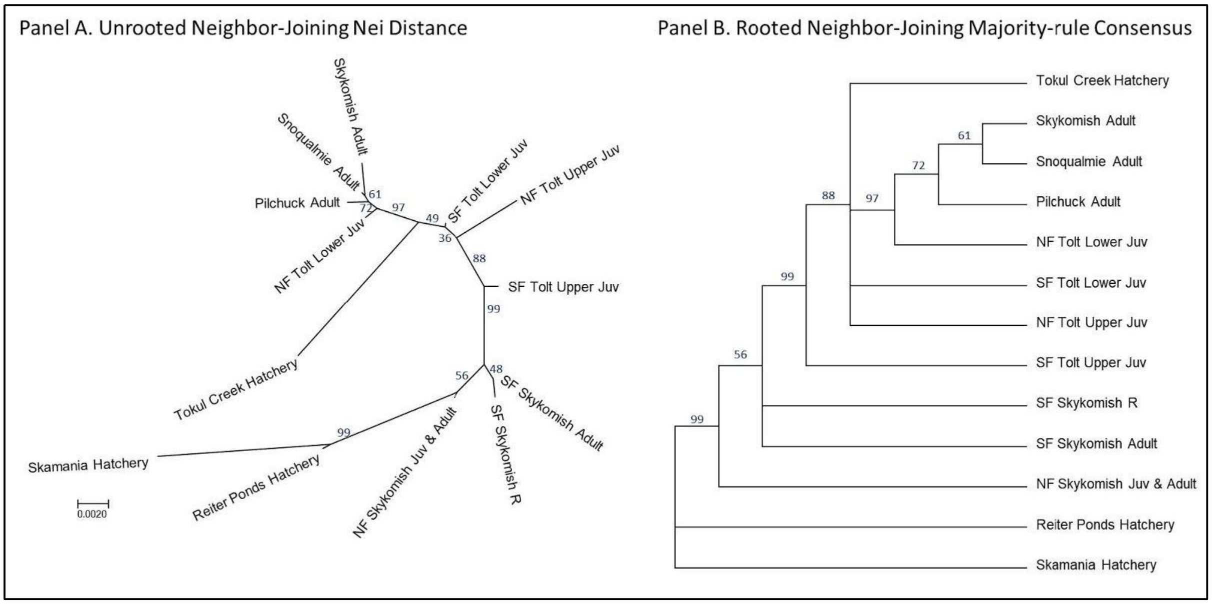

Figure 5. Unrooted neighbor-joining tree (Panel A) and majority-rule consensus tree rooted by Skamania Hatchery (Panel B). Percent support from 10,000 bootstrap trees are shown for each non-terminal branch in both trees. Branch lengths for the unrooted tree correspond to Nei's unbiased distances. The branch lengths for the rooted tree are uninformative. All branches with bootstrap values less than 50% are collapsed in the majority-rule consensus tree. The strongest support was found for separation of Skamania and Reiter Ponds Hatcheries from all other groups, separation of native winter groups from all other groups, and separation of the Skamania, Reiter Ponds, and Skykomish summer groups from all other groups (WDFW 2021).

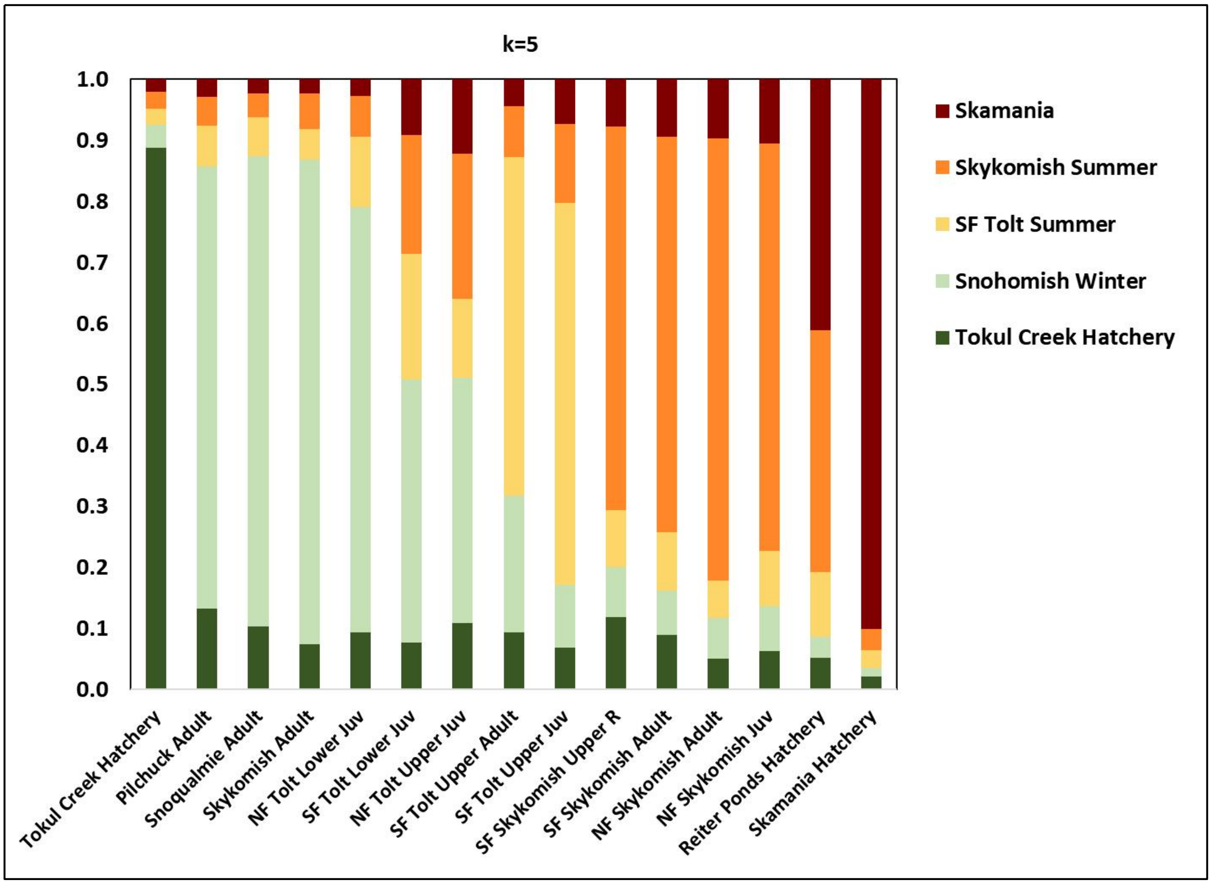

Figure 6. STRUCTURE estimates of the average genetic composition by group with k=5. The genomes of the SF and NF Skykomish are largely representative of Skykomish summer steelhead ancestry.

The analysis suggests that summer-run steelhead from the South Fork Skykomish and the North Fork Skykomish Rivers are closely related, as indicated by the F_{st} value of 0.015 (Warheit et al. 2021). The population dynamics leading to this low genetic differentiation and the biological significance of the difference is uncertain. It is possible that introgression with hatchery-origin summer steelhead released from the Reiter Ponds Hatchery has occurred at different levels to fish spawning in the South- and North Forks in the past, or it may reflect the recent change in management that limited transport of returning hatchery fish to the South Fork Skykomish River upstream of Sunset Falls. To summarize, South Fork Skykomish steelhead may not have had as much influence from the Skamania stock because the initial hatchery program included both the natural-origin Skykomish steelhead and hatchery-origin early spawning summer steelhead. The influence was recently reduced through selective transport of natural-origin summer steelhead into the upper South Fork Skykomish River. Furthermore, steelhead from the South Fork Skykomish and the North Fork Skykomish-may be more closely related than previously thought.

The implications of these findings for formal population identification (Myers et al. 2015) and recovery planning (NMFS 2019c) are uncertain and being reevaluated. While previous analyses (i.e., (Kassler et al. 2008)) have assumed a much larger impact from the Skamania stock, a thorough review of existing documents in light of this updated information is clearly warranted, especially regarding the genetic similarity of SF Skykomish summer steelhead and other summer steelhead in the Snohomish basin, to refine the population status and recovery role of South Fork Skykomish summer steelhead within the Puget Sound Steelhead DPS.

Historically, the Snohomish River basin was one of the primary producers of steelhead in Puget Sound (PSSTRT 2013). Historical abundance estimates are lacking but county harvest levels attributed to the Snohomish in the late 1800s and early 1900s indicate that the numbers of steelhead were quite high. Harvests recorded for Snohomish County during these years were indicative of runs over 100,000 fish (PSSTRT 2013). Escapement surveys by the Washington Department of Fish and Game in 1929 found large aggregations of steelhead in the Pilchuck, Sultan, Skykomish, and Tolt rivers, and medium aggregations in the North Fork and South Fork Skykomish, Wallace, Snoqualmie, and Raging rivers (Myers et al. 2015). NMFS (2019c) recovery goals for the three winter-run steelhead populations in the Snohomish basin ranged from 12,000 (high productivity) to 40,200 (low productivity).NMFS (2019c) recovery goals range from 6,100 to 20,600 adults for the Snohomish/Skykomish winter-run steelhead DIP; 2,500 to 8,200 adults for the Pilchuck River DIP; and 3,400 to 11,400 adults for the Snoqualmie River DIP. The recent 5-year (2015-2019) combined geometric mean escapement for the three winter-run populations in the Snohomish River basin is 1,828fish (Figure 7; Table 10), or 15.2% of the combined high productivity recovery plan goal. Winter-run steelhead escapements have declined significantly since the mid-1990s (Ford et al. 2011; PSSTRT 2013; Scott and Gill 2008).

The 5-year geometric mean abundance for the Snohomish/Skykomish population was 975 natural-spawners from 2010-2014, and 690 natural-spawners from 2015-2019; this indicates an overall decline of 29 percent (Table 10). Hard et al. (2015) estimated that the probability that the population would decline to a QET of 73 steelhead was approximately 40% within 100 years; (see Table 9) based on a mean population growth rate of -0.005 (λ=0.995). The 5-year geometric mean abundance for the Pilchuck population was 626 natural-origin spawners from 2010-2014 and 638 from 2015-2019; indicating an overall increase of 2 percent (Table 10). Hard et al. (2015) estimated that the probability that the population would decline to a QET of 34 steelhead was also approximately 40% within 100 years based on a mean population growth rate of -0.006 (λ=0.994). The 5-year geometric mean abundance for the Snoqualmie population was 1,249 natural-spawners from 2005 through 2009 and only 680 from 2010 through 2014; indicating an overall decline of 46% (NWFSC 2015). Hard et al. (2015) estimated that the probability that the population would decline to a QET of 73 steelhead was approximately 70% within 100 years based on a mean population growth rate of -0.027 (λ=0.973).

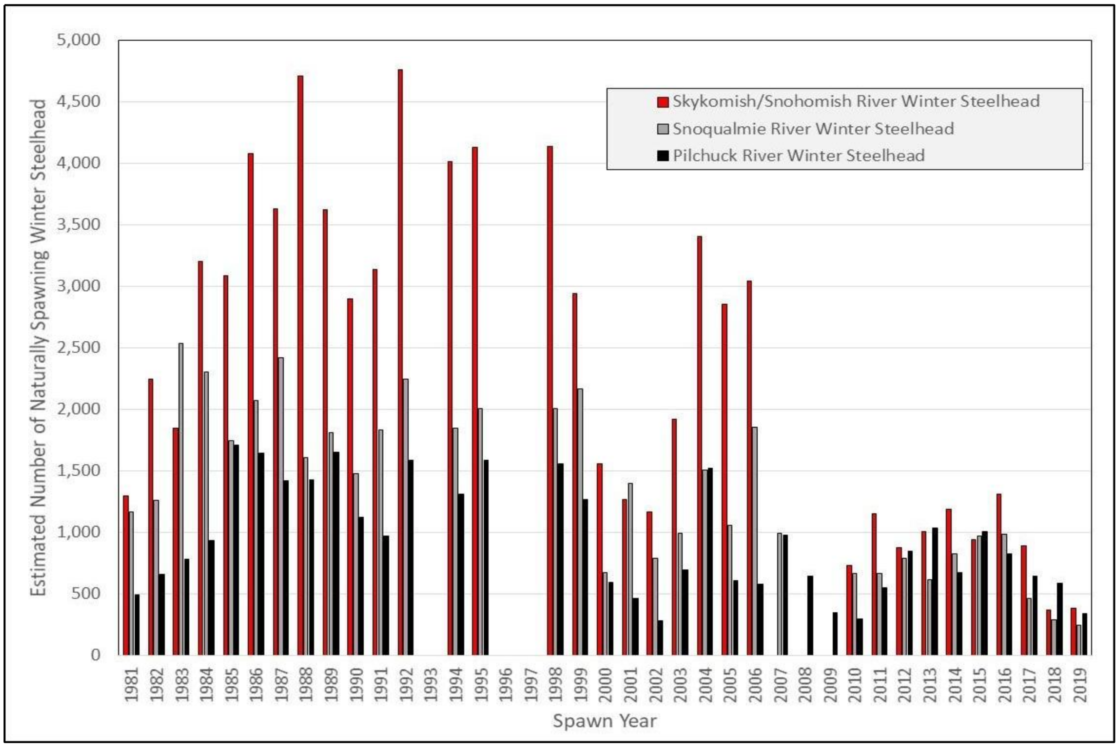

Figure 7. Snohomish Basin winter-run steelhead estimated escapement for 1980/1981 through 2018/2019. Escapement estimates based on redds enumerated on or after March 15 (source: Score database; WDFW and Tulalip Tribes unpublished data).

NMFS (2019) recovery goals for the two summer-run steelhead populations in the Snohomish basin ranged from 500 (high productivity) to 1,700 (low productivity). NMFS (2019) recovery goals range from 300-1,200 adults for the Tolt River summer-run steelhead DIP, and 200-500 adults for the North Fork Skykomish River DIP. For Tolt River summer-run steelhead (the only summer-run population in the basin for which redd count data are available), escapements have declined since the late 1990s. The 5-year geometric mean abundance for the Tolt population was 108 natural-origin spawners from 2010 through 2014 and 40 from 2015-2019; this indicates an overall decrease of 63 percent. Hard et al. (2015) estimated that the probability that the population would decline to a QET of 25 steelhead was approximately 80 percent within 100 years (see Table 9), based on a mean population growth rate of -0.013 (λ=0.987).

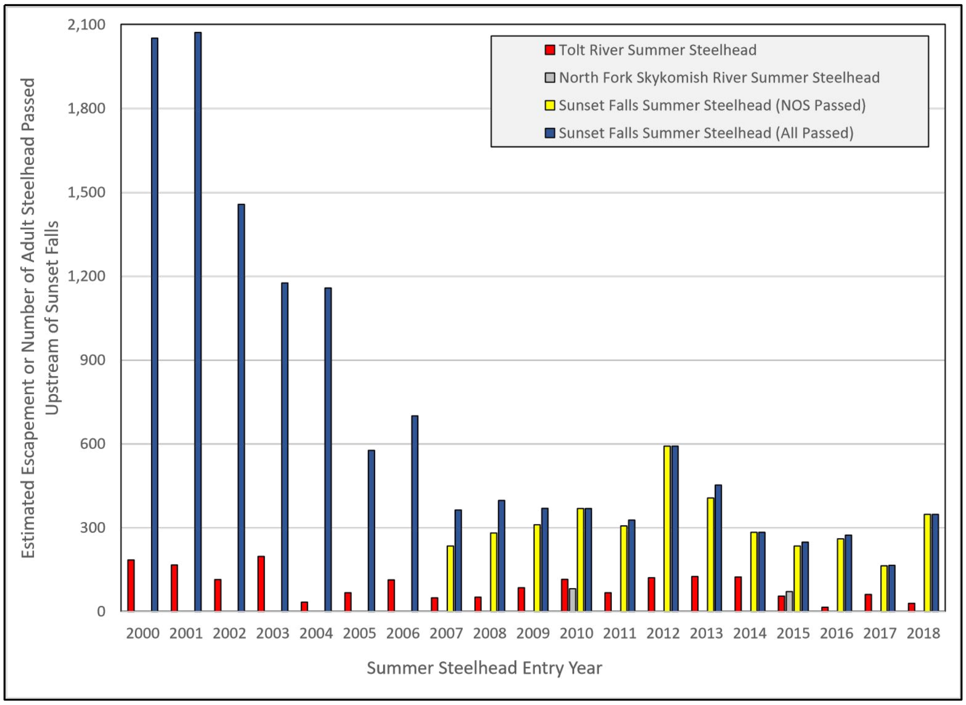

Figure 8. Snohomish Basin summer-run steelhead estimated escapement or number of fish transported upstream of Sunset Falls. (Source: Score database; WDFW and Tulalip Tribes unpublished data; WDFW annual reports submitted pursuant to permit# 14433).

Summer-run steelhead in the Snohomish basin are generally demographically depressed, with very low natural production in both the North Fork Skykomish River (82 in 2010) and South Fork Tolt River (mean of 76 from 2007 through 2018) summer-run populations (WDFW and Tulalip Tribes 2019). However, summer-run steelhead production is at a higher level in the South Fork Skykomish River, numbering in the hundreds[6] (Table 11). Although this group of fish is not considered a DIP (Myers et al. 2015), it is larger than the two summer-run steelhead populations in the basin classified as DIPs. The abundance of summer steelhead in the South Fork Skykomish River is thought to have been only minimally affected by hatchery releases in the last decade (WDFW 2019a), due to limitations on transport of hatchery-origin early summer steelhead upstream of Sunset Falls.

Data are not available to evaluate changes in the diversity of steelhead in the Snohomish River basin. However, it is likely that the degradation and loss of habitat in the watershed, and past harvest practices that disproportionately affected the earliest returning fish, have reduced the diversity of the species relative to that prior to hatchery production using early summer steelhead from Skamania Hatchery. Genetic diversity of the winter-run natural populations has likely been adversely affected by releases of non-native early-winter steelhead from basin hatcheries, in watershed areas where spawn timings for natural and hatchery-origin fish have overlapped.

[6]Average for the last 5 years is 294 in South Fork Skykomish River vs. 49 in South Fork Tolt River; in 2010, South Fork Skykomish River escapement was about four times that of the North Fork Skykomish River.

We are particularly concerned with impacts on the North Fork Skykomish summer steelhead population because (Myers et al. 2015) identified it as a DIP and NMFS maintained that either it or the South Fork Tolt summer steelhead population must be viable in order to recover the species (NMFS 2019c). The North Fork Skykomish River and the Tolt River contain populations that assure geographic spread, provide habitat diversity, reduce catastrophic risk, and increase life-history diversity of Puget Sound steelhead (NMFS 2019c) necessary for recovery of the species.

2.2.4. Status of Critical Habitat for Puget Sound Steelhead

Critical habitat has been designated for Puget Sound steelhead (81 FR 9252, February 24, 2016). Designated critical habitat for the Puget Sound steelhead DPS includes specific river reaches associated with the following subbasins: Strait of Georgia, Nooksack, Upper Skagit, Sauk, Lower Skagit, Stillaguamish, Skykomish, Snoqualmie, Snohomish, Lake Washington, Duwamish, Puyallup, Nisqually, Deschutes, Skokomish, Hood Canal, Kitsap, and Dungeness/Elwha. The designation does not include specific areas in the nearshore zone in Puget Sound because steelhead rapidly migrate out of freshwater and into offshore marine areas, unlike other salmonid species. Therefore, Puget Sound steelhead critical habitat does not include offshore marine areas. There are 18 subbasins (HUC4 basins) containing 66 occupied watersheds (HUC5 basins) within the range of this DPS. Nine watersheds received a low conservation value rating, 16 received a medium rating, and 41 received a high rating to the DPS (78 FR 2726, January 14, 2013). Of the nine watersheds within the Snohomish system (Skykomish River Forks, Skykomish River/Wallace River, Sultan River, Skykomish River/Woods Creek, Tye and Beckler Rivers, Pilchuck River, Snohomish River, Lower Snoqualmie River, and Middle Fork Snoqualmie River), seven received high and two received medium conservation value ratings.

The Puget Sound Critical Habitat Analytical Review Team found that habitat utilization by steelhead in a number of Puget Sound areas has been substantially affected by a variety of factors (NMFS 2013) including: dams and other anthropogenic barriers, poor forestry practices, urbanization, loss of wetland and riparian habitat, and reduced river braiding and sinuosity. In addition to limiting habitat accessibility, dams have affected steelhead habitat quality through changes in river hydrology, altered temperature profile, reduced downstream gravel recruitment, and the reduced recruitment of large woody debris. In addition, many upper tributaries in the Puget Sound region have been affected by poor forestry practices, while many of the lower reaches of rivers and their tributaries have been altered by agriculture and urban development. These actions have also constricted river flows, particularly during high flow events, increasing the likelihood of gravel scour and the dislocation of rearing juvenile steelhead. The loss of side-channel habitats has also reduced important areas for spawning, juvenile rearing, and overwintering habitats. Estuarine areas have been dredged and filled, resulting in the loss of important juvenile steelhead rearing areas.

In addition to being a factor that contributed to the present decline of Puget Sound steelhead natural populations, the continued destruction and modification of steelhead habitat is the principal factor limiting the viability of the Puget Sound Steelhead DPS into the foreseeable future (NMFS 2013). Because of their limited distribution in upper tributaries, summer-run steelhead may be at higher risk than winter-run steelhead from habitat degradation in larger, more complex watersheds.

NMFS determines the range-wide status of critical habitat by examining the condition of its physical and biological features (also called "primary constituent elements," or PCEs, in some designations) that were identified when the critical habitat was designated. These features are essential to the conservation of the listed species because they support one or more of the species' life stages (e.g., sites with conditions that support spawning, rearing, migration and foraging). In the proposed rule for Puget Sound steelhead (78 FR 2726, January 14, 2013), PCEs for the Snohomish populations included:

(1) Freshwater spawning sites with water quantity and quality conditions and substrate supporting spawning, incubation and larval development;
(2) Freshwater rearing sites with:
    i. Water quantity and floodplain connectivity to form and maintain physical habitat conditions and support juvenile growth and mobility;
    ii. Water quality and forage supporting juvenile development; and
    iii. Natural cover such as shade, submerged and overhanging large wood, log jams and beaver dams, aquatic vegetation, large rocks and boulders, side channels, and undercut banks.
(3) Freshwater migration corridors free of obstruction and excessive predation with water quantity and quality conditions and natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels, and undercut banks supporting juvenile and adult mobility and survival;
(4) Estuarine areas free of obstruction and excessive predation with:
    i. Water quality, water quantity, and salinity conditions supporting juvenile and adult physiological transitions between fresh- and saltwater;
    ii. Natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, side channels; and
    iii. Juvenile and adult forage, including aquatic invertebrates and fishes, supporting growth and maturation.
(5) Nearshore marine areas free of obstruction and excessive predation with:
    i. Water quality and quantity conditions and forage, including aquatic invertebrates and fishes, supporting growth and maturation; and
    ii. Natural cover such as submerged and overhanging large wood, aquatic vegetation, large rocks and boulders, and side channels.
(6) Offshore marine areas with water-quality conditions and forage, including aquatic invertebrates and fishes, supporting growth and maturation.

Critical habitat is designated for Puget Sound steelhead in the Snohomish River within the action area. Critical habitat includes the stream channels within the basin, and includes a lateral extent as defined by the ordinary high-water line (33 CFR 319.11). The Puget Sound Critical Habitat Analytical Review Team CHART) identified management activities that may affect the PCEs within the action area (NMFS 2013). These activities included agriculture, grazing, irrigation impoundments and withdrawals, channel modifications/diking, dams, forestry, urbanization, sand/gravel mining, wetland loss/removal, and road building/maintenance (81 FR 9252, February 24, 2016).

Urbanization has caused direct loss of riparian vegetation and soils, significantly altered hydrologic and erosional rates and processes (e.g., by creating impermeable surfaces such as roads, buildings, parking lots, sidewalks), and polluted waterways with storm-water and point-source discharges. The loss of wetland and riparian habitat has dramatically changed the hydrology of many streams all to the detriment of steelhead habitat, with increases in flood frequency and peak flow during storm events and decreases in groundwater driven summer flows. River braiding and sinuosity have been reduced through the construction of dikes, hardening of banks with riprap, and channelization of the mainstem rivers. These actions have led to constriction of river flows, particularly during high flow events, increasing the likelihood of gravel scour and the dislocation of rearing juvenile steelhead. The loss of side-channel habitats has also reduced important areas for spawning, juvenile rearing, and overwintering habitats. Estuarine areas have been dredged and filled, resulting in the loss of important juvenile steelhead rearing areas.

In addition to being a factor that contributed to the present decline of Puget Sound steelhead natural populations, the continued destruction and modification of steelhead habitat is the principal factor limiting the viability of the Puget Sound steelhead DPS into the foreseeable future (NMFS 2013). Because of their limited distribution in upper tributaries, summer-run steelhead may be at higher risk than winter-run steelhead from habitat degradation in larger, more complex watersheds.

2.3. Action Area

"Action area" means all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action (50 CFR 402.02). The action area resulting from this analysis includes all tributaries within the greater Snohomish River basin that are accessible to juvenile and adult hatchery steelhead (Figure 9). We define the greater Snohomish River basin as the Snohomish River and all its tributaries, including larger rivers such as the Skykomish River and Snoqualmie River, as well as other major tributaries such as the Pilchuck River, Sultan River, and Tolt River. These tributaries constitute all freshwater habitats within the greater Snohomish River basin accessible, either naturally or through operation of the Sunset Falls Trap and Haul Program, to steelhead originating from the proposed hatchery program would migrate, and spawn naturally. Several important areas within the greater Snohomish River basin are noted below.

- Everett Bay, in the vicinity of Mukilteo, Washington;
- The Snohomish River from RM 0.0 to near RM 8 is influenced by tidal exchange where the river branches into sinuous sidechannels such as Ebey's Slough;
- The Snohomish River from RM 8 to the upstream extent of anadromous fish access in Skykomish River and Snoqualmie river watersheds;
- Wallace River from its confluence with the Skykomish River at RM 35.7 to the upstream extent of anadromous fish access;
- The North Fork Skykomish River from its confluence with South Fork Skykomish River at RM 51.5 to the upstream extent of anadromous fish access;

- The South Fork Skykomish River from its confluence with the North Fork Skykomish River at RM 51.5,
- The South Fork Skykomish River from natural anadromous barriers at Sunset Falls, Canyon Falls, and Eagle Falls, to the upstream extent the river made accessible to anadromous fishes by operation of the WDFW's trap and haul facility.

The action area also includes the marine waters of Puget Sound and the Strait of Juan de Fuca to Cape Flattery off the Washington Coast in the Pacific Ocean.

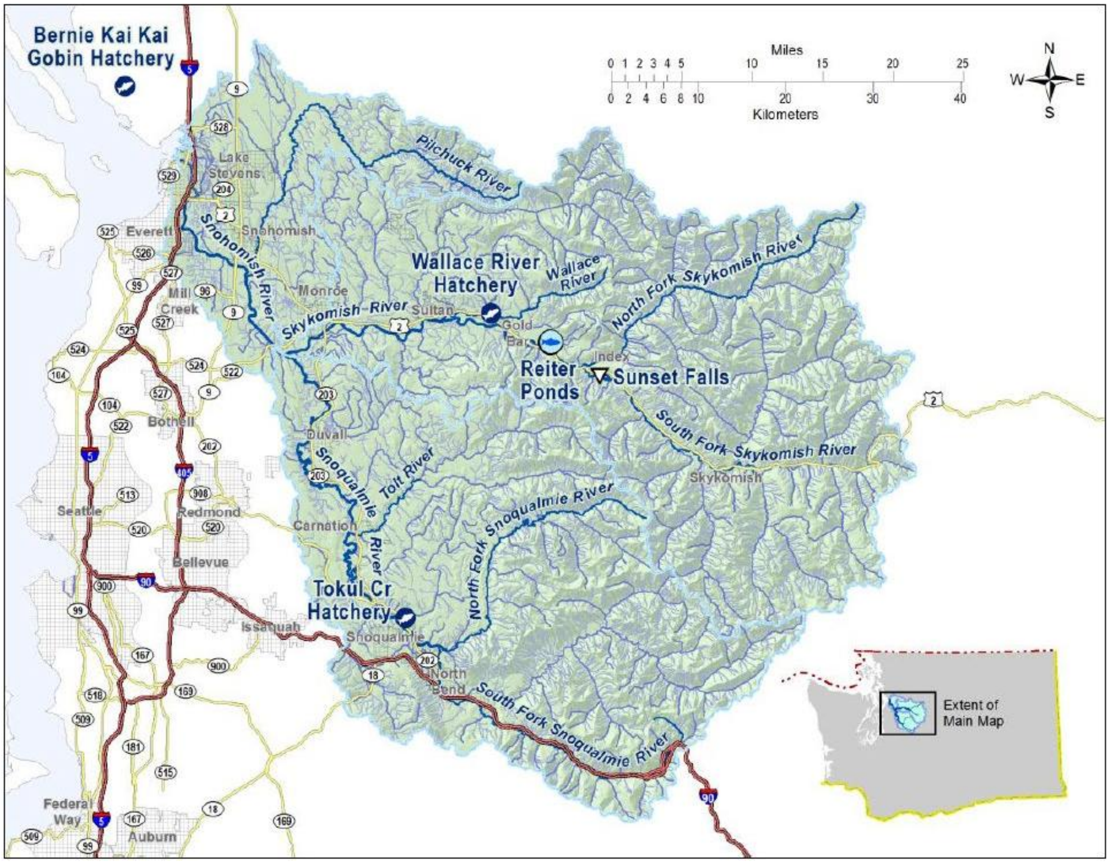

Figure 9. Action area, the Snohomish River watershed.

2.4. Environmental Baseline

The "environmental baseline" refers to the condition of the listed species or its designated critical habitat in the action area, without the consequences to the listed species or designated critical habitat caused by the proposed action. The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultations, and the impact of State or private actions that are contemporaneous with the consultation in process. The consequences to listed species or designated critical habitat from ongoing agency activities or existing agency facilities that are not within the agency's discretion to modify are part of the environmental baseline (50 CFR 402.02).

In order to understand what is affecting a species, it is first necessary to understand the biological requirements of the species. Each stage in a species' life-history has its own biological requirements (Groot and Margolis 1991; NRC 1996; Spence et al. 1996). Generally speaking, during spawning migrations, adult salmon require clean water with cool temperatures and access to thermal refugia, dissolved oxygen near 100 percent saturation, low turbidity, adequate flows and depths to allow passage over barriers to reach spawning sites, and sufficient holding and resting sites. Anadromous fish select spawning areas based on species-specific requirements of flow, water quality, substrate size, and groundwater upwelling. Embryo survival and fry emergence depend on substrate conditions (e.g., gravel size, porosity, permeability, and oxygen concentrations), substrate stability during high flows, and, for most species, water temperatures of 55ºF or less. Habitat requirements for juvenile rearing include seasonally suitable microhabitats for holding, feeding, and resting. Migration of juveniles to rearing areas, whether the ocean, lakes, or other stream reaches, requires free access to these habitats.

We consider the current conditions experienced by salmonids within the context of how numerous human activities have affected ESA-listed Chinook salmon and steelhead populations and the species' PCEs in the action area. Historical and on-going activities in the freshwater and marine environment have resulted in the degradation and loss of habitat sustaining ESA-listed fish species that have had detrimental effects on the short and long-term survival of the species. Fisheries have historically impacted the abundance of Chinook salmon and steelhead escaping to spawn in the action area. The operation of hatcheries to produce fish for harvest has impacted the viability status of Snohomish River basin salmon and steelhead populations. More recently, habitat restoration actions have been included that are having beneficial effects on fish habitat. Essential for considering environmental baseline effects on ESA-listed Chinook salmon and steelhead is how the habitat, harvest, and hatchery ("All H") activities described under the Environmental Baseline interact in determining the status of ESA-listed fish populations.

2.4.1. Habitat

At 1,856 square miles in area, the Snohomish River basin is the second largest watershed draining to Puget Sound (Snohomish Basin Salmonid Recovery Technical Committee 1999). The Snohomish River is formed by the confluence of the Skykomish and Snoqualmie rivers. Numerous tributaries enter the Snohomish River mainstem, with the largest being the Pilchuck River. Over 1,730 tributary rivers and streams have been identified in the basin, totaling approximately 2,718 miles in length (Williams et al. 1975). The Skykomish River originates in the Cascade Mountains. The upper Skykomish River mainstem has a steep gradient, transporting sediment quickly through confined channels (Snohomish Basin Salmon 2005). As the river gradient decreases downstream of Gold Bar, gravel and cobble settle out, forming multiple channels and excellent spawning riffles and rearing habitat (Snohomish Basin Salmon 2005). In the lower reaches, the river banks in many places are armored and this blocks access to side-channel rearing habitat(Snohomish Basin Salmonid Recovery Technical Committee 1999).

The Snohomish River basin is the major source of municipal water supply for Everett and southwest Snohomish County, and it contributes to water supplies in Seattle, Bellevue, and King County. Approximately 30 percent of land use in the mainstem-primary restoration group is currently in residential development. Residential land uses are, for the most part, located away from the river shorelines, which are zoned primarily for agricultural production. Pockets of rural residential development occur directly adjacent to mainstem river reaches near several small cities (Snohomish Basin Salmon 2005).

The Snohomish basin is one of the fastest growing areas in the Puget Sound region and the human population is projected to increase by 59 percent from 311,224 in 2000 to 528,293 in 2030 (SSPS 2007).The rapidly growing populations in the Seattle, Everett, and Marysville areas are spilling into the Snohomish basin as people look for places to live and work. The projected population growth rate in the Snohomish River basin between 2010 and 2035 is 36.9%. Most of this growth will occur in the western, incorporated portion of the watershed (Snohomish River Basin 2019). The areas that will experience the greatest population pressures are along the mainstem rivers and lowland tributaries as forest cover and ecosystem processes are altered or lost when these lands are converted to residential and urban areas.

Forestry is most dominant in the highest elevation areas, including the Upper North Fork Skykomish and South Fork Skykomish watershed upstream of Sunset Falls (Snohomish Basin Salmon 2005). Forest lands or wilderness comprise approximately 75 percent of the Snohomish River basin, which contributes to greater hydrologic and riparian function and better sediment conditions than are found in other basins across Puget Sound (SSPS 2007). Approximately 50 percent of forest lands within the basin are in federal ownership. Much of this federal land is contained within designated wilderness, and the remainder is managed under the Northwest Forest Plan that limits most activities to restoration. Although forest practice impacts on private and state-managed forest lands within the action area are limited by federally approved habitat conservation plans (HCPs), degradation and fragmentation of freshwater habitat from forest practice activities, with consequent effects on connectivity, are primary limiting factors and threats affecting salmon and steelhead natural populations in the Snohomish River basin. Logging road failures in the upper basins has resulted in channel destabilization and sedimentation, which has degraded the quality of salmon and steelhead spawning habitat (Snohomish Basin Salmonid Recovery Technical Committee 1999).

One primary habitat loss-related limiting factor in the action area has been the loss or impairment of floodplain function. Much of the historical salmon production capacity in the Snohomish River basin was associated with the presence of abundant floodplain and estuarine wetlands. Relative to historical levels, estuary wetland habitat has been reduced by 80-85% and side channel sloughs accessible by juvenile salmonids have been reduced by 55%. Riparian forest cover is only at 49% of the recommended 150-foot riparian buffer on the sides of fish habitat streams. Diking and bank armoring over the past century contributed to a 2-kilometer decrease in total length of side channels and a 55% reduction in the area of side channel sloughs on the Snohomish River. Dikes, bank armoring, and bridges have confined the mainstem Snohomish, Skykomish, and South Fork Skykomish Rivers that has eliminated or disconnected highly productive off-channel habitat, reduced edge-habitat complexity, and increase peak flows downstream. Riparian forest cover has been substantially degraded within these areas, reducing large woody debris recruitment to the waterways and further simplifying the habitat.

There has also been a 40 percent loss of beaver pond areas that function to moderate high flows, serve as fish refugia during low flows, and provide important salmon rearing areas. Extensive historical floodplain wetlands at Marshland and lower French Creek have been diked and drained, and no longer provide salmonid habitat. Estimates of lost natural Chinook and coho salmon production capacity associated with the historical loss of floodplain habitat are 40-61% and 50%, respectively (NWIFC 2016).Other habitat problems in the mainstem rivers include excessive erosion of stream banks, culverts that restrict or completely block fish access to streams, and degraded water quality, and high water temperature. Even brief periods in which water temperatures achieve 68°F can lead to migration delay or blockage (Goniea et al. 2006). Temperatures exceeding 72°F can be lethal to adult Chinook salmon (Richter and Kolmes 2005), however, multiple stressors (e.g., low dissolved oxygen content, high fecal coliform counts, or high levels of toxic metals) can cause mortality at lower temperatures.

Estuary and nearshore areas

Another primary limiting factor is the degradation and loss of estuary and nearshore habitats that have been and continue to be adversely affected by a number of activities (SSPS 2005). Approximately 70 percent of the Snohomish River basin nearshore shoreline has experienced significant modification and subsequent population declines in plant and animal species important for various salmon life stages (Snohomish Basin Salmon 2005). Riparian conditions, intertidal habitat conditions, and sediment delivery, transport, and storage have been extensively modified along the Snohomish nearshore, most notably due to construction of the Burlington Northern/Santa Fe railroad in the 1890s, construction of bulkheads, riprap, and piers in the industrial waterfront, and dredging of berths and the federal navigation channel (Snohomish Basin Salmon 2005).

The most substantial habitat impacts in the nearshore result from the railroad and from shoreline armoring. The effects of these actions have in many cases altered recruitment of sediment and large woody debris that has reduced primary and secondary productivity and reduced habitats for juvenile fish to seek refuge. The largest threat to estuary habitat is urbanization downstream of Interstate-5. Agricultural uses dominate the floodplain and account for 5 percent of the basin area (Snohomish Basin Salmonid Recovery Technical Committee 1999). Dikes and water control structures associated with these activities exist throughout the estuary, which limits the aquatic habitat accessible by fish and has reduced salmon rearing habitat in the lower mainstem and estuary by over 70 percent (Snohomish Basin Salmonid Recovery Technical Committee 1999). Some re-establishment of tidal influence has occurred since the late 1980’s due to both intentional and natural breaching of dikes at some locations. These actions have improved salmon habitat in the area.

Marine

Puget Sound, a fjord system of submerged glacier valleys formed during a previous ice age, is an estuary located in northwest Washington State and covers an area of about 900 square miles, including 2,500 miles) of shoreline. Puget Sound can be subdivided into five interconnected basins separated by shallow sills: (1) the San Juan/Strait of Juan de Fuca Basin (also referred to as “North Puget Sound”), (2) Main Basin, (3) Whidbey Basin, (4) South Puget Sound, and (5) Hood Canal. Each basin differs in features such as temperature regimes, water residence and circulation, biological conditions, depth profiles and contours, species, and habitats (Drake et al. 2010).

The discussion of marine habitat in Puget Sound that follows is summarized from information contained in the Shared Strategy for Puget Sound Chinook Salmon Recovery Plan (SSPS 2007) unless otherwise noted. This snapshot of habitat issues in Puget Sound highlights some of the challenges for ESA-listed species:

- 33 percent of marine shorelines in the Puget Sound have been modified with bulkheads or other armoring.
- 73 percent of the wetlands in major river deltas of Puget Sound have been lost in the last 100 years.
- Before 1900, approximately 4,000 acres of tidal marshes and mudflats once existed up to RM 5.5 where Harbor Island and the East and West Waterways now stand in Elliott Bay, Seattle.
- Of the 290 "pocket estuaries" formed by small independent streams and drainages have been identified throughout Puget Sound, 75 are stressed by urbanization.
- More than 40 aquatic nuisance species are currently found in the Puget Sound.
- 972 municipal and industrial wastewater discharges into the Puget Sound Basin are permitted by the Washington Department of Ecology.
- 180 permit holders had specific permission to discharge metals, including mercury and copper.
- Over 1 million pounds of chemicals were discharged into Puget Sound in 2000 by the 20 industrial facilities that reported their releases to the Environmental Protection Agency.
- An estimated 500,000 on-site sewage systems are estimated to occur in the Puget Sound basin.
- 16 major spills of oil and hazardous materials of greater than 10,000 gallons occurred in Puget Sound between 1985 and 2001.
- 191 smaller spills occurred from 1993 to 2001, releasing a total of more than 70,000 gallons.
- More than 2,800 acres of Puget Sound's bottom sediments are contaminated to the extent that cleanup is warranted.

These specific examples can be summarized by seven major stressors in the marine environment of Puget Sound: (1) Loss and/or simplification of deltas and delta wetlands; (2) Alteration of flows through major rivers; (3) Modification of shorelines by armoring, overwater structures and loss of riparian vegetation; (4) Contamination of nearshore and marine resources; (5) Alteration of biological populations and communities; (6) Transformation of land cover and hydrologic function of small marine discharges via urbanization; and (7) Transformation of habitat types and features via colonization by invasive plants.

Restoration and Mitigation efforts

The Snohomish River Basin Salmon Conservation Plan (Salmon Plan) was adopted in 2005. This plan defines a strategic approach to salmonid recovery over a 50-year period and identifies 10-year benchmarks for habitat restoration actions (Snohomish Basin Salmon 2005). Since 2005, there have been many in-situ successes on restoration projects in mainstems, estuaries, and tributaries. However, overall environmental conditions continue to decline.

The Salmon Plan focuses on restoring and protecting the natural processes that create and maintain floodplain features and support salmon throughout their life cycles. Restoration also benefits steelhead and other salmonids, such as bull trout (Snohomish River Basin 2019). According to Snohomish River Basin (2019), the two-pronged strategy for the first 10 years of implementation include the following:

- Improve habitat quantity and quality in the nearshore, estuary, and mainstem rivers
- Minimize habitat losses and make habitat gains through restoration in the rest of the Snohomish/Skykomish Basin

Restoration efforts have made progress toward the 10-year goals since 2005, but a process was not designed to track rates of additional degradation Snohomish River Basin (2019). The Salmon Plan defines 62 sub-basins in the Snohomish River basin and establishes 12 strategy groups in the nearshore area based on their location, habitat conditions, and current and potential salmon use. Habitat restoration targets are organized by nearshore, estuary, mainstem, and other sub-basin strategy groups Snohomish River Basin (2019).

The 2005 Salmon Plan set a 10-year target of 1,237 acres of estuary restoration, with the recognition that such restoration effort would only be the first step. To date, the Snohomish River estuary has the most restored area of any estuary in Puget Sound, with 1025.6 of the 10-year target of 1,237 acres restored Snohomish River Basin (2019). Estuary restoration projects take time to reach peak performance to support juvenile salmonids. Restoration work carried out to date has been more complex, expensive, and time consuming than was likely assumed in 2005 Snohomish River Basin (2019). In the mainstem, priorities include restoring riparian, edge, and off-channel habitat, and placing large woody debris where appropriate to support rearing of juvenile Chinook salmon and other species Snohomish River Basin (2019).

An example of a recent successful restoration project is the breaching of the levee and mitigation efforts at the Tulalip Tribes' Qwuloolt restoration site in 2015, which allowed fish access to 375 acres of tidal estuary for the first time in more than a century. Also, the footprint of the former levee, removed as part of the Lower Tolt River Floodplain Reconnection Project, now provides refuge to juvenile salmon from fast river flows. Also, many landowners have undertaken voluntary restoration efforts on their residential properties and farms, highlighting the depth of community commitment to protecting and restoring our environment for the benefit of fish, wildlife, and people Snohomish River Basin (2019).

The 2015 Snohomish Basin Protection Plan (SBPP) is an update to the Salmon Plan and serves as planning guidance for greater protection of hydrology and salmon habitat. The SBPP was developed to create watershed and ecosystem resilience in the face of growing populations and changing climatic conditions Snohomish River Basin (2019). The SBPP identified important steps for protecting hydrology and examined new and existing tools. By protecting hydrology, the SBPP aims to ultimately protect habitat quality, quantity, and diversity for fish and wildlife Snohomish River Basin (2019).

The Water Resource Inventory Area (WRIA) 7 Climate Change impacts on Salmon Issue Paper (leDoux et al. 2017) identifies key recommendations for restoration priorities to build resilience for salmon and the larger Snohomish Basin ecosystem. The proposed restoration priorities include work on hydrology, temperature, stormwater, sedimentation, sea level rise and ocean acidification (leDoux et al. 2017).

Aquatic habitat restoration is also expected as local transportation entities and the Washington State Department of Transportation repair or replace culverts that have blocked fish passage in the Snohomish River basin. Statewide, the Department is required to correct passage at over 400 culverts by 2030 to provide access to 90 percent of the habitat blocked by Department-owned barriers (WSDOT 2018).

2.4.2. Harvest

There are several hatchery programs within the greater Snohomish basin. Hatchery-origin Chinook salmon produced by WDFW and Tulalip Tribes are subject to directed harvest in U.S. waters in marine troll fisheries, terminal area net fisheries in marine waters, and recreational fisheries in marine waters, the Snohomish River, and the Skykomish River. The Tulalip Terminal Area Fishery (Commercial Catch Reporting Area 8D, or for recreational fisheries, the Tulalip Bay "bubble" area) is the primary terminal marine area where hatchery-origin Chinook salmon produced through the Tulalip Hatchery program are harvested, with an annual average of 5,749 fish harvested in tribal net fisheries (1988-2011) and 1,145 fish harvested in recreational fisheries (1994-2010) (Tulalip Tribes 2012). There is currently no fishery (tribal, commercial or recreational) that targets natural-origin Skykomish or Snoqualmie Chinook salmon. However, natural-origin Chinook salmon from the two populations are harvested (limited to certain time, gear, and area fisheries) or impacted incidentally in fisheries directed at hatchery-origin Chinook and coho salmon. Harvest of basin-origin natural and hatchery-origin Chinook salmon occurs in mixed-stock marine area fisheries in U.S. and Canadian waters. Exploitation rates on Skykomish and Snoqualmie natural-origin populations were nearly 80 percent for brood years 1980 through 1985. This level of harvest contributed to the decline in numbers of fish returning to the spawning grounds (PSIT and WDFW 2010). Harvest impacts on natural-origin Chinook salmon produced in the greater Snohomish basin have been substantially reduced over the last few decades (SSPS 2005).

Fishery impact modeling by the co-managers shows a declining trend in annual fishing year exploitation rate from 1983-2000 that have remained relatively stable since 2000 (PSIT and WDFW 2010). Declining from an annual average of 70 percent in the 1980s, exploitation rates from 2003 through 2010 on natural-origin Chinook salmon from the Snohomish River basin have ranged from 21 to 34 percent; averaging 28 percent (PSIT and WDFW 2013). These impacts occur incidentally in terminal area fisheries targeting hatchery-origin Chinook salmon and coho salmon, and in pre-terminal marine area mixed-stock fisheries. The goal of harvest management is to maintain rebuilding exploitation rates low enough (24 percent) so that natural-origin Chinook salmon escape in increasing numbers to spawn in protected or restored habitat. Prior to the Tulalip Tribes' development of an extreme terminal area fishery targeting hatchery-origin fish, the Tribes' harvest was composed of 50-60 percent natural-origin Chinook salmon. The Tribes' combined natural-origin Chinook salmon harvest during the past 20 years in Areas

8A and 8D have averaged less than 5 percent (Tulalip Tribes, unpublished Chinook salmon harvest data).

Within the action area, Tulalip tribal commercial and ceremonial and subsistence fisheries for primarily hatchery-origin salmon and steelhead occur seasonally in Everett Bay, Port Susan, Tulalip Bay, and in the lower Snohomish River, contingent on the availability of fish surplus to escapement needs. WDFW-managed non-tribal commercial fisheries in commercial harvest areas 8A and 8D target surplus returning coho, fall chum, and pink salmon. Between 2010 and 2019, annual tribal and all citizen net fishery harvests of coho salmon in the analysis area averaged 41,500 and 351, respectively (WDFW and PSTIT 2020). Between 2010 and 2019, odd-year tribal and all citizen net fishery harvests of pink salmon averaged 146,279 and 328,167, respectively. Between 2010 and 2019, annual tribal and all citizen net fishery harvests of fall-run chum salmon averaged 13,060 and 1,300, respectively.

Recreational fisheries for salmon managed by WDFW occur in the Snohomish, Skykomish, Wallace, and Snoqualmie rivers. Regulations vary by time, area, and species contingent on the availability of fish surplus to escapement needs. Annual recreational fisheries from 2013-2018 averaged 3,237, 1,020, 221, and 232 coho salmon harvested in the Snohomish, Skykomish, Snoqualmie, and Wallace river basins, respectively (all six reports). Annual recreational fisheries from 2013-2018 averaged 38,277, 7,916, 312, and 62 pink salmon harvested in the Snohomish, Skykomish, Snoqualmie, and Wallace river basins, respectively. Annual recreational fisheries from 2013-2018 averaged 353 Chinook salmon harvested in the Skykomish River basin (current sport harvest regulations limit Chinook salmon harvest to 1 or 2 adult hatchery Chinook salmon per day on only the Skykomish River (downstream of the Wallace River) in the months of June and July). Annual recreational fisheries from 2013-2018 averaged 36 chum salmon harvested in the Skykomish River basin.

Within the action area, Tulalip tribal commercial and ceremonial and subsistence fisheries for primarily hatchery-origin steelhead occur seasonally in Everett Bay, Port Susan, Tulalip Bay, and in the lower Snohomish River, contingent on the availability of fish surplus to escapement needs. Non-Indian commercial fishing is closed to steelhead in all areas, although there is some incidental harvest mortality in salmon-directed fisheries. Recreational fisheries for salmon and non ESA-listed steelhead managed by WDFW occur in the Snohomish River, Snoqualmie River, Skykomish River, and select tributaries. Between 2000 and 2012, annual tribal and non-Indian fishery harvests of non ESA-listed early winter steelhead (EWS) in the analysis area averaged 95 and 4,482 fish, respectively (WDFW 2014c). During this same period, recreational fisheries harvest of early summer steelhead averaged 2,895 fish per year.

2.4.3. Hatcheries

Included in the Environmental Baseline are the ongoing effects of hatchery programs or facilities which have undergone Federal review under the ESA, as well as the past effects of programs that have not yet undergone such review. This includes effects of the proposed action, which have not been previously authorized.

Recent or ongoing hatchery programs relevant to steelhead and considered within baseline effects start with the importation of EWS hatchery broodstock from Chambers Creek in the early-1960s (WDFW 2014b; WDFW 2014c and following). From the late-1970s to late-1990s, the co-managers released EWS at all sites in the basin from adult returns to Tokul Creek (and Whitehorse Ponds when insufficient broodstock was available). Prior to 1994, eggs collected at Tokul Creek were incubated to the eyed stage on-site and transferred to Lakewood Hatchery for further incubation, rearing, and mass-marking subsequent to dispersal of juvenile EWS for rearing and release in other Puget Sound areas, including the Snohomish basin. The current goal for the Snohomish River basin EWS program is to manage the two programs separately. Beginning in 2015, broodstock for the Wallace/Reiter EWS program have been maintained primarily through collection of adults returning to Wallace River Hatchery and Reiter Ponds. WDFW has implemented a genetic monitoring program and the biological opinions for early winter programs place limits on the genetic impact of these programs on ESA-listed steelhead. However, there is detectable genetic differentiation between the early summer-run steelhead broodstock that originated from Columbia basin and the natural-origin summer steelhead from the Puget Sound.

Similar to the EWS programs, WDFW began an early summer steelhead hatchery program using native Skykomish summer steelhead and broodstock from the Columbia River basin, known as Skamania summer steelhead. WDFW similarly developed hatchery release programs in the Stillaguamish, Snohomish, and Green River watersheds. WDFW produced early summer steelhead over a period of decades that resulted in straying and interbreeding with natural-origin fish. Interbreeding of early summer steelhead has resulted in a measurable Columbia-basin signature on the genetic profile of steelhead in the Snohomish basin and, more broadly, within other watersheds of the Puget Sound (NMFS 2019c). While the signature of Columbia-basin early summer steelhead may decrease over time due to natural selection and genetic drift, it cannot be fully eliminated from the Snohomish basin populations without further risking the persistence of the extant natural-origin summer steelhead in the Snohomish basin. Thus, some natural-origin summer steelhead populations with lineage to the early summer steelhead will be among the populations contributing to overall DPS viability, and to future hatchery programs. The long-term fitness consequences of the introduction of genetic material from the Columbia basin into the Puget Sound steelhead DPS are unknown, but continued releases of out-of-DPS early summer steelhead hatchery fish were considered a major concern for diversity in the DPS (Hard et al. 2007).

In addition to genetic influences, genetic analyses indicate that early summer steelhead spawned in sections of the Skykomish basin habitats that were subsequently utilized by natural-origin steelhead, particularly the North Fork Skykomish River. Although there is likely limited potential of redd superimposition by early summer steelhead on natural-origin steelhead, the earlier emerging early summer steelhead fry are at a competitive advantage to later emerging natural-origin steelhead. This is likely attenuated by the low reproductive success of hatchery-origin strays (Christie et al. 2014).

The genetic influence of the early summer steelhead releases in the Snohomish basin played a central role in development of the proposed new integrated summer steelhead hatchery program. In 2014, WDFW first analyzed the proportion of effective hatchery contribution (PEHC), a measurement of gene flow between populations, to assess the degree to which natural-origin populations were affected by early summer steelhead. In this case, WDFW estimated the impacts of Reiter Ponds early summer steelhead from the hatchery program on the natural-origin North

Fork Skykomish and Tolt summer steelhead populations. WDFW's analysis suggested that gene flow between hatchery and natural-origin populations was so large that the two natural-origin populations could be considered feral populations of Skamania-origin summer steelhead (Warheit 2014b).

Subsequent refinements by WDFW to the PEHC analysis estimates produced in the 2014 document have been revised considerably (Warheit et al. 2021), so the "feral population" conclusion now appears to be an overstatement. Nonetheless, impacts from the early summer steelhead releases on gene flow remain. Summer steelhead in the South Fork Skykomish River, which occur almost entirely upstream of Sunset Falls, also display some Skamania-origin signature (Warheit et al. 2021). As a measure to reduce gene flow from the Reiter Ponds early summer steelhead hatchery program, beginning in 2016, WDFW reduced annual early summer steelhead smolt release levels by 40 percent, from a recent five-year average of 193,000 fish to 116,000 fish (Unsworth 2016), thereby substantially decreasing the number of returning early summer steelhead adults that could stray into steelhead spawning areas. There are also persistent effects from early summer steelhead in other watersheds within the North Cascades MPG, such as the Green/Duwamish River basin, that may contribute a small number of stray fish into the greater Snohomish basin. Releases of early summer steelhead in the Green/Duwamish basin will end in 2031.

2.4.4. Hydropower

Two types of hydroelectric operations are present in the Snohomish River basin: storage facilities and run-of-the-river facilities. The Henry M. Jackson, located on the Sultan River, and the South Fork Tolt River hydroelectric projects are both storage facilities. These hydropower facilities have severely altered sediment transport, recruitment of large woody debris, altered the hydrograph, modified thermal conditions, and destroyed spawning and rearing habitats within the South Fork Tolt River and the Sultan River. Other projects in the Snohomish basin are run-of the- river operations with little or no storage, and they are all upstream of natural barriers to anadromous fish migration (Snohomish Basin Salmonid Recovery Technical Committee 1999).

Over the last several years, NMFS has completed several section 7 consultations on large-scale habitat projects affecting listed species in the action area. Among these are the Washington State Forest Practices Habitat Conservation Plan (NMFS 2006a), and consultations on Washington State Water Quality Standards (NMFS 2008c) and the National Floodplain Insurance Program (NMFS 2008d). These documents considered the effects of the proposed actions that would occur up to the next 50 years on the ESA-listed salmon and steelhead species in the action area, and more comprehensively, in the Puget Sound basin. Section 2.3 of these documents describe effects of forestry management, water quality standards, and floodplain management in the greater Snohomish basin and are hereby incorporated by reference.

2.4.5. Climate Change

Climate change has negative implications for designated critical habitats in the Pacific Northwest (Climate Impacts Group 2004; ISAB 2007; Scheuerell and Williams 2005; Zabel et al. 2006). The distribution and productivity of salmonid populations in the region are likely to be affected (Beechie et al. 2006). Average annual Northwest air temperatures have increased by approximately 1º Celsius since 1900, or about 50 percent more than the global average over the same period (ISAB 2007). The latest climate models project a warming of 0.1º Celsius to 0.6º Celsius per decade over the next century. According to the Independent Scientific Advisory Board (ISAB), these effects pose the following impacts over the next 40 years:

- Warmer air temperatures will result in diminished snowpacks and a shift to more winter/spring rain and runoff, rather than snow that is stored until the spring/summer melt season.
- Less snowpack within high elevation watersheds will result in changes in the hydrograph. Stream flows will be elevated earlier in the season and decreased for extended periods during later in the season, resulting in lower stream-flows in the June through September period. River flows, in general, and peak river flows are likely to increase during the winter due to more precipitation falling as rain rather than snow.
- Water temperatures are expected to rise, especially during the summer months when lower stream-flows co-occur with warmer air temperatures. As climate change progresses and stream temperatures warm, thermal refugia will be essential to persistence of many salmonid populations. Thermal refugia are important for providing salmon and steelhead with patches of suitable habitat while allowing them to undertake migrations through, or to make foraging forays into, areas with greater than optimal temperatures. To avoid waters above summer maximum temperatures, juvenile rearing may be increasingly found only in the confluence of colder tributaries or other areas of cold water refugia (Mantua et al. 2009).

These changes will not be spatially homogeneous across the entire Pacific Northwest. Low-lying areas are likely to be more affected. Climate change may have long-term effects that include, but are not limited to, depletion of cold water habitat, variation in quality and quantity of tributary rearing habitat, alterations to migration patterns, accelerated embryo development, premature emergence of fry, and increased competition among species (ISAB 2007). In the Snohomish River basin, the Engel et al. (2017) predicts that precipitation regimes will shift in timing and elevation/type of precipitation, resulting in more intense and frequent peak winter flows (Mauger et al. 2015).

As reported in the Green River basin, which borders the Snohomish to the south, temperature will likely a concern for the whole watershed, but temperatures are likely to be more problematic for salmonids in the mainstem sections, as these portions of rivers are already generally warmer than the tributaries (Engel et al. 2017). Increased peak flows and decreased summer base flows could also contribute to increased sedimentation and stormwater runoff. These effects could result in increased pollutant concentrations that could negatively affect fish physiology and survival. The persistence of cold water "refugia" within rivers and the diversity among salmon populations will be critical in helping salmon populations adapt to future climate conditions.

Similar types of effects on salmon may occur in the marine ecosystem, including warmer water temperatures, loss of coastal habitat due to sea level rise, ocean acidification, and changes in water quality and freshwater inputs (Mauger et al. 2015). More detailed discussions about the likely effects of large-scale environmental variation on salmonids, including climate change, are found in biological opinions on the Snohomish basin Salmonid Hatchery Operations (NMFS 2017a) and the implementation of the Mitchell Act (NMFS 2017b).

Habitat preservation and restoration actions can help mitigate the adverse impacts of climate change on salmonids. For example, restoring connections to historical floodplains and freshwater and estuarine habitats would provide fish refugia and areas to store excess floodwaters (Battin et al. 2007; ISAB 2007). Several actions could help mitigate climate change effects, such as protecting cold water refugia to moderate temperature effects, and restoring riparian buffers to moderate temperatures, reduce sediment inputs, and minimize erosion.

Harvest and hatchery actions can respond to changing conditions associated with climate change by incorporating greater uncertainty in assumptions about environmental conditions, and conservative assumptions about salmon survival, in setting management and program objectives and in determining rearing and release strategies (Beer and Anderson 2013). For example, productivity may decline following drought conditions and should be factored into hatchery production targets and harvest regimes (SSPS 2007).

2.5. Effects of the Action on ESA-listed species and Designated Critical Habitat

This section describes the effects of the Proposed Action, independent of the Environmental Baseline and Cumulative Effects. The methodology and best scientific information NMFS follows for analyzing hatchery effects is summarized in Section 2.5.1 and application of the methodology and analysis of the Proposed Action is in Section 2.5.2. The "effects of the action" means the direct and indirect effects of the action on the species and on designated critical habitat, together with the effects of other activities that are interrelated or interdependent, that will be added to the environmental baseline (50 CFR 402.02). Indirect effects are those that are caused by the Proposed Action and are later in time, but still are reasonably certain to occur. The Proposed Action, the status of ESA-protected species and designated critical habitat, the Environmental Baseline, and the Cumulative Effects are considered together later in this document to determine whether the Proposed Action is likely to appreciably reduce the likelihood of survival and recovery of ESA protected species or result in the destruction or adverse modification of their designated critical habitat.

2.5.1. Factors Considered When Analyzing Hatchery Effects

NMFS has substantial experience with hatchery programs and has developed and published a series of guidance documents for designing and evaluating hatchery programs following best available science (Hard et al. 1992; Jones 2006; McElhany et al. 2000; NMFS 2004b; NMFS 2005b; NMFS 2008b; NMFS 2011b). For Pacific salmon, NMFS evaluates extinction processes and effects of the Proposed Action beginning at the population scale (McElhany et al. 2000). NMFS defines population performance measures in terms of natural-origin fish and four key parameters or attributes; abundance, productivity, spatial structure, and diversity and then relates effects of the Proposed Action at the population scale to the MPG level and ultimately to the survival and recovery of an entire ESU or DPS.

"Because of the potential for circumventing the high rates of early mortality typically experienced in the wild, artificial propagation may be useful in the recovery of listed salmon species. However, artificial propagation entails risks as well as opportunities for salmon conservation" (Hard et al. 1992). A Proposed Action is analyzed for effects, positive and negative, on the attributes that define population viability: abundance, productivity, spatial structure, and diversity. The effects of a hatchery program on the status of an ESU or steelhead DPS and designated critical habitat "will depend on which of the four key attributes are currently limiting the ESU, and how the hatchery fish within the ESU affect each of the attributes" (70 FR 37215, June 28, 2005). The presence of hatchery fish within the ESU can positively affect the overall status of the ESU by increasing the number of natural spawners, by serving as a source population for repopulating unoccupied habitat and increasing spatial distribution, and by conserving genetic resources. "Conversely, a hatchery program managed without adequate consideration can affect a listing determination by reducing adaptive genetic diversity of the ESU, and by reducing the reproductive fitness and productivity of the ESU".

NMFS' analysis of the Proposed Action is in terms of effects it would be expected to have on ESA-listed species and on designated critical habitat, based on the best scientific information available. This allows for quantification (wherever possible) of the effects of the six factors of hatchery operation on each listed species, which in turn allows the combination of all such effects with other effects accruing to the species to determine the likelihood of posing jeopardy.

Information that NMFS needs to analyze the effects of a hatchery program on ESA-listed species must be included in an HGMP. Draft HGMPs are reviewed by NMFS for their sufficiency before formal review and analysis of the Proposed Action can begin. Analysis of an HGMP or Proposed Action for its effects on ESA-listed species and on designated critical habitat depends on six factors. These factors are:

1. The hatchery program does or does not remove fish from the natural population and use them for hatchery broodstock
2. Hatchery fish and the progeny of naturally spawning hatchery fish on spawning grounds and encounters with natural-origin and hatchery fish at adult collection facilities
3. Hatchery fish and the progeny of naturally spawning hatchery fish in juvenile rearing areas, migratory corridor, estuary and ocean
4. RM&E that exists because of the hatchery program
5. The operation, maintenance, and construction of hatchery facilities that exist because of the hatchery program
6. Fisheries that exist because of the hatchery program, including terminal fisheries intended to reduce the escapement of hatchery-origin fish to spawning grounds

NMFS' analysis assigns an effect category for each factor (negative, negligible, or positive/beneficial) on population viability. The effect category assigned is based on: (1) an analysis of each factor weighed against the affected population(s) current risk level for abundance, productivity, spatial structure and diversity; (2) the role or importance of the affected natural population(s) in salmon ESU or steelhead DPS recovery; (3) the target viability for the affected natural population(s) and; (4) the Environmental Baseline, including the factors currently limiting population viability. For more information on how NMFS evaluates each factor, please see (Appendix A; Section 6).

2.5.2. Analysis of the Effects of the Proposed Action on ESA-listed species

Analysis of the proposed action identified risk factors and take pathways that may have negative effects on ESA protected Puget Sound Chinook salmon and/or Puget Sound steelhead. We identified steelhead fisheries harvest as a consequence of the proposed action in the greater Snohomish basin and address that further in the analysis. A summarized analysis of applicable hatchery effect factors is presented below. The framework NMFS followed for analyzing effects of the proposed hatchery programs is described in Section 2.5 of this opinion.

As described in Section 2.2.2, whether the North Fork and South Fork steelhead should be treated as a single population remains uncertain. Thus, the following analysis assumes steelhead in the North Fork to be considered a demographically independent population (Myers et al. 2015) that may need to reach viability for recovery of the DPS (Hard et al. 2015; NMFS 2019c) and treat it as a separate population. However, the analysis also looks at circumstances that would occur once the decision on how to manage the North Fork and South Fork steelhead is made, including situations where the North Fork and South Fork steelhead are treated as a single population.

2.5.2.1.Factor 1: Broodstock collection

Skykomish summer steelhead integrated broodstock

Broodstock collection occurs on both hatchery-origin and natural-origin steelhead. In the discussion below, we consider the effects on both hatchery-origin and natural-origin steelhead for completeness.

The co-managers have selected a broodstock consisting of natural-origin summer steelhead returning to Sunset Falls on the South Fork Skykomish for the steelhead hatchery program. The co-managers have selected this broodstock source because it has the lowest level of genetic influence by early summer steelhead (discussed below) of all the summer steelhead spawning aggregations in the greater Snohomish basin (WDFW and Tulalip Tribes 2019). While removal of natural-origin fish for broodstock does constitute a negative effect on the short-term abundance of the South Fork Skykomish steelhead, the co-managers have proposed limitations on the abundance and proportion of the natural run used for broodstock. Over time, increased abundance of South Fork Skykomish summer steelhead caused by natural spawning of hatchery returnees will compensate for the removal of natural origin fish for broodstock.

For broodstock, the co-managers will remove no more than 120 natural-origin steelhead, or 30 percent of the natural-origin summer steelhead returning to Sunset Falls, whichever is lower. The 30 percent limit of natural-origin steelhead used for broodstock would minimize the impacts on the population in years in which few adults are collected at Sunset Falls Trap and Haul Fishway. The number of natural-origin adult steelhead observed at Sunset Falls Trap and Haul Fishway from 2009 to 2018 averaged 315 fish, and ranged from 164 to 586 fish (WDFW 2010a; WDFW 2010b; WDFW 2012; WDFW 2013a; WDFW 2014a; WDFW 2015; WDFW 2016; WDFW 2017; WDFW 2018; WDFW 2019a). As a result we expect the co-managers may remove a maximum of 120 adult summer steelhead, but less in some years. If the number of returning adult summer steelhead are not enough for full production, hatchery-origin steelhead from this new program will be used to achieve the 120 adults for broodstock. If the hatchery-origin steelhead are not used for broodstock, they would be surplussed or transported upstream of Sunset Falls. The co-managers anticipate that removing a maximum of 120 natural-origin steelhead or 30 percent of the natural-origin adults returning to the trap at Sunset Falls Trap and Haul Fishway (whichever is less) for broodstock[7] will not alter genetic diversity.

The limitations described above will reduce risk to ESA-listed North Fork Skykomish and Tolt summer-run populations because few, if any, individuals from these populations are likely to stray into the Sunset Falls Trap and Haul Fishway and be used as broodstock (WDFW 2021a). Moreover, the co-managers will exclusively rely on natural-origin steelhead as the broodstock source until the first cohort of hatchery-reared adult steelhead return to spawn. Thus, the overall effect on the South Fork Skykomish steelhead population will be limited, as will the potential adverse effects from further genetic effects.

We believe the proposed broodstock take presents a mix of positive and negative aspects to the management of summer steelhead given the current status of the listed populations in the greater Snohomish basin, the genetic effects resulting from early summer steelhead influence, and the level of habitat degradation throughout the greater Snohomish basin that are described in the Section 2.4 (Environmental Baseline). South Fork Skykomish summer steelhead are more abundant, and productive than the North Fork Skykomish and Tolt populations, while also having a lower level of early summer steelhead influence. These attributes make South Fork Skykomish steelhead a reasonable alternative for broodstock. Further, NMFS concludes that managing the proposed number of fish for broodstock to maintain a high level of PNI (e.g., genetic diversity) will allow the co-managers to increase long-term abundance of the South Fork Skykomish steelhead as well as genetic diversity and productivity while balancing the potential short-term reductions in abundance by using natural-origin summer steelhead for broodstock.

After the first generation of hatchery-origin steelhead begin to return in 2024, the co-managers will begin integrating hatchery-origin returns into the broodstock, thereby decreasing the need to rely solely on natural-origin steelhead for the broodstock. This will allow the co-managers to maintain genetic diversity between both hatchery and natural-origin steelhead in the South Fork Skykomish River by achieving the highest level of PNI possible given the number of adult returns. Moreover, by live-spawning some of the natural-origin steelhead, the co-managers may return some fish to the river, preserving the ability for some individuals to spawn in subsequent years. However, there will also be annual variation in the number of fish live-spawned due to differences in abundance and gender ratio. Repeat spawner rates in the Puget Sound vary between 5 and 10 percent (Busby et al. 1996; Hard et al. 2015; Scott and Gill 2008). Based on these data, we conservatively estimate the proportion of hatchery steelhead returning to spawn is less than that exhibited in the natural-origin population. Because the number of steelhead live-spawned by hatchery personnel may vary considerably, we anticipate that the number of live-spawned adults returning to spawn in subsequent years will be less than 10 fish each year.

[7] Broodstock will be composed of 100 percent natural-origin collected at Sunset Falls Trap and Haul Fishway during the first years in which the program is operational. Once hatchery returns are established, the broodstock composition will be as described in Section 2.5.2.2. The broodstock composition will be monitored along with egg to smolt survival rate.

2.5.2.2. Factor 2: Hatchery fish and the progeny of naturally spawning hatchery fish on the spawning grounds

The proposed hatchery program presents a mix of benefits and risks to local natural populations. An important consideration that we evaluate here is the effect of outplanting returning adult steelhead from the proposed program into the North Fork Skykomish River. The intention of outplanting hatchery-origin steelhead into the North Fork Skykomish River is to improve the abundance and productivity of this population, which is described below in Section 2.5.1.3. The new hatchery program and the proposed outplanting effort are also intended to reduce genetic effects of the previous early summer steelhead program throughout the basin. At the same time, the program poses genetic risk to the Skykomish winter steelhead population through outbreeding effects and to the local summer steelhead populations through hatchery-influenced selection and possibly outbreeding effects. NMFS considers three major areas of genetic effects: within-population diversity, outbreeding effects, and hatchery-influenced selection. The genetic effects on Chinook salmon resulting from the trap and haul operation are addressed in a separate consultation (NMFS 2017a).

Within-population genetic diversity

In this case, we considered the effect the Skykomish summer run hatchery program may have on the genetic diversity of North Fork Skykomish and South Fork Skykomish summer steelhead using effective population size as a metric. We analyzed effective size with the modified Tufto method (Tufto 2017)(see Section 6, Appendix A), using the pNOB and pHOS values and escapement counts estimated by Haggerty (2020a) and the proposed broodstock size of 120 fish. We modeled scenarios of pNOB=50% and 64% to basically bracket the values used in the PNI analysis below, no outplanting into the North Fork and outplanting 250 fish, no removal of hatchery-origin fish at Sunset Falls and removal of a number equal to the number of natural-origin broodstock. For the scenarios involving no outplanting, we computed the composite effective size for the combined hatchery-South Fork group; for the outplanting scenarios we computed effective size for the combined hatchery-South Fork-North Fork group. We conservatively assumed no increase in the natural populations due to the hatchery program. If the program performs as an integrated program should, effective size would be increased over the values indicated by the model.

Based on our modeling it appears that the composite effective population size of the hatchery-South Fork composite 46-53% over what it would be without the hatchery program, because of the increase in overall population size due to the hatchery program. With outplanting, the effective size increase ranged from 19% to 48% in the hatchery-South Fork-North Fork composite, with the lower value achieved with the higher pNOB value. The modelling method we use makes assumptions about some fine details of effective size calculations, so includes some imprecision. However, our objective in estimating effective size is to make sure the hatchery program does not adversely depress effective size. In this case, the values obtained are so high that we are confident that the proposed program will not depress the effective population size of Skykomish summer steelhead, either the South Fork or the South Fork-North Fork composite.

Outbreeding effects

Outbreeding effects are caused by gene flow from other populations. Gene flow occurs naturally among salmon and steelhead populations as individuals from other watersheds occasionally do not return to their natal stream, but stray and spawn with individuals in an adjacent watershed (Quinn 1993; Quinn 1997). The rate of salmon and steelhead straying that naturally occurs is important to preserving diversity that would otherwise be lost. This is because a limited number of fish breeding with each other over numerous generations would result in genetic drift. Furthermore, salmon and steelhead would be less able to re-colonize vacant habitats. Therefore, straying is considered a risk only when it occurs at unnatural levels or from unnatural sources.

Hatchery programs can cause straying outside natural patterns for two reasons. First, hatchery fish may exhibit reduced homing fidelity relative to natural-origin fish (Goodman 2005; Grant 1997; Jonsson et al. 2003; Quinn 1997), resulting in unnatural levels of gene flow into recipient populations, either in terms of sources or rates. Second, even if hatchery fish home at the same level of fidelity as natural-origin fish, their higher abundance can cause unnatural straying levels into recipient populations. One goal for hatchery programs should be to ensure that hatchery practices do not lead to higher rates of genetic exchange with fish from natural populations than would occur naturally (Ryman 1991). Rearing and release practices and ancestral origin of the hatchery fish can all play a role in straying (Quinn 1997).

One outbreeding issue that has come up repeatedly in discussions of the genetic status of summer steelhead in the Snohomish is the fact that the hatchery history of the basin includes use of Skamania stock steelhead, which were developed from Columbia Basin summer steelhead (Crawford 1979). Not only did these fish originate in another DPS, they likely also differed in chromosome number. The chromosome number of only a few steelhead populations in Puget Sound has been determined, but fish from the Stillaguamish basin, a Snohomish basin neighbor, possess 60 chromosomes (Ostberg and Thorgaard 1999). This finding, along with a general trend of 60 for other Puget Sound populations analyzed, make it likely that native Snohomish steelhead have 60 chromosomes. Skamania summer steelhead, on the other hand, have 58 chromosomes (Thorgaard 1983). Thus, 58-chromosome fish have been introduced into the Snohomish Basin through hatchery operations. In general, chromosome number differences imply potential fertility problems for hybrids between the two types. The fitness consequences of cross-breeding 58- and 60- chromosome *O. mykiss* are unknown. However, in a hybridization study involving rainbow trout and cutthroat trout (*O.clarkii bouvieri*) with the same chromosomal rearrangement as exists between 58- and 60-chromosome steelhead, Ostberg et al. (2013) found that the chromosomes paired properly, leading to no fitness problems. Thus, it is likely that in introductions of steelhead from the Columbia River into Puget Sound populations the chromosome number difference in and of itself would have a negligible fitness impact. Note that this does not mean that interbreeding between fish of different DPSs has no outbreeding effect impact, only that, of that impact, it is likely that little if any is attributable to the difference in chromosome number per se.

Here, we consider the potential gene flow from the new summer steelhead hatchery program and the steelhead outplanting effort on populations other than the South Fork Skykomish summer steelhead (i.e., the intended target for hatchery integration). Both actions will result in the potential for straying of hatchery adults into other portions of the greater Snohomish basin, where these individuals may interbreed with steelhead from other populations. These steelhead populations include: North Fork Skykomish summer-run, Pilchuck River winter-run, Snohomish/Skykomish winter-run, Snoqualmie winter-run, and Tolt summer-run. We evaluated the potential risk from gene flow between populations in the greater Snohomish basin using available baseline estimates provided by (Warheit et al. 2021) and (Haggerty 2020a) and by categorizing the potential for spatial and temporal separation during spawning with adult summer steelhead from the new hatchery program (Table 12).

Table 12. Past and predicted future gene flow between hatchery summer-run steelhead and natural-origin steelhead populations in the greater Snohomish basin (DGF: demographic gene flow; pHOS: proportion hatchery origin spawners; PNI: proportion natural influence).

Steelhead population[1]	Estimated gene flow from past summer steelhead program (PEHC)[2]	Estimated gene flow due to the proposed action (DGF, pHOS, or PNI)
Snohomish/Skykomish winter-run	0.01	DGF = 0.05
Snoqualmie winter-run	0.01	DGF ≦ 0.05
Pilchuck River winter-run	0.12	DGF ≦ 0.05
Tolt summer-run	0.01	pHOS[3] = 0.023
North Fork Skykomish summer-run[4]	0.20	pHOS = 0.156
South Fork Skykomish summer-run	0.09	PNI ≥ 0.67

[1] While South Fork Skykomish summer-run is listed as a population in this table, it has not been identified as an population by the Puget Sound Steelhead Technical Recovery Team (Myers et al. 2015) or assigned a recovery priority (Hard et al. 2015)
[2] These PEHC values were determined by analytical methods considerably improved over those used for earlier reports such as Warheit (2014a). Methodological improvements are described fully in Warheit et al. (2021).
[3] pHOS values were estimated from early summer steelhead hatchery releases (brood years 2009-2017), snorkel survey observations (return years 2012-2020) and redd-based escapement estimates (escapement years 2013-2020) (Haggerty 2021b)
[4] The pHOS estimate for the North Fork Skykomish population is based on projected smolt-adult-escapement survival and stray rates for the early summer steelhead program, and projected natural-origin abundance, and does not account for the potential outplanting of fish from the proposed hatchery program (Haggerty 2021b).

Gene flow risks to Snohomish/Skykomish winter-run population

There is potential for gene flow from the South Fork Skykomish hatchery summer steelhead to the Snohomish/Skykomish winter-run population due to possible spatial and temporal overlap during spawning. As the proposed Skykomish hatchery program is new, no genetic data are available to estimate gene flow resulting from it.

Because genetic data were not available, we used the Scott-Gill method (Scott and Gill 2008 with correction in Busack 2014) to calculate the expected gene flow between the proposed hatchery program and the Snohomish/Skykomish winter steelhead population based on demographic and life history data, hereafter called demographic gene flow (DGF). We calculated DGF values for the Skykomish winter steelhead natural population computed with the same assumed values for relative reproductive success (RRS) (0.60 for Hatchery × Natural) (Haggerty 2020a). This methodology was also used by Hoffmann (2014) cases 3 and 6 for analyzing the early winter steelhead hatchery programs (NMFS 2016b). In addition, we modified some parameters for the proposed program compared to the analysis in the NMFS (2019b) to better fit our specific situation:

- We discounted the hatchery × hatchery effects because mating of hatchery-origin summer steelhead does not constitute gene flow to the Skykomish winter steelhead population. This discount was achieved by setting the Hatchery × Hatchery RRS value to 0.

- We used the spawn timing of the Tolt summer steelhead population (on or after February 15) as a proxy for the expected spawn timing of fish from the proposed program because: 1) no information about the donor population spawn timing is available, and 2) integrated hatchery steelhead will exhibit a more natural spawn timing than Reiter Ponds early summer steelhead.

- We assumed 20-30 percent pHOS as proportion of hatchery-origin escapement from NMFS (2016b), which was considered to be greater in comparison to earlier estimates by the HSRG of 10-20 percent (and therefore a more conservative estimate), and applied a proportion based on the Intrinsic Potential (IP) of the habitat available (Haggerty 2020a). By applying this proportion, we assume that preference for spawning habitat among hatchery and natural-origin fish is similar. The Scott-Gill results indicate that gene flow from the proposed program should be about 5 percent. However, there is uncertainty around this conclusion because of the assumed stray rates and RRS values that require validation. Variability in the DGF estimate is predominantly due to parameter uncertainty, rather than error associated with assumed statistical distributions, so no confidence intervals are included with the estimates (Haggerty 2020a). We did not complete a comprehensive sensitivity analysis, but did discuss our concerns previously in NMFS (2016b), NMFS (2016a), and NMFS (2019b).

While uncertainty exists about whether outplanted adult steelhead would remain isolated from the Snohomish/Skykomish winter steelhead spawning population, we expect the genetic risk to be minimal because the outplanting effort would be temporary (up to 8 years). The acceptable rate of gene flow from the proposed program into the Skykomish winter steelhead population is unclear. Ideally, the rate should be no higher than the natural rate of gene flow from summer to winter steelhead in the Skykomish basin, but that natural rate is unknown. However, the estimated 5 percent is consistent with guidelines for acceptable gene flow between distinct populations (Grant 1997), which in this case include those populations described above in Table 12. Using the Scott-Gill method for this calculation as described above, we estimate that gene flow at rates of no greater than 5 percent will occur between the new hatchery-origin summer-run steelhead and the Snohomish/Skykomish winter-run populations (Haggerty 2020a).

A potential limitation of the demographic gene flow approach analysis described above is that it assumes that all the spawners are returning anadromous adults. Precocious juvenile hatchery-origin summer steelhead may residualize in freshwater. These fish would not be counted in the estimate of adult escapement, and may spawn with natural-origin adult winter steelhead. To the extent sexually mature residual hatchery steelhead spawn with natural-origin fish, they increase actual pHOS. pHOS estimates that do not take residuals into account that are used in any modeling of PNI or gene flow will result in underestimates of genetic effects.

The occurrence of precocious males in steelhead released from WDFW hatcheries varies from 1 to 5% (Tipping et al. 2003), a level where both the demographic and genetic influence of these fish would be insignificant. We believe residualism rates for the new integrated hatchery program are likely to be similar to other steelhead programs, and rates exceeding 10 percent would not be expected. The co-managers could reliably estimate the proportion of non-migrating hatchery steelhead by sampling fish during the release period using procedures outlined by (Tatara et al. 2019). These procedures include measurements of weight and length and a qualitative visual index of smolt condition/sexual precocity. These assessments will indicate the number of hatchery steelhead likely to residualize in freshwater, of which only a subset will be sexually mature males able to mate with natural-origin winter steelhead. The co-managers have proposed volitional releases of all steelhead, with force releasing any remaining fish at the end of the release period. These procedures, and monitoring to ensure steelhead are reared to the proper size and physiological condition will be important to minimizing the genetic effects from residualized *O. mykiss*.

Gene flow risks to Pilchuck River and Snoqualmie winter-run populations

As discussed above, winter steelhead populations will likely exhibit a high degree of spatial and temporal separation during spawning from the summer steelhead originating at the proposed South Fork Skykomish integrated program. Because gene flow between populations occurs when fish co-mingle during spawning, spatial or temporal separation is important when considering the overall likelihood of interbreeding to occur. We identified populations with considerable spatial and temporal separation to include winter-run populations in the Pilchuck and Snoqualmie. Because these populations are the farthest away from the South Fork Skykomish population, we expect minimal, if any, straying into these populations. That is, we expect the DGF levels to be lower than that expected into the Snohomish/Skykomish winter-run population (~5 percent; see above for further discussion) because these populations have similar numbers of natural-origin spawners and similar spawn timing and would have smaller numbers of hatchery-origin spawners compared to the Snohomish/Skykomish winter population. Previous estimates of gene flow from the early summer steelhead hatchery program were approximately 1 percent (Warheit et al. 2021).

Monitoring of gene flow into the winter-run populations

WDFW proposes to monitor gene flow from the new summer steelhead program into the Skykomish, Pilchuck, and Snoqualmie winter steelhead populations using the PEHC metric by enhancing an existing effort (Anderson et al. 2019) to monitor gene flow from steelhead hatchery programs throughout Puget Sound. To reduce the possibility of sampling fish that are not potentially the result of summer steelhead spawning with winter steelhead, only steelhead at the young of the year life stage will be sampled from the winter steelhead spawning areas (WDFW 2021b). Based on modeling the effects of sample size on the precision of PEHC estimates (Craig et al. 2017), WDFW considers sample sizes of 100-500 to be adequate (WDFW 2021b). If monitoring indicates gene flow levels are exceeded then managers can modify hatchery practices accordingly to minimize adverse effects on the relevant winter steelhead population.

Gene flow risks to Tolt summer-run population

Similar to the Pilchuck and Snoqualmie winter-run populations, the Tolt summer-run population is spatially separated from the Skykomish River by a considerable distance. Yet, due to the similar expected spawn timing of hatchery-origin Skykomish summer steelhead we need to consider the risk of gene flow into the Tolt summer steelhead population. We used a multi-year dataset of snorkel surveys conducted in the South Fork Tolt River during the previous decade to project a pHOS of 2 percent, or an average of one hatchery Skykomish summer-run steelhead spawning in the South Fork Tolt River each year, which is below the recommended 5% limit for gene flow to the Tolt River summer steelhead (Haggerty 2021b).

Gene flow risks to the North Fork Skykomish summer-run population

We anticipate that spatial and temporal overlap during spawning between the new Skykomish summer-run program and summer-run North Fork Skykomish populations may result in some level of gene flow. Perceptions of genetic risk that the proposed hatchery program poses to the North Fork Skykomish summer steelhead population depend on how the genetic relationship between the North Fork and South Fork populations is viewed. As pointed out previously in Section 2.2.2 (Status of the Species Puget Sound Steelhead DPS), recent genetic analysis of *O. mykiss* populations in the Snohomish Basin presents a picture of genetic relationships in the Skykomish Basin that differs considerably from earlier interpretations that are reflected in the Puget Sound Steelhead DPS population identification document (Myers et al. 2015), viability criteria document (Hard et al. 2015), and recovery plan (NMFS 2019c). These documents all reflected the conclusion of Kassler et al. (2008) that the South Fork population was derived from releases of early summer steelhead from the Columbia basin. Recent WDFW research involving more samples and incorporating more accurate assumptions about the origins of the Reiter Ponds hatchery stock indicate that the South Fork Skykomish population is of Skykomish origin, and that little genetic differentiation exists between the formally designated North Fork Skykomish population and the fish now populating the South Fork Skykomish River.

Outplanting summer steelhead into the North Fork Skykomish River at some level may make good conservation sense if the North Fork and South Fork spawning aggregations are regarded as the same population. The correct interpretation of the recent genetic analysis in view of the management history of the basin may be to consider the North Fork and South Fork Skykomish summer steelhead as a single population with two spawning aggregations. NMFS believes a plausible explanation for the observed genetic differentiation between summer steelhead in the North Fork and South Fork Skykomish River is that summer steelhead historically limited to the North Fork were allowed to colonize the South Fork once WDFW began transporting fish upstream of Sunset Falls.

However, if the two spawning aggregations are regarded as separate populations, supplementation at the proposed levels could erode the genetic differentiation between them, homogenizing the two groups within a few generations. Put more bluntly, supplementation of the North Fork with summer steelhead from the new hatchery program at the level proposed would "overwrite" the genetic profile of North Fork summer steelhead unless there is a simultaneous large increase in population size. Because the North Fork spawning aggregation is currently considered a demographically independent population (Myers et al. 2015) that may be required to reach viable status for recovery of the DPS (Hard et al. 2015; NMFS 2019c), the relationship of the North Fork and South Fork steelhead needs to be better understood before the proposed supplementation could occur. Supplementation of the North Fork summer steelhead population should be postponed until it can be shown that it is consistent with viability needs of the DPS.

Because uncertainties remain about the relationship between the North Fork and South Fork populations, a work group will be formed to meet at least on a quarterly basis (or more frequently as needed) and to continue exploring this relationship. Additional monitoring, both demographic and genetic, should be conducted by the co-managers for at least five years, during which NMFS, the co-managers, and other parties involved in recovery planning can review and discuss all the relevant information periodically to reach a decision about how North Fork and South Fork Skykomish steelhead should be managed.

We estimate that pHOS from the proposed hatchery program through straying during the five-year monitoring period may reach 15.6% per year [Haggerty, 2021 #XXXX]. Gene flow will be no greater than this, and possibly considerably less. A sustained pHOS level this high will likely homogenize the two groups over a few generations, but in view of the close genetic relationship between the South Fork and North Fork populations (F_{ST} of 0.015-0.018) (Warheit et al. 2021) we feel that allowing the straying for a short term is acceptable. Moreover, this will allow measurement of the straying rate, and will improve the abundance and productivity of the North Fork population by reducing the domestication and diversity effects that resulted from the previous Reiter Ponds hatchery program. This assumption will be re-examined once a decision is made about how North Fork and the South Fork Skykomish steelhead will be managed.

The genetic diversity of the South Fork Skykomish summer steelhead population could also be adversely affected if the proposed hatchery program inadvertently incorporated broodstock originating from other steelhead populations within the Puget Sound. We anticipate that only a few non-South Fork Skykomish natural-origin steelhead would get inadvertently incorporated as broodstock, as discussed in Section 2.5.2.1. Once the integrated hatchery program implements its long-term marking strategy (i.e., ad-clip only), the only potential hatchery-origin steelhead that could be mistaken for hatchery-origin steelhead from the new South Fork Skykomish program would be summer-run steelhead straying from the Green River hatchery program. Because summer-run steelhead from the Green River hatchery program are identified as hatchery fish by an adipose fin-clip, there is the possibility these fish may be incorrectly identified as summer steelhead from the South Fork Skykomish River and subsequently used for broodstock. Although the potential of encountering stray steelhead from the Green River may occur, it is likely that no more than 1 fish is inadvertently incorporated into broodstock (Haggerty 2021d) and constitutes minimal risk of gene flow from early summer steelhead into the South Fork Skykomish River. The planned termination of the Green program in 2031 will limit gene flow from this program.

Hatchery-influenced selection

The remaining genetic issue is the domesticating influence of the proposed South Fork Skykomish hatchery program on the South Fork summer steelhead through hatchery-influenced selection. The typical metric used to describe the influence of hatchery-origin spawners on the natural population in terms of hatchery-influenced selection is called proportionate natural influence (PNI). This metric is a function of the proportion of natural spawners consisting of hatchery-origin fish (pHOS) and the proportion of the broodstock consisting of natural-origin fish (pNOB). A PNI greater than 0.5 in theory indicates that the influence of natural selection is stronger than the influence of hatchery-influenced selection (HSRG 2009), whereas a PNI below 0.5 would indicate that hatchery influence is stronger (Appendix A, Section 1.2.1.4.2).

To analyze the potential for hatchery-influenced selection, we used the multipopulation PNI tool described by Busack (2015) to model gene flow patterns among the hatchery program and the South Fork Skykomish summer steelhead. We expect the PNI to range from 0.57 to 0.70 for the program. Because the PNI is primarily a function of pHOS and pNOB, hatchery operations can be adjusted to reach a PNI level of 0.67 by adjusting the number of natural-origin steelhead incorporated into the broodstock and/or removing hatchery-origin steelhead at Sunset Falls. If hatchery-origin fish are selectively removed at the Sunset Falls trap, with only enough transported upstream of Sunset Falls to replace the natural-origin fish removed for broodstock, and pNOB is 50%, the PNI will increase to 0.65.

During the years of low return (as defined by having less than 250 natural-origin summer steelhead predicted to reach Sunset Falls), the program would be managed to allow up to 250 summer steelhead (natural- and hatchery-origin combined) to be passed above Sunset Falls, while maximizing the natural-origin broodstock (up to 30 percent of the returns to Sunset Falls). To buffer against the gene flow effects from these low return years, PNI will be managed at higher than 0.67 during the years of good return.

If outplants to the North Fork occur, as previously mentioned, they would serve to homogenize the North Fork and South Fork at a rate dependent on the level of outplanting, so the "population" over which PNI needs to be considered is the combined North Fork-South Fork group. Because of the smaller natural-origin production capacity of the North Fork Skykomish River relative to the natural-origin production in South Fork Skykomish River, outplanting would result in PNI levels similar to those predicted for the South Fork alone.

Ecological Effects

The intent of the new hatchery program is to avoid increasing adverse effects from redd superimposition and spawning ground competition that occur when steelhead return as adults. We used observation data from snorkel surveys to project the future number of hatchery-origin spawners in the North Fork Skykomish River spawning reach upstream of Bear Creek Falls at 9 fish per year (pHOS = 15.6%), and 1 fish into the Tolt River (pHOS = 2%) (Haggerty), neither of which would be expected to have a substantial impacts on these populations. We believe the ecological impacts from the new integrated program would be about the same as the current rate into either the North Fork Skykomish River or the Tolt River.

While we do not anticipate that using a broodstock derived from Skykomish River summer steelhead will increase redd superimposition and spawning ground competition, these are density dependent interactions that we do anticipate will be altered by the proposed outplanting of up to 250 adult steelhead in the North Fork Skykomish River. Current estimates suggest that the number of natural-origin summer steelhead spawning in this watershed is approximately 63 fish (Mike Haggerty 2020, personal communication; WDFW 2020). (NMFS 2019c) estimated the amount of summer steelhead spawning and rearing habitat in this watershed historically supported 728 summer steelhead. The recovery plan goal recommended by NMFS for the North Fork Skykomish population varies from 200-500 adult summer steelhead depending on whether the population is in a high or low productivity scenario (NMFS 2019c). Thus, we estimate the current population in the North Fork Skykomish River is between 13 and 32 percent of the low and high productivity planning goals for summer steelhead. Even with the proposed outplanting of 250 summer steelhead into this watershed, we anticipate only 64 percent of the low productivity recovery plan abundance will be met. Therefore, we do not anticipate the proposed outplanting will result in adverse effects from density dependent interactions. Moreover, the intent of outplanting steelhead into the North Fork Skykomish River is to supplement the low abundance of summer steelhead in this watershed, which should increase productivity of this population by reducing the domesticating influence of past hatchery operations. Overall, there is minimal potential for hatchery-origin steelhead to superimpose or destroy the eggs and embryos of listed species.

In general, similar numbers of Chinook salmon and summer steelhead are transported from Sunset Falls Trap and Haul Fishway facility each year (see above, Table 8 and Table 11). Chinook salmon spawn from September through October, whereas summer steelhead spawn timing occurs several months later from mid-February through April (Table 13). This temporal disparity in spawn timing demonstrates no direct competition for spawning sites or redd superimposition between the two species. Steelhead may migrate through or hold within the same river reaches used by Chinook salmon for spawning, but each species will use different microhabitats associated with migration and holding or spawning and exhibit different behaviors that make interactions between the two species unlikely. The two species also prefer different spawning habitats. Chinook salmon spawn in mainstem rivers containing large substrates with significant hyporheic exchange (Cram et al. 2017), whereas steelhead spawn predominantly in high elevation areas of watersheds and select spawning sites in close proximity to highly complex habitats suitable for juvenile rearing (Falke et al. 2013), although they may spawn in mainstem rivers if the suitable habitat features are present. Moreover, because Chinook salmon spawn earlier and develop faster than steelhead, Chinook salmon alevins will disperse from redds prior to the onset of steelhead spawning activity. Thus, the potential for redd superimposition of Chinook salmon eggs and larvae, or competition between Chinook salmon and steelhead for spawning habitat as a result of the proposed steelhead hatchery program is very extremely unlikely.

Table 13. Run and spawn timing of salmon and steelhead in the Snohomish watershed.

Species	Run Timing	Holding	Spawning
Early summer steelhead	May – September[1,2]	June - December	January – March[2]
Skykomish Chinook Salmon	May – July[3]	mid-May – September	September – October[4]
Snohomish/Skykomish winter steelhead	November – April[5]	November - March	mid-March – mid-June[5]
Skykomish summer steelhead (proposed program)	early April– mid-December[5,6]	mid-July – March	mid-February – April[7]

[1, 2] From WDFW Weekly Hatchery Reports (2010-2015), accessible at https://wdfw.wa.gov/fishing/management/hatcheries/escapement#weekly-reports.
[3] PSIT and WDFW (2010)
[4] (Ruckelshaus et al. 2006)
[5] Myers et al. (2015)
[6] (WDFW 1994)
[7] Assumed based on South Fork Tolt summer-run steelhead spawn timing (Haggerty 2021b)

Adults returning back to hatchery and collection facilities can have pathogens and become infected upon their return to freshwater or that they have contracted during their juvenile rearing and outmigration. Fish mortality for the previous early summer steelhead program varied from year to year, and was largely attributed to cold water disease and *Columnaris*, particularly during early rearing at Wallace River Hatchery. Adults are also routinely screened for viral pathogens. Based on the endemic state of the pathogens and the lack of outbreaks, risk of disease transmission and amplification from returning adults is low.

2.5.2.3. Factor 3. Hatchery fish and the progeny of naturally spawning hatchery fish in juvenile rearing areas, the migration corridor, estuary, and ocean

The action area includes freshwater habitats of the greater Snohomish basin and marine habitats of the Puget Sound and the Pacific Ocean. Based on the science available, the ability to detect the effects of releasing hatchery steelhead smolts is somewhat proportional to the size of the habitat fish will occupy. We use a quantitative methodology to analyze effects of juvenile hatchery steelhead in freshwater migratory and rearing areas of the greater Snohomish basin because steelhead are present in the freshwater for a limited timeframe and reliable quantitative methods exist for determining the effects of predation and competition in these habitats. Much less is known about the degree to which steelhead interact with each other and other species in marine habitats, simply because the size and scope of marine habitats used by steelhead include the Puget Sound and the northeast Pacific Ocean. We believe that using a qualitative approach is a more reliable method to evaluate competition and predation in marine habitats given the available information, and the high degree of complexity and uncertainty.

While competition and predation are important factors to consider, these events are rarely if ever observed and directly calculated, particularly in large open systems characterized by saltwater ecosystems. However, researchers have analyzed these behaviors enough to where NMFS can model these potential effects on the species based on known factors that lead to competition or predation occurring. Here, we used the predation-competition-delayed mortality (PCD) Risk model version 4.0 of (Pearsons and Busack 2012) to quantify the potential number of natural-origin Chinook salmon and steelhead juveniles lost to competition and predation hatchery-origin juvenile steelhead from the integrated program.

The logic used in the PCD Risk model was described by (Pearsons and Busack 2012), but since that time has been modified to increase supportability and reliability. Notably, the current version no longer operates in a Windows environment and no longer has a probabilistic mode. We also further refined the model by allowing for multiple hatchery release groups of the same species to be included in a single run. The one modification to the logic was a 2018 elimination of competition equivalents and replacement of the disease function with a delayed mortality parameter.

The rationale behind the change described above was to make the model more realistic; in the model competition rarely directly results in death because it takes many competitive interactions to suffer enough weight loss to cause mortality. Weight loss is how adverse competitive interactions are captured in the model. However, fish that experience competition and resulting weight loss are likely more vulnerable to mortality from other factors such as disease. Now, at the end of each run, the competitive impacts for each fish are assessed, and the fish has a probability of delayed mortality based on the competitive impacts. This function will be subject to refinement based on research. For now, the probability of delayed mortality is equal to the proportion of a fish's weight loss. For example, if a fish has lost 10 percent of its body weight due to competition and a 50 percent weight loss kills a fish, then it has a 20 percent probability of delayed death, (0.2 = 0.1/0.5).

Similar to the use of models for biological systems elsewhere, this model cannot possibly account for all the variables that could influence competition and predation on natural-origin juveniles. For example, the model assumes that if a hatchery fish is piscivorous and stomach capacity is available, the hatchery fish will consume natural-origin prey. In reality, hatchery-origin fish could choose to eat a wide variety of invertebrates, such as other fish species (e.g., minnows), and other hatchery-origin fish in addition to natural-origin steelhead smolts. However, we believe that with this model we are estimating, to the best of our ability, a worst-case estimate for the effects on natural-origin juvenile steelhead.

We assumed some of the parameter inputs consistent with other consultations in which we use this model (Table 14). We assumed a 100 percent population overlap between hatchery fish and ESA-listed natural-origin Chinook salmon and steelhead[8] present. We acknowledge that a 100 percent population overlap in microhabitats is likely an overestimation, but represents the worst-case scenario.

[8] We aggregated summer-run and winter-run steelhead into a single group of natural-origin fish for this analysis.

Table 14. Parameters for Skykomish summer steelhead in the PCD Risk model that are the same across all programs.

Parameter	Value
Habitat Complexity	0.1
Population overlap	1.0
Habitat segregation	0.3 for conspecifics, 0.6 for all other species
Dominance mode	3
Probability dominance results in weight loss	0.05
Proportion of weight loss causing death	0.5
Maximum encounters per day	3
Predatory:prey length ratio for predation	0.33
Mean temperature across release sites	45°F/7°C (April 15) and 50°F/10°C (May 31)

Environmental conditions in the large watersheds, such as the Snohomish basin, are not uniform. Steelhead in the mainstem Skykomish River will experience cooler temperatures that delay emergence by weeks in comparison to Reiter Ponds hatchery. To address this issue we calculated accumulated thermal units (ATUs) of summer steelhead based upon water temperature and adult fish spawn timing necessary to result in 25, 50, 75, and 100 percent emergence dates for the North Fork Skykomish River population (Figure 10). These data demonstrate that presence of natural-origin steelhead in the freshwater migratory corridor will be substantially later such that juvenile natural-origin summer steelhead overlap with hatchery-origin steelhead for a period of days. Moreover, these data also demonstrate that juvenile summer steelhead from the North Fork Skykomish River population, due to their spatial separation miles upstream of Reiter Ponds, are not at risk to competition and predation with hatchery-origin fish.

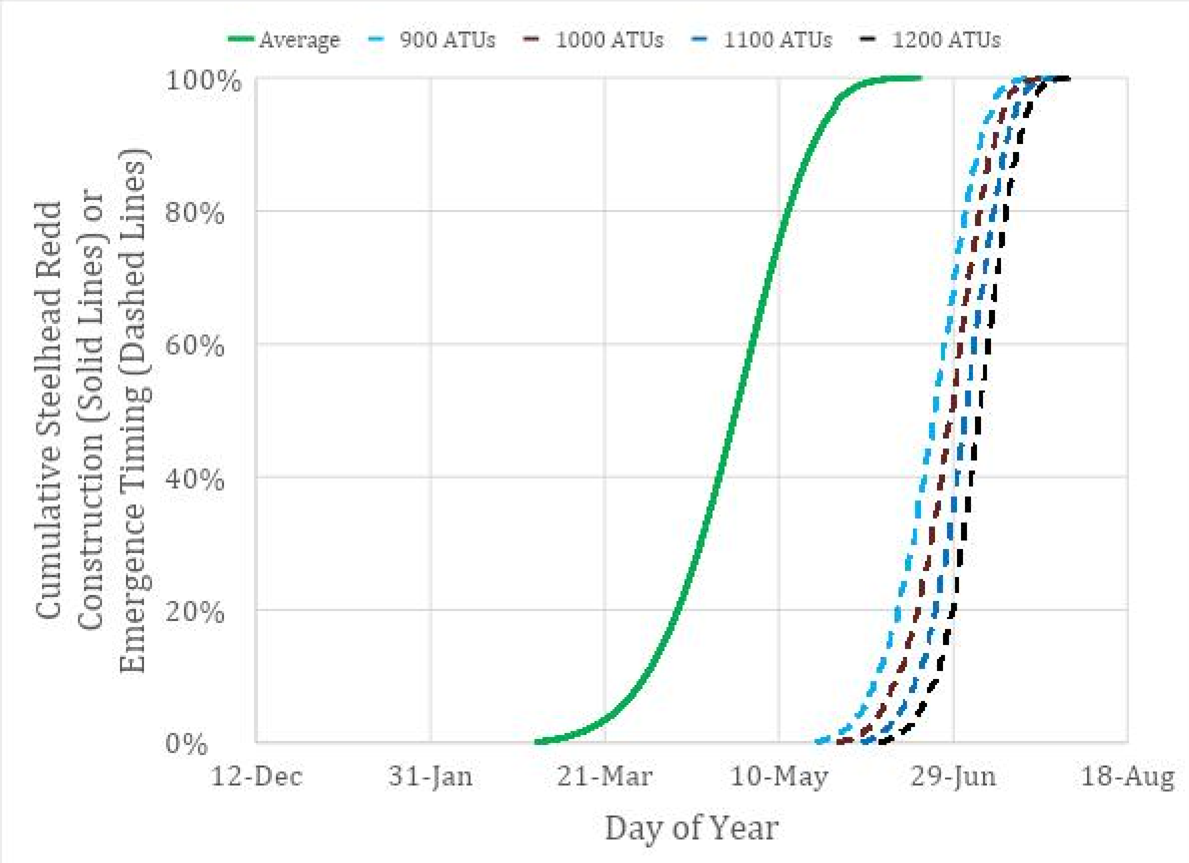

Figure 10. Estimated accumulated thermal units (ATUs) used to predict emergence timing of natural-origin summer steelhead fry in the mainstem Skykomish River based on spawn timing and water temperature.

We assumed that habitat complexity was low at only 10 percent to conservatively account for habitat degradation in the Snohomish/Skykomish River basin. We used habitat segregation estimates of 0.3 for conspecifics, and 0.6 for other Chinook salmon, a dominance mode of 3 and maximum encounters per day of 3, based on what was decided in the HETT (2014) database for hatchery programs of the same life stage and species. We used in-river temperature measurements in the Skykomish basin at RM 14.1 and RM 54 collected from 2013-2018 to calculate a mean temperature of 7°C (45°F) during the mid-April through late-May period when steelhead are released from the hatchery (Figure 11). The release on April 15 is modeled from April 15 through April 22 and the May 31 release is modeled from May 31 through June 7.

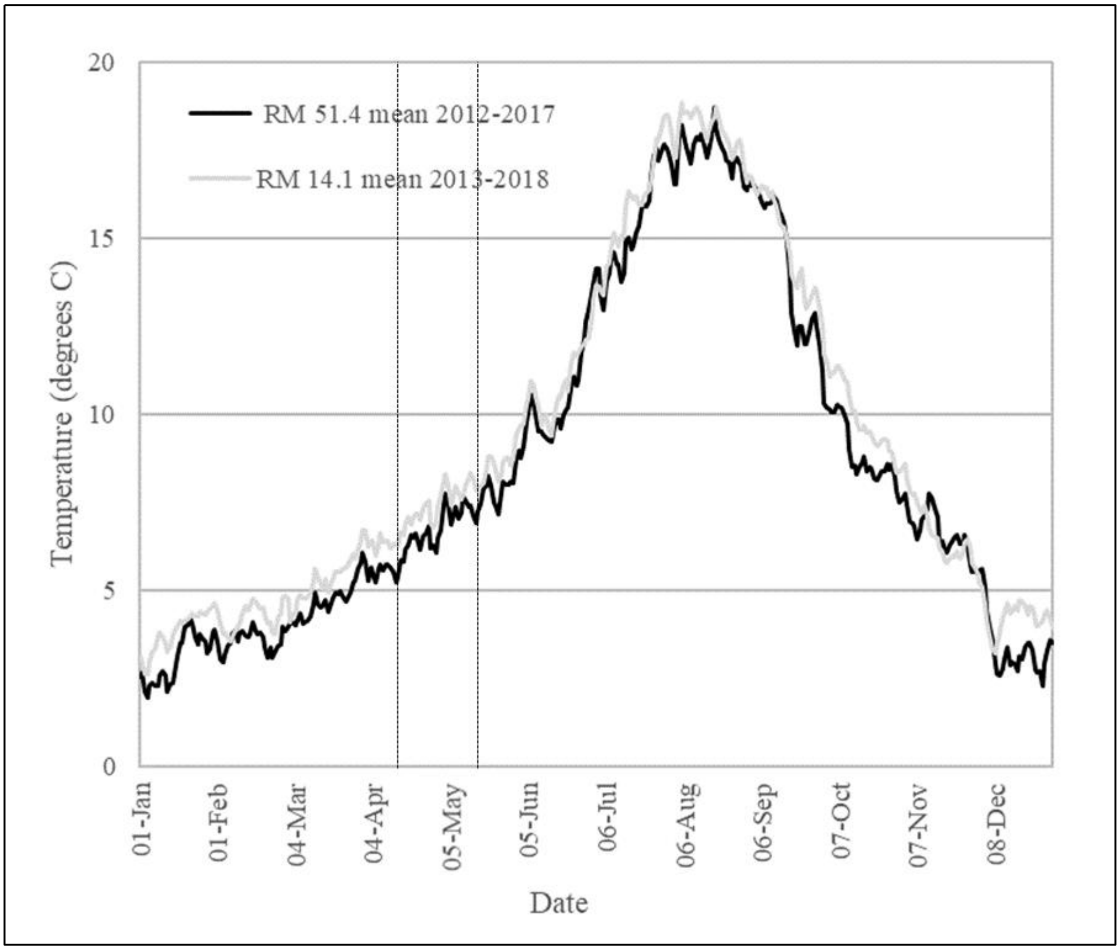

Figure 11. Mean water temperature in the Skykomish River from 2013-2018 (source: Snohomish County PUD).

We made other assumptions about parameter inputs for natural-origin populations that were consistent with all of the other consultations where this model was used (Table 14). We considered hatchery fish release windows and included only the proportion of steelhead fry that would have emerged assuming that hatchery fish are all released on the last day of their release window and assuming that all hatchery fish take the full length of travel time to the mouth of the Snohomish River. We calculated hatchery steelhead had a median travel speed 6.76 miles per day, calculated by emigration of 50 percent of the cohort from the hatchery to the smolt trap located at RM 26.5 of the Skykomish River (Haggerty 2021e). We also used the longest distance that a fish may travel from Reiter Ponds to Puget Sound, which would include Ebey's Slough (46 miles + 4.3 miles = 50.3 miles). This results in an estimated travel time of 7.4 days, which we round up to 8 days to capture effects of the last 0.4 days. Based on the estimate provided above, we conservatively assume 50 percent of the hatchery summer steelhead cohort will emigrate from the hatchery to saltwater in 8 days (i.e., 192 hours).

We anticipate an increase in travel time of 50 percent is likely an indicator of pre-release hatchery practices resulting in additional mortality from predation and competition by hatchery-origin steelhead that is not due to random variation in environmental conditions. We conservatively assumed a 100 percent population overlap between hatchery and natural-origin Chinook salmon and steelhead, with notable exceptions for natural-origin steelhead in the North Fork Skykomish River described above. Using this information, and considering the extended volitional release timing of hatchery fish, we modeled predation by hatchery steelhead to cover the entire six week release period and the range of environmental conditions present from late April to late May. We included the extended duration to cover fish force-released in late May.

We modeled the number of fish available for competitive and predatory interactions using survey estimates for Chinook salmon and steelhead in the Skykomish and Snoqualmie river basins adjusted by life stages applicable to juvenile outmigration (e.g., parr, subyearling, yearling, etc.) (Haggerty 2021a) (Table 15). We adjusted survival of each year-class using methods described by (Haggerty 2021a) available data sources. These methods included using available literature sources to estimate the number of fish from each year class that were available for each modeled series.

Table 15. Age, size, and occurrence of listed natural-origin Chinook salmon and steelhead encountered by steelhead released from the integrated hatchery program.

Release Period	Species	Age	Life Stage	Number of fish in PCD Model	Size fork length (mm)
April 15	Chinook salmon	Age 0+	Fry/Parr	841,340	41
	Chinook salmon	Age 1+	Yearling	61,820	114
	Steelhead	Age 0+	Fry	0	-
	Steelhead	Age 1+	Parr/Smolt	172,598	83
	Steelhead	Age 2+	Parr/Smolt	134,041	171
	Steelhead	Age 3+	Parr/Smolt	21,326	200
	Steelhead	Age 4+	Smolt	695	225
May 31	Chinook salmon	Age 0+	Fry/Parr	841,340	55
	Chinook salmon	Age 1+	Yearling	6,182	114
	Steelhead	Age 0+	Fry	68,855	27
	Steelhead	Age 1+	Parr/Smolt	171,903	83
	Steelhead	Age 2+	Parr/Smolt	17,248	171
	Steelhead	Age 3+	Parr/Smolt	470	200
	Steelhead	Age 4+	Smolt	0	-

Our model results suggest that juvenile hatchery steelhead will have a relatively uniform effect on age-0 and age-1 natural-origin Chinook salmon and steelhead given the overlap in timing, similar size of individuals, and similar habitat use. The potential for negative effects on this species was considered minimal, in part due to differences in release timing. The maximum numbers of juvenile fish lost for each species are shown in Table 16.

Table 16. Maximum numbers and percent of juvenile salmon and steelhead mortality due to predation, competition, or delayed mortality resulting from interactions with hatchery-origin steelhead.

Species	Age	April 15 Release		May 31 Release	
		Predation Mortality	Delayed Competition Mortality	Predation Mortality	Delayed Competition Mortality
Natural-origin Chinook salmon	Age 0+	2,059	30	1,322	281
	Age 1+	0	26	0	4
	Totals	2,070	56	1,322	285
Chinook salmon Adult Equivalents		**8**		**6**	
Natural-origin Steelhead	Age 0+	0	0	1,349	0
	Age 1+	5	421	11	605
	Age 2+	0	128	0	22
	Age 3+	0	11	0	1
	Age 4+	0	0	0	0
	Totals	5	560	1,360	629
Steelhead Adult Equivalents		**5**		**5**	

Based on the parameter inputs above, our model results show that the release of hatchery steelhead is likely to have a slightly lesser effect on natural-origin steelhead than on Chinook salmon. When we convert these to adult equivalents, we estimate that the equivalent of:

- 6 to 8 natural-origin Chinook salmon adults would be lost due to delayed mortality and predation.
- 5 natural-origin steelhead adults would be lost due to delayed mortality and predation.

We used the average number of natural-origin Chinook salmon returning to the Snohomish basin during 2000-2014 (5,554) presented by (Haggerty 2021a) to calculate the equivalent mortality of adults due competition and predation at the juvenile life stage. Using these data, we calculated a maximum potential mortality of 0.14 percent of adult Chinook salmon due competition and predation at the juvenile life stage. Using the same procedure we calculated the average number of natural-origin steelhead returning to the Snohomish basin during 2009-2019 (2,630). We calculated a maximum potential mortality of 0.23 percent[9] of adult steelhead due competition and predation at the juvenile life stage. Overall, the level of juvenile steelhead mortality is minor considering competition and predation at the juvenile life stage contributes to less than 0.5 percent of the reduction in adult fish returning to spawn.

Travel time of juvenile hatchery fish can lead to a substantial ecological effect. This is because longer travel time results in more time that fish may have interactions with natural-origin steelhead that are either competitive or predatory. Thus, NMFS recommends the co-managers monitor the average number of days required for rearing or release points throughout the

[9] Aggregate of winter-run and summer-run steelhead in the greater Snohomish basin.

watershed to migrate into the Puget Sound. If the value increases by more than five days over the course of a 4-year running average, this would indicate an increase in the potential for ecological effects beyond the findings presented here.

The displacement of natural-origin fish by hatchery steelhead might alter behavioral patterns and habitat use of natural-origin fish, making them more susceptible to predators (Hillman and Mullan 1989; Steward and Bjornn 1990). Hatchery-origin fish may also alter naturally produced salmonid migratory responses or movement patterns, leading to a decrease in foraging success (Hillman and Mullan 1989; Steward and Bjornn 1990). Actual impacts on naturally produced fish would thus depend on the degree of dietary overlap, food availability, size-related differences in prey selection, foraging tactics, and differences in microhabitat use (Steward and Bjornn 1990).

Effects of Residualization

Hatchery managers plan to rear juvenile steelhead as yearlings with smolts ready for outmigration voluntarily leaving as the gates open. This variation in outmigration is natural and thought to be a selective method to maximize smolt to adult survival by diversifying risk. However, hatchery strategies are generally designed to reduce the amount of rearing time to lessen impacts on natural-origin fish. Natural-origin fish may be competitively displaced by hatchery fish early in life, especially when hatchery fish are more numerous, are of equal or greater size, when hatchery fish take up residency before naturally produced fry emerge from redds, and if hatchery fish ‘residualize’, or remain in freshwater throughout their lifespan. These residual hatchery steelhead may compete for food and space with wild conspecifics as well as other native species (McMichael and Pearsons 2001; McMichael et al. 1999; McMichael et al. 1997). Because the PCD model described above does not account for competition or predation effects from juvenile hatchery steelhead that residualize in freshwater, we will evaluate these effects below.

Residualized steelhead may be produced from precocious maturation or failure to attain the proper size to initiate smoltification (Sharpe et al. 2007; Tipping et al. 1995). These are fish that do not initiate smoltification and residualize in freshwater habitats for their entire lifespan, which can be days, months, or years. Thus, the number, intensity, and severity of interactions from *O. mykiss* that residualize in freshwater is considerably more than the eight days that hatchery steelhead smolts are expected to spend in the freshwater environment during emigration.

Smoltification is regulated by environmental cues and complex physiological processes and ultimately culminates in downstream migration (Folmar and Dickhoff 1981). Smoltification is generally characterized by an increase in lipid metabolism and protein synthesis, increased growth in length relative to weight, and increased hypo-osmoregulatory ability relative to premigratory and nonmigratory individuals (Dickhoff et al. 1997; Folmar and Dickhoff 1981). The mechanistic cues that initiate smoltification have fundamental genetic linkages as described by (Nichols et al. 2008), but are influenced by length and body weight (Tipping et al. 1995) (Partridge 1985) and other environmental factors (Hausch and Melnychuk 2012). For example, (Tipping et al. 1995) found that body condition as measured by length to weight ratio, or K-value, from 0.90 to 0.99 resulted in optimal emigration rates for winter-run steelhead in a Puget Sound hatchery. (Hausch and Melnychuk 2012) reported a combination of factors affect the likelihood of steelhead to residualize, noting that steelhead reared in acclimation ponds, of intermediate size, and close post-release proximity to saltwater or a large river reduced the number of fish that residualized in freshwater. While some residual hatchery steelhead may survive and migrate seaward in subsequent years (Sharpe et al. 2007), best management practices suggest hatchery managers modify their hatchery practices to minimize or eliminate the number of residual fish released (HSRG 2004b; McMichael et al. 2000). (Tatara et al. 2019) and (Larsen et al. 2017) reported assessments of total length and qualitative visual smolt development index were effective methods for determining freshwater residualizing *O. mykiss*.

We suggest the co-managers assess body condition as measured by length to weight ratio and use the qualitative visual smolt development index (number of smolts, transitional smolts, sexually mature males, and immature parr) described by (Tatara et al. 2019) prior to release. These assessments will indicate if juvenile steelhead achieve the intended size, smolt development, and proportions of non-migratory or precocious juveniles prior to release. The co-managers can use these data to identify whether modification to rearing strategies are necessary. Also, the co-managers could further minimize effects of non-migratory steelhead by extending the period of volitional release for 4-6 weeks, followed by a forced release of all remaining juvenile steelhead. This strategy would reduce the number of large, two-year juveniles that are more likely to residualize in freshwater and the deleterious effects of these fish related to predation, competition, and genetic effects on Snohomish/Skykomish winter-run steelhead previously discussed in Section 2.5.2.2.

Competition and predation in the estuary and ocean

Given the proposed release timing and freshwater migration described above, we anticipate that juvenile hatchery steelhead will begin arriving into the Snohomish River estuary and the marine waters of Puget Sound from late April through late May. Hatchery-origin steelhead will be accompanied by natural-origin Chinook salmon and steelhead arriving in the estuary, as well as other species such as coho, chum, and pink salmon. Although it is important to note that not all species arrive in saltwater at the same time, or in similar abundances. Some species, like chum and pink salmon, typically migrate as fry (i.e., 55 mm or less) and move rapidly through the estuary earlier than other species. As such, juvenile steelhead are unlikely to interact with chum salmon and pink salmon during outmigration. Juvenile steelhead are typically more likely to overlap with coho and Chinook salmon, as these species are of similar size and exhibit greater similar timing and habitat use during outmigration. These factors are important to consider within saltwater environments because competition and predation within these systems are thought to be affected more by limitations in forage than space.

Similar to freshwater environments, hatchery-origin steelhead outmigrating into estuarine and marine waters of the action area may potentially interact with natural-origin Chinook salmon and steelhead through predation and competition for food and space. As juvenile salmon released from the proposed programs arrive in the estuary, they may compete with other Chinook salmon and steelhead in areas where they co-occur, if shared resources are limited. The hatchery-origin salmon may also prey on natural fish of sizes vulnerable to consumption. But, in contrast to brackish and freshwater habitats where fish are more concentrated, steelhead form schools with other similarly-sized salmonids and rapidly disperse within expansive saltwater habitats of the Puget Sound and the Pacific Ocean. This behavior is thought to limit predation and competition from individuals within the group while reducing risk of predation from larger species, such as marine mammals and seabirds. As discussed in Section 2.2, we expect that Skykomish River hatchery-origin steelhead smolts migrating in marine waters will exhibit an early offshore movement and a strong northward and westward seaward-bound orientation. Thus, competition between hatchery-origin steelhead and natural-origin Chinook salmon and steelhead in Puget Sound appears to be short in duration as steelhead quickly migrate offshore and seaward into habitats where food resources are more plentiful and space is less limiting.

In regard to competitive effects in estuarine and marine waters of Puget Sound, the main limiting resource for Chinook salmon and steelhead that could be affected through competition posed by hatchery-origin fish is food. The early estuarine and nearshore marine life stage, when juvenile fish have recently entered the estuary and populations are concentrated in a relatively small area, is a critical life history period during which there may be short-term reductions in growth and survival due to a temporary lack of forage items (Duffy 2003; Pearcy and McKinnell 2007; Rensel et al. 1984), as discussed in Section 2.2.2. The degree to which food is limiting depends upon the density of prey species. This does not discount limitations in available food resources in more seaward areas as a result of competition, some data suggest that marine survival rates for salmon are density dependent, and thus possibly a reflection of the amount of food available within the Pacific Ocean (Brodeur 1991; Holt et al. 2008; Rensel et al. 1984).

Researchers have investigated whether marine carrying capacity can limit salmonid survival (Beamish et al. 1997; HSRG 2004a). Some evidence associated with cyclical patterns of ocean productivity (Beamish and Bouillon 1993; Beamish et al. 1997; Nickelson et al. 1986) does suggest that density-dependence does affect the abundance of returning adult salmonids (Bradford 1995; Emlen et al. 1990; Lichatowich et al. 1993). Collectively, these studies indicate that competition for limited food resources, even in the marine environment of the Pacific Ocean, may affect survival (Brodeur et al. 2003). The possibility that large-scale hatchery production could exacerbate density dependent effects in the ocean, particularly when ocean productivity is low, deserves consideration. For example, Puget Sound origin salmon survival may be intermittently limited by competition with almost entirely natural-origin odd-year pink salmon originating from Puget Sound and the Fraser River watersheds (Ruggerone and Goetz 2004), particularly when ocean productivity is low (Beamish and Bouillon 1993) (Beamish et al. 1997; Mahnken et al. 1998; Nickelson et al. 1986). Yet, it is important to note that forage items that salmonids rely upon are not equally distributed within the Puget Sound or the Pacific Ocean, and the lack of forage at critical points in life history development are important determinants of adult return rates.

2.5.2.4. Factor 4. Research, monitoring, and evaluation

Research, monitoring, and evaluation (RM&E) occur on both hatchery-origin steelhead and natural-origin Chinook salmon and steelhead. RM&E activities include handling and transportation at the trap-and-haul facility for both hatchery-origin steelhead and natural-origin Chinook salmon and steelhead, while marking and tagging will be done on hatchery-origin steelhead. In the discussion below, we consider the effects on both hatchery-origin steelhead and natural-origin Chinook salmon and steelhead for completeness.

The co-managers propose to continue operating the Sunset Falls Trap and Haul Fishway facility as the primary method to collect summer steelhead for broodstock included in the new integrated program and to enumerate fish transported upstream of the falls (see Section 2.5.2.1). The co-managers also proposed to use the capture, handling, and tagging of fish at the trap-and-haul facility to identify the fate of steelhead transported to either the upper South Fork Skykomish basin or the North Fork Skykomish River. The co-managers will also continue to carry out spawning surveys (when flow and weather conditions allow) and snorkel surveys to estimate the abundance and origin of steelhead in the North Fork Skykomish River. Hatchery personnel will tag all juvenile steelhead of hatchery-origin with either a BWT, CWT, or PIT tag during the first phase of the program, which will enable researchers to differentiate migratory behavior, growth, and survival between hatchery and natural-origin steelhead. The co-managers will also rely on adipose fin-clipping in subsequent years to identify juvenile migrants and adult returns from the integrated program, thereby reducing misidentification of hatchery fish as natural-origin fish (i.e., masking). Marking and tagging methods will also enable biologists to identify and discern effects of hatchery-origin steelhead in the natural environment.

The fundamental purpose of the Sunset Falls Trap and Haul Fishway facility is to transport fish to the upper South Fork Skykomish basin, and the ability to gather information for RM&E purposes is ancillary to operations of the facility. All fish entering the facility will be subject to some level of handling and transportation, though handling effects are minimized for those fish that are transported using the water-to-water transfer method. Effects associated with the Sunset Falls Trap and Haul Fishway facility discussed are limited to monitoring the adult steelhead returns as a measure of long-term status and trends in the South Fork Skykomish population. See Section 2.5.2.5 for further discussions about handling effects on steelhead and Chinook salmon. No direct marking or tagging of natural-origin steelhead is proposed, which will preclude natural-origin fish from experiencing those effects. All hatchery-origin fish are marked or tagged (i.e., up to 116,000 annually).

Any physical handling or psychological disturbance is known to be stressful to fish (see Appendix A, Section 1.4.3). Section 1.4.3 for further discussions about effects of marking and tagging). The frequency, duration, and intensity of disturbance is determinative of the level of stress incurred by the fish. Decreased survival can result from high stress levels because stress can be immediately debilitating, and may also increase the potential for vulnerability to subsequent challenges (Sharpe et al. 1998). Primary factors contributing to stress and death from handling are excessive doses of anesthetic, differences in water temperatures (between the river and holding vessel), dissolved oxygen conditions, the amount of time fish are held out of the water, and physical trauma. Stress increases rapidly if the water temperature exceeds 64°F or dissolved oxygen is below saturation. Fish transferred to holding tanks can experience trauma if care is not taken in the transfer process, and fish can experience stress and injury from overcrowding.

An additional impact resulting from the proposed action is disturbance caused by surveying activities. The co-managers propose to conduct spawning and snorkel surveys to estimate abundance and origin of steelhead in the North Fork Skykomish River. Redd surveys are conducted from land with minimal crossing through shallow habitats that are unlikely to be occupied by steelhead and thus extremely unlikely to result in disturbance. Surveyors that swim through the North Fork Skykomish River in the course of completing snorkel surveys may frighten or startle steelhead holding in pools or preparing redds. This form of take may be characterized as harassment because fish are likely to respond by scattering, abandoning cover, and temporarily altering spawning behavior. The duration of effects on individual fish will likely be short-term and last for minutes after exposure occurs. We expect fish will resume normal activity within minutes with no latent effects from exposure, and it would not lead to impacts on population viability. We estimated the number of adult natural-origin steelhead harassed as the result of monitoring efforts based on the current population of natural-origin steelhead in the North Fork Skykomish River (i.e., 82 fish), the maximum number of steelhead that may be collected from the South Fork Skykomish River and outplanted (i.e., 250), and an additional 20 percent that may result from increased productivity because of outplanting—a total of approximately 400 adult summer steelhead that would be exposed to surveying activities.

2.5.2.5.Factor 5. The operation, maintenance, and construction of hatchery and trap-and-haul facilities

Of the facilities analyzed in this Proposed Action, there are no hatchery facilities that NMFS believes are a risk to ESA-listed salmonids. The co-managers propose to release up to 116,000 juvenile steelhead, a reduction in comparison to about 190,000 juvenile steelhead released from the Reiter Ponds facility in 2015 (Unsworth 2016). The co-managers will continue operations at both Reiter Ponds and Wallace River Hatchery facilities without modifying water use, rearing methodology, or effluent treatment. The continued operations at both hatchery facilities does not suggest threats to listed species and their critical habitats that are heretofore unidentified. Yet, we evaluated each facility for aspects that may affect both species, including: water source, characterization of surface water intake (if applicable), diversion distance, and water consumption. We also address below the same issues related to water use at the Sunset Falls Trap and Haul Fishway facility.

Further, the continued operations at hatchery facilities will not change effects on ESA-listed salmonids because:

1. WDFW has not documented the presence of listed fish upstream of hatchery surface intakes at Reiter Ponds. A natural barrier to anadromous fish passage exists just upstream of the water intake structure on Austin Creek limiting the effects on ESA-listed anadromous fish at this location. WDFW confirmed that surface water intakes at the Wallace River Hatchery meet screening criteria where juvenile fish may be present, but has not yet updated all screens at both facilities to meet current standards (NMFS 2011a).
2. Distances between surface water intakes and outfalls are relatively short. Water intakes on May Creek and the Wallace River are located less than 80 feet upstream of the intake points. Water intakes on Austin Creek and Hogarty Creek supplying water to Reiter Ponds are located 0.55 to 0.75 miles upstream of the outfalls.
3. Water use is non-consumptive, and is returned to the waterway within conditions that support features for the species and their critical habitats.
4. The proportion of water withdrawn is relatively low. Based on the amount of water available in each waterway described in Section 1.3, WDFW allocates a small proportion of water, typically less than ten percent of the total available streamflow,

5. Most water use, except that for alternate rearing at Wallace River Hatchery, is from spring-fed tributary sources.

We also note that the Sunset Falls Trap and Haul Fishway facility is used primarily to collect and transport fish upstream of a series of impassable falls on the South Fork Skykomish River. The water intake for this facility is located upstream of the falls where there is no potential effect on adult fish that may occasionally fall back downstream of Sunset Falls or migratory movements of juveniles occasional downstream movement. The water intake is located within the non-anadromous section adjacent to Sunset Falls and is diverted back to the South Fork Skykomish River within about 380 feet, with no measurable impact on water quality.

Facility operations

WDFW initiated improvements in the Wallace River Hatchery facility operations in 2020 that include monthly transfers of fish from the May Creek holding site to ponds supplied with additional cool water from the Wallace River and administering chemotherapeutic treatments during and after handling as warranted. WDFW anticipates additional improvements to water supply will follow with an existing well planned for 2020-2021 (contingent on permitting) and water re-use and disinfection system that is funded and currently in the design development phase. WDFW may install this system as early as 2023. A capital improvement funding request has been submitted for the development of additional horizontal and vertical wells at the Wallace River Hatchery. The aforementioned construction projects at Wallace River Hatchery may yield improvements to this facility. However, these proposals may nonetheless remain speculative. Nonetheless, there are no changes in hatchery facilities that would result in adverse effects on ESA-listed species that were not accounted for and authorized in previous consultations.

Operation of the Sunset Falls Trap and Haul Fishway facility

We also consider effects associated with the Sunset Falls Trap and Haul Fishway facility and the trap and haul operations. Hatchery personnel will collect all fish entering the trap at Sunset Falls and transport natural-origin and hatchery-origin individuals upstream of Sunset Falls. Some hatchery-origin steelhead may be transported and released into the North Fork Skykomish River. As noted previously in the Environmental Baseline, Section 2.4, the number of fish transported from the Sunset Falls Trap and Haul Fishway in the previous ten years varies from 126 to 591 Chinook salmon (Table 6), 0 to 59 hatchery-origin summer steelhead, and 164 to 592 natural-origin summer steelhead (Table 11). Hatchery personnel operate the Sunset Falls Trap and Haul Fishway using a water-to-water transfer system to move some fish from the trap to the transport tank. Thus, hatchery personnel can select and remove individual fish for broodstock from those in the trap without using nets and hand-removal methods that eliminates netting and removing fish by hand. Use of this transfer system reduces descaling and handling stress because fish can be herded into different areas without need of capture and removal of each individual. However, fish that are transported without the use of the water-to-water transfer system would experience temporary handling effects (see Appendix A Section 1.4.2 for further discussion). Using the figures from Tables 6 and 11, noted above, we estimate the maximum number of Chinook salmon and steelhead captured, handled, and transported into the upper South Fork Skykomish River by adding the maximum number of fish observed at Sunset Falls in the previous ten years and included a 10 percent buffer to compensate for years in which high productivity year occurs. The previous maximum number of Chinook salmon and steelhead transported from Sunset Falls

Trap and Haul Fishway in the previous ten years occurred in 2012 (591) and 2015 (592), respectively. We estimate the annual maximum number of fish transported upstream in future years at 650 Chinook salmon and 650 summer steelhead.

In this case, the trap and haul facility differs from fish handling procedures during routine collection and scientific research where fish are captured in a net or other device, anesthetized, removed from the water, handled in air, and then returned into the water for reacclimation. Each of these steps induces stress to the fish. Operations at the trap and haul facility differ because fish are moved to the transport vehicle using a water-to-water transfer system. As described above in Section 2.5.2.1, all hatchery steelhead will be subjected to some form of marking and/or tagging as juveniles prior to release. The effects of transporting both hatchery and natural-origin steelhead, which are similar to, but of lesser intensity than, marking and tagging, are characterized by short-term stress and alteration of normal behaviors that will not affect the ability of individual fish to forage, shelter, or reproduce.

Hatchery personnel may hold fish that are not selected as broodstock with other species in a common transport tank until they are released into the upper South Fork Skykomish basin. Based upon the numbers of steelhead observed at the Sunset Falls Trap and Haul Fishway facility in the previous ten years, as described above in Section 2.5.2.1, we anticipate this will be approximately 155 to 472 steelhead. The distance from the trap-and-haul facility to the upstream release point is 11 miles, requiring about 20 minutes of drive time to the release site, which will reduce the intensity of adverse handling effects. The time required for biologists to capture and transfer all fish for a single load will vary from minutes to hours. We conservatively estimate the number of listed species transported into the upper South Fork Skykomish basin may likely be 10 percent greater than the maximum number of each species observed in the previous ten years (see above Table 6 and Table 11). This results in an estimate of 650 Chinook salmon and 650 summer steelhead.

Researchers have broadly grouped physiological responses of fishes associated with handling and other stressors as primary, secondary, and tertiary. Primary responses involve the initial neuroendocrine responses that include the release of catecholamines from chromaffin tissue (Randall and Perry 1992; Reid et al. 1998), and the stimulation of the hypothalamic-pituitary-interrenal axis culminating in the release of corticosteroid hormones into circulation (Mommsen et al. 1999; Wendelaar Bonga 1997)(Donaldson 1981). Secondary responses include changes in plasma and tissue ion and metabolite levels, hematological features, and heat shock or stress proteins, all of which relate to physiological adjustments in metabolism, respiration, acid-base status, hydromineral balance, immune function and cellular responses (Iwama et al. 1992; Mommsen et al. 1999)(Pickering 1981). Tertiary responses may also occur changes in growth, condition, overall resistance to disease, metabolic scope for activity, behavior, and ultimately survival (Wedemeyer 1972; Wedemeyer et al. 1984). The number, duration, and intensity of stressors are factors determining whether the fish's homeostatic response mechanisms are restored, or exceeded, which may cause a sustained reduction in fitness or death (Schreck 1981; 2000). In summary, researchers can detect minor, short-term responses of fish to stress by measuring blood cortisol 'stress hormones' resulting from changes in metabolism and respiratory function at the cellular level. These changes in cellular function, if sustained at high intensity and/or extended duration, may alter the scope or behavior of fish to such an extent that impacts survival.

The effects of handling, transport, and release will most likely result in harm (e.g., stress) and minor physical injury (e.g., descaling) that will result in elevated blood cortisol levels, as characterized above, for a limited period. Elevated blood cortisol levels will likely persist for hours to days after fish are released depending on the duration of transport and environmental factors such as ambient air and water temperature. Generally speaking, handling fish can delay migration as individuals recover, which can have negative effects on individuals and the population (Anttila et al. 2008; Sharpe et al. 1998). Yet, in this case, we can expect Chinook salmon and steelhead to begin spawning within days to months after they are released into the upper South Fork Skykomish basin, so there appears to be sufficient time for individuals to recover from the stress of handling and transportation to preclude any adverse effect on the abundance or productivity of the relevant populations.

There is one potential exception to the generally low level of effects occurring from the trap-and-haul operation. Even though hatchery personnel use transport trucks equipped with continuous water flow and oxygenation systems and duration of transport to the upper South Fork Skykomish basin is short transporting adult salmon and steelhead is not without risks. In several decades since WDFW first began transporting fish via tanker truck upstream of Sunset Falls there has been one instance of vehicle malfunction that resulted in the death of all fish contained in the transport tank. While we do not anticipate such an episode occurring, the possibility of mortality to adult salmon and steelhead during transport does exist. WDFW limits transport up to 25 steelhead or Chinook salmon (WDFW 2019b). Therefore, this figure represents the maximum number of either species that may die as the result of a catastrophic event. Given the single occurrence of a catastrophic event during several decades of operation, the potential of such an event occurring within the ten-year lifetime of the permit is extremely unlikely. We anticipate the frequency of such a catastrophic event is limited to a single occurrence in the ten-year permitted operation of the trap and haul program.

As discussed in Section 1.3 (Proposed Action) the operation of broodstock collection facilities and the Sunset Falls Trap and Haul Fishway facility will result in the capture and handling of all natural and hatchery-origin Chinook salmon and steelhead entering these facilities. Although we do not anticipate any Chinook salmon will enter the weir at Reiter Ponds, a large number of the species is collected and transported upstream of Sunset Falls annually. In general, the effects of operating collection facilities include the potential for delayed migration and changes in spatial distribution of listed species. Though adult passage may be delayed slightly, operational guidelines and daily monitoring of collection facilities by the co-managers will minimize the delays to and impacts on fish; fish generally are not delayed for more than 24 hours throughout the trapping season. In addition, the spatial distribution of juvenile and adult listed species is not expected to be affected by weir operation in these areas because the weirs are designed to allow juvenile passage, and natural-origin adults are passed upstream when not required for broodstock.

Until WDFW constructed the Sunset Falls Trap and Haul Fishway and began transporting fish upstream in 1958, there was no influx of marine-derived nutrients to drive primary productivity. Annual reports of salmon and steelhead passed upstream into the upper South Fork Skykomish basin number in the thousands, most of which were coho and pink salmon. Operation of the Sunset Falls Trap and Haul Fishway facility and passage of large numbers of fish into the upper

South Fork Skykomish basin represents a considerable benefit to maintaining productivity of listed Chinook salmon and steelhead.

Water withdrawals

There are potential effects on water quality due to ~~and~~ effluent at the Reiter Ponds and Wallace River hatchery facilities, which were addressed by NMFS in previous Section 7 consultations and included in the environmental baseline for the purposes of this opinion, though to aid the discussion we summarize them here (NMFS 2017a). The previous biological opinion on Chinook salmon programs in the Snohomish watershed (NMFS 2017a) noted that the surface water intake structures at Wallace River Hatchery and May Creek do not meet (NMFS 2011a) intake screening criteria; however, no fish mortality related to the current surface water intake structures has been observed. WDFW has allocated funding to update the intake screens at Wallace River Hatchery and May Creek and this work may be completed as soon as 2023. While any unscreened intake where the source is surface water potentially poses a risk to juvenile salmonids, the lack of impingement observed at this facility suggests no harmful effects are likely to occur on salmonids prior to the intake being properly screened. Thus, NMFS does not currently consider the Wallace River Hatchery intake structure to pose substantial risks to fish passage because the current intake screens meet earlier screening criteria (NMFS 1996), which is adequately protective of listed Chinook salmon and steelhead from impingement and entrainment effects until the structures are renovated(NMFS 2008a; NMFS 2011a). Further improvements to water supply will follow with development of an existing well planned for 2020-2021 (contingent on permitting). Additional improvements scheduled for Wallace River Hatchery include installation of a water re-use and disinfection system that is funded and in the design development phase. WDFW may install this system as early as 2023.

There is no analogous concern associated with water sources used by WDFW at the Reiter Ponds facility because this facility uses water from Austin Creek and Hogarty Creek, both spring-fed systems. Neither creek supports ESA-listed species, and therefore no screening is necessary for the intakes nor is there potential for adverse effects from use of these water sources.

Effluent

The direct discharge of effluents from the hatchery facilities is regulated by the Environmental Protection Agency (EPA) under the Clean Water Act through National Pollutant Discharge Elimination System (NPDES) permits. The EPA has delegated its regulatory oversight to Washington State for hatchery discharges not located on Federal or tribal lands within the state. Washington Department of Ecology (DOE) is responsible for issuing and enforcing NPDES permits that ensure water quality standards for surface and marine waters remain consistent with public health and enjoyment, and the propagation and protection of fish, shellfish, and wildlife (WAC 173-201A).

WDFW operates the facilities under the ‘Upland Fin-Fish Hatching and Rearing’ National Pollution Discharge Elimination System administered by the DOE (WDOE 2015) with separate permits for each hatchery facility (i.e., WAG 13-3006 for Wallace River Hatchery; WAG 13-3005 for Reiter Ponds). Monthly water monitoring reports to the DOE are a requirement of these permits. The water quality parameters selected by EPA and DOE as important for determining hatchery-related water quality effects are as follows:

- Total Suspended Solids (Fleming et al.) - 1 to 2 times per month on composite effluent, maximum effluent and influent samples.
- Settleable Solids - 1 to 2 times per week through effluent and influent sampling.
- In-hatchery Water Temperature - daily maximum and minimum readings.

While compliance with NPDES permit conditions does not preclude the potential for adverse effects on ESA-listed salmonids, DOE did consult on the potential for adverse effects on listed species as a result of adopting standards for water quality (EPA 2008; EPA 2015; WDOE 2015). When examining steelhead mortality rates in hatchery and non-hatchery environments it is apparent that a relatively low mortality rate of 7 percent exists within the hatchery, where water quality is generally worse, in comparison to natural conditions (non-hatchery environment) where steelhead mortality rates of about 45 percent are expected in the natural environment (Bradford 1995). This suggests that other factors besides water quality are critical in steelhead mortality rates. Consistent with WDFW's NPDES permit for Wallace River Hatchery, hatchery managers will use a settling pond for pollution abatement to remove solid material from effluents prior to discharge of water (WDFW 2013b). WDFW reports that from 2008 through 2012, the Wallace River Hatchery program has been in compliance with all NPDES effluent discharge permit requirements, with three exceptions (WDFW 2013b). In 2008, the program recorded two instances where sampling indicated the Total Suspended Solids limit in the hatchery effluent was exceeded. In 2009, the program recorded one instance where sampling indicated the TSS limit in the hatchery effluent was exceeded. Heavy rains and an undersized abatement pond contributed to the three TSS limit exceedances. A new abatement pond will be constructed by fall 2020 to reduce the risk of TSS limit exceedance in the future (WDFW 2013b), though these past exceedances are of minimal risks to the ESA-listed natural-origin fish because the exceedance is rare, and the effects of exceedance is likely to be limited to the areas surrounding the facility (i.e., effects are diluted further downstream).

Hatchery managers also use therapeutic chemicals (e.g., formaldehyde, sodium chloride, iodine, potassium permanganate, hydrogen peroxide, antibiotics) to control or eliminate pathogens at Reiter Ponds or Wallace River hatchery facilities when necessary. As such these chemicals may also be present in hatchery effluent. Therapeutic chemicals are not likely to be problematic for ESA-listed species because they are quickly diluted beyond manufacturer's instructions when added to the total effluent and further reduced when discharged into the receiving water body. Moreover, therapeutants are used periodically, not constantly, during the hatchery rearing phase. This limits the potential use of therapeutants to weeks to months. In addition, many of them break down quickly in the water and/or are not likely to bioaccumulate. For example, formaldehyde readily biodegrades within 30 to 40 hours in stagnant waters. Similarly, potassium permanganate would be reduced to compounds of low toxicity within minutes. Aquatic organisms are also capable of transforming formaldehyde through various metabolic pathways into non-toxic substances, preventing bioaccumulation in organisms (EPA 2015).

In summary, there will be no change in the operation, maintenance, and construction resulting from the proposed action. Any changes to hatchery facility operation or construction at these facilities have already undergone consultation or will do so prior to completion. Therefore, we are reasonably certain the proposed action will not result in adverse effects on listed species.

2.5.2.6.Factor 6. Fisheries that Exist Because of the Hatchery Program

As described in Section 2.4.2, the effects of all fisheries on ESA-listed species are expected to continue at levels similar to those described in the Environmental Baseline. The recreational steelhead fishery in the greater Snohomish basin is in part a consequence of the proposed action and may not exist without the proposed action, though making a precise connection is difficult because harvest actions in general are subject to separate management and consultation on an annual or multi-year basis (NMFS 2016b; Unsworth and Grayum 2016); (Warren and Bowhay 2016). In this case, NMFS has considered the effects of the expected Snohomish basin fishery NMFS (within the total fishery-related impacts on Puget Sound Chinook salmon and Puget Sound steelhead from all recreational, commercial, ceremonial, subsistence, and take-home salmon and steelhead fisheries throughout the greater Puget Sound area. In that consultation NMFS (2020), estimated an average tribal and non-tribal harvest rate from 2007/2008 through 2018/2019 of winter-run steelhead from the greater Snohomish basin at 1.10 percent. NMFS (2020) found these fishery-related effects and those from test fisheries throughout the Puget Sound would not likely jeopardize the continued existence of the Puget Sound Chinook Salmon ESU and the Puget Sound Steelhead DPS or to destroy or adversely modify designated critical habitat. We do not have any information on proposed fisheries in the South Fork Skykomish River that may be proposed in future years, but will consider these actions if and when suitable information is presented.

2.5.2.7.Effects of the Action on Critical Habitat

As described above, the proposed action will result in a continuation of activities at the Wallace River Hatchery and Reiter Ponds and the effects associated with rearing summer steelhead. These activities include continued water use, effluent discharge, and operation of facilities for broodstock collection. The proposed action includes no new construction or changes in methods used in the production of summer steelhead, including numbers of fish reared and released. Thus, there are no new adverse effects on physical and biological features of critical habitat of Puget Sound Chinook salmon or Puget Sound steelhead.

Water intakes and screens used to supply water for Wallace River Hatchery are in compliance with NMFS (1995); NMFS (1996) screening criteria, but have not been updated based on the most recent criteria (NMFS 2011a). WDFW intends to upgrade fish screens at Wallace River Hatchery to ensure compliance with current NMFS fish passage and screening criteria. WDFW expects operating screened water intakes will adequately protect critical habitat features for safe passage of listed species until the structure is renovated to be in compliance with current NMFS criteria. Improvements in Wallace River Hatchery operations and facilities, which include updating the intake screens to become compliant with the most recent screening requirements (NMFS 2011a), were expected to be initiated in 2020 to achieve the desired construction timeline for completion in 2023. While funding appears to have been allocated for the requested improvements, WDFW has not initiated the design process, which will likely delay the construction timeline by 1-3 years. .

The co-managers do not anticipate discharge of effluent from hatchery rearing facilities will result in degradation to water quality that were not already characterized and authorized by federal and state entities. Consistent with effluent discharge permit requirements developed by

EPA and the DOE for upland fish hatcheries, water used for fish production at Wallace River Hatchery and Reiter Ponds will be adequately-treated prior to discharge into downstream areas to ensure that federal and state water quality standards for receiving waters are met and that downstream aquatic life, including salmon and steelhead. As described in Section 2.4.4 EPA and DOE consulted on effects resulting from effluent discharge and water quality authorizations with NMFS by maintaining water quality standards (EPA 2008; EPA 2015; WDOE 2015), we expect the co-managers' proposed hatchery operations will not adversely affect water quality features of designated critical habitat for either species.

Wallace River Hatchery has a current NPDES permit (#WAG 13-3006) that requires monitoring, measurement, and monthly reporting to WDOE of water use, chemical use, and effluent discharge levels (WDFW 2013b). The following water quality parameters, selected by EPA and WDOE as important for determining hatchery-related water quality effects, are monitored under NPDES permits issued for the hatchery programs (WDFW 2013b):

- Total Suspended Solids - 1 to 2 times per month on composite effluent, maximum effluent and influent samples.
- Settleable Solids - 1 to 2 times per week through effluent and influent sampling.
- In-hatchery Water Temperature - daily maximum and minimum readings.

Consistent with WDFW's NPDES permit for Wallace River Hatchery, hatchery managers will use a settling pond for pollution abatement to remove solid material from effluents prior to discharge of water (WDFW 2013b). WDFW reports that from 2008 through 2012, the Wallace River Hatchery program has been in compliance with all NPDES effluent discharge permit requirements, with three exceptions (WDFW 2013b). In 2008, the program recorded two instances where sampling indicated the Total Suspended Solids limit in the hatchery effluent was exceeded. In 2009, the program recorded one instance where sampling indicated the TSS limit in the hatchery effluent was exceeded. Heavy rains and an undersized abatement pond contributed to the three TSS limit exceedances. In the funding requests to update intake screens, WDFW included a proposal to construct a two-bay pollution abatement pond to reduce the risk of TSS limit exceedance at Wallace River Hatchery (WDFW 2013b). However, as noted above, funding was allocated only recently, and it appears the construction timeline will be delayed for 1-3 years.

The effects of hatchery effluent discharge on downstream aquatic life, including listed Chinook salmon and steelhead, resulting from implementation of the proposed hatchery programs would be adequately minimized through compliance with federal and state permit requirements. For these reasons, the proposed hatchery programs are not expected to pose substantial risks through water quality impairment to downstream aquatic life, including listed salmon and steelhead. No hatchery maintenance activities are expected to adversely modify designated critical habitat or habitat proposed for critical designation.

2.6. Cumulative Effects

"Cumulative effects" are those effects of future state or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation (50 CFR 402.02 and 402.17(a)). Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the ESA.

Some continuing non-Federal activities are reasonably certain to contribute to climate effects within the action area. However, it is difficult if not impossible to distinguish between the action area's future environmental conditions caused by global climate change that are properly part of the environmental baseline *vs.* cumulative effects. Therefore, all relevant future climate-related environmental conditions in the action area are described in the environmental baseline (Section 2.4).

Non-Federal actions are likely to continue affecting ESA-listed species. State, tribal, and local governments have developed plans and initiatives designed to protect and recover listed salmon and steelhead populations (Snohomish Basin Salmon 2005; SSPS 2005). Consistent with these plans, WDFW and the Puget Sound tribes will continue to implement hatchery management plans within the Puget Sound region similar to those evaluated in this opinion that can benefit or adversely affect listed Puget Sound Chinook salmon ESU and Puget Sound steelhead DPS populations in other watersheds.

Puget Sound salmon and steelhead harvest management plans will be implemented to meet ESA-listed fish protection needs, consistent with recovery exploitation rate strategies evaluated and authorized by NMFS for listed fish effects (e.g., (NMFS 2017c)). The cumulative effects of these and other non-Federal actions in the action area are difficult to analyze considering the geographic landscape of this opinion, the political variation in the action area, the uncertainties associated with government and private actions affecting salmon and steelhead habitat, and the changing economies of the region.

Whether the aforementioned effects will increase or decrease is a matter of speculation, with the likelihood for future effects depending on the activity affecting the species, the non-federal entity regulating the activity, and the condition of natural habitat, as affected by natural variance in environmental factors and climate change. However, we expect the activities identified in the baseline to continue at similar magnitudes and intensities as in the recent past. Ongoing state, tribal, and local government salmon restoration and recovery actions implemented through the Shared Strategy Plan (SSPS 2005) and through other associated plans and initiatives are expected to continue and to help lessen the effects of non-federal land and water use activities on the status of listed fish species.

The rate of such decreases are reasonably likely to be similar to those observed in recent years. With these improvements, however, based on the trends discussed above, there is also the potential for adverse cumulative effects associated with some non-Federal actions to increase (Judge 2011). State, tribal, and local governments have developed resource use plans and initiatives to benefit listed fish and offset any growing adverse effects that are proposed to be applied and sustained in a comprehensive way (e.g., (Snohomish Basin Salmon 2005)). These actions would likely be in the form of legislation, administrative rules, or policy initiatives, and land-use and other types of permits, and that government actions are subject to political, legislative, and fiscal uncertainties.

Habitat restoration within the Snohomish basin has been conducted by several entities, including the Tulalip Tribes, Salmon Recovery Funding Board through the Washington State Recreation and Conservation Office, Snohomish Conservation District, and the U.S. Forest Service, among others (NWIFC 2016). In addition, the Washington State Department of Transportation is required to correct passage at over 400 culverts by 2030 to provide access to 90 percent of the habitat state-wide that are blocked by roadway infrastructure owned by Department (NWIFC 2016). Some of these culverts are present in the greater Snohomish basin and will be corrected in the near future. Completion of these restoration projects has restored riparian vegetation, removed invasive plants and bank hardening, replaced or removed fish-blocking culverts and other aquatic barriers, installed log jams, and helped to increase habitat value in the greater Snohomish basin (NWIFC 2016). Altogether, since 1998, salmon recovery funding for the greater Snohomish basin has included 102 completed projects, 22 active projects, 2 conceptual projects, and 2 proposed projects focused on protecting and/or increasing salmon habitat and removing salmon migration barriers (NWIFC 2016). While these projects have improved habitat conditions and may improve access to spawning and rearing habitat in the foreseeable future, it is unclear if the rate of improvement to salmon and steelhead habitat will mitigate changes in habitat conditions caused by state and local authorities and those resulting from climate change.

2.7. Integration and Synthesis

The Integration and Synthesis section is the final step in our assessment of the risk posed to species and critical habitat as a result of implementing the proposed action. In this section, we add the effects of the action (Section 2.5) to the environmental baseline (Section 2.4) and the cumulative effects (Section 2.6), taking into account the status of the species and critical habitat (Section 2.2), to formulate the agency's biological opinion as to whether the proposed action is likely to: (1) Reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing its numbers, reproduction, or distribution; or (2) appreciably diminish the value of designated or proposed critical habitat as a whole for the conservation of the species.

In assessing the overall risk of the Proposed Action on each species, NMFS considers the risks of each factor discussed above in Section 2.5, in combination, considering their potential additive effects with each other and with other actions in the area (environmental baseline and cumulative effects). This combination serves to translate the threats posed by each factor of the Proposed Action into a determination as to whether the Proposed Action as a whole would appreciably reduce the likelihood of survival and recovery of the listed species.

2.7.1. Puget Sound Chinook salmon

The Snohomish River basin has been altered by residential and industrial development that has reduced the quality and quantity of habitats in estuary and floodplain areas that are important for juvenile fish to rear and prepare for saltwater migration. Agricultural and infrastructure development has simplified channel structure, and increased pollutant and nutrient loading throughout much of the Snohomish basin. Forestry practices in the upper portion of the basin continue to degrade habitat important for juvenile rearing and adult spawning by altering sediment transport. Considering these and other modifications, the Chinook salmon populations in the greater Snohomish basin are depressed, but have remained relatively stable over the course of the past three decades. Below we consider adding the effects from the Proposed Action in context of the aforementioned habitat conditions within the watershed and make our conclusion whether the proposed action is likely to jeopardize the species.

We anticipate competition and predation from hatchery steelhead on juvenile Chinook salmon during freshwater migration will result in the equivalent mortality of up to 8 adult Chinook salmon, or less than 0.14 percent of the Snohomish/Skykomish population. We believe this is a conservative estimate of mortality that is small considering the annual abundance of Chinook salmon returning to spawn. Moreover, this level of mortality is likely to be less than that occurring as a result of the existing early summer steelhead program. Recent estimates for the Skykomish population of Chinook salmon suggest the reduction in abundance of 8 adults will not alter the potential for this population to recover, especially when the number transported upstream of Sunset Falls regularly exceeds 300 fish. The Skykomish Chinook salmon population is categorized as a tier 2 for recovery, as indicated by generally sustained productivity among populations within the Whidbey/Main Basin bioregion. Overall, the mortality resulting from predation and competition with juvenile hatchery steelhead will slightly reduce abundance, but not productivity, spatial distribution, or genetic diversity. The effect of the hatchery program will be too small to impact the recovery of this Chinook salmon ESU.

A large portion of Snohomish/Skykomish Chinook salmon population will be subjected to effects related to capture, handling, and transport from Sunset Falls Trap and Haul Fishway facility and release into the upper South Fork Skykomish River. The average number of Chinook salmon captured and transported into the upper South Fork Skykomish basin is about 383 fish, which represents approximately 25 percent of adult Chinook salmon escapement in the Skykomish River basin. The effects associated with the trap-and-haul facility are short-term and low-intensity handling that will, in turn, allow access to high quality spawning and rearing habitat. Because the effects of the trap-and-haul operation are temporary and low intensity in nature, these actions will have minimal effect on the recovery trajectory of the Snohomish Chinook salmon population. More importantly, continuing transport of adult Chinook salmon into the upper South Fork Skykomish basin will maintain access to high quality spawning and rearing habitat that will prevent reductions in abundance, productivity, and spatial distribution. Therefore, these beneficial aspects of the proposed action are necessary to maintain recovery of Chinook salmon populations within the greater Snohomish basin.

Information and analysis from the most recent status review suggest that Puget Sound Chinook salmon remain listed as threatened (NWFSC 2015), and the viability status of the two Chinook salmon populations within the greater Snohomish basin is poor. Both the Skykomish River and Snoqualmie populations are below targets for rebuilding and the remaining population diversity, spatial structure, and productivity are below desired levels required for the populations to recover to a self-sustaining condition. Although these populations currently do not assume primary roles for recovery of the Puget Sound Chinook Salmon ESU, maintaining or improving both populations is necessary to ensure spatial structure and genetic diversity of the ESU. The ESA-listed natural Chinook salmon populations in the watershed have not progressed beyond what is described in the tribal approach as the “preservation” stage (Snoqualmie Chinook salmon) or the initial phase of the “recolonization” stage (Skykomish Chinook salmon), considering their current and recent past low viability status, and the poor to fair condition of habitat (Rawson and

Crewson 2017), and best management practices are necessary to maintain the recoverability of the two native Chinook salmon populations.

The proposed action will allow the Snohomish/Skykomish population continued access to important spawning and rearing habitat in the Snohomish basin via continued operation of the Sunset Falls Trap and Haul program. Releases of steelhead from the integrated summer steelhead hatchery program will have minimal effect on the abundance of returning adult Chinook salmon from either of the Snohomish basin populations. Recovery of the ten Chinook salmon populations in the Whidbey Basin bioregion is an important component to minimize the risk to the ESU because other populations in the Puget Sound face greater threats to recovery. Overall, maintaining viability parameters for the two Snohomish basin populations by implementation of the proposed action is important to recovery of the ESU.

2.7.2. Puget Sound steelhead

Best available information indicates that the Puget Sound Steelhead DPS remains threatened (NWFSC 2015). Spawner abundance is currently depressed, and population diversity, spatial structure, and productivity are also below desired levels required for the two populations in the Snohomish basin to recover to a self-sustaining condition (Section 2.2.3). Our Environmental Baseline considers the effects of hydropower, habitat, fisheries, and hatcheries. Although all may have contributed to the listing of the DPS, all factors have also seen improvements in the way they are managed/operated. As we continue to deal with a changing climate, the steady improvement of habitat conditions, harvest strategies that reduce impacts on listed steelhead and/or target hatchery-origin adults may also alleviate some of the potential adverse effects (e.g., hatcheries serving as a genetic reserve for natural populations).

The majority of effects of the Proposed Action on this DPS are the result of the genetic legacy of previous early summer steelhead hatchery operations (which included releases of Skamania-origin summer steelhead) in the greater Snohomish basin, ecological interactions between hatchery and natural-origin fish on the spawning grounds, incorporating natural-origin steelhead into the broodstock. The effects on the Puget Sound Steelhead DPS from RM&E and capture and transport at the Sunset Falls Trap and Haul Fishway facility are minor, low-intensity effects with little potential to affect recovery status.

We anticipate that the genetic effects on the South Fork Skykomish summer steelhead from the hatchery program will be limited by managing the integrated population to achieve an average PNI value of 0.67 in most years. PNI may be lower during the years of low adult returns, though it will be as high as possible while taking passage above Sunset Falls in consideration. The long-term expected effects are improved abundance, productivity, and genetic diversity of South Fork Skykomish summer steelhead. We anticipate that pHOS for the North Fork summer steelhead population will be, on average, around 15.6%, which is an acceptable short-term rate[10]. In addition, we anticipate that the genetic effects of the proposed hatchery program on the Tolt summer population will be limited to a pHOS of 2 percent, well below the recommended limit of

[10]This pHOS figure pertains to the assumption in this Opinion that the North Fork and South Fork groups are considered as separate populations.

5 percent. The overall result is an improvement in population viability that is important to sustaining genetic diversity present in the few extant summer-run populations in the Puget Sound steelhead DPS. In addition, if outplanting hatchery-origin adults into the North Fork population is deemed to be consistent with viability needs, these benefits may be extended to the North Fork population.

We anticipate gene flow into winter-run steelhead populations will be low, but does pose a minor risk of reduced fitness to the Skykomish winter steelhead population. The proposed program will result in gene flow, as measured by PEHC analysis, that NMFS expects to average 5 percent to the Skykomish winter steelhead population, and much less to the Pilchuck and Snoqualmie winter steelhead populations. The affected populations (Pilchuck, Snoqualmie, and Skykomish winter steelhead populations) are the only three winter-run populations out of seven in the large and diverse North Cascade MPG affected by this program. In addition, because the level of gene flow to those affected populations is at or below the 5% limit, we believe that the Puget Sound steelhead DPS can sustain this level of risk.

The effects of competition and predation between hatchery-origin and natural-origin steelhead resulted in an estimated mortality of less than 0.25 percent. While mortality from competition and predation at the juvenile life stage will reduce the number of adult steelhead spawners, it is not large enough to meaningfully decrease the abundance or productivity of any of the listed populations and to affect recovery of the DPS.

The initial years of establishing integrated hatchery broodstock involves collecting up to 120 natural-origin summer steelhead or up to 30 percent of the natural returns annually. The number of natural-origin steelhead collected from the North Fork Skykomish population used as broodstock is likely fewer than five fish, so the potential effect on this population is low. The likelihood of collecting steelhead from the Tolt River population is even lower. Straying of natural-origin summer steelhead into the South Fork Skykomish is thus likely to occur at such a low level that it will not decrease the potential for recovery of either the North Fork Skykomish or the Tolt populations. Live-spawning and release of hatchery broodstock, if successful, will further reduce adverse effects on the South Fork Skykomish population because these fish can spawn again in nature. Considering the status of the South Fork Skykomish summer steelhead population and relatively sustained number of natural-origin adult steelhead returns to the Sunset Falls Trap and Haul Fishway facility, we believe the limited number of broodstock collected is too small to decrease the overall abundance or productivity ratings of either summer-run or winter-run steelhead populations included in the listed DPS, and therefore of little risk to the abundance and productivity of the DPS itself.

RM&E proposed by the co-managers include collecting genetic samples from 100-500 juvenile winter-run steelhead as well as adult hatchery- and natural-origin steelhead returning to the basin to evaluate gene flow. Maintaining standards for gene flow will limit the potential for adverse effects on Snohomish/Skykomish winter-run steelhead, preserving the genetic diversity of this population. There are additional effects from marking and tagging of juvenile hatchery-origin steelhead.

Ecological interactions from redd superimposition and spawning ground competition related to the hatchery steelhead program are unlikely to result in a meaningful decrease of either of the listed populations because these are density-dependent interactions. The Reiter Ponds early summer steelhead program will be replaced by the new integrated program, which will not result in any additional steelhead that stray into either watershed. Even with the proposed outplanting of natural-origin steelhead, adverse effects from redd superimposition and spawning ground competition on the North Fork Skykomish River or Tolt River populations are unlikely and infrequent and will not reduce the abundance or productivity of either population. As described in the intrinsic potential analysis, the North Fork Skykomish basin is under-utilized and has sufficient spawning, rearing, and forage resources to accommodate 200 to 300 more summer steelhead than is currently proposed. Moreover, the proposed outplanting effort is of sufficient magnitude to yield long-term improvements in the abundance, productivity, and genetic diversity of the North Fork Skykomish summer steelhead population. The overall effect of the outplanting will be to improve the recovery trajectory for the DPS by bolstering an important summer-run population as identified by NMFS in the recovery plan (NMFS 2019c).

Given the average number of adult summer steelhead returning to the Skykomish basin each year, as estimated by fish transported from Sunset Falls Trap and Haul Fishway facility and returns to the North Fork Skykomish River, is about 400 fish (see Section 2.2.3), a large portion of adult summer steelhead will be subjected to effects related to capture, handling, and transport from Sunset Falls Trap and Haul Fishway facility and release into the upper South Fork Skykomish River. Recent estimates suggest that the average number of natural-origin adult steelhead returning to the Sunset Falls Trap and Haul Fishway facility is 315 fish, with approximately 82 fish estimated in the North Fork Skykomish River. Because the number of steelhead from the North Fork Skykomish observed at the Sunset Falls Trap and Haul Fishway facility is likely few, the overall effect on this population is minimal to moderate stress that is of short-term duration. Fish may be transported upstream to access highly-productive spawning and rearing habitat in the upper South Fork Skykomish basin while still retaining the potential to migrate downstream of Sunset Falls and access the rest of the Skykomish basin. Very few listed steelhead will be subjected to the short-term delay in migration.

The recovery plan for Puget Sound steelhead describes the on-going and proposed state, tribal, and local government actions that are targeted to reduce known threats to the species (NMFS 2019c). Such actions include improving habitat conditions, and hatchery and harvest practices to protect listed steelhead DPSs, and NMFS expects this trend to continue, potentially leading to increases in abundance, productivity, spatial structure and diversity. Habitat conditions are the same for both Puget Sound Chinook salmon and Puget Sound steelhead in the greater Snohomish basin. Large portions of the basin, particularly in the estuary and low-elevation areas near the city of Everett, are severely degraded with very limited spawning and rearing habitat for anadromous species. Development in and near this urban center will continue to prevent needed restoration of habitats and environmental processes upon which salmonids rely, although recent improvements in estuary and tidal habitats at the Great Heron Slough Conservation Bank have restored highly productive habitats for migration and juvenile rearing. The measured pace of habitat restoration elsewhere in the greater Snohomish basin will continue to restore function to other habitats necessary for salmonids to spawn and rear. Overall, of the 32 populations included in the listed Puget Sound Steelhead DPS, only two populations within the Skykomish basin (i.e., Snohomish/Skykomish winter-run and North Fork Skykomish summer-run) are likely to experience any meaningful decrease in abundance and productivity due to the proposed action. Other populations, including those within the greater Snohomish basin (i.e., Pilchuck winter-run, Snoqualmie winter-run, Tolt summer-run), will experience effects from the proposed action that are too minimal to diminish recovery of the DPS. The other steelhead populations in the North Cascades MPG have a positive abundance trend (see Table 10). Thus, our analysis leads NMFS to conclude, after considering all factors, that the Proposed Action will not appreciably reduce the likelihood of survival and recovery of the Puget Sound Steelhead DPS.

2.7.3. Critical Habitat

Critical habitat for ESA-listed Puget Sound Chinook salmon and Puget Sound steelhead is described in Sections 2.2.2 and 2.2.4 of this opinion. In reviewing the proposed action and evaluating its effects, NMFS has determined that the proposed action will not degrade habitat designated as critical for listed fishes. The existing hatchery facilities have not altered channel morphology and stability, reduced or degraded floodplain connectivity, excessive sediment input, or the loss of habitat diversity, and no new facilities or changes to existing facilities are proposed.

The proposed operations at the hatchery facilities and the Sunset Falls Trap and Haul Fishway could also result in impacts on water quality features related to surface water withdrawals. However, the co-managers have proposed water usage within guidelines that establish the ~~at~~ maximum permitted levels to maintain water quantity and quality commensurate for salmon and steelhead migration and rearing between hatchery water intake and water discharge points. As a result, adverse effects on critical habitat for either species are unlikely, because water withdrawal amounts for hatchery fish rearing during the summertime low flow periods, when any effects would be most pronounced, will be much less than the permitted maximum levels. Fish biomass at the hatchery rearing locations, and required water withdrawal amounts, would reach maximum permitted levels only in the late winter and spring months just prior to fish release dates, when the fish are at their largest size, and flows in the Skykomish River basin approach their annual maximums. At these times, the water withdrawals would not be a substantial proportion of the streamflow, and so critical habitat would not be adversely modified.

Improvements in hatchery facilities expected to yield an improvement in water quality conditions may occur in the near future when funds are allocated and final construction plans permitted. Until then the hatchery facilities will continue to operate within acceptable limits with no potential for further degradation to water quality in the Skykomish River basin.

Steelhead and Chinook salmon populations in the greater Snohomish basin may be adversely affected by climate change (see Section 2.4.5) characterized by decreases in winter snowpack, which would be expected to reduce spring and summer flows, impairing water quantity and water quality in freshwater rearing habitats within the greater Snohomish basin. Predicted increases in rain-on-snow events would increase the frequency and intensity of floods in mainstem river areas. The proposed action would ensure listed species have access to high-quality habitat that supports spawning, rearing, and holding, as well as buffering variability in population productivity via hatchery production and improving productivity in the North Fork Skykomish River. The overall effects of all three components of the action would result in minimal adverse effects on critical habitat features while supporting or improving those features necessary for listed species to recover in the greater Snohomish basin.

2.8. Conclusion

After reviewing the current status of the listed species, the environmental baseline within the action area, the effects of the proposed actions, including effects of the Proposed Actions that are likely to persist following expiration of the proposed actions, and cumulative effects, it is NMFS' biological opinion that the proposed actions are not likely to jeopardize the continued existence of the Puget Sound Chinook Salmon ESU and the Puget Sound Steelhead DPS or to destroy or adversely modify designated critical habitat.

2.9. Incidental Take Statement

Section 9 of the ESA and Federal regulation pursuant to section 4(d) of the ESA prohibit the take of endangered and threatened species, respectively, without a special exemption. Take is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Harm is further defined by regulation to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering. Incidental take is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity. For purposes of this consultation, we interpret "harass" to mean an intentional or negligent action that has the potential to injure an animal or disrupt its normal behaviors to a point where such behaviors are abandoned or significantly altered. Section 7(b) and section 7(o)(2) provide that taking that is incidental to an otherwise lawful agency action is not prohibited under the ESA, if that action is performed in compliance with the terms and conditions of this Incidental Take Statement (ITS).

While the ITS is only required to address incidental take, certain anticipated direct take is discussed below solely to provide context.

2.9.1. Amount or Extent of Take

In the biological opinion, NMFS determined that incidental take of ESA-listed Puget Sound steelhead is reasonably certain to occur. NMFS expects incidental take of ESA-listed salmon and steelhead is reasonably certain to occur as follows:

- Genetic and ecological effects of hatchery-origin adult steelhead on the spawning grounds.
- Handling, tagging, and transport of adult Puget Sound Chinook salmon and Puget Sound steelhead at the Sunset Falls Trap and Haul Fishway facility to an in-river release or hatchery holding, including resulting injury or mortality.
- Mortality resulting from a catastrophic event during transport of fish from Sunset Falls Trap and Haul Fishway facility.
- Ecological effects from competition and predation of hatchery-produced juveniles with hatchery-origin steelhead during juvenile migration.
- Ecological and genetic effects of releasing non-migratory juvenile steelhead (residuals) in the greater Snohomish basin.

- Effects of conducting RM&E actions.

For genetic effects, take occurs through a reduction in genetic diversity resulting from straying of adult steelhead and non-migratory precocious juveniles, outbreeding depression, and hatchery-influenced selection resulting from hatchery steelhead spawning with natural-origin steelhead. Take from ecological effects occurs through intraspecific competition among hatchery adults on the spawning grounds such as competition for spawning sites and redd superimposition and between natural and hatchery-origin summer steelhead. Take due to these pathways cannot be directly measured because it is not possible to reliably measure gene flow or interbreeding between hatchery and natural-origin fish, or to reliably quantify spawning site competition or redd superimposition. For these take pathways, NMFS will therefore rely on five surrogate take indicators.

The following set of take surrogate measurements is logically related to the genetic and ecological take pathways through analysis of hatchery-origin steelhead on the spawning grounds, which contributes to gene flow, redd superimposition, and spawning site competition. Steelhead from the integrated hatchery program that spawn-with either winter-run or summer-run steelhead can cause both ecological and genetic effects on these listed populations. Similarly, precocious or non-migratory juvenile steelhead can reproduce with steelhead from the listed Snohomish/Skykomish winter-run population. Each of these take surrogates will therefore adequately identify the potential for genetic and ecological effects to exceed the amount of take that is expected to occur under the Proposed Action. Finally, each of these surrogates can be reliably monitored by the individual methods described below.

1. The ecological and genetic impacts on the Tolt summer steelhead population would be measured by using a 4-year running average (a full steelhead generation) pHOS from the proposed program. Until 2024, pHOS will be determined annually; after 2024, pHOS will be determined as a 4-year running average. Take is considered exceeded when the pHOS exceeds 5 percent. This surrogate is rationally connected to the extent of incidental take because pHOS estimates the number of hatchery fish present on the spawning grounds where the potential impacts to natural-origin spawners could take place. This take surrogate can be reliably monitored using snorkel surveys.
2. The ecological and genetic impacts on the North Fork summer steelhead population would be measured by using a 4-year running average pHOS from the proposed program. Until 2024, pHOS will be determined annually; after 2024, pHOS will be determined as a 4-year running average. Take is considered exceeded when the pHOS exceeds 15.6 percent. The rational connection of pHOS to the extent of take is the same as discussed in #1. This take surrogate can be reliably monitored using snorkel surveys.
3. The ecological and genetic impacts on South Fork summer steelhead would be measured by using a 4-year-running average PNI, averaging across only those years when at least 250 natural-origin steelhead were passed upstream at the Sunset Falls Trap and Haul Fishway. Take is considered exceeded when the PNI is below 0.67 and at least 250 natural-origin steelhead were passed upstream at the Sunset Falls Trap and Haul Fishway. PNI will be determined annually until 2024, at which point, PNI will be determined as a 4-year running average. PNI is rationally connected to the extent of take because, like pHOS, it estimates the extent of hatchery fish influence on natural-origin populations.

This take surrogate can be reliably calculated, based on the number of natural-origin summer steelhead incorporated into broodstock and observed at the Sunset Falls Trap and Haul Fishway facility or hatchery facilities. For years where natural-origin summer steelhead passage is 250 individuals or lower, the take surrogate will be measured by the number of hatchery-origin summer steelhead passed above Sunset Falls. Take is considered to be exceeded when the number of hatchery-origin fish passed above Sunset Falls is more than needed (i.e., more than 250 when combined with natural-origin steelhead). This surrogate is rationally connected to the potential incidental take, which would increase or decrease in direct proportion to the numbers of fish passed above Sunset Falls. This surrogate can be reliably measured and monitored by counting the number of hatchery-origin fish passed above Sunset Falls.

4. The ecological and genetic impacts on the Skykomish, Snoqualmie, and Pilchuck winter-run steelhead populations would be measured by using a 4-year-running average PEHC. PEHC will be determined annually until 2024, at which point, PEHC will be determined as a 4-year running average. Take is considered exceeded when the total PEHC annually, after subtracting the average PEHC of 2018-2022 period (i.e., time period of when PEHC measures the exclusive influence of the Reiter Ponds early summer steelhead program), exceeds 5 percent because PEHC does not allow distinctions with influence from the existing early summer steelhead program. Like PNI, PEHC is rationally connected to the extent of take because it estimates the extent of hatchery influence on natural populations. This take surrogate can be reliably measured using the Warheit Method described in Section 2.5.1.
5. The ecological and genetic impacts from precocious or non-migrating hatchery-origin steelhead would be measured by a 4-year running average resulting from a qualitative visual index to categorize maturation status. Until 2025, visual indexing will be measured on an annual basis. Take is considered exceeded when the proportion of sexually mature males and immature parr relative to the release numbers each year exceeds 10 percent. Calculating the rate of residualism is rationally connected to the extent of take because the impacts from residualizing fish would rise or fall in proportion to the number of residualizing fish. This take surrogate can be reliably measured by visual assessments.

Encounters with natural-origin and hatchery Chinook salmon and steelhead at Sunset Falls Trap and Haul Fishway Facility and hatchery collection facilities

We anticipate that take will occur as a result of handling/tagging of listed hatchery and natural-origin salmon and steelhead at adult collection facilities to facilitate broodstock collection, and sampling of fish for monitoring and evaluation. A total of up to 120 steelhead will be lethally taken as a result of being collected for broodstock, and up to an additional 250 hatchery-origin steelhead may be captured, transported, and released into the North Fork Skykomish River. Additionally, we estimate that up to 650 Chinook salmon and 650 summer steelhead would be handled to be passed above Sunset Falls (Table 17).

Table 17. Incidental take and sources of take associated with the proposed action annually.

Species	Life stage	Capture, handling, tagging, transport upstream of Sunset Falls Trap and Haul Fishway (Hatchery + Natural origin)	Capture, handling, and Transport and release into the North Fork Skykomish River[1] (Hatchery-origin)	Mortality caused by catastrophic event during transport (Hatchery + Natural origin)	Direct take mortality for broodstock selection (Hatchery + Natural origin)
Puget Sound steelhead	Adult	650	250	25	120
Puget Sound Chinook salmon	Adult/jack	650	0	25	N/A

[1]This transport would occur only if outplanting is deemed to be consistent with viability needs.

Mortality resulting from catastrophic events during transport of fish from Sunset Falls Trap and Haul Fishway facility

A catastrophic event during transport of fish to hatchery or in-river release sites may result in the loss of the entire allotment (i.e., mortality of up to 25 fish; see Table 17). These allotments may contain one species only, or multiple species. We anticipate that a total loss of 25 fish will be rare and expect it to occur no more than once (if at all) over the course of the ten-year permit for operation of the Sunset Falls Trap and Haul Fishway facility.

Mortality from competition and predation and other interactions at the juvenile life stage

Predation, competition, or pathogen transmission, collectively referred to as ecological interactions, between natural-origin juvenile Chinook salmon and steelhead and hatchery steelhead smolts could result in take of listed Chinook salmon and steelhead. In addition, non-migratory juvenile steelhead could pose risks from competitive and predatory interactions with listed Chinook salmon and steelhead at the juvenile life stage. However, it is difficult to quantify this take because ecological interactions cannot be directly measured and/or observed. Thus, we will use two take surrogates to represent effects of interaction in the juvenile life stage; one to address the effects of migrating hatchery juveniles, and a second to address the effects of non-migrating residual steelhead.

We will quantify the extent of take caused by outmigrating fish using travel time of juvenile hatchery fish, calculated as described in Section 2.5.1.3. This is a reasonable surrogate for the take that occurs because, the slower fish travel, the greater the time available for preying on and competing with ESA-listed natural-origin juveniles in the action area. Take is considered to be exceeded when the travel time is 12 days. This take surrogate will be monitored annually for the first three years and using a 4-year running average beginning in 2024 (years 2021-202). The applicants will notify NMFS if the take surrogate exceeds 12 days. This surrogate will be monitored using emigration estimates from screw traps, or other juvenile monitoring techniques approved by NMFS.

Take associated with releasing non-migrating or precocious hatchery steelhead (i.e., residuals) occurs in the form of increased competition, predation, and genetic effects. These effects cannot be reliably observed or measured. Therefore, NMFS will rely on a surrogate measure of this take, in the form of the proportion of smolts released that residualize, which should not exceed 10 percent of the hatchery fish released. Calculating the rate of residualism is rationally connected to the extent of take because the impacts from residualizing fish would rise or fall in proportion to the number of residualizing fish. The surrogate can be reliably calculated as follows: NMFS will rely on two assessments as described in Section 2.5.2.3 to determine the proportion of juvenile steelhead likely to residualize in freshwater: body condition factor (i.e., a ratio of length and weight measurements), and a qualitative visual index to categorize maturation status. To be effective, these assessments must be completed by the co-managers at the time juveniles are released.

Take from conducting RM&E actions

Take of steelhead will occur as a result of RM&E actions such as genetic sampling and two yearly snorkel surveys.

Genetic sampling to estimate PEHC will include the following:

- Up to 600 juvenile steelhead from the Skykomish River
- Up to 50 adult steelhead from the Skykomish River
- Up to 50 adult steelhead from the Snoqualmie River
- Up to 50 adult steelhead from the Pilchuck River
- Up to 150 juvenile steelhead from the North Fork Skykomish River
- Up to 100 smolts from the Skykomish River smolt trap
- Up to 100 smolts from the Snoqualmie River smolt trap

We anticipate up to 400 adult steelhead may be harassed as a result of conducting snorkel surveys.

2.9.2. Effect of the Take

In the biological opinion, NMFS determined that the amount or extent of anticipated take, coupled with other effects of the proposed action, is not likely to result in jeopardy of the Puget Sound Steelhead DPS or Puget Sound Chinook Salmon ESU, or result in the destruction or adverse modification of their critical habitat.

2.9.3. Reasonable and Prudent Measures

"Reasonable and prudent measures" are non-discretionary measures that are necessary or appropriate for the action agency, NMFS, to work with the applicants (in this case, WDFW and Tulalip Tribes) to minimize the impact of the amount or extent of incidental take (50 CFR 402.02). NMFS has determined that the following reasonable and prudent measures (RPMs) are as follows:

RPM 1: NMFS shall assure that the applicants implement all measures specified in each authorization issued as well as guidelines specified in this opinion to limit and reduce take and the effect of take of Puget Sound Chinook salmon and steelhead.

RPM 2: NMFS shall assure that the applicants provide reports to SFD annually for all hatchery programs and associated RM&E.

2.9.4. Terms and Conditions

The terms and conditions described below are non-discretionary, and the National Marine Fisheries Service or any applicant must comply with them in order to implement the RPMs (50 CFR 402.14). As the action agency, NMFS shall assure that the applicants meet their continuing duty to monitor the impacts of incidental take and must report the progress of the action and its impact on the species as specified in this ITS (50 CFR 402.14). If the entity to whom a term and condition is directed does not comply with the following terms and conditions, protective coverage for the proposed action would likely lapse.

1a. To limit genetic introgression from the integrated hatchery summer steelhead to natural-origin winter-run steelhead and to natural-origin summer steelhead, the applicants shall monitor and report annually:

- The annual production level, not to exceed over 110% of 116,000 smolts in any single year, and a running 4-year average production (beginning in the release year 2023) of no more than 116,000 smolts.
- Running 4-year average of the proportion of effective hatchery contribution (PEHC) of summer-run steelhead to Skykomish, Pilchuck, and Snoqualmie winter-run steelhead populations, as adjusted per the description in Section 2.9.1, to be no greater than 5 percent.
- Running 4-year average pHOS from the proposed program, to be less than 5 percent for the Tolt summer steelhead population.
- Running 4-year average pHOS from the proposed program, to be less than 15.6 percent for the North Fork summer steelhead population. This condition will apply only until the work group makes a decision is made about how to manage North Fork and South Fork summer steelhead.
- Running 4-year average PNI being no less than 0.67 for years where natural-origin summer steelhead passage upstream at the Sunset Falls Trap and Haul Fishway is at least 250.
- Number of hatchery-origin and natural-origin summer steelhead passed upstream of Sunset Falls does not exceed 250 where natural-origin summer steelhead passage upstream at the Sunset Falls Trap and Haul Fishway is less than 250.

1b. To minimize take of Puget Sound Chinook salmon and Puget Sound steelhead for ecological and genetic effects, the applicants shall monitor and report annually:

- If outplanting into the North Fork is to take place, the sex ratio (male:female) and return-year classes (i.e., 3-year adults, 4-year returns) of adult steelhead outplanted will be approximately equal (plus/minus 10%).
- That no more than 10 percent of juvenile steelhead released from hatcheries residualize in freshwater as assessed by the methods described in Section 2.5.2.3.

1c. Applicants shall convene a work group consisting of NMFS, the co-managers, and other parties involved in recovery planning to review and discuss all the relevant information about how the North Fork and South Fork Skykomish summer steelhead should be managed. This discussion will include whether the outplanting would be consistent with viability needs of Puget Sound Steelhead DPS and monitoring needs.

1d. If outplanting is deemed consistent with viability needs through condition 1c., then the applicants shall submit a report detailing how the outplanting would be consistent with viability, and include proposals for monitoring genetic and ecological impacts of outplanting on Puget Sound steelhead DPS and bull trout. Outplanting shall not occur until NMFS concurs that the outplant is consistent with viability needs and that the monitoring plan is sufficient.

2. The applicants shall provide reports to SFD annually for their respective programs, including associated RM&E. All reports and required notifications are to be submitted electronically to the NMFS, West Coast Region, Sustainable Fisheries Division, Anadromous Production and Inland Fisheries Branch. The current point of contact for document submission is Emi Melton (503-736-4739, emi.melton@noaa.gov).

An annual RM&E report(s) is submitted by applicants no later than April 15 of the year following releases and associated RM&E (e.g., release/RM&E in year 2021, report due April 2022) that will include:

a. The number and origin (new integrated hatchery program, legacy/early summer hatchery program, or natural) of each listed species handled and incidental mortality across all activities and facilities and their post-release distribution and disposition (e.g., normal, injury, or mortality).
b. Number and composition of broodstock, dates of collection, and egg to smolt survival rates.
c. Numbers, dates, locations, size, coefficient of variation, and tag/mark information of juvenile steelhead.
d. Disease occurrence at hatcheries.
e. Any problems that may have arisen during hatchery activities.
f. Any unforeseen effects on ESA-listed fish.
g. Estimate emigration rate of hatchery fish collected in smolt traps.
h. Conduct representative sampling of at least 200 juvenile steelhead prior to volitional release and measure the following attributes:
    i. Length
    ii. Weight
    iii. Use the qualitative visual index of smolt condition/sexual precocity according to methods described in Section 2.5.2.3 to categorize fish within four phenotypic categories (i.e., smolt, transitional smolt, mature male, and immature parr) and report the proportion of juvenile steelhead that exhibit ‘residual’ or precocious development.

2.10. Conservation Recommendations

Section 7(a)(1) of the ESA directs Federal agencies to use their authorities to further the purposes of the ESA by carrying out conservation programs for the benefit of the threatened and endangered species. Specifically, conservation recommendations are suggestions regarding discretionary measures to minimize or avoid adverse effects of a proposed action on listed species or critical habitat or regarding the development of information (50 CFR 402.02).

1. Investigate post-release residency timing of juvenile steelhead in the Snohomish/Skykomish River basin.
2. Develop a monitoring program to collect outmigrating smolts from the integrated program and the North Fork Skykomish River to compare size, condition, and demographic and genetic structure between these groups.
3. Extend the period of volitional release for 4-6 weeks.

2.11. Reinitiation of Consultation

This concludes formal consultation for the Hatchery Program for Summer Steelhead in the Skykomish River and the Sunset Falls Trap and Haul Fishway Program in the South Fork Skykomish River.

As 50 CFR 402.16 states, reinitiation of consultation is required and shall be requested by the Federal agency or by the Service where discretionary Federal agency involvement or control over the action has been retained or is authorized by law and if: (1) The amount or extent of incidental taking specified in the ITS is exceeded, (2) new information reveals effects of the agency action that may affect listed species or critical habitat in a manner or to an extent not considered in this opinion, (3) the identified action is subsequently modified in a manner that causes an effect on the listed species or critical habitat that was not considered in the biological opinion, or (4) a new species is listed or critical habitat designated that may be affected by the action.

2.12. "Not Likely to Adversely Affect" Determinations

After reviewing the current status of the listed species and critical habitat, the environmental baseline within the action area, the effects of the proposed action, any activities resulting as a consequence of the proposed action, and cumulative effects, NMFS concluded that the proposed action is not likely to adversely affect the Lake Ozette Sockeye Salmon ESU or the Hood Canal Summer Chum Salmon ESU or their designated critical habitats for these two species. The rationale for these determinations is based on the geographical extent of these two species and their critical habitats. We address determinations for both species below.

2.12.1. Lake Ozette Sockeye Salmon

The Ozette Lake Sockeye Salmon ESU was listed as a threatened species in 1999 (64 FR 14528; March 25, 1999). The ESU includes all naturally spawned populations of sockeye salmon in Ozette Lake and streams and tributaries flowing into Ozette Lake, Washington. The Puget Sound

Technical Recovery Team considers the Ozette Lake Sockeye Salmon ESU to comprise one historical population with multiple spawning aggregations. The primary existing spawning aggregations occur in two beach locations—Allen's and Olsen's Beaches—and in two tributaries—Umbrella Creek and Big River. The ESU also includes fish originating from two artificial propagation programs: the Umbrella Creek and Big River sockeye hatchery programs.

After hatching, most juvenile sockeye salmon spend one winter in Ozette Lake rearing before outmigrating to the ocean as two-year-old fish during April and May (Dlugokenski et al. 1981). The fish typically spend two years in the northeast Pacific Ocean foraging on zooplankton, squid, and, infrequently, on small fishes (Scott and Crossman 1973). Migration of adult sockeye salmon up the Ozette River generally occurs from mid-April to mid-August (Washington Department of Fisheries and Washington Department of Wildlife 1993). From 1977 to 2011, the estimated natural spawners ranged from 699 to 5,313 (NWFSC 2015), well below the 31,250 – 121,000 viable population range proposed in the recovery plan (NMFS 2009b). Over the last few decades, productivity appears to have remained stable around 3,000 fish, although well below the viability range of 31,250 to 121,000 returning adults (NWFSC 2015). The Umbrella Creek Hatchery program has successfully introduced a tributary spawning aggregate, increasing the diversity of age at return. However, the beach spawning aggregate is considered the core group of interest for recovery; the current number of beach spawners is well below historical levels and restricted to a subset of historical spawning beaches (NWFSC 2015).

The Lake Ozette sockeye salmon (coastal Washington) and Skykomish River summer steelhead (North Puget Sound) populations are separated by approximately 135 miles of saltwater habitat in the Puget Sound and Strait of Juan de Fuca. The two species may only encounter each other during the ocean migration life history stage, when salmonids tend to disperse over wide distances. Lake Ozette sockeye salmon emigrate to marine areas in April to May (Haggerty et al.), and would likely reach marine areas of the Pacific Ocean earlier than most of the releases of hatchery fish in the Skykomish River because they are released during the same timeframe, but have a much greater distance to travel. In addition, juvenile sockeye salmon are present close to shore from Cape Flattery to Yakutat in July and August and then move offshore in late autumn or winter. The nearshore around the Ozette River is a productive, shallow sub-tidal environment (Haggerty et al. 2009), and it is assumed that very few if any juvenile Lake Ozette sockeye salmon migrate into Puget Sound marine areas where it would be possible to encounter species released as part of the proposed action. Thus, NMFS believes that effects of the Proposed Action on Lake Ozette sockeye salmon are discountable.

2.12.2. Hood Canal Summer Chum Salmon

On June 28, 2005, NMFS listed Hood Canal Summer (HCS) chum salmon—both natural-origin and some artificially-propagated fish—as a threatened species (70 FR 37160). The species comprises all naturally spawned populations of summer-run chum salmon in Hood Canal and its tributaries as well as populations in Olympic Peninsula rivers between Hood Canal and Dungeness Bay, Washington. The ESU has two populations, each containing multiple stocks or spawning aggregations. Juveniles, typically as fry, emerge from the gravel and outmigrate almost immediately to seawater. For their first few weeks, they reside in the top two to three centimeters of estuarine surface waters while staying extremely close to the shoreline (WDFW/PNPTT 2000). Subadults and adults forage in coastal and offshore waters of the North Pacific Ocean before returning to spawn in their natal streams. HCS chum salmon spawn from mid-September to mid-October in the mainstems and lower river basins.

Natural-origin spawner abundance has increased since their 1999 ESA-listing (64 FR 14508) and spawning abundance targets in both populations have been met in some years (NWFSC 2015). Productivity was quite low at the time of the last review (Ford 2011), though rates have increased in the last five years, and have been greater than replacement rates in the past two years for both populations. For each population, spatial structure and diversity viability parameters have increased and nearly meet the viability criteria. However, only two of eight individual spawning aggregates have viable performance. Despite substantive gains towards meeting viability criteria in the Hood Canal and Strait of Juan de Fuca summer chum salmon populations, the ESU still does not meet all of the recovery criteria for population viability at this time .

The potential for interaction between Skykomish summer steelhead and HCS chum salmon is limited to geographical overlap in the marine habitats of Admiralty Inlet and the Strait of Juan de Fuca. HCS chum salmon may encounter juvenile steelhead released from the proposed integrated program during the early-marine life stage when both species are migrating through the Puget Sound and Strait of Juan de Fuca. We anticipate the only interactions among the two species occurring during this period will be competition and predation. Steelhead rapidly migrate through openwater habitats after entering saltwater (Quinn 2005) and are unlikely to be found in the shallow, nearshore littoral habitats occupied by chum salmon in the Puget Sound (Fresh 2006). Thus, the potential for adverse interactions between Skykomish summer steelhead and HCS chum salmon chum salmon in these areas is extremely low because the two species are unlikely to overlap at any point during migration to saltwater. Moreover, once summer steelhead from the new integrated program migrate into Admiralty Inlet and the Strait of Juan de Fuca, they will be dispersed within openwater habitats and it will be impossible to distinguish the effects from these individuals from those of other species. For these reasons, NMFS concludes the effects from the proposed integrated Skykomish summer steelhead program on Ozette sockeye salmon and HCS chum salmon chum salmon are discountable.

3. MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT ESSENTIAL FISH HABITAT RESPONSE

Section 305(b) of the MSA directs Federal agencies to consult with NMFS on all actions or proposed actions that may adversely affect EFH. The MSA (section 3) defines EFH as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” Adverse effect means any impact that reduces quality or quantity of EFH, and may include direct or indirect physical, chemical, or biological alteration of the waters or substrate and loss of (or injury to) benthic organisms, prey species and their habitat, and other ecosystem components, if such modifications reduce the quality or quantity of EFH. Adverse effects on EFH may result from actions occurring within EFH or outside of it and may include site-specific or EFH-wide impacts, including individual, cumulative, or synergistic consequences of actions (50 CFR 600.810). Section 305(b) also requires NMFS to recommend measures that can be taken by the action agency to conserve EFH.

This analysis is based, in part, on the EFH assessment provided by the NMFS and descriptions of EFH for Pacific Coast salmon (PFMC 2014) contained in the fishery management plans developed by the PFMC and approved by the Secretary of Commerce. We also considered effects on EFH for the coastal pelagic species listed in (PFMC 2016b) and (PFMC 2016a), which include Pacific sardine (*Sardinops sagax*), Pacific mackerel (*Scomber japonicus*), jack mackerel (*Trachurus symmetricus*), northern anchovy (*Engraulis mordax*), market squid (*Loligo opalescens*), and eight species of krill (*Euphausia pacifica*, *Thysanoessa spinifera*, *Nyctiphanes simplex*, *Nematocelis difficilis*, *T. gregaria*, *E. recurva*, *E. gibboides*, and *E. eximia*).

3.1. Essential Fish Habitat Affected by the Project

The areas affected by the proposed juvenile and adult released from the new integrated Skykomish summer steelhead hatchery program include:

- The Snohomish River basin from RM 0.0 to the upstream extent of anadromous fish access in the Skykomish River and Snoqualmie river watersheds;
- Wallace River from its confluence with the Skykomish River at RM 35.7 to the upstream extent of anadromous fish access;
- The North Fork Skykomish River from its confluence with South Fork Skykomish River at RM 51.5 to the upstream extent of anadromous fish access;
- The South Fork Skykomish River from its confluence with the North Fork Skykomish River at RM 51.5, to the upstream extent of anadromous fish access;
- Everett Bay, in the vicinity of Mukilteo, Washington.

Freshwater EFH for Pacific salmon, includes all those streams, lakes, ponds, wetlands, and other water bodies currently, or historically accessible to salmon in Washington, Oregon, Idaho, and California, except areas upstream of certain impassable manmade barriers, and long-standing, naturally-impassable barriers (i.e., natural waterfalls in existence for several hundred years) (PFMC 2014). As described by PFMC (2014), within these areas, freshwater EFH for Pacific salmon consists of four major components: (1) spawning and incubation; (2) juvenile rearing; (3) juvenile migration corridors; and (4) adult migration corridors and adult holding habitat.

The Snohomish River, Skykomish River, and Snoqualmie River and their tributaries accessible to anadromous salmon have been designated EFH for Chinook, coho, and pink salmon. Assessment of the potential adverse effects on these salmon species' EFH from the Proposed Action is based, in part, on these descriptions. The aspects of EFH that might be affected by the Proposed Action include: effects of hatchery operations on adult and juvenile fish migration corridors in the Snohomish River basin; ecological interactions and genetic effects in Chinook, coho, and pink salmon spawning areas in the watershed; and ecological effects in rearing areas for the species in the basin, including its estuary and adjacent nearshore marine areas.

3.2. Adverse Effects on Essential Fish Habitat

The biological opinion describes in considerable detail the impacts the integrated hatchery program may have on natural-origin salmon populations (Section 2.5). Naturally spawning adult steelhead produced by the proposed hatchery program may lead to effects on natural-origin salmon EFH through spawning ground competition and redd superimposition. The biological opinion describes impacts the hatchery program may have on naturally spawning salmon populations (Section 2.5.2.2).

The intent of the hatchery program is to produce an integrated steelhead broodstock that will return to marine and freshwater commercial and recreational fishing areas to augment harvests and conserve the genetic lineage of natural-origin Skykomish River steelhead. The majority of steelhead produced through the program will be harvested in pre-terminal and terminal area fisheries, reducing the number of fish that would escape to spawn in freshwater EFH. A substantial proportion of hatchery-produced steelhead will escape from marine and freshwater fisheries to their hatchery releases locations that may reduce the number of salmon escaping into natural spawning areas that are part of EFH in the basin. Further, any naturally spawning steelhead will not overlap temporally and/or spatially to a substantial degree with natural-origin salmon in natural spawning areas, limiting effects of competition or redd superimposition.

The release of steelhead through the proposed hatchery program may lead to effects on EFH through predation on and competition with juvenile Chinook salmon, coho salmon, and pink salmon. Hatchery-origin predation on and competition with natural-origin juvenile Chinook salmon was approximately 3 percent of the natural-origin adult equivalents, meaning approximately 3 percent of natural-origin adults are not available as part of the food web of Pacific Coast salmon. It is likely to be less than this for pink salmon because pinks emigrate soon after emergence around February-March, before hatchery fish are released. Both pink and coho salmon also have greater natural-origin abundances; meaning that even if the adult equivalents are similar among species, the proportional effect would be less on those species that have larger populations. Predation on and competition with natural-origin salmon in the marine environment is possible, but is likely limited by the release of hatchery fish that are ready to emigrate to the ocean quickly and the lack of a usable estuary for rearing outside of the Snohomish River

Regarding hatchery facility operation effects on salmon EFH, the adult salmon holding and spawning habitat, and juvenile salmon rearing locations are not expected to be affected by the operation of the hatchery programs, as no modifications to these areas would occur. Our analysis of facility effects did not reveal any substantial concerns related to screening, water withdrawal, or effluent (Section 2.5.2.5).

The proposed action is not likely to have adverse effects on EFH for the coastal pelagic species. Of the potential adverse effects listed in (PFMC 2016b) and (PFMC 2016a), effects of hatchery operations could be analogous to adverse effects of aquaculture; organic waste, release of high levels of antibiotics, disease, and escapees. However, these analogous concerns for hatchery operations are not likely to adversely affect coastal pelagic species because all relevant facilities have NPDES permits to minimize effects of organic waste, and antibiotics would be diluted to manufacturer labeling. Concerns of disease transfer from escapees of salmonid species are not likely to be a concern because coastal pelagic species are not closely related to the salmonid species.

3.3. Essential Fish Habitat Conservation Recommendations

For each of the potential adverse effects by the Proposed Action on EFH for Chinook, coho, and pink salmon, NMFS believes that the Proposed Action, as described in the HGMPs and the ITS, includes the best approaches to avoid or minimize those adverse effects. The Reasonable and Prudent Measures and Terms and Conditions included in the ITS associated with ecological interactions constitute NMFS recommendations to address potential EFH effects. NMFS shall ensure that the ITS, including Reasonable and Prudent Measures and implementing Terms and Conditions, are carried out.

3.4. Statutory Response Requirement

As required by section 305(b)(4)(B) of the MSA, the federal agency must provide a detailed response in writing to NMFS within 30 days after receiving an EFH Conservation Recommendation. Such a response must be provided at least 10 days prior to final approval of the action if the response is inconsistent with any of NMFS' EFH Conservation Recommendations unless NMFS and the Federal agency have agreed to use alternative time frames for the Federal agency response. The response must include a description of measures proposed by the agency for avoiding, minimizing, mitigating, or otherwise offsetting the impact of the activity on EFH. In the case of a response that is inconsistent with the Conservation Recommendations, the Federal agency must explain its reasons for not following the recommendations, including the scientific justification for any disagreements with NMFS over the anticipated effects of the action and the measures needed to avoid, minimize, mitigate, or offset such effects (50 CFR 600.920(k)(1)).

In response to increased oversight of overall EFH program effectiveness by the Office of Management and Budget, NMFS established a quarterly reporting requirement to determine how many conservation recommendations are provided as part of each EFH consultation and how many are adopted by the action agency. Therefore, as the sole action agency responsible for this consultation, NMFS should, in it's your statutory reply to the EFH portion of this consultation identify the number of conservation recommendations accepted.

3.5. Supplemental Consultation

The co-managers will reinitiate EFH consultation with NMFS if the proposed action is substantially revised in a way that may adversely affect EFH, or if new information becomes available that affects the basis for NMFS' EFH Conservation Recommendations (50 CFR 600.920(l)).

4. DATA QUALITY ACT DOCUMENTATION AND PRE-DISSEMINATION REVIEW

The Data Quality Act (DQA) specifies three components contributing to the quality of a document. They are utility, integrity, and objectivity. This section of the opinion addresses these DQA components, documents compliance with the DQA, and certifies that this opinion has undergone pre-dissemination review.

4.1. Utility

Utility principally refers to ensuring that the information contained in this consultation is helpful, serviceable, and beneficial to the intended users. The intended users of this opinion are the Tulalip Tribes and Washington Department of Fish and Wildlife (co-managers), and NMFS (regulatory agency). Other interested users could include the Washington Department of Ecology, the Steelhead Trout Club of Washington, and the Wild Fish Conservancy. The document will be available within two weeks at the NOAA Library Institutional Repository [https://repository.library.noaa.gov/welcome]. The format and naming adheres to conventional standards for style.

4.2. Integrity

This consultation was completed on a computer system managed by NMFS in accordance with relevant information technology security policies and standards set out in Appendix III, 'Security of Automated Information Resources,' Office of Management and Budget Circular A-130; the Computer Security Act; and the Government Information Security Reform Act.

4.3. Objectivity

Information Product Category: Natural Resource Plan

Standards: This consultation and supporting documents are clear, concise, complete, and unbiased; and were developed using commonly accepted scientific research methods. They adhere to published standards including the NMFS ESA Consultation Handbook, ESA regulations, 50 CFR 402.01 et seq., and the MSA implementing regulations regarding EFH, 50 CFR 600.

Best Available Information: This consultation and supporting documents use the best available information, as referenced in the References section. The analyses in this opinion EFH consultation contain more background on information sources and quality.

Referencing: All supporting materials, information, data and analyses are properly referenced, consistent with standard scientific referencing style.

Review Process: This consultation was drafted by NMFS staff with training in ESA and MSA, and reviewed in accordance with West Coast Region ESA quality control and assurance processes.

5. REFERENCES

Anderson, J., B. Craig, T. Seamons, and K. Warheit. 2019. Genetic monitoring of hatchery-wild introgressive hybridization in Puget Sound steelhead. Updated August 13, 2019. 18p.

Anttila, K., M. Järvilehto, and S. Mänttäri. 2008. Ca^{2+} handling and oxidative capacity are greatly impaired in swimming muscles of hatchery-reared versus wild Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 65(1):10-16.

Battin, J., and coauthors. 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Science 104(16):6720-6725.

Beamish, R. J., and D. R. Bouillon. 1993. Pacific salmon production trends in relation to climate. Canadian Journal of Fisheries and Aquatic Sciences 50:1002-1016.

Beamish, R. J., C. Mahnken, and C. M. Neville. 1997. Hatchery and wild production of Pacific salmon in relation to large-scale, natural shifts in the productivity of the marine environment. ICES Journal of Marine Science 54:1200-1215.

Beechie, T. J., E. Buhle, M. Ruckelshaus, A. Fullerton, and L. Holsinger. 2006. Hydrologic regime and the conservation of salmon life history diversity. Biological Conservation 130(4):560-572.

Beer, N. W., and J. J. Anderson. 2013. Sensitivity of salmonid freshwater life history in western U.S. streams to future climate conditions. Global Change Biology 19:2547-2556.

Behnke, R. J., and American Fisheries Society. 1992. Native Trout of Western North America. American Fisheries Society, Bethesda, Maryland. 275p.

Bradford, M. J. 1995. Comparative review of Pacific salmon survival rates. Canadian Journal of Fisheries and Aquatic Sciences 52:1327-1338.

Brodeur, R. 1991. Ontogenetic variations in the type and size of prey consumed by juvenile coho, *Oncorhynchus kisutch*, and Chinook, *O. tshawytscha*, salmon. Environmental Biology of Fishes 30:303-315.

Brodeur, R. D., K. W. Myers, and J. H. Helle. 2003. Research conducted by the United States on the early ocean life history of Pacific salmon. North Pacific Anadromous Fish Commission 3:89-131.

Busack, C. 2015. Extending the Ford model to three or more populations. August 31, 2015. Sustainable Fisheries Division, West Coast Region, National Marine Fisheries Service. 5p.

Busby, P. J., and coauthors. 1996. Status Review of West Coast steelhead from Washington, Idaho, Oregon, and California. August 1996. U.S. Dept. Commer. NOAA Tech. Memo., NMFS-NWFSC-27. NMFS, Seattle, Washington. 275p.

Christie, M. R., M. J. Ford, and M. S. Blouin. 2014. On the reproductive successs of early-generation hatchery fish in the wild. Evolutionary Applications 7:883-896.

Climate Impacts Group. 2004. Overview of Climate Change Impacts in the U.S. Pacific Northwest. July 29, 2004. Climate Impacts Group, University of Washington, Seattle, Washington. 13p.

Craig, B., J. Anderson, T. Seamons, and K. Warheit. 2017. The effects of genetic sample collection size on precision and accuracy of PEHC estimates. April 14, 2017. 11p.

Cram, J. M., and coauthors. 2017. Spatial Variability of Chinook Salmon Spawning Distribution and Habitat Preferences. Transactions of the American Fisheries Society 146: 206-221. 2017.

Crawford, B. A. 1979. The Origin and History of the Trout Brood Stocks of the Washington Department of Game. WDG, Olympia, Washington. 86p.

Dickhoff, W. W., B. R. Beckman, D. A. Larsen, C. Duan, and S. Moriyama. 1997. The role of growth in endocrine regulation of salmon smoltification. Fish Physiology and Biochemistry 17(1):231-236.

Dlugokenski, C., W. Bradshaw, and S. Hager. 1981. An investigation of the limiting factors to Lake Ozette sockeye salmon production and a plan for their restoration. U.S. Fish and Wildlife Service, Fisheries Assistance Office, Olympia, Washington. 52p.

Drake, J. S., and coauthors. 2010. Status Review of Five Rockfish Species in Puget Sound, Washington Bocaccio (*Sebastes paucispinis*), Canary Rockfish (*S. pinniger*), Yelloweye Rockfish (*S. ruberrimus*), Greenstriped Rockfish (*S. elongatus*), and Redstripe Rockfish (*S. proriger*). December 2010. NOAA Technical Memorandum NMFS-NWFSC-108. 247p.

Duffy, E. J. 2003. Early Marine Distribution and Trophic Interactions of Juvenile Salmon in Puget Sound. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science. University of Washington. 186p.

Emlen, J. M., R. R. Reisenbichler, A. M. McGie, and T. E. Nickelson. 1990. Density-dependence at sea for coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 47:1765-1772.

Engel, J., K. F. Higgins, and E. Ostergaard. 2017. Final WRIA 9 Climate Change Impacts on Salmon. July 2017. 28p.

EPA. 2008. Proposes to Issue a General Wastewater Discharge Permit for Discharges from Federal Aquaculture Facilities and Aquaculture Facilities Located in Indian Country, as defined in 18 USC § 1151, and the Lummi Nation, the Makah Tribe, and the Tulalip Tribes Propose to Certify the Permit for Discharges to Waters in Indian Country Fact Sheet. November 12, 2008. NPDES Permit Number: WAG-130000. 70p.

EPA. 2015. Federal Aquaculture Facilities and Aquaculture Facilities Located in Indian Country within the Boundaries of Washington State. Biological Evaluation for Endangered Species Act Section 7 Consultation with the National Marine Fisheries Service and the U.S. Fish and Wildlife Service. NPDES General Permit WAG130000. December 23, 2015. 191p.

Falke, J. A., J. B. Dunham, C. E. Jordan, K. M. McNyset, and G. H. Reeves. 2013. Spatial ecological processes and local factors predict the distribution and abundance of spawning by steelhead (*Oncorhynchus mykiss*) across a complex riverscape. PLoS ONE 8(11):1-11.

Fleming, I. A., T. Agustsson, B. Finstad, J. I. Johnsson, and B. T. Bjornsson. 2002. Effects of domestication on growth physiology and endocrinology of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 59:1323-1330.

Folmar, L. C., and W. W. Dickhoff. 1981. Evaluation of Some Physiological Parameters as Predictive Indices of Smoltification. Aquaculture, 23 (1981) 309-324.

Ford, M. J., and coauthors. 2011. Status Review Update for Pacific Salmon and Steelhead Listed Under the Endangered Species Act: Pacific Northwest. November 2011. U.S. Dept. Commer., NOAA Tech. Memo., NMFS-NWFSC-113. 307p.

Fresh, K. L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, Washington. 28p.

Goniea, T. M., and coauthors. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. Transactions of the American Fisheries Society 135(2):408-419.

Goodman, D. 2005. Selection equilibrium for hatchery and wild spawning fitness in integrated breeding programs. Canadian Journal of Fisheries and Aquatic Sciences 62(2):374-389.

Grant, W. S. 1997. Genetic Effects of Straying of Non-Native Hatchery Fish into Natural Populations. Proceedings of the workshop, June 1-2, 1995, Seattle, Washington. U.S. Department of Commerce, NOAA Tech. Memo., NMFS-NWFSC-30. 157p.

Groot, C., and L. Margolis. 1991. Pacific Salmon Life Histories. UBC Press. Vancouver, British Columbia, Canada. 588p.

Haggerty, M. 2020a. Final Draft. Memorandum to Emi Melton from Mike Haggerty. Data and Analyses used for the Evaluation of the Skykomish River Summer-Run Steelhead HGMP. December 15, 2020. 23p.

Haggerty, M. 2020b. Memorandum to Morgan Robinson (NMFS) from Mike Haggerty. Snohomish Basin Chinook salmon pHOS and PNI estimates for EA and Biological Opinion, with attachment. July 21, 2020. 4p.

Haggerty, M. 2020c. Memorandum to Morgan Robinson (NMFS) from Mike Haggerty. Snohomish Natural-Origin Coho Abundance and Hatchery-Origin Coho Emigration Rates from Wallace River Hatchery. August 3, 2020. 15p.

Haggerty, M. 2021a. Memorandum re: Final PCD model inputs and outputs from Skykomish Summer Steelhead Hatchery Program Biological Opinion. April 19, 2021. 4p.

Haggerty, M. 2021b. Memorandum re: Projected hatchery stray summer steelhead into the S.F. Tolt population from the proposed release of 116,000 summer steelhead at Reiter Ponds. February 18, 2021. 2p.

Haggerty, M. 2021c. Memorandum to Emi Melton and Scott Sebring from Mike Haggerty. Projected hatchery stray summer steelhead into the S.F. Tolt population from the proposed release of 116,000 summer steelhead at Reiter Ponds. 2/18/2021. 2p.

Haggerty, M. 2021d. Memorandum to Emi Melton from Mike Haggerty. Green ESS in SSS brood. April 20, 2021. 2p.

Haggerty, M. 2021e. PCD Summer Steelhead Inputs Excel file

Haggerty, M. J., A. Ritchie, J. Shellberg, M. Crewson, and J. Jalonen. 2009. Lake Ozette Sockeye Limiting Factors Analysis. May 2009. Prepared for the Makah Indian Tribe and NOAA Fisheries in cooperation with the Lake Ozette Sockeye Steering Committee, Port Angeles, Washington. 565p.

Hard, J. J., R. P. Jones, M. R. Delarm, and R. S. Waple. 1992. Pacific Salmon and Artificial Propagation under the Endangered Species Act. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-2. October 1992. 64p.

Hard, J. J., and coauthors. 2015. Viability Criteria for Steelhead within the Puget Sound Distinct Population Segment. May 2015. U.S. Dept. Commer., NOAA Tech. Memo., NMFS-NWFSC-129. 367p.

Hard, J. J., and coauthors. 2007. Status review of Puget Sound steelhead (*Oncorhynchus mykiss*). June 2007. NOAA Technical Memorandum NMFS-NWFSC-81. 137p.

Haring, D. 2002. Salmonid Habitat Limiting Factors Analysis Snohomish River Watershed Water Resource Inventory Area 7. Final report. December 2002. Washington State Conservation Commission. 331p.

Hartt, A. C., and M. B. Dell. 1986. Early Oceanic Migrations and Growth of Juvenile Pacific Salmon and Steelhead Trout. Bulletin number 46. 111p.

Hausch, S. J., and M. C. Melnychuk. 2012. Residualization of hatchery steelhead: A meta-analysis of hatchery practices. North American Journal of Fisheries Management 32(5):905-921.

Healey, M. C. 1991. Life History of Chinook Salmon (*Oncorhynchus tshawytscha*). *In* C. Groot and L. Margolis (eds.), Life history of Pacific Salmon, pages 311-393. University of British Columbia Press. Vancouver, B.C. 89p.

HETT. 2014. NTTOC.accdb. (database for NTTOC simulations). Douglas County Public Utility District ftp site.

Hillman, T. W., and J. W. Mullan. 1989. Effect of Hatchery Releases on the Abundance of Wild Juvenile Salmonids. Chapter 8 *in* Summer and Winter Ecology of Juvenile Chinook salmon and steelhead trout in the Wenatchee River, Washington. Report to Chelan County PUD by D.W. Chapman Consultants, Inc. Boise, Idaho. 22p.

Hoffmann, A. 2014. Estimates of Gene Flow for Puget Sound Hatchery Steelhead Programs. Unpublished report. October 10, 2014. Washington Department of Fish and Wildlife, Mill Creek, Washington. 22p.

Holt, C. A., M. B. Rutherford, and R. M. Peterman. 2008. International cooperation among nation-states of the North Pacific Ocean on the problem of competition among salmon for a common pool of prey resources Marine Policy 32:607-617.

HSRG. 2004a. Emerging issues - Marine carrying capacity. Hatchery Reform: Principles and recommendations. April 2004. 3p.

HSRG. 2004b. Hatchery reform: Principles and Recommendations of the Hatchery Scientific Review Group. April 2004. Available at Long Live the Kings. 329p.

HSRG. 2009. Columbia River Hatchery Reform Project Systemwide Report. Appendix A. White Paper No. 1. Predicted Fitness Effects of Interbreeding between Hatchery and Natural Populations of Pacific Salmon and Steelhead. 38p.

ISAB. 2007. Climate Change Impacts on Columbia River Basin Fish and Wildlife. May 11, 2007. Report ISAB 2007-2. Northwest Power and Conservation Council, Portland, Oregon. 146p

Iwama, G. K., J. C. McGeer, and N. J. Bernier. 1992. The effects of stock and rearing history on the stress response in juvenile coho salmon *(Oncorhynchus kisutch*). ICES Marine Science Symposium 194:67-83.

Jones, R. P. 2006. Memo to File - Updates to the salmonid hatchery inventory and effects evaluation report: An evaluation of the effects of artificial propagattion on the status and likelihood of extinction of West Coast salmon and steelhead under the Federal Endangered Species Act. January 19, 2006. NMFS, Portland, Oregon.

Jonsson, B., N. Jonsson, and L. P. Hansen. 2003. Atlantic salmon straying from the River Imsa. Journal of Fish Biology 62:641-657.

Judge, M. M. 2011. A Qualitative Assessment of the Implementation of the Puget Sound Chinook Salmon Recovery Plan. Lighthouse Natural Resource Consulting, Inc. 45p.

Kassler, T. W., D. K. Hawkins, and J. M. Tipping. 2008. Summer-run hatchery steelhead have naturalized in the South Fork Skykomish River, Washington. Transactions of the American Fisheries Society 137(3):763-771.

Larsen, D. A., and coauthors. 2017. Use of morphological and physiological indices to characterize life history diversity in juvenile hatchery winter-run steelhead. Transactions of the American Fisheries Society 146(4):663-679.

leDoux, B., J. Engle, M. Ruff, and C. Wahl. 2017. WRIA 7 Climate Change Impacts to Salmon Issue Paper. Final Draft. January 2017. 24p.

Lichatowich, J., I. S.P. Cramer & Associates, U.S. Department of Energy, Bonneville Power Administration, and Division of Fish and Wildlife. 1993. Ocean Carrying Capacity. Recovery Issues for Threatened and Endangered Snake River Salmon Technical Report 6 of 11. June 1993. Technical Report 1993. Project No. 93-013, BPA report DOE/BP-99654-6. 32p.

Mahnken, C., G. T. Ruggerone, W. Waknitz, and T. Flagg. 1998. A historical perspective on salmonid production from Pacific Rim hatcheries. North Pacific Anadromous Fish Commission Bulletin 1:38-53.

Mangel, M., R. J. Hofman, E. A. Norse, and J. John R. Twiss. 1993. Sustainability and ecological research. Ecological Applications 3(4):573-575.

Mantua, N., I. Tohver, and A. Hamlet. 2009. Impacts of Climate Change on Key Aspects of Freshwater Salmon Habitat in Washington State. Pages 217 to 253 (Chapter 6) *in*: Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate. Climate Impacts Group, University of Washington, Seattle, Washington. 37p.

Mauger, G. S., and coauthors. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. 309p.

McElhany, P., M. H. Rucklelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-42. 174p.

McMichael, G. A., and T. N. Pearsons. 2001. Upstream movement of residual hatchery steelhead into areas containing Bull Trout and Cutthroat Trout. North American Journal of Fisheries Management 21(4):943-946.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 1999. Behavioral interactions among hatchery-reared steelhead smolts and wild *Oncorhynchus mykiss* in natural streams. North American Journal of Fisheries Management 19(4):948-956.

McMichael, G. A., T. N. Pearsons, and S. A. Leider. 2000. Minimizing ecological impacts of hatchery-reared juvenile steelhead trout on wild salmonids in a Yakima Basin watershed. Pages 365-380 *in* E. E. Knudson, C. R. Steward, D. D. MacDonald, J. E. Williams, and D. W. Reiser editors. Sustainable fisheries management: Pacific salmon. CRC Press, Boca Raton, Florida

McMichael, G. A., C. S. Sharpe, and T. N. Pearsons. 1997. Effects of residual hatchery-reared steelhead on growth of wild rainbow trout and spring Chinook salmon. Transactions of the American Fisheries Society 126(2):230-239.

Mommsen, T. P., M. M. Vijayan, and T. W. Moon. 1999. Cortisol in teleosts: dynamics, mechanisms of action, and metabolic regulation. Reviews in Fish Biology and Fisheries, 9(3):211-268.

Myers, J. M., and coauthors. 2015. Identifying Historical Populations of Steelhead within the Puget Sound Distinct Population Segment. March 2015. U.S. Dept. Commer., NOAA Technical Memorandum NMFS NWFSC-128. 175p.

Myers, J. M., and coauthors. 1998. Status Review of Chinook Salmon from Washington, Idaho, Oregon, and California. February 1998. U.S. Dept. Commer., NOAA Tech Memo., NMFS-NWFSC-35. 476p.

Nichols, K. M., A. F. Edo, P. A. Wheeler, and G. H. Thorgaard. 2008. The genetic basis of smoltification-related traits in *Oncorhynchus mykiss*. Genetics 179:1559-1575.

Nickelson, T. E., M. F. Solazzi, and S. L. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. Canadian Journal of Fisheries and Aquatic Sciences 43:2443-2449.

NMFS. 1995. Juvenile Fish Screen Criteria. Revised February 16, 1995. NMFS, Portland, Oregon. 15p.

NMFS. 1996. Juvenile Fish Screen Criteria for Pump Intakes: Addendum. May 9, 1996. NMFS Environmental and Technical Services Division, Portland, Oregon. 4p.

NMFS. 2000. RAP - A Risk Assessment Procedure for Evaluating Harvest Mortality of Pacific salmonids. May 30, 2000. NMFS, Seattle, Washington. 34p.

NMFS. 2002. Endangered Species Act Section 7 Consultation and Magnuson-Stevens Act Essential Fish Habitat Consultation. Biological Opinion on Artificial Propagation in the Hood Canal and Eastern Strait of Juan de Fuca Regions of Washington State. Hood Canal Summer Chum Salmon Hatchery Programs by the U.S. Fish and Wildlife Service and the Washington Department of Fish and Wildlife and Federal and Non-Federal Hatchery Programs Producing Unlisted Salmonid Species. National Marine Fisheries Service, Portland, Oregon. 285p.

NMFS. 2004a. NOAA Fisheries' Approach to Making Determinations Pursuant to the Endangered Species Act about the Effects of Harvest Actions on Listed Pacific Salmon and Steelhead. November 16, 2004. Prepared by the Northwest Region Sustainable Fisheries Division. 85p.

NMFS. 2004b. Salmonid Hatchery Inventory and Effects Evaluation Report (SHIEER). An Evaluation of the Effects of Artificial Propagation on the Status and Likelihood of Extinction of West Coast Salmon and Steelhead under the Federal Endangered Species Act. Technical Memorandum NMFS-NWR/SWR. May 28, 2004. U.S. Dept. of Commerce, National Marine Fisheries Service, Portland, Oregon. 557p.

NMFS. 2005a. Appendix A CHART assessment for the Puget Sound salmon evolutionary significant unit from final assessment of NOAA Fisheries' Critical Habitat Analytical Review Teams for 12 ESUs of West Coast salmon and steelhead. August 2005. 55p.

NMFS. 2005b. Policy on the consideration of hatchery-origin fish in Endangered Species Act listing determinations for Pacific salmon and steelhead. Pages 37204-37216 *in*. Federal Register, Volume 70 No. 123.

NMFS. 2006a. Endangered Species Act Section 7 Consultation Biological Opinion and Section 10 Statement of Findings and Magnuson-Stevens Fishery Conservation and Managment Act Essential Fish Habitat Consultation. Washington State Forest Practices Habitat Conservation Plan. NMFS Consultation No.: NWR-2005-07225. 335p.

NMFS. 2006b. Final Supplement to the Shared Strategy's Puget Sound Salmon Recovery Plan. November 17, 2006. NMFS, Portland, Oregon. 47p.

NMFS. 2008a. Anadromous Salmonid Passage Facility Design. February 2008. NMFS, Portland, Oregon. 137p.

NMFS. 2008b. Assessing Benefits and Risks & Recommendations for Operating Hatchery Programs consistent with Conservation and Sustainable Fisheries Mandates. Appendix C of Supplementary Comprehensive Analysis of the Federal Columbia River Power System and Mainstem Effects of the Upper Snake and other Tributary Actions. May 5, 2008. NMFS, Portland, Oregon.

NMFS. 2008c. Endangered Species Act Section 7 Consultation Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation on EPA's Proposed Approval of Revised Washington Water Quality Standards for Designated Uses, Temperature, Dissolved Oxygen, and Other Revisions. February 5, 2008. NMFS Consultation No.: NWR-2007-02301. 137p.

NMFS. 2008d. Endangered Species Act Section 7 Consultation Final Biological Opinion and Magnuson-Stevens Fishery Conservation and Managment Act Essential Fish Habitat Consultation. Implementation of the National Flood Insurance Program in the State of Washington Phase One Document-Puget Sound Region. NMFS Consultation No.: NWR-2006-00472. 226p.

NMFS. 2009a. Final ESA Section 7 Consultation Number 2009/00982 National Marine Fisheries Service Endangered Species Act (ESA) Section 7 Consultation Biological Opinion and Magnuson-Stevens Act (MSA) Essential Fish Habitat Consultation. Issuance of Permit 14433 to the Washington Department of Fish and Wildlife (WDFW). July 2, 2009. 68p.

NMFS. 2009b. Recovery plan for Lake Ozette sockeye salmon (*Oncorhynchus nerka*). May 4, 2009. Prepared by NMFS, Salmon Recovery Division. Portland, Oregon.

NMFS. 2010. Draft Puget Sound Chinook Salmon Population Recovery Approach (PRA). NMFS Northwest Region Approach for Distinguishing Among Individual Puget Sound Chinook Salmon ESU Populations and Watersheds for ESA Consultation and Recovery Planning Purposes. November 30, 2010. Puget Sound Domain Team, NMFS, Seattle, Washington. 19p.

NMFS. 2011a. Anadromous Salmonid Passage Facility Design. July 2011. National Marine Fisheries Service, Northwest Region, Portland, Oregon. 140p.

NMFS. 2011b. Evaluation of and recommended determination on a Resource Management Plan (RMP), pursuant to the salmon and steelhead 4(d) Rule comprehensive management plan for Puget Sound Chinook: Harvest management component. Salmon Management Division, Northwest Region, Seattle, Washington.

NMFS. 2013. Appendix B Chart Assessment for the Puget Sound Steelhead DPS. 72p.

NMFS. 2016a. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation. National Marine Fisheries Service (NMFS) Evaluation of Three Hatchery and Genetic Management Plans for Early Winter Steelhead in the Dungeness, Nooksack, and Stillaguamish River basins under Limit 6 of the Endangered Species Act Section 4(d) Rule. April 15, 2016. NMFS Consultation No.: WCR-2015-2024. 220p.

NMFS. 2016b. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation. National Marine Fisheries Service (NMFS) Evaluation of Two Hatchery and Genetic Management Plans for Early Winter Steelhead in the Snohomish River basin under Limit 6 of the Endangered Species Act Section 4(d) Rule. April 15, 2016. NMFS Consultation No.: WCR-2015-3441. 189p.

NMFS. 2017a. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation. National Marine Fisheries Service (NMFS) Evaluation of Six Hatchery and Genetic Management Plans for Snohomish River basin Salmon under Limit 6 of the Endangered Species Act Section 4(d) Rule. September 27, 2017. NMFS Consultation No.: NWR-2013-9699. 189p.

NMFS. 2017b. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation. NOAA's National Marine Fisheries Service's implementation of the Mitchell Act Final Environmental Impact Statement preferred alternative and administration of Mitchell Act hatchery funding. January 15, 2017. NMFS Consultation No.: WCR-2014-697. 535p.

NMFS. 2017c. National Marine Fisheries Service Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation. Consultation on the "Evaluation and Recommended Determination of a Tribal Resource Management Plan Submitted for Consideration Under the Endangered Species Act's Tribal Plan Limit [50 CFR 223.204] for the Period January 1, 2017 – December 31, 2021" affecting Salmon, Steelhead, and Eulachon in the West Coast Region. April 5, 2017. NMFS Consultation No.: WCR-2016-5800. 95p.

NMFS. 2019a. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response: Impacts of the Role of the BIA Under its Authority to Assist with the Development of the 2019-2020 Puget Sound Chinook Harvest Plan, Salmon Fishing Activities Authorized by the U.S. Fish and Wildlife Service, and Fisheries Authorized by the U.S. Fraser Panel in 2019. May 3, 2019. National Marine Fisheries Service, West Coast Region. NMFS Consultation No.: WCR-2019-00381. 284p.

NMFS. 2019b. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and MagnusonStevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation. Ten Hatchery Programs for Salmon and Steelhead in the Duwamish/Green River Basin. April 15, 2019. NMFS Consultation No.: WCR-2016-00014. 160p.

NMFS. 2019c. ESA Recovery Plan for the Puget Sound Steelhead Distinct Population Segment (*Oncorhynchus mykiss*). WCR/NMFS/NOAA. December 20, 2019. 174p.

NMFS. 2020. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Response Impacts of the Role of the BIA Under its Authority to Assist with the Development of the 2020-2021 Puget Sound Chinook Harvest Plan, Salmon Fishing Activities Authorized by the U.S. Fish and Wildlife Service, and Fisheries Authorized by the U.S. Fraser Panel in 2020. May 8, 2020. NMFS Consultation No: WCR-2020-00960. 345p.

NRC. 1996. Upstream: Salmon and Society in the Pacific Northwest. National Academy Press: Washington, D.C. 452p.

NWFSC. 2015. Status Review Update for Pacific Salmon and Steelhead listed under the Endangered Species Act: Pacific Northwest. December 21, 2015. NWFSC, Seattle, Washington. 356p.

NWIFC. 2016. 2016 State of Our Watersheds, WRIAs 1-23. A report by the Treaty Tribes in Western Washington. Northwest Indian Fisheries Commission Member Tribes. 336p.

Ostberg, C. O., L. Hauser, V. L. Pritchard, J. C. Garza, and K. A. Naish. 2013. Chromosome rearrangements, recombination suppression, and limited segregation distortion in hybrids between Yellowstone cutthroat trout (Oncorhynchus clarkii bouvieri) and rainbow trout (O. mykiss). BMC Genomics 2013, 14:570. 16p.

Ostberg, C. O., and G. H. Thorgaard. 1999. Geographic distribution of chromosome and microsatellite DNA polymorphisms in *Oncorhynchus mykiss* native to western Washington. Copeia 1999(2):287-298.

Partridge, F. E. 1985. Effects of Steelhead Smolt Size on Residualism and Adult Return Rates. USFWS, Lower Snake River Compensation Plan. Contract No. 14-16-001-83605. IDFG, Boise, Idaho.

Pearcy, W. G., and S. M. McKinnell. 2007. The ocean ecology of salmon in the Northeast Pacific Ocean - An abridged history. American Fisheries Society Symposium 57:7-30.

Pearsons, T. N., and C. A. Busack. 2012. PCD Risk 1: A tool for assessing and reducing ecological risks of hatchery operations in freshwater. Environmental Biology of Fishes 94:45-65.

PFMC. 2014. Pacific Coast Salmon Fishery Management Plan for Commercial and Recreational Salmon Fisheries off the Coasts of Washington, Oregon, and California as amended through Amendment 18. PFMC, Portland, Oregon. 90p.

PFMC. 2016a. Coastal Pelagic Species Fishery Management Plan as amended through Amendment 15. February 2016. Pacific Fishery Management Council, Portland, Oregon. 49p.

PFMC. 2016b. Pacific Coast Groundfish Fishery Management Plan for the California, Oregon, and Washington Groundfish Fishery. August 2016. Pacific Fishery Management Council, Portland, Oregon. 160p.

Phelps, S. R., S. A. Leider, P. L. Hulett, B. M. Baker, and T. Johnson. 1997. Genetic Analysis of Washington Steelhead: Preliminary results incorporating 36 new collections from 1995 and 1996. Progress report. February 1997. WDFW, Olympia, Washington.

PSIT, and WDFW. 2010. Comprehensive Management Plan for Puget Sound Chinook: Harvest Management Component. April 12. 2010. Puget Sound Indian Tribes and the Washington Department of Fish and Wildlife. 237p.

PSIT, and WDFW. 2013. Puget Sound Chinook Harvest Management Performance Assessment 2003-2010. July, 2013. Puget Sound Indian Tribes and Washington Department of Fish and Wildlife, Olympia, Washington. 111p.

PSSTRT. 2013. Viability Criteria for Puget Sound Steelhead. Final Review Draft. April 2013. 372p.

PSTT, and WDFW. 2004. Resource Management Plan. Puget Sound Hatchery Strategies for steelhead, coho salmon, chum salmon, sockeye salmon and pink salmon. March 31, 2004. 194p.

Quinn, T. P. 1993. A review of homing and straying of wild and hatchery-produced salmon. Fisheries Research 18:29-44.

Quinn, T. P. 1997. Homing, Straying, and Colonization. Genetic Effects of Straying of Non-Native Fish Hatchery Fish into Natural Populations. NOAA Tech. Memo., NMFS-NWFSC-30. 13p.

Quinn, T. P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. University of Washington Press, Bethesda, Maryland. 391p.

Rawson, K., and M. Crewson. 2017. Draft Snohomish Chinook Recovery Plan: Phases of Recovery and Integrated Adaptive Management Strategy. May 26, 2017. Tulalip Natural Resources, Tulalip, Washington. 41p.

Rensel, J., and coauthors. 1984. Evaluation of Potential Interaction Effects in the Planning and Selection of Salmonid Enhancement Projects. J. Rensel, and K. Fresh editors. Report prepared by the Species Interaction Work Group for the Enhancement Planning Team for implementation of the Salmon and Steelhead Conservation and Enhancement Act of 1980. WDFW, Olympia, Washington. 90p.

Richter, A., and S. A. Kolmes. 2005. Maximum temperature limits for Chinook, coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13(1):23-49.

Ruckelshaus, M. H., and coauthors. 2006. Independent Populations of Chinook Salmon in Puget Sound. July 2006. U.S. Dept. Commer., NOAA Technical Memorandum NMFS-NWFSC-78. 145p.

Ryman, N. 1991. Conservation genetics considerations in fishery management. Journal of Fish Biology 39 (Supplement A):211-224.

Scheuerell, M. D., and J. G. Williams. 2005. Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Fisheries Oceanography 14(6):448-457.

Scott, J. B., and W. T. Gill, editors. 2008. *Oncorhynchus mykiss*: Assessment of Washington State's Steelhead Populations and Programs. Preliminary draft for Washington Fish & Wildlife Commission. February 1, 2008. WDFW, Olympia, Washington. 424p.

Scott, W. B., and E. J. Crossman. 1973. Freshwater Fishes of Canada; Bulletin 184.

Sharpe, C. S., B. R. Beckman, K. A. Cooper, and P. L. Hulett. 2007. Growth modulation during juvenile rearing can reduce rates of residualism in the progeny of wild steelhead broodstock. North American Journal of Fisheries Management 27(4):1355-1368.

Sharpe, C. S., D. A. Thompson, H. L. Blankenship, and C. B. Schreck. 1998. Effects of routine handling and tagging procedures on physiological stress responses in juvenile Chinook salmon. The Progressive Fish-Culturist 60(2):81-87.

Snohomish Basin Salmon. 2005. Snohomish River Basin Salmon Conservation Plan. June 2005. Snohomish County Department of Public Works, Surface Water Management Division. Everett, Washington. 402p.

Snohomish Basin Salmonid Recovery Technical Committee. 1999. Initial Snohomish River Basin Chinook Salmon Conservation/Recovery Technical Work Plan Executive Summary. Snohomish Basin Salmonid Recovery Technical Committee. 15p.

Snohomish County. 2013. Final Environmental Impact Statement. December 2013. Snohomish County Smith Island Restoration Project. Everett, Washington. 185p.

Snohomish River Basin. 2019. Salmon Conservation Plan Status and Trends. April 2019. 51p.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzki. 1996. An Ecosystem Approach to Salmonid Conservation. December 1996. TR-4501-96-6057. Corvallis, Oregon. 206p.

SSPS. 2005. Snohomish Watershed Profile, WRIA 7. Shared Strategy Development Committee, Seattle, Washington.

SSPS. 2007. Puget Sound Salmon Recovery Plan. Volumes I, II and III. Plan Adopted by the National Marine Fisheries Service (NMFS) January 19, 2007. Submitted by the Shared Strategy Development Committee. Shared Strategy for Puget Sound. Seattle, Washington. 503p.

Steward, C. R., and T. C. Bjornn. 1990. Supplementation of Salmon and Steelhead Stocks with Hatchery Fish: A Synthesis of Published Literature. Technical Report 90-1. Idaho Cooperative Fish and Wildlife Research Unit, Moscow, Idaho. 132p.

Tatara, C. P., and coauthors. 2019. Age at release, size, and maturation status influence residualism in hatchery steelhead. North American Journal of Fisheries Management 39(3):468-484.

Thom, B. A. 2017. Letter to Jim Unsworth (WDFW) from Barry Thom (NMFS). Management plans (HGMPs) for Puget Sound salmon and steelhead hatchery programs. July 21, 2017. NMFS, Portland, Oregon. 3p.

Thorgaard, G. H. 1983. Chromosomal differences among rainbow trout populations. Copeia 1983(3):650-662.

Tipping, J. M., R. V. Cooper, J. B. Byrne, and T. H. Johnson. 1995. Communications: length and condition factor of migrating and nonmigrating hatchery-reared winter steelhead smolts. The Progressive Fish-Culturist 57(2):120-123.

Tipping, J. M., A. L. Gannam, T. D. Hilson, and J. B. Poole. 2003. Use of size for early detection of juvenile hatchery steelhead destined to become precocious males. North American Journal of Aquaculture 65:318-323.

Tufto, J. 2017. RE: Tufto and Hindar 2003. Emails describing R code for effective size estimation, January 18 and 20, 2017. From Jarle Tufto, Norwegian University of Science and Technology, Trondheim, Norway, to Craig Busack, NOAA.

Tulalip Tribes. 2012. Skykomish River Summer Chinook (*Oncorhynchus tshawytscha*) Hatchery Genetic Management Plan (HGMP). December 20, 2012. 99p.

Unsworth, J. 2016. Email to Robert Turner (NMFS) from James Unsworth (WDFW). Modifications to steelhead hatchery programs. Olympia, Washington. January 19, 2016. 14p.

Unsworth, J., and M. Grayum. 2016. Letter to Robert Turner (NMFS) from James Unsworth (WDFW) and Mike Grayum (NWIFC). Joint Puget Sound Chinook. June 13, 2016. 2p.

Warheit, K. I. 2014a. Measuring reproductive interaction between hatchery-origin and Wild steelhead (*Oncorhynchus mykiss*) from northern Puget Sound populations potentially affected by segregated hatchery programs. November 10, 2014. Unpublished Final Report. WDFW, Olympia, Washington. 14p.

Warheit, K. I. 2014b. Measuring Reproductive Interaction between Hatchery-origin and Wild Steelhead (*Oncorhynchus mykiss*) from Northern Puget Sound Populations Potentially Affected by Segregated Hatchery Programs. Unpublished Final Report. October 10, 2014. WDFW, Olympia, Washington. 92p.

Warheit, K. I., T. R. Seamons, B. E. Craig, and J. B. Scott. 2021. Population Structure and Genetic Characteristics of Snohomish River Basin Steelhead. March 30, 2021. WDFW, Olympia, Washington. 72p.

Warren, R., and C. Bowhay. 2016. Letter to Amilee Wilson (NMFS) from Ron Warren (WDFW) and Craig Bowhay (NWIFC). Co-manager Incidental Steelhead Impacts. June 15, 2016. 2p.

Watershed Resource Inventory Area 9 Steering Committee. 2005. Salmon Habitat Plan: Making Our Watershed Fit for a King. Green/Duwamish and Central Puget Sound Watershed Resource Inventory Area 9. August 2005. Prepared for the WRIA 9 Forum. 246p.

WDFW. 1994. 1992 Washington State Salmon and Steelhead Stock Inventory (SASSI). Appendix one. Puget Sound Stocks. North Puget Sound Volume. Washington Department of Fish and Wildlife and Western Washington Treaty Indian Tribes, Olympia, Washington. June, 1994. 432p.

WDFW. 2010a. 2009 Annual Report for the Operation and Maintenance of the Sunset Fall Trap and haul Fishway. Permit #14433. January 20, 2010. WDFW, Olympia, Washington. 10p.

WDFW. 2010b. 2010 Sunset Falls Trap and Haul Summary. December 7, 2010. WDFW, Olympia, Washington. 3p.

WDFW. 2012. 2011 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and haul Fishway. Permit #14433. January 27, 2012. WDFW, Olympia, Washington. 8p.

WDFW. 2013a. 2012 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and haul Fishway. Permit #14433. February 11, 2013. WDFW, Olympia, Washington. 7p.

WDFW. 2013b. Wallace River Summer Chinook Hatchery Program (Integrated), Skykomish River Summer Chinook (*Oncorhynchus tshawytscha*) HGMP. Feburary 11, 2013. Olympia, Washington. 67p.

WDFW. 2014a. 2013 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and Haul Fishway. Permit #14433. March 28, 2014. WDFW, Olympia, Washington. 8p.

WDFW. 2014b. Washington State Sport Catch Report 2010. August 2014. WDFW, Olympia, Washington. 98p.

WDFW. 2014c. Washington State Sport Catch Report 2011. December 2014. WDFW, Olympia, Washington. 94p.

WDFW. 2015. 2014 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and Haul Fishway. Permit #14433. January 15, 2015. WDFW, Olympia, Washington. 7p.

WDFW. 2016. 2015 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and Haul Fishway. Permit #14433. January 14, 2016. WDFW, Olympia, Washington. 7p.

WDFW. 2017. 2016 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and Haul Fishway. Permit #14433. February 9, 2017. WDFW, Olympia, Washington. 7p.

WDFW. 2018. 2017 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and Haul Fishway. Permit #14433. February 1, 2018. WDFW, Olympia, Washington. 5p.

WDFW. 2019a. 2018 Annual Report for the Operation and Maintenance of the Sunset Falls Trap and Haul Fishway. Permit #14433. January 7, 2019. WDFW, Olympia, Washington. 6p.

WDFW. 2019b. Sunset Falls Section 10 application for re-issuance from NMFS. August 8, 2019. WDFW, Olympia, Washington. 26p.

WDFW. 2021a. Mixed Stock Analysis of Adult Steelhead Collected at the Sunset Falls Fishway. April 20, 2021. WDFW, Olympia, Washington. 2p.

WDFW. 2021b. Proposed Enhancements to Genetic Monitoring Program Associated with Implementation of Skykomish Summer Steelhead Hatchery Program. April 13, 2021. WDFWy, Olympia, Washington. 19p.

WDFW, and PSIT. 2014. Puget Sound Steelhead Harvest Management Annual Report Covering the 2012-2013 Fishing Season. April 2014. Olympia, Washington. 12p.

WDFW, and PSTIT. 2005. Comprehensive Management Plan for Puget Sound Chinook: Harvest Management Component Annual Postseason Report, 2004-2005 Fishing Season. June 28, 2005. 115p.

WDFW, and PSTIT. 2008. Puget Sound Chinook Comprehensive Harvest Management Plan Annual Report Covering the 2007-2008 Fishing Season. Olympia, Washington. 58p.

WDFW, and PSTIT. 2009. Puget Sound Chinook Comprehensive Harvest Management Plan Annual Report Covering the 2008-2009 Fishing Season. May 11, 2009. Olympia, Washington. 136p.

WDFW, and PSTIT. 2010. Puget Sound Chinook Comprehensive Harvest Management Plan Annual Report Covering the 2009-2010 Fishing Season. June 21, 2010. Olympia, Washington. 152p.

WDFW, and PSTIT. 2011. Puget Sound Chinook Comprehensive Harvest Management Plan Annual Report Covering the 2010-2011 Fishing Season. August 1, 2011. Olympia, Washington. 125p.

WDFW, and PSTIT. 2012. Puget Sound Chinook Comprehensive Harvest Management Plan Annual Report Covering the 2011-2012 Fishing Season. October 3, 2012. Olympia, Washington. 125p.

WDFW, and PSTIT. 2020. 2018/2019 Puget Sound Steelhead Harvest Management Report. February 19, 2020. 13p.

WDFW, and Tulalip Tribes. 2019. South Fork Skykomish River Summer Steelhead Hatchery Program HGMP. April 12, 2019. WDFW, Auburn, Washington. 61p.

WDOE. 2015. Upland Fin-Fish Hatching and Rearing General Permit. December 16, 2015. WDOE, Olympia, Washington. A National Pollutant Discharge Elimination System and State Waste Discharge General Permit. 49p.

Wedemeyer, G. A. 1972. Some physiological consequences of handling stress in the juvenile coho salmon *(Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Board of Canada 29(12):1780-1783.

Wedemeyer, G. A., D. J. McLeay, and C. P. Goodyear. 1984. Assessing the tolerance of fish and fish populations to environmental stress: The problems and methods of monitoring. Advances in Environmental Science and Technology.

Wendelaar Bonga, S. E. 1997. The stress response in fish. Physiological reviews. 77 3:591-625.

Williams, R. W., R. M. Laramie, and J. J. Ames. 1975. A Catalog of Washington Streams and Salmon Utilization. Volume 1. November 1975. Washington Department of Fisheries, Olympia, Washington. 814p.

WSDOT. 2018. WSDOT Fish Barrier Correction: Moving Forward, Connecting Habitat. February 2018. 2p.

Zabel, R. W., M. D. Scheuerell, M. M. McClure, and J. G. Williams. 2006. The interplay between climate variability and density dependence in the population viability of Chinook salmon. Conservation Biology 20(1):190-200.

6. Appendix A: Effects of Hatchery Programs on Salmon and Steelhead Populations: Reference Document for NMFS ESA Hatchery Consultations (Revised July 29, 2020)[11]

NMFS applies available scientific information, identifies the types of circumstances and conditions that are unique to individual hatchery programs, then refines the range in effects for a specific hatchery program. Our analysis of a Proposed Action addresses six factors:

(1) The hatchery program does or does not remove fish from the natural population and use them for hatchery broodstock,
(2) Hatchery fish and the progeny of naturally spawning hatchery fish on spawning grounds and encounters with natural-origin and hatchery fish at adult collection facilities,
(3) Hatchery fish and the progeny of naturally spawning hatchery fish in juvenile rearing areas, the migration corridor, estuary, and ocean,
(4) RM&E that exists because of the hatchery program,
(5) Operation, maintenance, and construction of hatchery facilities that exist because of the hatchery program, and
(6) Fisheries that would not exist but for the hatchery program, including terminal fisheries intended to reduce the escapement of hatchery-origin fish to spawning grounds.

Because the purpose of biological opinions is to evaluate if proposed actions pose unacceptable risk (jeopardy) to listed species, much of the language in this appendix addresses risk. However, we also consider that hatcheries can be valuable tools for conservation or recovery, for example when used to prevent extinction or conserve genetic diversity in a small population, or to produce fish for reintroduction.

The following sections describe each factor in detail, including as appropriate, the scientific basis for and our analytical approach to assessment of effects. The material presented in this Appendix is only scientific support for our approach; social, cultural, and economic considerations are not included. The scientific literature on effects of salmonid hatcheries is large and growing rapidly. This appendix is thus not intended to be a comprehensive literature review, but rather a periodically updated overview of key relevant literature we use to guide our approach to effects analysis. Because this appendix can be updated only periodically, it may sometimes omit very recent findings, but should always reflect the scientific basis for our analyses. Relevant new information not cited in the appendix will be cited in the other sections of the opinion that detail our analyses of effects.

In choosing the literature we cite in this Appendix, our overriding concern is our mandate to use "best available science". Generally, this means recent peer-reviewed journal articles and books. However, as appropriate we cite older peer-reviewed literature that is still relevant, as well as "gray" literature. Although peer-review is typically considered the "gold standard" for scientific information, occasionally there are well-known and popular papers in the peer-reviewed literature

[11] This version of the appendix supersedes all earlier dated versions and the NMFS (2012) standalone document of the same name.

we do not cite because we question the methodology, results, or conclusions. In citing sources, we also consider availability, and try to avoid sources that are difficult to access. For this reason, we generally avoid citing master's theses and doctoral dissertations, unless they provide unique information.

1.1. Factor 1. The hatchery program does or does not remove fish from the natural population and use them for hatchery broodstock

A primary consideration in analyzing and assessing effects for broodstock collection is the origin and number of fish collected. The analysis considers whether broodstock are of local origin and the biological benefits and risks of using ESA-listed fish (natural or hatchery-origin) for hatchery broodstock. It considers the maximum number of fish proposed for collection and the proportion of the donor population collected for hatchery broodstock. "Mining" a natural population to supply hatchery broodstock can reduce population abundance and spatial structure

1.2. Factor 2. Hatchery fish and the progeny of naturally spawning hatchery fish on spawning grounds and encounters with natural and hatchery fish at adult collection facilities.

There are three aspects to the analysis of this factor: genetic effects, ecological effects, and encounters at adult collection facilities. We present genetic effects first. For the sake of simplicity, we discuss genetic effects on all life stages under factor 2.

1.2.1. Genetic effects

1.2.1.1. Overview

Based on currently available scientific information, we generally view the genetic effects of hatchery programs as detrimental to the ability of a salmon population's ability to sustain itself in the wild. We believe that artificial breeding and rearing is likely to result in some degree of change of genetic diversity and fitness reduction in hatchery-origin. Hatchery-origin fish can thus pose a risk to diversity and to salmon population rebuilding and recovery when they interbreed with natural-origin fish. However, conservation hatchery programs may prevent extinction or accelerate recovery of a target population by increasing abundance faster than may occur naturally (Waples 1999). Hatchery programs can also be used to create genetic reserves for a population to prevent the loss of its unique traits due to catastrophes (Ford et al. 2011).

We recognize that there is considerable debate regarding aspects of genetic risk. The extent and duration of genetic change and fitness loss and the short- and long-term implications and consequences for different species (i.e., for species with multiple life-history types and species subjected to different hatchery practices and protocols) remain unclear and should be the subject of further scientific investigation. As a result, we believe that hatchery intervention is a legitimate and useful tool to alleviate short-term extinction risk, but otherwise managers should seek to limit interactions between hatchery and natural-origin fish and implement hatchery practices that harmonize conservation with the implementation of treaty Indian fishing rights and other applicable laws and policies (NMFS 2011d). We expect the scientific uncertainty surrounding genetic risks to be reduced considerably in the next decade due to the rapidly increasing power of genomic analysis (Waples et al. 2020).

Four general processes determine the genetic composition of populations of any plant or animal species(e.g., Falconer and MacKay 1996):

- Selection- changes in genetic composition over time due to some genotypes being more successful at survival or reproduction (i.e, more fit) than others
- Migration- individuals, and thus their genes, moving from one population to another
- Genetic drift- random loss of genetic material due to finite population size
- Mutation- generation of new genetic diversity through changes in DNA

Mutations are changes in DNA sequences that are generally so rare[12] that they can be ignored for relatively short-term evaluation of genetic change, but the other three processes are considerations in evaluating the effects of hatchery programs on the productivity and genetic diversity of natural salmon and steelhead populations. Although there is considerable biological interdependence among them, we consider three major areas of genetic effects of hatchery programs in our analyses (Figure 12):

- Within-population genetic diversity
- Among-population genetic diversity/outbreeding
- Hatchery-influenced selection

The first two areas are well-known major concerns of conservation biology (e.g., Allendorf et al. 2013; Frankham et al. 2010), but our emphasis on what conservation geneticists would likely call “adaptation to captivity” (Allendorf et al. 2013, pp. 408-409) reflects the fairly unique position of salmon and steelhead among ESA-listed species. In ESA-listed Pacific salmon and steelhead, artificial propagation in hatcheries has been used as a routine management tool for many decades, and in some cases the size and scope of hatchery programs has been a factor in listing decisions.

In the sections below we discuss these three major areas of risk, but preface this with an explanation of some key terms relevant to genetic risk, and in some cases terms relevant to ecological risk as well.

[12] For example, the probability of a random base in a DNA molecule in coho salmon is .000000008 (Rougemont et al. 2020).

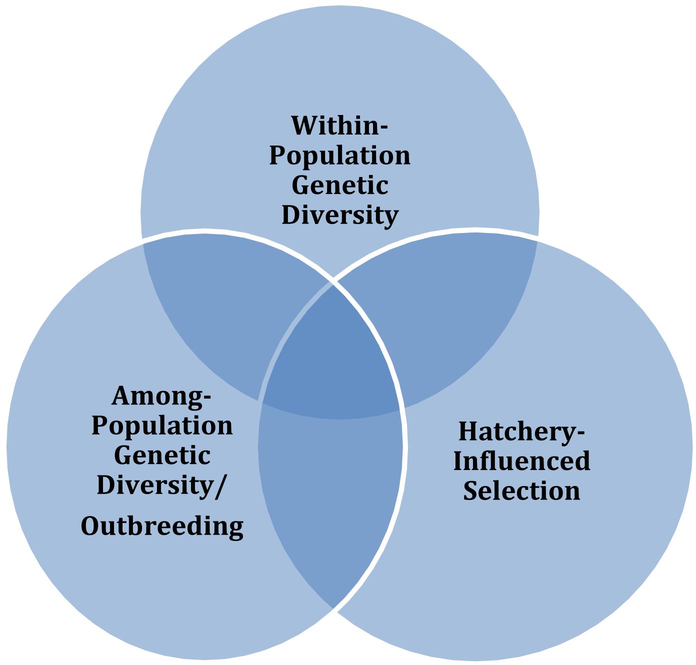

Figure 12. Major categories of hatchery program genetic effects analyzed by NMFS.

Key Terms

The terms "wild fish" and "hatchery fish" are commonly used by the public, management biologists, and regulatory biologists, but their meaning can vary depending on context. For genetic risk assessment, more precise terminology is needed:

- **Hatchery-origin (HO)**- refers to fish that have been reared and released by a hatchery program, regardless of the origin of their parents. A series of acronyms has been developed for subclasses of HO fish:
    - **Hatchery-origin recruits (HOR)** – HO fish returning to freshwater as adults or jacks. Usage varies, but typically the term refers to post-harvest fish that will either spawn in nature, used for hatchery broodstock, or surplused.
    - **Hatchery-origin spawners (HOS)**- hatchery-origin fish spawning in nature.
    - **Hatchery-origin broodstock (HOB)**- hatchery-origin fish that are spawned in the hatchery (i.e., are used as broodstock).
- **Natural-origin (NO)**- refers to fish that have resulted from spawning in nature, regardless of the origin of their parents. A series of acronyms has been developed for subclasses of NO fish:
    - **Natural-origin recruits (NOR)** – NO fish returning to freshwater as adults or jacks. Usage varies, but typically the term refers to post-harvest fish that will either spawn in nature or used for hatchery broodstock.

- **Natural-origin spawners (NOS)**- natural-origin fish spawning in nature.

- **Natural-origin broodstock (NOB)**- natural-origin fish that are spawned in the hatchery (i.e., are used as broodstock).

These terms have led to development of three metrics that are very important to genetic risk assessment. They are commonly attributed to the Hatchery Scientific Review Group (HSRG), but were developed in 2004 technical discussions between the HSRG and scientists from the Washington Department of Fish and Wildlife (WDFW) and the Northwest Indian Fisheries Commission (HSRG 2009a). All three are typically computed as means based on multiple spawning seasons:

- **pHOS -** proportion of fish on the spawning grounds consisting of HO fish. Mathematically, pHOS = HOS/(HOS + NOS. Assuming random mating, equal reproductive success of HO and NO spawners, and no selection, pHOS is the expected genetic contribution of HO spawners to the naturally spawning population, i.e., the expected level of gene flow from HO fish into the naturally spawning population.

  Genetic risk guidelines discussed in Section 1.2.1.4 have been developed based on refinements of pHOS:

  - **$pHOS_{census}$ -** pHOS based on census information (e.g., redd counts, spawner counts). pHOS without a subscript usually means $pHOS_{census}$

  - **$pHOS_{eff}$** - $pHOS_{census}$ discounted by the spawning success of HO fish relative to that of NO fish. For example, if HO fish are assumed to be 80 percent as reproductively capable as NO fish, then $pHOS_{eff} \approx 0.8 * pHOS_{census}$[13]

Because of expected differences in spatial distribution and spawning success between HO and NO fish, we consider pHOS an estimate of maximum potential gene flow. As a surrogate metric for gene flow, $pHOS_{census}$ computed over an entire basin becomes increasingly less satisfactory as biological complexity is considered (e.g., spawner distributions, sex ratios, varying fecundity). In response, approaches for finer scaled computation of pHOS have been developed (Falcy 2019; HSRG 2017), in addition to the previously mentioned adjustment for relative reproductive success.

- **pNOB -** proportion of fish in the hatchery broodstock consisting of NO fish. Mathematically, pNOB = NOB/(HOB + NOB).

- **Proportionate natural influence (PNI) -** in a population affected by hatchery programs, the relative selective influence of the natural environment. In populations affected by integrated hatchery programs, PNI is represented mathematically as PNI ≈ pNOB/(pNOB + pHOS). PNI is a confusing concept that we explain in greater detail in Section 1.2.1.4.

[13] We present a more precise equation in Section 1.2.1.4.

1.2.1.1.1.1. pHOS and mating-type frequency

Figure 13 illustrates the expected proportion of mating types in a mixed population of NO and HO fish (denoted as N and H, respectively, in the figure) as a function of $pHOS_{census}$, assuming that NO and HO adults mate randomly[14] (Figure 14). For example, at a $pHOS_{census}$ level of 10 percent, 81 percent of the matings would be expected to be NxN, 18 percent NxH, and 1 percent HxH.

You can also interpret the curves in the diagram as probability of naturally produced progeny of specified mating types, assuming random mating and equal reproductive success of all mating types. Under this interpretation, for example, progeny produced by a population with a pHOS level of 10 percent will have an 81 percent chance of having two NO parents. This logic has specific application to Canada's Wild Salmon Policy (WSP) (DFO 2005), in which wild fish are defined as naturally produced fish whose parents were naturally produced. Withler et al. (2018) used mating type probabilities to refine and extend HSRG gene flow guidelines for compatibility with the WSP.

[14] We made these computations using the simple mathematical binomial squared expansion $(a+b)^2=a^2 + 2ab + b^2$.

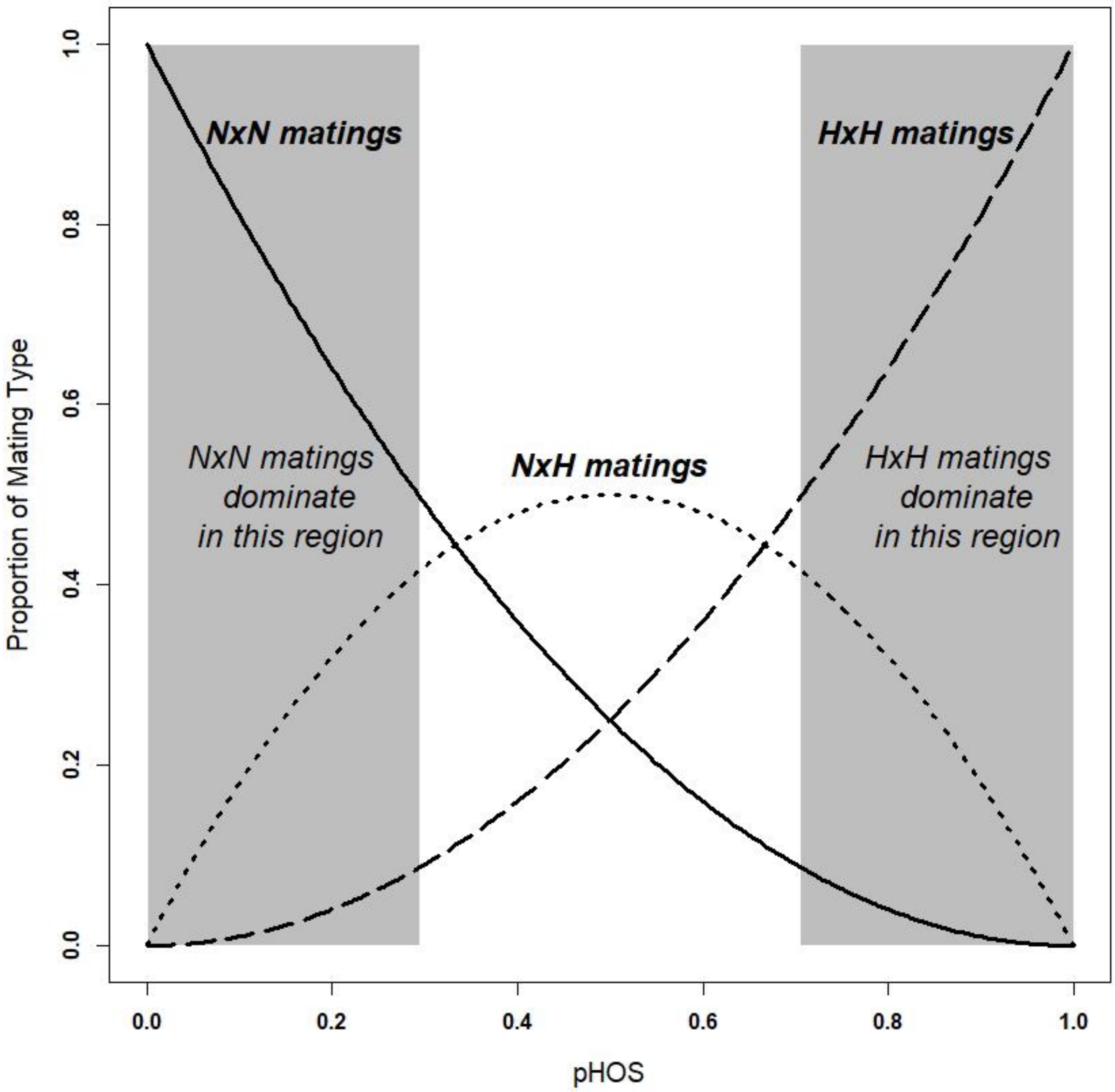

Figure 13. Relative proportions of mating types as a function of proportion of hatchery-origin fish on the spawning grounds (pHOS), assuming random mating. Line codes: solid = NxN, dashed = NxH, dotted = HxH. Shaded rectangles on left and right denote pHOS ranges at which NxN and HxH matings are most probable, respectively.

1.2.1.2. Within-population diversity effects

Within-population genetic diversity is a general term for the quantity, variety, and combinations of genetic material in a population (Busack and Currens 1995). Within-population diversity is gained through mutations or gene flow from other populations (described below under outbreeding effects) and is lost primarily due to genetic drift. In hatchery programs diversity may also be lost through biased or nonrepresentational sampling incurred during hatchery operations, particularly broodstock collection and spawning protocols.

1.2.1.2.1. Genetic drift

Genetic drift is random loss of diversity due to population size. The rate of drift is determined not by the census population size (N_c), but rather by the effective population size (N_e). The effective size of a population is the size of a genetically "ideal" population (i.e., equal numbers of males and females, each with equal opportunity to contribute to the next generation) that will display as much genetic drift as the population being examined (e.g., Allendorf et al. 2013; Falconer and MacKay 1996)[15].

This definition can be baffling, so an example is useful. A commonly used effective-size equation is $Ne = 4 * N_m * N_f / (N_m + N_f)$, where N_m and N_f are the number of male and female parents, respectively. Suppose a steelhead hatchery operation spawns 5 males with 29 females. According to the equation, although 34 fish were spawned, the skewed sex ratio made this equivalent to spawning 17 fish (half male and half female) in terms of conserving genetic diversity because half of the genetic material in the offspring came from only 5 fish.

Various guidelines have been proposed for what levels of N_e should be for conservation of genetic diversity. A long-standing guideline is the 50/500 rule (Franklin 1980; Lande and Barrowclough 1987): 50 for a few generations is sufficient to avoid inbreeding depression, and 500 is adequate to conserve diversity over the longer term. One recent review (Jamieson and Allendorf 2012) concluded the rule still provided valuable guidance; another (Frankham et al. 2014) concluded that larger values are more appropriate, basically suggesting a 100/1000 rule. See Frankham et al. (2010) for a more thorough discussion of these guidelines.

Although *Ne* can be estimated from genetic or demographic data, often-insufficient information is available to do this, so for conservation purposes it is useful to estimate effective size from census size. As illustrated by the example above, N_e can be considerably smaller than N_c. This is typically the case. Frankham et al. (2014) suggested a N_e:N_c range of ~0.1-0.2 based on a large review of the literature on effective size. For Pacific salmon populations over a generation, Waples (2004) arrived at a similar range of 0.05-0.3.

In salmon and steelhead management, effective size concerns are typically dealt with using the term effective number of breeders (N_b) in a single spawning season, with per-generation N_e equal to the generation time (average age of spawners) times the average N_b (Waples 2004). We will use N_b rather than N_e where appropriate in the following discussion.

Hatchery programs, simply by virtue of being able to create more progeny than natural spawners are able to, can increase N_b in a fish population. In very small populations, this increase can be a benefit, making selection more effective and reducing other small-population risks (e.g., Lacy 1987; Whitlock 2000; Willi et al. 2006). Conservation hatchery programs can thus serve to protect genetic diversity; several programs, such as the Snake River sockeye salmon program, are important genetic reserves. However, hatchery programs can also directly depress N_b by three principal pathways:

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[15] There are technically two subcategories of N_e: inbreeding effective size and variance effective size. The distinction between them is usually not a concern in our application of the concept.

- Removal of fish from the naturally spawning population for use as hatchery broodstock. If a substantial portion of the population is taken into a hatchery, the hatchery becomes responsible for that portion of the effective size, and if the operation fails, the effective size of the population will be reduced (Waples and Do 1994).

- Mating strategy used in the hatchery. N_b is reduced considerably below the census number of broodstock by using a skewed sex ratio, spawning males multiple times (Busack 2007), and by pooling gametes. Pooling milt is especially problematic because when milt of several males is mixed and applied to eggs, a large portion of the eggs may be fertilized by a single male (Gharrett and Shirley 1985; Withler 1988). This problem can be avoided by more structured mating schemes such as 1-to-1 mating. Factorial mating schemes, in which fish are systematically mated multiple times, can be used to increase N_b (Busack and Knudsen 2007; Fiumera et al. 2004) over what would be achievable with less structured designs. Considerable benefit in N_b increase over what is achievable by 1-to-1 mating can be achieved through a factorial design as simple as a 2 x 2 (Busack and Knudsen 2007).

- Ryman-Laikre effect. On a per-capita basis, a hatchery broodstock fish can often contribute many more progeny to a naturally spawning population than a naturally spawning fish can contribute This difference in reproductive contribution causes the composite N_b to be reduced, which is called a Ryman-Laikre (R-L) effect (Ryman et al. 1995; Ryman and Laikre 1991). The key factors determining the magnitude of the effect are the numbers of hatchery and natural spawners, and the proportion of natural spawners consisting of hatchery returnees.

The initial papers on the R-L effect required knowledge of N_b in the two spawning components of the population. Waples et al. (2016) have developed R-L equations suitable for a wide variety of situations in terms of knowledge base. A serious limitation of any R-L calculation however, is that it is a snapshot in time. What happens in subsequent generations depends on gene flow between the hatchery broodstock and the natural spawners. If a substantial portion of the broodstock are NO fish, the long-term effective size depression can be considerably less than would be expected from the calculated per-generation N_b.

Duchesne and Bernatchez (2002), Tufto and Hindar (2003), and Wang and Ryman (2001) have developed analytical approaches to deal with the effective-size consequences of multiple generations of interbreeding between HO and NO fish. One interesting result of these models is that effective size reductions caused by a hatchery program can easily be countered by low levels of gene flow from other populations. Tufto (2017) recently provided us with R code (R Core Team 2019) updates to the Tufto and Hindar (2003) method that yield identical answers to the Duchesne and Bernatchez (2002) method, and we use an R (R Core Team 2019) program incorporating them to analyze the effects of hatchery programs on effective size.

Inbreeding depression, another N_e-related phenomenon, is a reduction in fitness and survival caused by the mating of closely related individuals (e.g., siblings, half-siblings, cousins). Related individuals are genetically similar and produce offspring characterized by low genetic variation, low heterozygosity, lower survival, and increased expression of recessive deleterious mutations (Allendorf et al. 2013; Frankham et al. 2010; Hedrick and Garcia-Dorado 2016; Rollinson et al. 2014). Lowered fitness due to inbreeding depression exacerbates genetic risk relating to small population size and low genetic variation which further shifts a small population toward extinction (Nonaka et al. 2019). The protective hatchery environment masks the effects of inbreeding which becomes apparent when fish are released into the natural environment and experience decreased survival (Thrower and Hard 2009). Inbreeding concerns in salmonids related to hatcheries have been reviewed by Wang et al. (2002) and Naish et al. (2008).

Ne affects the level of inbreeding in a population, as the likelihood of matings between close relatives is increased in populations with low numbers of spawners. Populations exhibiting high levels of inbreeding are generally found to have low Ne (Dowell Beer et al. 2019). Small populations are at increased risk of both inbreeding depression and genetic drift (e.g., Willi et al. 2006). Genetic drift is the stochastic loss of genetic variation, which is most often observed in populations with low numbers of breeders. Inbreeding exacerbates the loss of genetic variation by increasing genetic drift when related individuals with similar allelic diversity interbreed (Willoughby et al. 2015).

Hatchery populations should be managed to avoid inbreeding depression. If hatcheries produce inbred fish which return to spawn in natural spawning areas the low genetic variation and increased deleterious mutations can lower the fitness, productivity, and survival of the natural population (Christie et al. 2014b). A captive population, which has been managed so genetic variation is maximized and inbreeding is minimized, may be used for a genetic rescue of a natural population characterized by low genetic variation and low Ne.

1.2.1.2.2. Biased/nonrepresentational sampling

Even if effective size is large, the genetic diversity of a population can be negatively affected by hatchery operations. Although many operations aspire to randomly use fish for spawning with respect to size, age, and other characteristics, this is difficult to do. For example, male Chinook salmon that mature precociously in freshwater are rarely if ever used as broodstock because they are not captured at hatchery weirs. Pressure to meet egg take goals is likely responsible for advancing run/spawn timing in at least some coho and Chinook salmon hatcheries (Ford et al. 2006; Quinn et al. 2002). Ironically, random mating, a common spawning guideline for conservation of genetic diversity has been hypothesized to be effectively selecting for younger, smaller fish (Hankin et al. 2009).

The sampling examples mentioned thus far are more or less unintentional actions. There are also established hatchery practices with possible diversity consequences that are clearly intentional. A classic example is use of jacks in spawning, where carefully considered guidelines range from random usage to near exclusion of jacks (e.g., IDFG et al. 2020; Seidel 1983). Another is the deliberate artificial selection in the hatchery of summer and winter steelhead to smolt at one year of age, which has resulted in early spawning stocks of both ecotypes (Crawford 1979).

Another source of biased sampling is non-inclusion of precocious males in broodstock. Precociousness, or early male maturation, is an alternative reproductive tactic employed by Atlantic salmon (Bagliniere and Maisse 1985; Myers et al. 1986), Chinook salmon (Bernier et al.

1993; Larsen et al. 2004), coho salmon (Iwamoto et al. 1964; Silverstein and Hershberger 1992), steelhead (McMillan et al. 2012; Schmidt and House 1979) , sockeye salmon (Ricker 1959), as well as several salmonid species in Asia and Europe (Dellefors and Faremo 1988; Kato 1991; Morita et al. 2009; Munakata et al. 2001).

Unlike anadromous males and females that migrate to the ocean to grow for a year or more before returning to their natal stream, precocious males generally stay in headwater reaches or migrate shorter distances downstream (Larsen et al. 2010) before spawning. They are orders of magnitude smaller than anadromous adults and use a 'sneaker' strategy to spawn with full size anadromous females (Fleming 1996). Precocious males are typically not subject to collection as broodstock, because of either size or location. Thus, to the extent this life history is genetically determined, hatchery programs culturing species that display precociousness unintentionally select against it.

The examples above illustrate the overlap between diversity effects and selection. Selection, natural or artificial, affects diversity, so could be regarded as a subcategory of within-population diversity. Analytically, here we consider specific effects of sampling or selection on genetic diversity. Broodstock collection or spawning guidelines that include specifications about non-random use of fish with respect to age or size, spawn timing, etc. (e.g., Crawford 1979) are of special interest. We consider general non-specific effects of unintentional selection due to the hatchery that are not related to individual traits in Section 1.2.1.4.

1.2.1.3. Among-population diversity/ Outbreeding effects

Outbreeding effects result from gene flow from other populations into the population of interest. Gene flow occurs naturally among salmon and steelhead populations, a process referred to as straying (Keefer and Caudill 2012; Quinn 1997; Westley et al. 2013). Natural straying serves a valuable function in preserving diversity that would otherwise be lost through genetic drift and in re-colonizing vacant habitat, and straying is considered a risk only when it occurs at unnatural levels or from unnatural sources.

Hatchery fish may exhibit reduced homing fidelity relative to NO fish (Goodman 2005; Grant 1997; Jonsson et al. 2003; Quinn 1997), resulting in unnatural levels of gene flow into recipient populations from strays, either in terms of sources or rates. Based on thousands of coded-wire tag (CWT) recoveries, Westley et al. (2013) concluded that species propagated in hatcheries vary in terms of straying tendency: Chinook salmon > coho salmon > steelhead. Also, within Chinook salmon, "ocean-type" fish stray more than "stream-type" fish. However, even if hatchery fish home at the same level of fidelity as NO fish, their higher abundance relative to NO fish can cause unnaturally high gene flow into recipient populations.

Rearing and release practices and ancestral origin of the hatchery fish can all play a role in straying (Quinn 1997). Based on fundamental population genetic principles, a 1995 scientific workgroup convened by NMFS concluded that aggregate gene flow from non-native HO fish from all programs combined should be kept below 5 percent (Grant 1997), and this is the recommendation NMFS uses as a reference in hatchery consultations. It is important to note that this 5% criterion was developed independently and for a different purpose than the HSRG's 5% pHOS criterion that is presented in Section 1.2.1.4.

Gene flow from other populations can increase genetic diversity (e.g., Ayllon et al. 2006), which can be a benefit in small populations, but it can also alter established allele frequencies (and co-adapted gene complexes) and reduce the population's level of adaptation, a phenomenon called outbreeding depression (Edmands 2007; McClelland and Naish 2007). In general, the greater the geographic separation between the source or origin of hatchery fish and the recipient natural population, the greater the genetic difference between the two populations (ICTRT 2007), and the greater potential for outbreeding depression. For this reason, NMFS advises hatchery action agencies to develop locally derived hatchery broodstock.

In addition, unusual high rates of straying into other populations within or beyond the population's MPG, salmon ESU, or a steelhead DPS, can have a homogenizing effect, decreasing intra-population genetic variability (e.g., Vasemagi et al. 2005), and increasing risk to population diversity, one of the four attributes measured to determine population viability (McElhany et al. 2000). The practice of backfilling — using eggs collected at one hatchery to compensate for egg shortages at another—has historically a key source of intentional large-scale "straying". Although it now is generally considered an unwise practice, it still is common.

There is a growing appreciation of the extent to which among-population diversity contributes to a "portfolio" effect (Schindler et al. 2010), and lack of among-population genetic diversity is considered a contributing factor to the depressed status of California Chinook salmon populations (Carlson and Satterthwaite 2011; Satterthwaite and Carlson 2015). Eldridge et al. (2009) found that among-population genetic diversity had decreased in Puget Sound coho salmon populations during several decades of intensive hatchery culture.

As discussed in Section 1.2.1.4, pHOS[16] is often used as a surrogate measure of gene flow. Appropriate cautions and qualifications should be considered when using this proportion to analyze outbreeding effects.

- Adult salmon may wander on their return migration, entering and then leaving tributary streams before spawning (Pastor 2004). These "dip-in" fish may be detected and counted as strays, but may eventually spawn in other areas, resulting in an overestimate of the number of strays that potentially interbreed with the natural population (Keefer et al. 2008). On the other hand, "dip-ins" can also be captured by hatchery traps and become part of the broodstock.

- Strays may not contribute genetically in proportion to their abundance. Several studies demonstrate little genetic impact from straying despite a considerable presence of strays in the spawning population (Blankenship et al. 2007; e.g., Saisa et al. 2003). The causes of poor reproductive success of strays are likely similar to those responsible for reduced productivity of HO fish in general, e.g., differences in run and spawn timing, spawning in less productive habitats, and reduced survival of their progeny (Leider et al. 1990; Reisenbichler and McIntyre 1977; Williamson et al. 2010).

[16] It is important to reiterate that as NMFS analyzes them, outbreeding effects are a risk only when the HO fish are from a *different* population than the NO fish.

1.2.1.4. Hatchery-influenced selection effects

Hatchery-influenced selection (often called domestication[17]), the third major area of genetic effects of hatchery programs that NMFS analyses, occurs when selection pressures imposed by hatchery spawning and rearing differ greatly from those imposed by the natural environment and causes genetic change that is passed on to natural populations through interbreeding with HO fish. These differing selection pressures can be a result of differences in environments or a consequence of protocols and practices used by a hatchery program.

Hatchery-influenced selection can range from relaxation of selection that would normally occur in nature, to selection for different characteristics in the hatchery and natural environments, to intentional selection for desired characteristics (Waples 1999), but in this section, for the most part, we consider hatchery-influenced selection effects that are general and unintentional. Concerns about these effects, often noted as performance differences between HO and NO fish have been recorded in the scientific literature for more than 60 years (Vincent 1960, and references therein).

Genetic change and fitness reduction in natural salmon and steelhead due to hatchery-influenced selection depends on:

- The difference in selection pressures presented by the hatchery and natural environments. Hatchery environments differ from natural environments in many ways (e.g., Thorpe 2004). Some obvious ones are food, density, flows, environmental complexity, and protection from predation.

- How long the fish are reared in the hatchery environment. This varies by species, program type, and by program objective. Steelhead, coho and "stream-type" Chinook salmon are usually released as yearlings, while "ocean-type" Chinook, pink, and chum salmon are usually released at younger ages.

- The rate of gene flow between HO and NO fish, which is usually expressed as pHOS for segregated programs and PNI for integrated programs.

All three factors should be considered in evaluating risks of hatchery programs. However, because gene flow is generally more readily managed than the selection strength of the hatchery environment, current efforts to control and evaluate the risk of hatchery-influenced selection are

[17] We prefer the term "hatchery-influenced selection" or "adaptation to captivity" (Fisch et al. 2015) to "domestication" because in discussions of genetic risk in salmon "domestication" is often taken as equivalence to species that have been under human management for thousands of years; e.g., perhaps 30,000 yrs for dogs (Larson and Fuller 2014), and show evidence of large-scale genetic change (e.g., Freedman et al. 2016). By this standard, the only domesticated fish species is the carp (*Cyprinus carpio*) (Larson and Fuller 2014). "Adaptation to captivity", a term commonly used in conservation biology (e.g., Allendorf et al. 2013; Frankham 2008), and becoming more common in the fish literature (Christie et al. 2011; Fisch et al. 2015) is more precise for species that have been subjected to semi-captive rearing for a few decades. We feel "hatchery-influenced selection" is even more precise, and less subject to confusion.

currently largely focused on gene flow between NO and HO fish[18]. Strong selective fish culture with low hatchery-wild interbreeding can pose less risk than relatively weaker selective fish culture with high levels of interbreeding.

1.2.1.4.1. Relative Reproductive Success Research

Although hundreds of papers in the scientific literature document behavioral, morphological and physiological differences between NO and HO fish, the most frequently cited research has focused on RRS of HO fish compared to NO fish determined through pedigree analysis. The influence of this type of research derives from the fact that it addresses fitness, the ability of the fish to produce progeny that will then return to sustain the population. The RRS study method is simple: genotyped NO and HO fish are released upstream to spawn, and their progeny (juveniles, adults, or both) are sampled genetically and matched with the genotyped parents. In some cases, multiple-generation pedigrees are possible.

RRS studies can be easy to misinterpret (Christie et al. 2014a) for at least three reasons:

- RRS studies often have little experimental power because of limited sample sizes and enormous variation among individual fish in reproductive success (most fish leave no offspring and a few leave many). This can lead to lack of statistical significance for HO:NO comparisons even if a true difference does exist. Kalinowski and Taper (2005) provide a method for developing confidence intervals around RRS estimates that can shed light on statistical power.

- An observed difference in RRS may not be genetic. For example, Williamson et al. (2010) found that much of the observed difference in reproductive success between HO and NO fish was due to spawning location; the HO fish tended to spawn closer to the hatchery. Genetic differences in reproductive success require a multiple generation design, and only a handful of these studies are available.

- The history of the natural population in terms of hatchery ancestry can bias RRS results. Only a small difference in reproductive success of HO and NO fish might be expected if the population had been subjected to many generations of high pHOS (Willoughby and Christie 2017).

For several years, the bulk of the empirical evidence of fitness depression due to hatchery-influenced selection came from studies of species that are reared in the hatchery environment for an extended period— one to two years—before release (Berejikian and Ford 2004). Researchers and managers wondered if these results were applicable to species and life-history types with shorter hatchery residence, as it seemed reasonable that the selective effect of the hatchery

[18] Gene flow between NO and HO fish is often interpreted as meaning actual matings between NO and HO fish. In some contexts, it can mean that. However, in this document, unless otherwise specified, gene flow means contributing to the same progeny population. For example, HO spawners in the wild will either spawn with other HO fish or with NO fish. NO spawners in the wild will either spawn with other NO fish or with HO fish. But all these matings, to the extent they are successful, will generate the next generation of NO fish. In other words, all will contribute to the NO gene pool.

environment would be less on species with shorter hatchery residence times (e.g., RIST 2009). Especially lacking was RRS information on "ocean-type" Chinook. Recent RRS work on Alaskan pink salmon, the species with the shortest hatchery residence time has found very large differences in reproductive success between HO and NO fish. The RRS was 0.42 for females and 0.28 for males (Lescak et al. 2019). This research suggests the "less residence time, less effect" paradigm needs to be revisited.

In addition to pink salmon, RRS results are now available for:

- Coho salmon(Theriault et al. 2011)
- Chum salmon (Berejikian et al. 2009)
- "Ocean-type" Chinook salmon (Anderson et al. 2012; Evans et al. 2019; Sard et al. 2015)
- "Stream-type" Chinook salmon (Ford et al. 2012; Ford et al. 2015; Ford et al. 2009; Hess et al. 2012; Janowitz-Koch et al. 2018; Williamson et al. 2010)
- Steelhead (Araki et al. 2007; Araki et al. 2009; Berntson et al. 2011; Christie et al. 2011)

Although the size of the effect may vary, and there may be year-to-year variation and lack of statistical significance, the general pattern is clear: HO fish have lower reproductive success than NO fish.

As mentioned above, few studies have been designed to detect unambiguously a genetic component in RRS. Two such studies have been conducted with steelhead and both detected a statistically significant genetic component in steelhead (Araki et al. 2007; Christie et al. 2011; Ford et al. 2016), but the two conducted with "stream-type" Chinook salmon have not (Ford et al. 2012; Janowitz-Koch et al. 2018).

This suggests that perhaps the impacts of hatchery-influenced selection on fitness differs between Chinook salmon and steelhead.[19] The possibility that steelhead may be more affected by hatchery-influenced selection than Chinook salmon by no means suggest that effects on Chinook are trivial, however. A small decrement in fitness per generation can lead to large fitness loss.

1.2.1.4.2. Hatchery Scientific Review Group (HSRG) Guidelines

Key concepts concerning the relationship of gene flow to hatchery-influenced selection were developed and promulgated throughout the Pacific Northwest by the Hatchery Scientific Review Group (HSRG). Because these concepts have been so influential, we devote the next few paragraphs to them.

The HSRG developed gene-flow guidelines based on mathematical models developed by Ford (2002) and by Lynch and O'Hely (2001). Guidelines for segregated programs are based on pHOS, but guidelines for integrated programs also include PNI, which is a function of pHOS and pNOB.

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[19] This would not be surprising. Although steelhead are thought of as being quite similar to the "other" species of salmon, genetic evidence suggests the two groups diverged well over 10 million years ago (Crête-Lafrenière et al. 2012).

PNI is, in theory, a reflection of the relative strength of selection in the hatchery and natural environments; a PNI value greater than 0.5 indicates dominance of natural selective forces.

The HSRG guidelines (HSRG 2009b) vary according to type of program and conservation importance of the population. The HSRG used conservation importance classifications that were developed by the Willamette/Lower Columbia Technical Recovery Team (McElhany et al. 2003).[20] (Table 18). In considering the guidelines, we equate "primary" with a recovery goal of "viable" or "highly viable", and "contributing" with a recovery goal of "maintain". We disregard the guidelines for "stabilizing", because we feel they are inadequate for conservation guidance.

Table 18. HSRG gene flow guidelines (HSRG 2009b).

	Program classification	
Population conservation importance	**Integrated**	**Segregated**
Primary	**PNI ≥ 0.67 and pHOS ≤ 0.30**	**pHOS ≤ 0.05**
Contributing	**PNI ≥ 0.50 and pHOS ≤ 0.30**	**pHOS ≤ 0.10**
Stabilizing	**Existing conditions**	**Existing conditions**

Although they are controversial, the HSRG gene flow guidelines have achieved a considerable level of regional acceptance. They were adopted as policy by the Washington Fish and Wildlife Commission (WDFW 2009), and were recently reviewed and endorsed by a WDFW scientific panel, who noted that the "…HSRG is the primary, perhaps only entity providing guidance for operating hatcheries in a scientifically defensible manner…" (Anderson et al. 2020). In addition, HSRG principles have been adopted by the Canadian Department of Fisheries and Oceans, with very similar gene-flow guidelines for some situations (Withler et al. 2018).

The gene flow guidelines developed by the HSRG have been implemented in areas of the Pacific Northwest for at most 15 years, so there has been insufficient time to judge their effect. They have also not been applied consistently, which complicates evaluation. However, the benefits of high pNOB (in the following cases 100 percent) has been credited with limiting genetic change and fitness loss in supplemented Chinook populations in the Yakima (Washington) (Waters et al. 2015) and Salmon (Idaho) (Hess et al. 2012; Janowitz-Koch et al. 2018) basins.

Little work toward developing guidelines beyond the HSRG work has taken place. The only notable effort along these lines has been the work of Baskett and Waples (2013), who developed a model very similar to that of Ford (2002), but added the ability to impose density-dependent survival and selection at different life stages. Their qualitative results were similar to Ford's, but the model would require some revision to be used to develop guidelines comparable to the HSRG's.

NMFS has not adopted the HSRG gene flow guidelines per se. However, at present the HSRG guidelines, along with the 5% stray guideline from Grant (1997) are the only acknowledged

[20] Development of conservation importance classifications varied among technical recovery teams (TRTs); for more information, documents produced by the individual TRT's should be consulted.

scientifically based quantitative guidelines for gene flow available. NMFS has considerable experience with the HSRG guidelines. They are based on a model (Ford 2002) developed by a NMFS geneticist, they have been evaluated by a NMFS-lead scientific team (RIST 2009), and NMFS scientists have extended the Ford model for more flexible application of the guidelines to complex situations (Busack 2015) (Section 1.2.1.4.3).

At minimum, we consider the HSRG guidelines a useful screening tool. For a particular program, based on specifics of the program, broodstock composition, and environment, we may consider a pHOS or PNI level to be a lower risk than the HSRG would but, generally, if a program meets HSRG guidelines, we will typically consider the risk levels to be acceptable. However, our approach to application of HSRG concepts varies somewhat from what is found in HSRG documents or in typical application of HSRG concepts. Key aspects of our approach warrant discussion here.

1.2.1.4.2.1. PNI and segregated hatchery programs

The PNI concept has created considerable confusion. Because it is usually estimated by a simple equation that is applicable to integrated programs, and applied in HSRG guidelines only to integrated programs, PNI is typically considered to be a concept that is relevant only to integrated programs. This in turn has caused a false distinction between segregated and integrated programs in terms of perceptions of risk. The simple equation for PNI is:

$PNI \approx pNOB / (pNOB + pHOS)$.

In a segregated program, pNOB equals zero, so by this equation PNI would also be zero. You could easily infer that PNI is zero in segregated programs, but this would be incorrect. The error comes from applying the equation to segregated programs. In integrated programs, PNI can be estimated accurately by the simple equation, and the simplicity of the equation makes it very easy to use. In segregated programs, however, a more complicated equation must be used to estimate PNI. A PNI equation applicable to both integrated and segregated programs was developed over a decade ago by the HSRG (HSRG 2009a, equation 9), but has been nearly completed ignored by parties dealing with the gene flow guidelines:

$$PNI \approx \frac{h^2 + (1.0 - h^2 + \omega^2) * pNOB}{h^2 + (1.0 - h^2 + \omega^2) * (pNOB + pHOS)},$$

where h^2 is heritability and ω^2 is the strength of selection in standard deviation units, squared. Ford (2002) used a range of values for the latter two variables. Substituting those values that created the strongest selection scenarios in his simulations (h^2 of 0.5 and ω^2 of 10), which is appropriate for risk assessment, results in:

$$PNI \approx \frac{0.5 + 10.5 * pNOB}{0.5 + 10.5 * (pNOB + pHOS)}$$

HSRG (2004) offered additional guidance regarding isolated programs, stating that risk increases dramatically as the level of divergence increases, especially if the hatchery stock has been selected directly or indirectly for characteristics that differ from the natural population. More recently, the HSRG concluded that the guidelines for isolated programs may not provide as much protection from fitness loss as the corresponding guidelines for integrated programs (HSRG 2014). This can be easily demonstrated using the equation presented in the previous paragraph: a pHOS of 0.05, the standard for a primary population affected by a segregated program, yields a PNI of 0.49, whereas a pHOS of 0.024 yields a PNI of 0.66, virtually the same as the standard for a primary population affected by an integrated program.

1.2.1.4.2.2. The effective pHOS concept

The HSRG recognized that HO fish spawning naturally may on average produce fewer adult progeny than NO spawners, as described above. To account for this difference, the HSRG (2014) defined *effective* pHOS as:

$$pHOS_{eff} = (RRS * HOS_{census}) / (NOS + RRS * HOS_{census}),$$

where RRS is the reproductive success of HO fish relative to that of NO fish. They then recommend using this value in place of $pHOS_{census}$ in PNI calculations.

We feel that adjustment of census pHOS by RRS for this purpose should be done not nearly as freely as the HSRG document would suggest because the Ford (2002) model, which is the foundation of the HSRG gene-flow guidelines, implicitly includes a genetic component of RRS. In that model, hatchery fish are expected to have RRS < 1 (compared to natural fish) due to selection in the hatchery. A component of reduced RRS of hatchery fish is therefore already incorporated in the model and by extension the calculation of PNI. Therefore, reducing pHOS values by multiplying by RRS will result in underestimating the relevant pHOS and therefore overestimating PNI. Such adjustments would be particularly inappropriate for hatchery programs with low pNOB, as these programs may well have a substantial reduction in RRS due to genetic factors already incorporated in the model.

In some cases, adjusting pHOS downward may be appropriate, particularly if there is strong evidence of a non-genetic component to RRS. Wenatchee spring Chinook salmon (Williamson et al. 2010) is an example case with potentially justified adjustment by RRS, where the spatial distribution of NO and HO spawners differs, and the HO fish tend to spawn in poorer habitat. However, even in a situation like the Wenatchee spring Chinook salmon, it is unclear how much of an adjustment would be appropriate.

By the same logic, it might also be appropriate to adjust pNOB in some circumstances. For example, if hatchery juveniles produced from NO broodstock tend to mature early and residualize (due to non-genetic effects of rearing), as has been documented in some spring Chinook salmon and steelhead programs, the "effective" pNOB might be much lower than the census pNOB.

It is important to recognize that PNI is only an approximation of relative trait value, based on a model that is itself very simplistic. To the degree that PNI fails to capture important biological information, it would be better to work to include this biological information in the underlying models rather than make ad hoc adjustments to a statistic that was only intended to be a rough guideline to managers. We look forward to seeing this issue further clarified in the near future. In the meantime, except for cases in which an adjustment for RRS has strong justification, we feel that census pHOS, rather than effective pHOS, is the appropriate metric to use for genetic risk evaluation.

1.2.1.4.2.3. Gene flow guidelines in phases of recovery

In 2012 the HSRG expanded on the original gene flow guidelines/standards by introducing the concept of recovery phases for natural populations (HSRG 2012), and then refined the concept in later documents (HSRG 2014; HSRG 2015; HSRG 2017). They defined and described four phases:

1. Preservation
2. Re-colonization
3. Local adaptation
4. Fully restored

The HSRG provided guidance on development of quantitative "triggers" for determining when a population had moved (up or down) from one phase to another. As explained in HSRG (2015), in the preservation and re-colonization phase, no PNI levels were specified for integrated programs (Table 19). The emphasis in these phases was to "Retain genetic diversity and identity of the existing population". In the local adaptation phase, when PNI standards were to be applied, the emphasis shifted to "Increase fitness, reproductive success and life history diversity through local adaptation (e.g., by reducing hatchery influence by maximizing *PNI*)". The HSRG provided additional guidance in HSRG (2017), which encouraged managers to use pNOB to "…the extent possible…" during the preservation and recolonization phases.

Table 19. HSRG gene flow guidelines/standards for conservation and harvest programs, based on recovery phase of impacted population (Table 2 from HSRG 2015).

Natural Population		Hatchery Broodstock Management	
Designation	Status	Segregated	Integrated
Primary	Fully Restored	pHOS<5%	PNI>0.67
	Local Adaptation	pHOS<5%	PNI>0.67
	Re-colonization	pHOS<5%	Not Specified
	Preservation	pHOS<5%	Not Specified
Contributing	Fully Restored	pHOS<10%	PNI>0.50
	Local Adaptation	pHOS<10%	PNI>0.50
	Re-colonization	pHOS<10%	Not Specified
	Preservation	pHOS<10%	Not Specified
Stabilizing	Fully Restored	Current Condition	Current Condition
	Local Adaptation	Current Condition	Current Condition
	Re-colonization	Current Condition	Current Condition
	Preservation	Current Condition	Current Condition

We agree that conservation of populations at perilously low abundance may require prioritization of demographic over genetic concerns, but is concerned that high pHOS/low PNI regimes imposed on small recovering populations may prevent them from advancing to higher recovery phases[21]. A WDFW scientific panel reviewing HSRG principles and guidelines reached the same conclusion (Anderson et al. 2020).

1.2.1.4.3. Extension of PNI modeling to more than two population components

The Ford (2002) model considered a single population affected by a single hatchery program—basically two population units connected by gene flow—but the recursion equations underlying the model are easily expanded to more than two populations (Busack 2015). This has resulted in tremendous flexibility in applying the PNI concept to hatchery consultations.

A good example is a system of genetically linked hatchery programs, an integrated program in which in which returnees from a (typically smaller) integrated hatchery program are used as broodstock for a larger segregated program, and both programs contribute to pHOS. It seems logical that this would result in less impact on the natural population than if the segregated program used only its own returnees as broodstock, but because the two-population implementation of the Ford model did not apply, there was no way to calculate PNI for this system.

Extending Ford's recursion equations (equations 5 and 6) to three populations allowed us to calculate PNI for a system of this type. We successfully applied this approach to link two spring Chinook salmon hatchery programs: Winthrop NFH (segregated) and Methow FH (integrated). By using some level of Methow returnees as broodstock for the Winthrop program, PNI for the natural population could be increased significantly[22](Busack 2015). We have since used the multi-population PNI model in numerous hatchery program consultations in Puget Sound and the Columbia basin, and have extended to it to include as many as ten hatchery programs and natural production areas.

[21] According to Andy Appleby, past HSRG co-chair, the HSRG never intended this guidance to be interpreted as total disregard for pHOS/PNI standards in the preservation and recovery phases (Appleby 2020).
[22] Such programs can lower the effective size of the system, but the model of Tufto (Section 1.2.1.3) can easily be applied to estimate this impact.

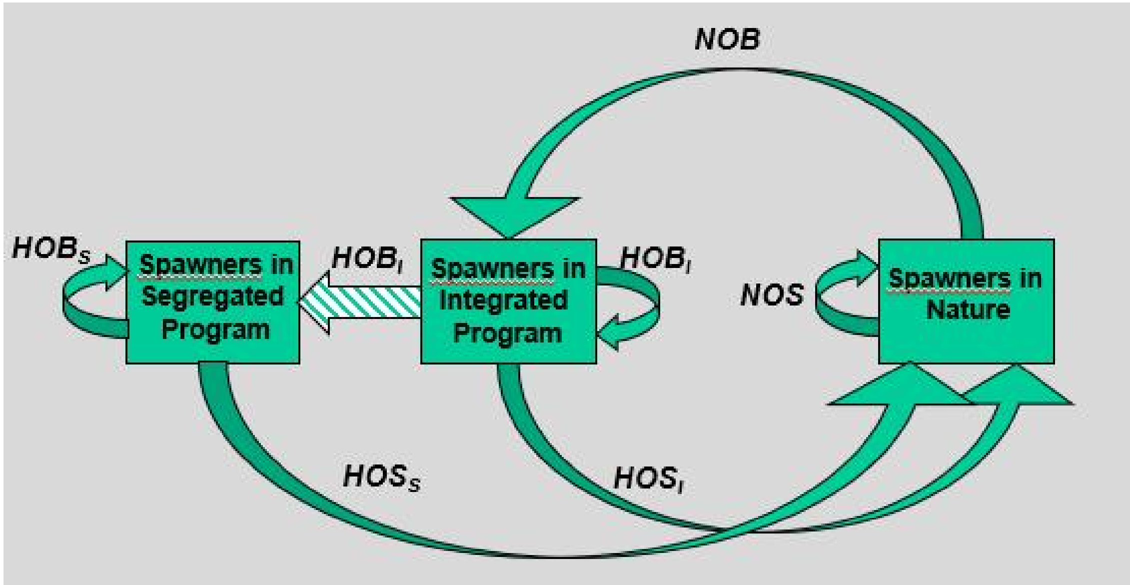

Figure 14. Example of genetically linked hatchery programs. The natural population is influenced by hatchery-origin spawners from an integrated (HOSI) and a segregated program (HOSS). The integrated program uses a mix of natural-origin (NOB) and its own returnees (HOBI) as broodstock, but the segregated uses returnees from the integrated program (HOBI above striped arrow) as all or part of its broodstock, genetically linking the two programs. The system illustrated here is functionally equivalent to the HSRG's (HSRG 2014) "stepping stone" concept.

1.2.1.4.4. California HSRG

Another scientific team was assembled to review hatchery programs in California and this group developed guidelines that differed somewhat from those developed by the "Northwest" HSRG (California HSRG 2012). The California team:

- Felt that truly isolated programs in which no HO returnees interact genetically with natural populations were impossible in California, and was "generally unsupportive" of the concept of segregated programs. However, if programs were to be managed as isolated, they recommend a pHOS of less than 5 percent.

- Rejected development of overall pHOS guidelines for integrated programs because the optimal pHOS will depend upon multiple factors, such as "the amount of spawning by NO fish in areas integrated with the hatchery, the value of pNOB, the importance of the integrated population to the larger stock, the fitness differences between HO and NO fish, and societal values, such as angling opportunity."

- Recommended that program-specific plans be developed with corresponding population-specific targets and thresholds for pHOS, pNOB, and PNI that reflect these factors. However, they did state that PNI should exceed 50 percent in most cases, although in supplementation or reintroduction programs the acceptable pHOS could be much higher than 5 percent, even approaching 100 percent at times.

- Recommended for conservation programs that pNOB approach 100 percent, but pNOB levels should not be so high they pose demographic risk to the natural population by taking too large a proportion of the population for broodstock.

1.2.2. Ecological effects

Ecological effects for this factor (i.e., hatchery fish and the progeny of naturally spawning hatchery fish on the spawning grounds) refer to effects from competition for spawning sites and redd superimposition, contributions to marine-derived nutrients, and the removal of fine sediments from spawning gravels. Ecological effects on the spawning grounds may be positive or negative.

To the extent that hatcheries contribute added fish to the ecosystem, there can be positive effects. For example, when anadromous salmonids return to spawn, hatchery-origin and natural-origin alike, they transport marine-derived nutrients stored in their bodies to freshwater and terrestrial ecosystems. Their carcasses provide a direct food source for juvenile salmonids and other fish, aquatic invertebrates, and terrestrial animals, and their decomposition supplies nutrients that may increase primary and secondary production (Gresh et al. 2000; Kline et al. 1990; Larkin and Slaney 1996; Murota 2003; Piorkowski 1995; Quamme and Slaney 2003; Wipfli et al. 2003). As a result, the growth and survival of juvenile salmonids may increase (Bell 2001; Bilton et al. 1982; Bradford et al. 2000; Brakensiek 2002; Hager and Noble 1976; Hartman and Scrivener 1990; Holtby 1988; Johnston et al. 1990; Larkin and Slaney 1996; Quinn and Peterson 1996; Ward and Slaney 1988).

Additionally, studies have demonstrated that perturbation of spawning gravels by spawning salmonids loosens cemented (compacted) gravel areas used by spawning salmon (e.g., (Montgomery et al. 1996). The act of spawning also coarsens gravel in spawning reaches, removing fine material that blocks interstitial gravel flow and reduces the survival of incubating eggs in egg pockets of redds.

The added spawner density resulting from hatchery-origin fish spawning in the wild can have negative consequences, such as increased competition, and potential for redd superimposition. Although males compete for access to females, female spawners compete for spawning sites. Essington et al. (2000) found that aggression of both sexes increases with spawner density, and is most intense with conspecifics. However, females tended to act aggressively towards heterospecifics as well. In particular, when there is spatial overlap between natural-and hatchery-origin spawners, the potential exists for hatchery-derived fish to superimpose or destroy the eggs and embryos of ESA-listed species. Redd superimposition has been shown to be a cause of egg loss in pink salmon and other species (e.g., Fukushima et al. 1998).

1.2.3. Adult Collection Facilities

The analysis also considers the effects from encounters with natural-origin fish that are incidental to broodstock collection. Here, NMFS analyzes effects from sorting, holding, and handling natural-origin fish in the course of broodstock collection. Some programs collect their broodstock from fish voluntarily entering the hatchery, typically into a ladder and holding pond, while others sort through the run at large, usually at a weir, ladder, or sampling facility. The more a hatchery program accesses the run at large for hatchery broodstock – that is, the more fish that are handled or delayed during migration – the greater the negative effect on natural- and hatchery-origin fish that are intended to spawn naturally and on ESA-listed species. The information NMFS uses for this analysis includes a description of the facilities, practices, and protocols for collecting broodstock, the environmental conditions under which broodstock collection is conducted, and the encounter rate for ESA-listed fish.

NMFS also analyzes the effects of structures, either temporary or permanent, that are used to collect hatchery broodstock, and remove hatchery fish from the river or stream and prevent them from spawning naturally, on juvenile and adult fish from encounters with these structures. NMFS determines through the analysis, for example, whether the spatial structure, productivity, or abundance of a natural population is affected when fish encounter a structure used for broodstock collection, usually a weir or ladder.

1.3. Factor 3. Hatchery fish and the progeny of naturally spawning hatchery fish in juvenile rearing areas, the migratory corridor, estuary, and ocean (Revised June 1, 2020)

NMFS also analyzes the potential for competition, predation, and disease when the progeny of naturally spawning hatchery fish and hatchery releases share juvenile rearing areas.

1.3.1. Competition

Competition and a corresponding reduction in productivity and survival may result from direct or indirect interactions. Direct interactions occur when hatchery-origin fish interfere with the accessibility to limited resources by natural-origin fish, and indirect interactions occur when the utilization of a limited resource by hatchery fish reduces the amount available for fish from the natural population (Rensel et al. 1984). Natural-origin fish may be competitively displaced by hatchery fish early in life, especially when hatchery fish are more numerous, are of equal or greater size, take up residency before natural-origin fry emerge from redds, and residualize. Hatchery fish might alter natural-origin salmon behavioral patterns and habitat use, making natural-origin fish more susceptible to predators (Hillman and Mullan 1989; Steward and Bjornn 1990). Hatchery-origin fish may also alter natural-origin salmonid migratory responses or movement patterns, leading to a decrease in foraging success by the natural-origin fish (Hillman and Mullan 1989; Steward and Bjornn 1990). Actual impacts on natural-origin fish would thus depend on the degree of dietary overlap, food availability, size-related differences in prey selection, foraging tactics, and differences in microhabitat use (Steward and Bjornn 1990).

Several studies suggest that salmonid species and migratory forms that spend longer periods of time in lotic habitats (e.g., coho salmon and steelhead) are more aggressive than those that outmigrate at an earlier stage Hutchison and Iwata (1997). The three least aggressive species generally outmigrate to marine (chum salmon) or lake (kokanee and sockeye salmon) habitats as post-emergent fry. The remaining (i.e., more aggressive) species all spend one year or more in stream habitats before outmigrating. Similarly, Hoar (1951) did not observe aggression or territoriality in fry of early migrants (chum and pink salmon), in contrast to fry of a later migrating species (coho salmon) which displayed high levels of each. Hoar (1954) rarely observed aggression in sockeye salmon fry, and observed considerably less aggression in sockeye than coho salmon smolts. Taylor (1990) found that Chinook salmon populations that outmigrate as fry are less aggressive than those that outmigrate as parr, which are less aggressive than those that outmigrate as yearlings.

Although *intraspecific* interactions are expected to be more frequent/intense than *interspecific* interactions (e.g., Hartman 1965; Tatara and Berejikian 2012), this apparent relationship between aggression and stream residence appears to apply to *interspecific* interactions as well. For example, juvenile coho salmon are known to be highly aggressive toward other species (e.g., Stein et al. 1972; Taylor 1991). Taylor (1991) found that coho salmon were much more aggressive toward size-matched *ocean*-type Chinook salmon (early outmigrants), but only moderately more aggressive toward size-matched *stream*-type Chinook salmon (later outmigrants). Similarly, the findings of Hasegawa et al. (2014) indicate that masu salmon (*O. masou*) , which spend 1 to 2 years in streams before outmigrating, dominate and outcompete the early-migrating chum salmon.

A few exceptions to this general stream residence-aggression pattern have been observed (e.g., Hasegawa et al. 2004; Lahti et al. 2001; Young 2003; Young 2004), but all the species and migratory forms evaluated in these studies spend one year or more in stream habitat prior to outmigrating. Other than the Taylor (1991) and Hasegawa et al. (2014) papers noted above, we are not aware of any other studies that have looked specifically at interspecific interactions between early-outmigrating species (e.g., sockeye, chum, and pink salmon) and those that rear longer in streams.

En masse hatchery salmon and steelhead smolt releases may cause displacement of rearing natural-origin juvenile salmonids from occupied stream areas, leading to abandonment of advantageous feeding stations, or to premature out-migration by natural-origin juveniles. Pearsons et al. (1994) reported small-scale displacement of naturally produced juvenile rainbow trout from stream sections by hatchery steelhead. Small-scale displacements and agonistic interactions observed between hatchery steelhead and natural-origin juvenile trout were most likely a result of size differences and not something inherently different about hatchery fish.

A proportion of the smolts released from a hatchery may not migrate to the ocean but rather reside for a time near the release point. These non-migratory smolts (residuals) may compete for food and space with natural-origin juvenile salmonids of similar age (Bachman 1984; Tatara and Berejikian 2012). Although this behavior has been studied and observed, most frequently in the case of hatchery steelhead, residualism has been reported as a potential issue for hatchery coho and Chinook salmon as well (Parkinson et al. 2017). Adverse impacts of residual hatchery Chinook and coho salmon on natural-origin salmonids can occur, especially given that the number of smolts per release is generally higher; however, the issue of residualism for these species has not been as widely investigated compared to steelhead. Therefore, for all species, monitoring of natural stream areas near hatchery release points may be necessary to determine the potential effects of hatchery smolt residualism on natural-origin juvenile salmonids.

The risk of adverse competitive interactions between hatchery- and natural-origin fish can be minimized by:

- Releasing hatchery smolts that are physiologically ready to migrate. Hatchery fish released as smolts emigrate seaward soon after liberation, minimizing the potential for

competition with juvenile natural-origin fish in freshwater (California HSRG 2012; Steward and Bjornn 1990)
- Rearing hatchery fish to a size sufficient to ensure that smoltification occurs
- Releasing hatchery smolts in lower river areas, below areas used for stream-rearing by natural-origin juveniles
- Monitoring the incidence of non-migratory smolts (residuals) after release and adjusting rearing strategies, release location, and release timing if substantial competition with natural-origin juveniles is likely

Critical to analyzing competition risk is information on the quality and quantity of spawning and rearing habitat in the action area,[23] including the distribution of spawning and rearing habitat by quality and best estimates for spawning and rearing habitat capacity. Additional important information includes the abundance, distribution, and timing for naturally spawning hatchery fish and natural-origin fish; the timing of emergence; the distribution and estimated abundance for progeny from both hatchery and natural-origin natural spawners; the abundance, size, distribution, and timing for juvenile hatchery fish in the action area; and the size of hatchery fish relative to co-occurring natural-origin fish.

1.3.2. Predation

Another potential ecological effect of hatchery releases is predation. Salmon and steelhead are piscivorous and can prey on other salmon and steelhead. Predation, either direct (consumption by hatchery fish) or indirect (increases in predation by other predator species due to enhanced attraction), can result from hatchery fish released into the wild. Considered here is predation by hatchery-origin fish, the progeny of naturally spawning hatchery fish, and avian and other predators attracted to the area by an abundance of hatchery fish.

Hatchery fish originating from egg boxes and fish planted as non-migrant fry or fingerlings can prey upon fish from the local natural population during juvenile rearing. Hatchery fish released at a later stage, so they are more likely to migrate quickly to the ocean, can prey on fry and fingerlings that are encountered during the downstream migration. Some of these hatchery fish do not emigrate and instead take up residence in the stream where they can prey on stream-rearing juveniles over a more prolonged period, as discussed above. The progeny of naturally spawning hatchery fish also can prey on fish from a natural population and pose a threat.

Predation may be greatest when large numbers of hatchery smolts encounter newly emerged fry or fingerlings, or when hatchery fish are large relative to natural-origin fish (Rensel et al. 1984). Due to their location in the stream, size, and time of emergence, newly emerged salmonid fry are likely to be the most vulnerable to predation. Their vulnerability is believed to be greatest immediately upon emergence from the gravel and then their vulnerability decreases as they move into shallow, shoreline areas (USFWS 1994). Emigration out of important rearing areas and foraging inefficiency of newly released hatchery smolts may reduce the degree of predation on salmonid fry (USFWS 1994).

[23] "Action area," in ESA section 7 analysis documents, means all areas to be affected directly or indirectly by the action in which the effects of the action can be meaningfully detected and evaluated.

Some reports suggest that hatchery fish can prey on fish that are up to 1/2 their length (HSRG 2004; Pearsons and Fritts 1999), but other studies have concluded that salmonid predators prey on fish up to 1/3 their length (Beauchamp 1990; Cannamela 1992; CBFWA 1996; Daly et al. 2009; Hillman and Mullan 1989; Horner 1978). Hatchery fish may also be less efficient predators as compared to their natural-origin conspecifics, reducing the potential for predation impacts (Bachman 1984; Olla et al. 1998; Sosiak et al. 1979).

Size is an important determinant of how piscivorous hatchery-origin fish are. Keeley and Grant (2001) reviewed 93 reports detailing the relationship between size and piscivory in 17 species of stream-dwelling salmonids. *O. mykiss* and Pacific salmon were well represented in the reviewed reports. Although there is some variation between species, stream-dwelling salmonids become piscivorous at about 100 mm FL, and then piscivory rate increases with increasing size. For example:

- For 140 mm fish, 15% would be expected to have fish in their diet but would not be primarily piscivorous; 2% would be expected to be primarily piscivorous (> 60% fish in diet).
- For 200 mm fish, those figures go to 32% (fish in diet) and 11% (primarily piscivorous).

The implication for hatchery-origin fish is pretty clear: larger hatchery-origin fish present a greater predation risk because more of them eat fish, and more of them eat primarily fish.

There are several steps that hatchery programs can implement to reduce or avoid the threat of predation:

- Ensuring that a high proportion of the hatchery fish have physiologically achieved full smolt status. Juvenile salmon tend to migrate seaward rapidly when fully smolted, limiting the duration of interaction between hatchery- and natural-origin fish present within, and downstream of, release areas.
- Releasing hatchery smolts in lower river areas near river mouths and below upstream areas used for stream-rearing young-of-the-year naturally produced salmon fry, thereby reducing the likelihood for interaction between the hatchery and naturally produced fish.
- Operating hatchery programs to minimize the potential for residualism.

1.3.3. Disease

The release of hatchery fish and hatchery effluent into juvenile rearing areas can lead to transmission of pathogens, contact with chemicals or altering of environmental parameters (e.g., dissolved oxygen) that can result in disease outbreaks. Fish diseases can be subdivided into two main categories: infectious and non-infectious. Infectious diseases are those caused by pathogens such as viruses, bacteria, and parasites. Noninfectious diseases are those that cannot be transmitted between fish and are typically caused by genetic or environmental factors (e.g., low dissolved oxygen). Pathogens can also be categorized as exotic or endemic. For our purposes, exotic pathogens are those that have little to no history of occurrence within state boundaries. For example, *Oncorhynchus masou* virus (OMV) would be considered an exotic pathogen if identified anywhere in Washington state. Endemic pathogens are native to a state, but may not be present in all watersheds.

In natural fish populations, the risk of disease associated with hatchery programs may increase through a variety of mechanisms (Naish et al. 2008), including:

- Introduction of exotic pathogens
- Introduction of endemic pathogens to a new watershed
- Intentional release of infected fish or fish carcasses
- Continual pathogen reservoir
- Pathogen amplification

The transmission of pathogens between hatchery and natural fish can occur indirectly through hatchery water influent/effluent or directly via contact with infected fish. Within a hatchery, the likelihood of transmission leading to an epizootic (i.e., disease outbreak) is increased compared to the natural environment because hatchery fish are reared at higher densities and closer proximity than would naturally occur. During an epizootic, hatchery fish can shed relatively large amounts of pathogen into the hatchery effluent and ultimately, the environment, amplifying pathogen numbers. However, few, if any, examples of hatcheries contributing to an increase in disease in natural populations have been reported (Naish et al. 2008; Steward and Bjornn 1990). This lack of reporting is because both hatchery and natural-origin salmon and trout are susceptible to the same pathogens (Noakes et al. 2000), which are often endemic and ubiquitous (e.g., *Renibacterium salmoninarum,* the cause of Bacterial Kidney Disease).

Adherence to a number of state, federal, and tribal fish health policies limits the disease risks associated with hatchery programs (IHOT 1995; ODFW 2003; USFWS 2004; WWTIT and WDFW 2006). Specifically, the policies govern the transfer of fish, eggs, carcasses, and water to prevent the spread of exotic and endemic reportable pathogens. For all pathogens, both reportable and non-reportable, pathogen spread and amplification are minimized through regular monitoring (typically monthly) removing mortalities, and disinfecting all eggs. Vaccines may provide additional protection from certain pathogens when available (e.g., *Vibrio anguillarum*). If a pathogen is determined to be the cause of fish mortality, treatments (e.g., antibiotics) will be used to limit further pathogen transmission and amplification. Some pathogens, such as *infectious hematopoietic necrosis virus* (IHNV), have no known treatment. Thus, if an epizootic occurs for those pathogens, the only way to control pathogen amplification is to cull infected individuals or terminate all susceptible fish. In addition, current hatchery operations often rear hatchery fish on a timeline that mimics their natural life history, which limits the presence of fish susceptible to pathogen infection and prevents hatchery fish from becoming a pathogen reservoir when no natural fish hosts are present.

In addition to the state, federal, and tribal fish health policies, disease risks can be further minimized by preventing pathogens from entering the hatchery facility through the treatment of incoming water (e.g., by using ozone) or by leaving the hatchery through hatchery effluent (Naish et al. 2008). Although preventing the exposure of fish to any pathogens prior to their release into the natural environment may make the hatchery fish more susceptible to infection after release into the natural environment, reduced fish densities in the natural environment compared to hatcheries likely reduces the risk of fish encountering pathogens at infectious levels (Naish et al. 2008).

Treating the hatchery effluent would also minimize amplification, but would not reduce disease outbreaks within the hatchery itself caused by pathogens present in the incoming water supply. Another challenge with treating hatchery effluent is the lack of reliable, standardized guidelines for testing or a consistent practice of controlling pathogens in effluent (LaPatra 2003). However, hatchery facilities located near marine waters likely limit freshwater pathogen amplification downstream of the hatchery without human intervention because the pathogens are killed before transmission to fish when the effluent mixes with saltwater.

Noninfectious diseases are those that cannot be transmitted between fish and are typically caused by genetic or environmental factors (e.g., low dissolved oxygen). Hatchery facilities routinely use a variety of chemicals for treatment and sanitation purposes. Chlorine levels in the hatchery effluent, specifically, are monitored with a National Pollutant Discharge Elimination System (NPDES) permit administered by the Environmental Protection Agency. Other chemicals are discharged in accordance with manufacturer instructions. The NPDES permit also requires monitoring of settleable and unsettleable solids, temperature, and dissolved oxygen in the hatchery effluent on a regular basis to ensure compliance with environmental standards and to prevent fish mortality.

In contrast to infectious diseases, which typically are manifest by a limited number of life stages and over a protracted time period, non-infectious diseases caused by environmental factors typically affect all life stages of fish indiscriminately and over a relatively short period of time. One group of non-infectious diseases that are expected to occur rarely in current hatchery operations are those caused by nutritional deficiencies because of the vast literature available on successful rearing of salmon and trout in aquaculture.

1.3.4. Ecological Modeling

While competition, predation, and disease are important effects to consider, they are events which can rarely, if ever, be observed and directly calculated. However, these behaviors have been established to the point where NMFS can model these potential effects on the species based on known factors that lead to competition or predation occurring. In our Biological Opinions, we use the Predation, Competition, Decrement (PCD) Risk model version 3.2 based on Pearsons and Busack (2012). PCD Risk is an individual-based model that simulates the potential number of ESA-listed natural-origin juveniles lost to competition, predation, and disease from the release of hatchery-origin juveniles in the freshwater environment.

The PCD Risk model has undergone considerable modification since 2012 to increase supportability and reliability. Notably, the current version no longer operates in a Windows environment and no longer has a probabilistic mode. We also further refined the model by allowing for multiple hatchery release groups of the same species to be included in a single run.

There have also been a few recent modifications to the logic of the model. The first was the elimination of competition equivalents and replacement of the disease function with a delayed mortality parameter. The rationale behind this change was to make the model more realistic;

competition rarely directly results in death in the model because it takes many competitive interactions to suffer enough weight loss to kill a fish. Weight loss is how adverse competitive interactions are captured in the model. However, fish that are competed with and suffer some degree of weight loss are likely more vulnerable to mortality from other factors such as disease. Now, at the end of each run, the competitive impacts for each fish are assessed, and the fish has a probability of delayed mortality based on the competitive impacts. This function will be subject to refinement based on research. For now, the probability of delayed mortality is equal to the proportion of a fish's weight loss. For example, if a fish has lost 10% of its body weight due to competition and a 50% weight loss kills a fish, then it has a 20% probability of delayed death, (0.2 = 0.1/0.5).

The second logic change was to the habitat segregation parameter to make it size-independent or size-dependent based on hatchery species. Some species, such as coho salmon, are more aggressive competitors than other species, such as chum and sockeye salmon. To represent this difference in behavior more accurately in the model, for less aggressive species such as chum and sockeye salmon, hatchery fish segregation is random, whereas for more aggressive species, segregation occurs based on size, with the largest fish eliminated from the model preferentially.

1.3.5. Acclimation

One factor that can affect hatchery fish distribution and the potential to spatially overlap with natural-origin spawners, and thus the potential for genetic and ecological impacts, is the acclimation (the process of allowing fish to adjust to the environment in which they will be released) of hatchery juveniles before release. Acclimation of hatchery juveniles before release increases the probability that hatchery adults will home back to the release location, reducing their potential to stray into natural spawning areas.

Acclimating fish for a time also allows them to recover from the stress caused by the transportation of the fish to the release location and by handling. Dittman and Quinn (2008) provide an extensive literature review and introduction to homing of Pacific salmon. They note that, as early as the 19th century, marking studies had shown that salmonids would home to the stream, or even the specific reach, where they originated. The ability to home to their home or "natal" stream is thought to be due to odors to which the juvenile salmonids were exposed while living in the stream (olfactory imprinting) and migrating from it years earlier (Dittman and Quinn 2008; Keefer and Caudill 2014). Fisheries managers use this innate ability of salmon and steelhead to home to specific streams by using acclimation ponds to support the reintroduction of species into newly accessible habitat or into areas where they have been extirpated (Dunnigan 1999; Quinn 1997; YKFP 2008).

Dittman and Quinn (2008) reference numerous experiments that indicated that a critical period for olfactory imprinting is during the parr-smolt transformation, which is the period when the salmonids go through changes in physiology, morphology, and behavior in preparation for transitioning from fresh water to the ocean (Beckman et al. 2000; Hoar 1976). Salmon species with more complex life histories (e.g., sockeye salmon) may imprint at multiple times from emergence to early migration (Dittman et al. 2010). Imprinting to a particular location, be it the hatchery, or an acclimation pond, through the acclimation and release of hatchery salmon and steelhead is employed by fisheries managers with the goal that the hatchery fish released from these locations will return to that particular site and not stray into other areas (Bentzen et al. 2001; Fulton and

Pearson 1981; Hard and Heard 1999; Kostow 2009; Quinn 1997; Westley et al. 2013). However, this strategy may result in varying levels of success in regards to the proportion of the returning fish that stray outside of their natal stream. (e.g., (Clarke et al. 2011; Kenaston et al. 2001).

Increasing the likelihood that hatchery salmon and steelhead home to a particular location is one measure that can be taken to reduce the proportion of hatchery fish in the naturally spawning population. When the hatchery fish home to a particular location, those fish can be removed (e.g., through fisheries, use of a weir) or they can be isolated from primary spawning areas. Factors that can affect the success of acclimation as a tool to improve homing include:

- The timing of acclimation, such that a majority of the hatchery juveniles are going through the parr-smolt transformation during acclimation
- A water source unique enough to attract returning adults
- Whether or not the hatchery fish can access the stream reach where they were released
- Whether or not the water quantity and quality is such that returning hatchery fish will hold in that area before removal and/or their harvest in fisheries.

1.4. Factor 4. Research, monitoring, and evaluation that exists because of the hatchery program

NMFS also analyzes proposed RM&E for its effects on listed species and on designated critical habitat. Negative effects on the fish from RM&E are weighed against the value or benefit of new information, particularly information that tests key assumptions and that reduces uncertainty. RM&E actions can cause harmful changes in behavior and reduced survival; such actions include, but are not limited to:

- Observation during surveying
- Collecting and handling (purposeful or inadvertent)
- Sampling (e.g., the removal of scales and tissues)
- Tagging and fin-clipping, and observing the fish (in-water or from the bank)

NMFS also considers the overall effectiveness of the RM&E program. There are five factors that NMFS takes into account when it assesses the beneficial and negative effects of hatchery RM&E: (1) the status of the affected species and effects of the proposed RM&E on the species and on designated critical habitat, (2) critical uncertainties concerning effects on the species, (3) performance monitoring and determining the effectiveness of the hatchery program at achieving its goals and objectives, (4) identifying and quantifying collateral effects, and (5) tracking compliance of the hatchery program with the terms and conditions for implementing the program. After assessing the proposed hatchery RM&E, and before it makes any recommendations to the action agency(s) NMFS considers the benefit or usefulness of new or additional information, whether the desired information is available from another source, the effects on ESA-listed species, and cost.

1.4.1. Observing/Harassing

For some activities, listed fish would be observed in-water (e.g., by snorkel surveys, wading surveys, or observation from the banks). Direct observation is the least disruptive method for determining a species' presence/absence and estimating their relative numbers. Its effects are also generally the shortest-lived and least harmful of the research activities discussed in this section because a cautious observer can effectively obtain data while only slightly disrupting fishes' behavior.

Fish frightened by the turbulence and sound created by observers are likely to seek temporary refuge in deeper water, or behind/under rocks or vegetation. In extreme cases, some individuals may leave a particular pool or habitat type and then return when observers leave the area. These avoidance behaviors are expected to be in the range of normal predator and disturbance behaviors.

1.4.2. Capturing/handling

Any physical handling or psychological disturbance is known to be stressful to fish (Sharpe et al. 1998). Primary contributing factors to stress and death from handling are excessive doses of anesthetic, differences in water temperatures (between the river and holding vessel), dissolved oxygen conditions, the amount of time fish are held out of the water, and physical trauma. Stress increases rapidly if the water temperature exceeds 18ºC or dissolved oxygen is below saturation. Fish transferred to holding tanks can experience trauma if care is not taken in the transfer process, and fish can experience stress and injury from overcrowding in traps if the traps are not emptied regularly. Decreased survival can result from high stress levels, and may also increase the potential for vulnerability to subsequent challenges (Sharpe et al. 1998).

NMFS has developed general guidelines to reduce impacts when collecting listed adult and juvenile salmonids (NMFS 2000; NMFS 2008) that have been incorporated as terms and conditions into section 7 opinions and section 10 permits for research and enhancement. Additional monitoring principles for supplementation programs have been developed by the (Galbreath et al. 2008).

1.4.3. Fin clipping and tagging

Many studies have examined the effects of fin clips on fish growth, survival, and behavior. The results of these studies are somewhat varied, but fin clips do not generally alter fish growth (Brynildson and Brynildson 1967; Gjerde and Refstie 1988). Mortality among fin-clipped fish is variable, but can be as high as 80 percent (Nicola and Cordone 1973). In some cases, though, no significant difference in mortality was found between clipped and un-clipped fish (Gjerde and Refstie 1988; Vincent-Lang 1993). The mortality rate typically depends on which fin is clipped. Recovery rates are generally higher for adipose- and pelvic-fin-clipped fish than for those that have clipped pectoral, dorsal, or anal fins (Nicola and Cordone 1973), probably because the adipose and pelvic fins are not as important as other fins for movement or balance (McNeil and Crossman 1979). However, some work has shown that fish without an adipose fin may have a more difficult time swimming through turbulent water (Buckland-Nicks et al. 2011; Reimchen and Temple 2003).

In addition to fin clipping, PIT tags and CWTs are additional ways available to differentially mark fish. PIT tags are inserted into the body cavity of the fish just in front of the pelvic girdle. The tagging procedure requires that the fish be captured and extensively handled. Thus, tagging needs to take place where there is cold water of high quality, a carefully controlled environment for administering anesthesia, sanitary conditions, quality control checking, and a recovery tank.

Most studies have concluded that PIT tags generally have very little effect on growth, mortality, or behavior. Early studies of PIT tags showed no long-term effect on growth or survival (Prentice et al. 1987; Prentice and Park 1984; Rondorf and Miller 1994). In a study between the tailraces of Lower Granite and McNary Dams (225 km), Hockersmith et al. (2000) concluded that the performance of yearling Chinook salmon was not adversely affected by orally or surgically implanted sham radio tags or PIT tags. However, (Knudsen et al. 2009) found that, over several brood years, PIT tag induced smolt-adult mortality in Yakima River spring Chinook salmon averaged 10.3 percent and was at times as high as 33.3 percent.

Coded-wire tags are made of magnetized, stainless-steel wire and are injected into the nasal cartilage of a salmon and thus cause little direct tissue damage (Bergman et al. 1968; Bordner et al. 1990). The conditions under which CWTs should be inserted are similar to those required for PIT tags. A major advantage to using CWTs is that they have a negligible effect on the biological condition or response of tagged salmon (Vander Haegen et al. 2005); however, if the tag is placed too deeply in the snout of a fish, it may kill the fish, reduce its growth, or damage olfactory tissue (Fletcher et al. 1987; Peltz and Miller 1990). This latter effect can create problems for species like salmon because they use olfactory clues to guide their spawning migrations (Morrison and Zajac 1987).

Mortality from tagging is both acute (occurring during or soon after tagging) and delayed (occurring long after the fish have been released into the environment). Acute mortality is caused by trauma induced during capture, tagging, and release—it can be reduced by handling fish as gently as possible. Delayed mortality occurs if the tag or the tagging procedure harms the animal. Tags may cause wounds that do not heal properly, may make swimming more difficult, or may make tagged animals more vulnerable to predation (Howe and Hoyt 1982; Matthews and Reavis 1990; Moring 1990). Tagging may also reduce fish growth by increasing the energetic costs of swimming and maintaining balance.

1.4.4. Masking

Hatchery actions also must be assessed for risk caused by masking effects, defined as when hatchery fish included in the Proposed Action are not distinguishable from other fish. Masking undermines and confuses RM&E, and status and trends monitoring. Both adult and juvenile hatchery fish can have masking effects. When presented with a proposed hatchery action, NMFS analyzes the nature and level of uncertainties caused by masking, and whether and to what extent listed salmon and steelhead are at increased risk as a result of misidentification in status evaluations. The analysis also takes into account the role of the affected salmon and steelhead population(s) in recovery and whether unidentifiable hatchery fish compromise important RM&E.

1.5. Factor 5. Construction, operation, and maintenance, of facilities that exist because of the hatchery program

The construction/installation, operation, and maintenance of hatchery facilities can alter fish behavior and can injure or kill eggs, juveniles, and adults. These actions can also degrade habitat function and reduce or block access to spawning and rearing habitats altogether. Here, NMFS analyzes changes to: riparian habitat, channel morphology, habitat complexity, in-stream substrates, and water quantity and quality attributable to operation, maintenance, and construction activities. NMFS also confirms whether water diversions and fish passage facilities are constructed and operated consistent with NMFS criteria.

1.6. Factor 6. Fisheries that exist because of the hatchery program

There are two aspects of fisheries that are potentially relevant to NMFS' analysis:

1) Fisheries that would not exist but for the program that is the subject of the Proposed Action, and listed species are inadvertently and incidentally taken in those fisheries.
2) Fisheries that are used as a tool to prevent the hatchery fish associated with the HGMP, including hatchery fish included in an ESA-listed salmon ESU or steelhead DPS, from spawning naturally.

"Many hatchery programs are capable of producing more fish than are immediately useful in the conservation and recovery of an ESU and can play an important role in fulfilling trust and treaty obligations with regard to harvest of some Pacific salmon and steelhead populations. For ESUs listed as threatened, NMFS will, where appropriate, exercise its authority under section 4(d) of the ESA to allow the harvest of listed hatchery fish that are surplus to the conservation and recovery needs of the ESU, in accordance with approved harvest plans" (NMFS 2005). In any event, fisheries must be carefully evaluated and monitored based on the take, including catch and release effects, of ESA-listed species.

1.7. References

Allendorf, F. W., G. Luikart, and S. N. Aitken. 2013. Conservation and the genetics of populations. Second edition. Wiley-Blackwell, Oxford, U.K.

Anderson, J. H., P. L. Faulds, W. I. Atlas, and T. P. Quinn. 2012. Reproductive success of captively bred and naturally spawned Chinook salmon colonizing newly accessible habitat. Evolutionary Applications 6(2):165-179.

Anderson, J. H., K. I. Warheit, B. E. Craig, T. R. Seamons, and A. H. Haukenes. 2020. A review of hatchery reform science in Washington state: Final report to the Washingotn Fish and Wildlife Commission. WDFW, Olympia, Washington. 168p.

Appleby, A. 2020. Personal communication email from Andy Appleby to Craig Busack. Thoughts on pHOS/PNI standards. March 31, 2020. 2p.

Araki, H., W. R. Ardren, E. Olsen, B. Cooper, and M. S. Blouin. 2007. Reproductive success of captive-bred steelhead trout in the wild: Evaluation of three hatchery programs in the Hood River. Conservation Biology 21(1):181-190.

Araki, H., B. Cooper, and M. S. Blouin. 2009. Carry-over effect of captive breeding reduces reproductive fitness of wild-born descendants in the wild. Biology Letters 5(5):621-624.

Ayllon, F., J. L. Martinez, and E. Garcia-Vazquez. 2006. Loss of regional population structure in Atlantic salmon, *Salmo salar* L., following stocking. ICES Journal of Marine Science 63:1269-1273.

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113(1):1-32.

Bagliniere, J. L., and G. Maisse. 1985. Precocious maturation and smoltification in wild Atlantic salmon in the Armorican Massif, France. Aquaculture 45(1-4):249-263.

Baskett, M. L., and R. S. Waples. 2013. Evaluating alternative strategies for minimizing unintended fitness consequences of cultured individuals on wild populations. Conservation Biology 27(1):83-94.

Beauchamp, D. A. 1990. Seasonal and diet food habit of rainbow trout stocked as juveniles in Lake Washington. Transactions of the American Fisheries Society 119:475-485.

Beckman, B. R., and coauthors. 2000. Physiological status of naturally reared juvenile spring Chinook salmon in the Yakima River: Seasonal dynamics and changes associated with smolting. Transactions of the American Fisheries Society 129:727-753.

Bell, E. 2001. Survival, Growth and Movement of Juvenile Coho Salmon (*Oncorhynchus kisutch*) Over-wintering in Alcoves, Backwaters, and Main Channel Pools in Prairie Creek, California. September, 2001. A Thesis presented to the faculty of Humboldt State University. 85p.

Bentzen, P., J. B. Olsen, J. E. McLean, T. R. Seamons, and T. P. Quinn. 2001. Kinship analysis of Pacific salmon: Insights into mating, homing, and timing of reproduction. Journal of Heredity 92:127-136.

Berejikian, B. A., and M. J. Ford. 2004. Review of Relative Fitness of Hatchery and Natural Salmon. December 2004. U.S. Dept. Commer., NOAA Technical Memorandum NMFS-NWFSC-61. 43p.

Berejikian, B. A., D. M. Van Doornik, J. A. Scheurer, and R. Bush. 2009. Reproductive behavior and relative reproductive success of natural- and hatchery-origin Hood Canal summer chum salmon (*Oncorhynchus keta*). Canadian Journal of Fisheries and Aquatic Sciences 66:781-789.

Bergman, P. K., K. B. Jefferts, H. F. Fiscus, and R. C. Hager. 1968. A preliminary evaluation of an implanted, coded wire fish tag. Fisheries Research Papers, Washington Department of Fisheries 3(1):63-84.

Bernier, N. J., D. D. Heath, D. J. Randall, and G. K. Iwama. 1993. Repeat sexual maturation of precocious male Chinook salmon *(Oncorhynchus tshawytscha*) transferred to seawater. Canadian Journal of Zoology 71(4):683-688.

Berntson, E. A., R. W. Carmichael, M. W. Flesher, E. J. Ward, and P. Moran. 2011. Diminished reproductive success of steelhead from a hatchery supplementation program (Little Sheep Creek, Imnaha Basin, Oregon). Transactions of the American Fisheries Society 140:685-698.

Bilton, T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Canadian Journal of Fisheries and Aquatic Sciences 39(3):426-447.

Blankenship, S. M., M. P. Small, J. Bumgarner, M. Schuck, and G. Mendel. 2007. Genetic relationships among Tucannon, Touchet, and Walla Walla river summer steelhead (*Oncorhynchus mykiss*) receiving mitigation hatchery fish from Lyons Ferry Hatchery. WDFW, Olympia, Washington. 39p.

Bordner, C. E., and coauthors. 1990. Evaluation of marking techniques for juvenile and adult white sturgeons reared in captivity. American Fisheries Society Symposium 7:293-303.

Bradford, M. J., B. J. Pyper, and K. S. Shortreed. 2000. Biological responses of sockeye salmon to the fertilization of Chilko Lake, a large lake in the interior of British Columbia. North American Journal of Fisheries Management 20:661-671.

Brakensiek, K. E. 2002. Abundance and Survival Rates of Juvenile Coho Salmon (*Oncorhynchus kisutch*) in Prairie Creek, Redwood National Park. January 7, 2002. MS Thesis. Humboldt State University, Arcata, California. 119p.

Brynildson, O. M., and C. L. Brynildson. 1967. The effect of pectoral and ventral fin removal on survival and growth of wild brown trout in a Wisconsin stream. Transactions of the American Fisheries Society 96(3):353-355.

Buckland-Nicks, J. A., M. Gillis, and T. E. Reimchen. 2011. Neural network detected in a presumed vestigial trait: ultrastructure of the salmonid adipose fin. Proceedings of the Royal Society B: Biological Sciences 297:553-563.

Busack, C. 2007. The impact of repeat spawning of males on effective number of breeders in hatchery operations. Aquaculture 270:523-528.

Busack, C. 2015. Extending the Ford model to three or more populations. August 31, 2015. Sustainable Fisheries Division, West Coast Region, National Marine Fisheries Service. 5p.

Busack, C., and K. P. Currens. 1995. Genetic risks and hazards in hatchery operations: Fundamental concepts and issues. AFS Symposium 15:71-80.

Busack, C., and C. M. Knudsen. 2007. Using factorial mating designs to increase the effective number of breeders in fish hatcheries. Aquaculture 273:24-32.

California HSRG. 2012. California Hatchery Review Report. Prepared for the U.S. Fish and Wildlife Service and Pacific States Marine Fisheries Commission. June 2012. 110p.

Cannamela, D. A. 1992. Potential Impacts of Releases of Hatchery Steelhead Trout "Smolts" on Wild and Natural Juvenile Chinook and Sockeye Salmon, Appendix A. A White Paper. March 1992. Idaho Department of Fish and Game, Boise, Idaho. 26p.

Carlson, S. M., and W. H. Satterthwaite. 2011. Weakened portfolio effect in a collapsed salmon population complex. Canadian Journal of Fisheries and Aquatic Sciences 68(Watershed Resource Inventory Area 9 Steering Committee):1579-1589.

CBFWA. 1996. Draft Programmatic Environmental Impact Statement. Impacts of Artificial Salmon and Steelhead Production Strategies in the Columbia River Basin. December 10, 1996. Prepared by the Columbia Basin Fish and Wildlife Authority, Portland, Oregon. 475p.

Christie, M. R., M. J. Ford, and M. S. Blouin. 2014a. On the reproductive successs of early-generation hatchery fish in the wild. Evolutionary Applications 7:883-896.

Christie, M. R., R. A. French, M. L. Marine, and M. S. Blouin. 2014b. How much does inbreeding contribute to the reduced fitness of hatchery-born steelhead (*Oncorhynchus mykiss*) in the Wild? Journal of Heredity 105(1):111–119.

Christie, M. R., M. L. Marine, R. A. French, and M. S. Blouin. 2011. Genetic adaptation to captivity can occur in a single generation. Proceedings of the National Academy of Sciences 109(1):238–242.

Clarke, L. R., M. W. Flesher, S. M. Warren, and R. W. Carmichael. 2011. Survival and straying of hatchery steelhead following forced or volitional release. North American Journal of Fisheries Management 31:116-123.

Crawford, B. A. 1979. The Origin and History of the Trout Brood Stocks of the Washington Department of Game. WDG, Olympia, Washington. 86p.

Crête-Lafrenière, A., L. K. Weir, and L. Bernatchez. 2012. Framing the Salmonidae family phylogenetic portrait: a more complete picture from increased taxon sampling. PLOS ONE 7(10):1-19.

Daly, E. A., R. D. Brodeur, and L. A. Weitkamp. 2009. Ontogenetic shifts in diets of juvenile and subadult coho and Chinook salmon in coastal marine waters: Important for marine survival? Transactions of the American Fisheries Society 138(6):1420-1438.

Dellefors, C., and U. Faremo. 1988. Early sexual maturation in males of wild sea trout, *Salmo trutta* L., inhibits smoltification. Journal of Fish Biology 33(5):741-749.

DFO. 2005. Canada's policy for conservation of wild Pacific salmon. Fisheries and Oceans, Canada. 49p. .

Dittman, A. H., and coauthors. 2010. Homing and spawning site selection by supplemented hatchery- and natural-origin Yakima River spring Chinook salmon. Transactions of the American Fisheries Society 139(4):1014-1028.

Dittman, A. H., and T. P. Quinn. 2008. Assessment of the Effects of the Yakima Basin Storage Study on Columbia River Fish Proximate to the Proposed Intake Locations. A component of Yakima River Basin Water Storage Feasibility Study, Washington. Technical Series No. TS-YSS-13. U.S. Department of the Interior, Denver, Colorado. 179p.

Duchesne, P., and L. Bernatchez. 2002. An analytical investigation of the dynamics of inbreeding in multi-generation supportive breeding. Conservation Genetics 3:47-60.

Dunnigan, J. L. 1999. Feasibility and Risks of Coho Reintroduction to Mid-Columbia Tributaries: 1999 Annual Report. Project number 1996-040-00. BPA, Portland, Oregon. 61p.

Edmands, S. 2007. Between a rock and a hard place: Evaluating the relative risks of inbreeding and outbreeding for conservation and management. Molecular Ecology 16:463-475.

Eldridge, W. H., J. M. Myers, and K. A. Naish. 2009. Long-term changes in the fine-scale population structure of coho salmon populations (*Oncorhynchus kisutch*) subject to extensive supportive breeding. Heredity 103:299-309.

Essington, T. E., T. P. Quinn, and V. E. Ewert. 2000. Intra- and inter-specific competition and the reproductive success of sympatric Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences 57:205-213.

Evans, M. L., J. J. Hard, A. N. Black, N. M. Sard, and K. G. O'Malley. 2019. A quantitative genetic analysis of life-history traits and lifetime reproductive success in reintroduced Chinook salmon. Conservation Genetics 20(4):781-799.

Falconer, D. S., and T. F. C. MacKay. 1996. Introduction to Quantitative Genetics, 4th edition. Pearson Education Ltd., Essex, U.K. 464p.

Falcy, M. 2019. Estimating the weighted proportion of hatchery-origin spawners, $pHOS_W$. ODFW Information Reports 2019-08. Corvallis, Oregon. 6p.

Fisch, K. M., C. C. Kozfkay, J. A. Ivy, O. A. Ryder, and R. S. Waples. 2015. Fish hatchery genetic management techniques: integrating theory with implementation. North American Journal of Aquaculture 77(3):343-357.

Fiumera, A. C., B. A. Porter, G. Looney, M. A. Asmussen, and J. C. Avise. 2004. Maximizing offspring production while maintaining genetic diversity in supplemental breeding programs of highly fecund managed species. Conservation Biology 18(1):94-101.

Fleming, I. A. 1996. Reproductive strategies of Atlantic salmon: Ecology and evolution. Reviews in Fish Biology and Fisheries 6:379-416.

Fletcher, D. H., F. Haw, and P. K. Bergman. 1987. Retention of coded-wire tags implanted into cheek musculature of largemouth bass. North American Journal of Fisheries Management 7:436-439.

Ford, M., A. Murdoch, and S. Howard. 2012. Early male maturity explains a negative correlation in reproductive success between hatchery-spawned salmon and their naturally spawning progeny. Conservation Letters 5:450-458.

Ford, M., T. N. Pearsons, and A. Murdoch. 2015. The spawning success of early maturing resident hatchery Chinook salmon in a natural river system. Transactions of the American Fisheries Society 144(3):539-548.

Ford, M. J. 2002. Selection in captivity during supportive breeding may reduce fitness in the wild. Conservation Biology 16(3):815-825.

Ford, M. J., and coauthors. 2011. Status Review Update for Pacific Salmon and Steelhead Listed Under the Endangered Species Act: Pacific Northwest. November 2011. U.S. Dept. Commer., NOAA Tech. Memo., NMFS-NWFSC-113. 307p.

Ford, M. J., and coauthors. 2006. Changes in run timing and natural smolt production in a naturally spawning coho salmon (*Oncorhynchus kisutch*) population after 60 years of intensive hatchery supplementation. Canadian Journal of Fisheries and Aquatic Sciences 63(10):2343-2355.

Ford, M. J., A. R. Murdoch, M. S. Hughes, T. R. Seamons, and E. S. LaHood. 2016. Broodstock history strongly influences natural spawning success in hatchery steelhead (*Oncorhynchus mykiss*). PLoS ONE 11(10):1-20.

Ford, M. J., K. S. Williamson, A. R. Murdoch, and T. W. Maitland. 2009. Monitoring the reproductive success of naturally spawning hatchery and natural spring Chinook salmon in the Wenatchee River. May 2009. 84p.

Frankham, R. 2008. Genetic adaptation to captivity in species conservation programs. Molecular Ecology 17:325-333.

Frankham, R., J. D. Ballou, and D. A. Briscoe. 2010. Introduction to conservation genetics, 2nd edition. Cambridge University Press, Cambridge, U.K.

Frankham, R., C. J. A. Bradshaw, and B. W. Brook. 2014. Genetics in conservation management: revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. Biological Conservation 170:56-63.

Franklin, I. R. 1980. Evolutionary change in small populations. Pages 135-140 *in* M. E. Soule, and B. A. Wilcox, editors. Conservation Biology: An Evolutionary-Ecological Perspective. Sinauer Associates, Sunderland, Massachusetts.

Freedman, A. H., K. E. Lohmueller, and R. K. Wayne. 2016. Evolutionary history, selective sweeps, and deleterious variation in the dog. Annual Review of Ecology, Evolution, and Systematics 47:73–96.

Fukushima, M., T. J. Quinn, and W. W. Smoker. 1998. Estimation of eggs lost from superimposed pink salmon (*Oncorhynchus gorbuscha*) redds. Canadian Journal of Fisheries and Aquatic Sciences 55:618-625.

Fulton, L. A., and R. E. Pearson. 1981. Transplantation and Homing Experiments on salmon, *Oncorhynchus* spp., and steelhead trout, *Salmo gairdneri*, in the Columbia River System: Fish of the 1939-44 broods. July 1981. NOAA Technical Memorandum NMFS F/NWC-12. 109p.

Galbreath, P. F., and coauthors. 2008. Recommendations for Broad Scale Monitoring to Evaluate the Effects of Hatchery Supplementation on the Fitness of Natural Salmon and Steelhead Populations. October 9, 2008. Final report of the Ad Hoc Supplementation Monitoring and Evaluation Workgroup (AHSWG). 87p.

Gharrett, A. J., and S. M. Shirley. 1985. A genetic examination of spawning methodology in a salmon hatchery. Aquaculture 47:245-256.

Gjerde, B., and T. Refstie. 1988. The effect of fin-clipping on growth rate, survival and sexual maturity of rainbow trout. Aquaculture 73(1-4):383-389.

Goodman, D. 2005. Selection equilibrium for hatchery and wild spawning fitness in integrated breeding programs. Canadian Journal of Fisheries and Aquatic Sciences 62(2):374-389.

Grant, W. S. 1997. Genetic Effects of Straying of Non-Native Hatchery Fish into Natural Populations. Proceedings of the workshop, June 1-2, 1995, Seattle, Washington. U.S. Department of Commerce, NOAA Tech. Memo., NMFS-NWFSC-30. 157p.

Gresh, T., J. Lichatowich, and P. Schoonmaker. 2000. An estimation of historic and current levels of salmon production in the Northeast Pacific Ecosystem: Evidence of a nutrient deficit in the freshwater systems of the Pacific Northwest Fisheries Habitat. Fisheries 25(1):15-21.

Hager, R. C., and R. E. Noble. 1976. Relation of size at release of hatchery-reared coho salmon to age, size, and sex composition of returning adults. The Progressive Fish-Culturist 38(3):144-147.

Hankin, D. G., J. Fitzgibbons, and Y. Chen. 2009. Unnatural random mating policies select for younger age at maturity in hatchery Chinook salmon (*Oncorhynchus tshawytscha*) populations. Canadian Journal of Fisheries and Aquatic Sciences 66:1505-1521.

Hard, J. J., and W. R. Heard. 1999. Analysis of straying variation in Alaskan hatchery Chinook salmon (*Oncorhynchus tshawytscha*) following transplantation. Canadian Journal of Fisheries and Aquatic Sciences 56:578- 589.

Hartman, G. F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal Fisheries Research Board of Canada 22(4):1035-1081.

Hartman, G. F., and J. C. Scrivener. 1990. Impacts of forestry practices on a coastal stream ecosystem, Carnation Creek, British Columbia. Canadian Bulletin of Fisheries and Aquatic Sciences 223. 80p.

Hasegawa, K., K. Morita, K. Ohkuma, T. Ohnuki, and Y. Okamoto. 2014. Effects of hatchery chum salmon fry on density-dependent intra- and interspecific competition between wild chum and masu salmon fry. Canadian Journal of Fisheries and Aquatic Sciences 71(10):1475–1482.

Hasegawa, K., T. Yamamoto, M. Murakami, and K. Maekawa. 2004. Comparison of competitive ability between native and introduced salmonids: evidence from pairwise contests. Ichthyological Research 51(3):191–194.

Hedrick, P. W., and A. Garcia-Dorado. 2016. Understanding inbreeding depression, purging, and genetic rescue. Trends in Ecology & Evolution 31:940-952.

Hess, M. A., and coauthors. 2012. Supportive breeding boosts natural population abundance with minimal negative impacts on fitness of a wild population of Chinook salmon. Molecular Ecology 21:5236-5250.

Hillman, T. W., and J. W. Mullan. 1989. Effect of Hatchery Releases on the Abundance of Wild Juvenile Salmonids. Chapter 8 *in* Summer and Winter Ecology of Juvenile Chinook salmon and steelhead trout in the Wenatchee River, Washington. Report to Chelan County PUD by D.W. Chapman Consultants, Inc. Boise, Idaho. 22p.

Hoar, W. S. 1951. The behaviour of chum, pink and coho salmon in relation to their seaward migration. Journal of the Fisheries Board of Canada 8(4):241-263.

Hoar, W. S. 1954. The behaviour of juvenile Pacific salmon, with particular reference to the sockeye (*Oncorhynchus nerka*). 11(1):69-77.

Hoar, W. S. 1976. Smolt transformation: Evolution, behavior and physiology. Journal of the Fisheries Research Board of Canada 33:1233-1252.

Hockersmith, E. E., W. D. Muir, S. G. Smith, and B. P. Sandford. 2000. Comparative performance of sham radio-tagged and PIT-tagged juvenile salmon. Report to U.S. Army Corps of Engineers, Contract W66Qkz91521282. 25p.

Holtby, L. B. 1988. Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 45:502-515.

Horner, N. J. 1978. Survival, Densities and Behavior of Salmonid Fry in Stream in Relation to Fish Predation. July 1978. A Master's Thesis, University of Idaho, Moscow, Idaho. 132p.

Howe, N. R., and P. R. Hoyt. 1982. Mortality of juvenile brown shrimp Penaeus aztecus associated with streamer tags. Transactions of the American Fisheries Society 111(3):317-325.

HSRG. 2004. Hatchery reform: Principles and Recommendations of the Hatchery Scientific Review Group. April 2004. Available at Long Live the Kings. 329p.

HSRG. 2009a. Columbia River Hatchery Reform Project Systemwide Report. Appendix A. White Paper No. 1. Predicted Fitness Effects of Interbreeding between Hatchery and Natural Populations of Pacific Salmon and Steelhead. 38p.

HSRG. 2009b. Columbia River Hatchery Reform System-Wide Report. February 2009. Prepared by Hatchery Scientific Review Group. 278p.

HSRG. 2012. Review of the Elwha River fish restoration plan and accompanying HGMPs. January 2012. Hatchery Science Review Group. Portland, Oregon. 194p.

HSRG. 2014. On the Science of Hatcheries: An updated perspective on the role of hatcheries in salmon and steelhead management in the Pacific Northwest. June 2014, (updated October 2014). 160p.

HSRG. 2015. Annual Report to Congress on the Science of Hatcheries, 2015. July 2015. 42p.

HSRG. 2017. Implementation of hatchery reform in the context of recovery planning using the AHA/ISIT tool. 64p.

Hutchison, M. J., and M. Iwata. 1997. A comparative analysis of aggression in migratory and non-migratory salmonids. Environmental Biology of Fishes 50(2):209-215.

ICTRT. 2007. Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs. Review draft. March 2007. 93p.

IDFG, NPT, and USFWS. 2020. Standard Operating Procedures for Fish Production Programs in the Clearwater River Basins. Final. 72p.

IHOT. 1995. Policies and procedures for Columbia basin anadromous salmonid hatcheries. Annual report 1994 to Bonneville Power Administration, project No. 199204300, (BPA Report DOE/BP-60629). Bonneville Power Administration.

Iwamoto, R. N., B. A. Alexander, and W. K. Hershberger. 1964. Genotypic and environmental effects on the incidence of sexual precocity in coho salmon (*Oncorhynchus kisutch*). Aquaculture 1-3(105-121).

Jamieson, I. G., and F. W. Allendorf. 2012. How does the 50/500 rule apply to MVPs? Trends in Ecology and Evolution 27(10):578-584.

Janowitz-Koch, I., and coauthors. 2018. Long-term evaluation of fitness and demographic effects of a Chinook salmon supplementation program. Evolutionary Applications 12(3):1-14.

Johnston, N. T., C. J. Perrin, P. A. Slaney, and B. R. Ward. 1990. Increased juvenile salmonid growth by whole-river fertilization. Canadian Journal of Fisheries and Aquatic Sciences 47:862-872.

Jonsson, B., N. Jonsson, and L. P. Hansen. 2003. Atlantic salmon straying from the River Imsa. Journal of Fish Biology 62:641-657.

Kalinowski, S., and M. Taper. 2005. Likelihood-based confidence intervals of relative fitness for a common experimental design. Canadian Journal of Fisheries and Aquatic Sciences 62:693-699.

Kato, F. 1991. Life histories of masu and amago salmon (*Oncorhynchus masou* and *Oncorhynchus rhodurus*). Pages 447–520 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver.

Keefer, M. L., and C. C. Caudill. 2012. A Review of Adult Salmon and Steelhead Straying with an Emphasis on Columbia River Populations. Technical Report 2012-6. 86p.

Keefer, M. L., and C. C. Caudill. 2014. Homing and straying by anadromous salmonids: a review of mechanisms and rates. Reviews in Fish Biology and Fisheries 24:333-368.

Keefer, M. L., C. C. Caudill, C. A. Peery, and C. T. Boggs. 2008. Non-direct homing behaviours by adult Chinook salmon in a large, multi-stock river system. Journal of Fish Biology 72:27-44.

Keeley, E. R., and J. W. A. Grant. 2001. Prey size of salmonid fishes in streams, lakes, and oceans. Canadian Journal of Fisheries and Aquatic Sciences 58(6):1122–1132.

Kenaston, K. R., R. B. Lindsay, and R. K. Schroeder. 2001. Effect of acclimation on the homing and survival of hatchery winter steelhead. North American Journal of Fisheries Management 21:765-773.

Kline, T. C., Jr., J. J. Goering, O. A. Mathisen, P. H. Poe, and P. L. Parker. 1990. Recycling of elements transported upstream by runs of Pacific salmon: I, δ15N and δ13C evidence in Sashin Creek, Southeastern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 47(1):136-144.

Knudsen, C. M., and coauthors. 2009. Effects of passive integrated transponder tags on smolt-to-adult recruit survival, growth, and behavior of hatchery spring Chinook salmon. North American Journal of Fisheries Management 29:658-669.

Kostow, K. 2009. Factors that contribute to the ecological risks of salmon and steelhead hatchery programs and some mitigating strategies. Reviews in Fish Biology and Fisheries 19:9-31.

Lacy, R. C. 1987. Loss of genetic variation from managed populations: Interacting effects of drift, mutation, immigration, selection, and population subdivision. Conservation Biology 1:143-158.

Lahti, K., A. Laurila, K. Enberg, and J. Piionen. 2001. Variation in aggressive behaviour and growth rate between populations and migratory forms in the brown trout, *Salmo trutta*. Animal Behaviour 62(5): 935-944.

Lande, R., and G. F. Barrowclough. 1987. Effective population size, genetic variation, and their use in population management. Pages 87-123 *in* M. E. Soule, editor. Viable Populations for Conservation. Cambridge University Press, Cambridge and New York.

LaPatra, S. E. 2003. The lack of scientific evidence to support the development of effluent limitations guidelines for aquatic animal pathogens Aquaculture 226:191–199.

Larkin, G. A., and P. A. Slaney. 1996. Trends in Marine-Derived Nutrient Sources to South Coastal British Columbia Streams: Impending Implications to Salmonid Production. Report No. 3. Watershed Restoration Program, Ministry of Environment, Lands and Parks and Ministry of Forests. 59p.

Larsen, D. A., and coauthors. 2004. Assessment of high rates of precocious male maturation in a Spring Chinook salmon supplementation hatchery program. Transactions of the American Fisheries Society 133:98–120.

Larsen, D. A., B. R. Beckman, and K. A. Cooper. 2010. Examining the conflict between smolting and precocious male maturation in spring (stream-type) Chinook salmon. Transactions of the American Fisheries Society 139(2):564-578.

Larson, G., and D. Q. Fuller. 2014. The evolution of animal domestication. Annual Review of Ecology, Evolution, and Systemmatics 45:115-136.

Leider, S. A., P. L. Hulett, J. J. Loch, and M. W. Chilcote. 1990. Electrophoretic comparison of the reproductive success of naturally spawning transplanted and wild steelhead trout through the returning adult stage. Aquaculture 88(3-4):239-252.

Lescak, E., K. Shedd, and T. Dann. 2019. Relative productivity of hatchery pink salmon in a natural stream. NPRB Project 1619.

Lynch, M., and M. O'Hely. 2001. Captive breeding and the genetic fitness of natural populations. Conservation Genetics 2:363-378.

Matthews, K. R., and R. H. Reavis. 1990. Underwater tagging and visual recapture as a technique for studying movement patterns of rockfish. American Fisheries Society Symposium 7:168-172.

McClelland, E. K., and K. A. Naish. 2007. What is the fitness outcome of crossing unrelated fish populations? A meta-analysis and an evaluation of future research directions. Conservation Genetics 8:397-416.

McElhany, P., and coauthors. 2003. Interim report on viability criteria for Willamette and Lower Columbia basin Pacific salmonids. March 31, 2003. Willamette/Lower Columbia Technical Recovery Team. 331p.

McElhany, P., M. H. Rucklelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-42. 174p.

McMillan, J. R., J. B. Dunham, G. H. Reeves, J. S. Mills, and C. E. Jordan. 2012. Individual condition and stream temperature influence early maturation of rainbow and steelhead trout, *Oncorhynchus mykiss*. Environmental Biology of Fishes 93(3):343-355.

McNeil, F. I., and E. J. Crossman. 1979. Fin clips in the evaluation of stocking programs for muskellunge *(Esox masquinongy)*. Transactions of the American Fisheries Society 108:335-343.

Montgomery, D. R., J. M. Buffington, N. P. Peterson, D. Schuett-Hames, and T. P. Quinn. 1996. Stream-bed scour, egg burial depths, and the influecne of salmonid spawning on bed surface mobility and embryo survival. Canadian Journal of Fisheries and Aquatic Sciences 53:1061-1070.

Moring, J. R. 1990. Marking and tagging intertidal fishes: Review of techniques. American Fisheries Society Symposium 7:109-116.

Morita, K., J. I. Tsuboi, and T. Nagasawa. 2009. Plasticity in probabilistic reaction norms for maturation in a salmonid fish. Biology Letters 5(5):628-631.

Morrison, J., and D. Zajac. 1987. Histologic effect of coded wire tagging in chum salmon. North American Journal of Fisheries Management 7:439-441.

Munakata, A., M. Amano, K. Ikuta, S. Kitamura, and K. Aida. 2001. The effects of testosterone on upstream migratory behavior in masu salmon, *Oncorhynchus masou*. General and Comparative Endocrinology 122(3):329-340.

Murota, T. 2003. The marine nutrient shadow: A global comparison of anadromous fishery and guano occurrence. Pages 17-31 *in* J.G. Stockner, ed. Nutrients in salmonid ecosystems. American Fisheries Society Symposium 34, Bethesda, Maryland. AFS Symposium 34:17-31.

Myers, R. A., J. A. Hutchings, and R. J. Gibson. 1986. Variation in male parr maturation within and among populations of Atlantic salmon, *Salmo salar*. Canadian Journal of Fisheries and Aquatic Sciences 43(6):1242-1248.

Naish, K. A., and coauthors. 2008. An evaluation of the effects of conservation and fishery enhancement hatcheries on wild populations of salmon. Advances in Marine Biology 53:61-194.

Nicola, S. J., and A. J. Cordone. 1973. Effects of fin removal on survival and growth of rainbow trout *(Salmo gairdneri)* in a natural environment. Transactions of the American Fisheries Society 102:753-759.

NMFS. 2000. Guidelines for electrofishing waters containing salmonids listed under the Endangered Species Act. NMFS, Northwest Region, Portland, Oregon.

NMFS. 2005. Policy on the consideration of hatchery-origin fish in Endangered Species Act listing determinations for Pacific salmon and steelhead. Pages 37204-37216 *in*. Federal Register, Volume 70 No. 123.

NMFS. 2008. Assessing Benefits and Risks & Recommendations for Operating Hatchery Programs consistent with Conservation and Sustainable Fisheries Mandates. Appendix C of Supplementary Comprehensive Analysis of the Federal Columbia River Power System and Mainstem Effects of the Upper Snake and other Tributary Actions. May 5, 2008. NMFS, Portland, Oregon.

NMFS. 2012. Effects of Hatchery Programs on Salmon and Steelhead Populations: Reference Document for NMFS ESA Hatchery Consultations. December 3, 2012. Northwest Region, Salmon Managment Division, Portland, Oregon. 50p.

Noakes, D. J., R. J. Beamish, and M. L. Kent. 2000. On the decline of Pacific salmon and speculative links to salmon farming in British Columbia. Aquaculture 183:363-386.

Nonaka, E., and coauthors. 2019. Scaling up the effects of inbreeding depression from individuals to metapopulations. Journal of Animal Ecology 88(8):1202-1214.

ODFW. 2003. Fish Health Management Policy, September 12, 2003. Oregon Department of Fish and Wildlife. 10p.

Olla, B. L., M. W. Davis, and C. H. Ryer. 1998. Understanding how the hatchery environment represses or promotes the development of behavioral survival skills. Bulletin of Marine Science 62(2):531-550.

Parkinson, E. A., C. J. Perrin, D. Ramos-Espinoza, and E. B. Taylor. 2017. Evidence for freshwater residualism in Coho Salmon, *Oncorhynchus kisutch*, from a watershed on the north coast of British Columbia. Canadian Field-Naturalist 130(4):336-343.

Pastor, S. M. 2004. An evaluation of fresh water recoveries of fish released from national fish hatcheries in the Columbia River basin, and observations of straying. AFS Symposium 44:87-98.

Pearsons, T. N., and C. A. Busack. 2012. PCD Risk 1: A tool for assessing and reducing ecological risks of hatchery operations in freshwater. Environmental Biology of Fishes 94:45-65.

Pearsons, T. N., and A. L. Fritts. 1999. Maximum size of Chinook salmon consumed by juvenile coho salmon. North American Journal of Fisheries Management 19(1):165-170.

Pearsons, T. N., and coauthors. 1994. Yakima River Species Interaction Studies. Annual report 1993. December 1994. Division of Fish and Wildlife, Project No. 1989-105, Bonneville Power Administration, Portland, Oregon. 264p.

Peltz, L., and J. Miller. 1990. Performance of half-length coded wire tags in a pink salmon hatchery marking program. American Fisheries Society Symposium 7:244-252.

Piorkowski, R. J. 1995. Ecological effects of spawning salmon on several south central Alaskan streams. Ph.D. dissertation, University of Alaska, Fairbanks, Alaska. 191p.

Prentice, E. F., T. A. Flagg, and S. McCutcheon. 1987. A Study to Determine the Biological Feasibility of a New Fish Tagging System, 1986-1987. December 1987. Contract DE-AI79-84BP11982, Project 83-319. NMFS, Seattle, Washington. 120p.

Prentice, E. F., and D. L. Park. 1984. A Study to Determine the Biological Feasibility of a New Fish Tagging System, 1983-1984. May 1984. Contract DEA179-83BP11982, Project 83-19. BPA, Portland, Oregon. 44p.

Quamme, D. L., and P. A. Slaney. 2003. The relationship between nutrient concentration and stream insect abundance. American Fisheries Society Symposium 34:163-175.

Quinn, T. P. 1997. Homing, Straying, and Colonization. Genetic Effects of Straying of Non-Native Fish Hatchery Fish into Natural Populations. NOAA Tech. Memo., NMFS-NWFSC-30. 13p.

Quinn, T. P., J. A. Peterson, V. F. Gallucci, W. K. Hershberger, and E. L. Brannon. 2002. Artificial selection and environmental change: Countervailing factors affecting the timing of spawning by coho and Chinook salmon. Transactions of the American Fisheries Society 131:591-598.

Quinn, T. P., and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (*Oncorhynchus kisutch*) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:1555-1564.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Reimchen, T. E., and N. F. Temple. 2003. Hydrodynamic and phylogenetic aspects of the adipose fin in fishes. Canadian Journal of Zoology 82:910-916.

Reisenbichler, R. R., and J. D. McIntyre. 1977. Genetic differences in growth and survival of juvenile hatchery and wild steelhead trout, *Salmo gairdneri*. Journal of the Fisheries Research Board of Canada 34:123-128.

Rensel, J., and coauthors. 1984. Evaluation of Potential Interaction Effects in the Planning and Selection of Salmonid Enhancement Projects. J. Rensel, and K. Fresh editors. Report prepared by the Species Interaction Work Group for the Enhancement Planning Team for implementation of the Salmon and Steelhead Conservation and Enhancement Act of 1980. WDFW, Olympia, Washington. 90p.

Ricker, W. E. 1959. Additional observations concerning residual sockeye and kokanee *(Oncorhynchus nerka*). Journal of the Fisheries Research Board of Canada 16(6):897-902.

RIST. 2009. Hatchery Reform Science. A review of some applications of science to hatchery reform issues. April 9, 2009. National Marine Fisheries Service, Northwest Fisheries Science Center, Seattle, Washington. 93p.

Rollinson, N., and coauthors. 2014. Risk Assessment of Inbreeding and Outbreeding Depression in a Captive-Breeding Program. Conservation Biology 28(2):529–540.

Rondorf, D. W., and W. H. Miller. 1994. Identification of the Spawning, Rearing, and Migratory Requirements of Fall Chinook Salmon in the Columbia River Basin. Annual report 1994. Project 9l-029, (Report DOE/BP-21708-4). Bonneville Power Administration, Portland, Oregon.

Rougemont, Q., and coauthors. 2020. Demographic history shaped geographical patterns of deleterious mutation load in a broadly distributed Pacific Salmon. bioRxiv.

Ryman, N., P. E. Jorde, and L. Laikre. 1995. Supportive breeding and variance effective population size. Conservation Biology 9(6):1619-1628.

Ryman, N., and L. Laikre. 1991. Effects of supportive breeding on the genetically effective population size. Conservation Biology 5(3):325-329.

Saisa, M., M.-L. Koljonen, and J. Tahtinen. 2003. Genetic changes in Atlantic salmon stocks since historical times and the effective population size of a long-term captive breeding programme. Conservation Genetics 4:613–627.

Sard, N. M., K. G. O'Malley, D. P. Jacobson, M. J. Hogansen, and M. A. Johnson. 2015. Factors influencing spawner success in a spring Chinook salmon (*Oncorhynchus tshawytscha*) reintroduction program. Canadian Journal of Fisheries and Aquatic Sciences 72:1390-1397.

Satterthwaite, W. H., and S. M. Carlson. 2015. Weakening portfolio effect strength in a hatchery-supplemented Chinook salmon population complex. Journal of Fisheries and Aquatic Sciences 72(2):1860–1875.

Schindler, D. E., and coauthors. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465(7298):609-612.

Schmidt, S. P., and E. W. House. 1979. Precocious sexual development in hatchery-reared and laboratory maintained steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 36:90-93.

Seidel, P. 1983. Spawning Guidelines for Washington Department of Fisheries Hatcheries. 18p.

Sharpe, C. S., D. A. Thompson, H. L. Blankenship, and C. B. Schreck. 1998. Effects of routine handling and tagging procedures on physiological stress responses in juvenile Chinook salmon. The Progressive Fish-Culturist 60(2):81-87.

Silverstein, J. T., and W. K. Hershberger. 1992. Precocious maturation in coho salmon (*Oncorhynchus kisutch*): Estimation of the additive genetic variance. Journal of Heredity 83:282-286.

Sosiak, A. J., R. G. Randall, and J. A. McKenzie. 1979. Feeding by hatchery-reared and wild Atlantic salmon (*Salmo salar*) parr in streams. Journal of the Fisheries Research Board of Canada 36:1408-1412.

Stein, R. A., P. E. Reimers, and J. D. Hall. 1972. Social interaction between juvenile coho (*Oncorhynchus kisutch*) and fall Chinook salmon (*O. tshawytscha*) in Sixes River, Oregon. Journal Fisheries Research Board of Canada 29(12):1737-1748.

Steward, C. R., and T. C. Bjornn. 1990. Supplementation of Salmon and Steelhead Stocks with Hatchery Fish: A Synthesis of Published Literature. Technical Report 90-1. Idaho Cooperative Fish and Wildlife Research Unit, Moscow, Idaho. 132p.

Tatara, C. P., and B. A. Berejikian. 2012. Mechanisms influencing competition between hatchery and wild juvenile anadromous Pacific salmonids in fresh water and their relative competitive abilities. Environmental Biology of Fishes 94(1):7-19.

Taylor, E. B. 1990. Variability in agonistic behaviour and salinity tolerance between and within two populations of juvenile Chinook salmon, *Oncorhynchus tshawytscha*, with contrasting life histories. Canadian Journal of Fisheries and Aquatic Sciences 47:2172-2180.

Taylor, E. B. 1991. Behavioral interaction and habitat use in juvenile Chinook, *Oncorhynchus tshawytscha*, and coho *O. kisutch*, salmon. Animal Behaviour 42:729-744.

Theriault, V., G. R. Moyer, L. S. Jackson, M. S. Blouin, and M. A. Banks. 2011. Reduced reproductive success of hatchery coho salmon in the wild: Insights into most likely mechanisms. Molecular Ecology 20:1860-1869.

Thrower, F. P., and J. J. Hard. 2009. Effects of a single event of close inbreeding on growth and survival in steelhead. Conservation Genetics 10(5):1299-1307.

Tufto, J. 2017. RE: Tufto and Hindar 2003. Emails January 18 and 20, 2017 from J. Tufto, Norwegian University of Science and Technology, Trondheim, Norway, to Craig Busack, NOAA.

Tufto, J., and K. Hindar. 2003. Effective size in management and conservation of subdivided populations. Journal of Theoretical Biology 222:273-281.

USFWS. 1994. Biological Assessments for Operation of USFWS Operated or funded hatcheries in the Columbia River Basin in 1995-1998. Submitted with cover letter dated August 2, 1994, from W.F. Shake, USFWS, to B. Brown, NMFS, Portland, Oregon.

USFWS. 2004. U.S. Fish & Wildlife Service handbook of aquatic animal health procedures and protocols.

Vander Haegen, G. E., H. L. Blankenship, A. Hoffman, and O. A. Thompson. 2005. The effects of adipose fin clipping and coded wire tagging on the survival and growth of spring Chinook salmon. North American Journal of Fisheries Management 25:1160-1170.

Vasemagi, A., R. Gross, T. Paaver, M. L. Koljonen, and J. Nilsson. 2005. Extensive immigration from compensatory hatchery releases into wild Atlantic salmon population in the Baltic sea: Spatio-temporal analysis over 18 years. Heredity 95(1):76-83.

Vincent-Lang, D. 1993. Relative Survival of Unmarked and Fin-Clipped Coho Salmon from Bear Lake, Alaska. The Progressive Fish-Culturist 55(3):141-148.

Vincent, R. E. 1960. Some influences of domestication upon three stocks of brook trout (*Salvelinus fontinalis* Mitchill). Transactions of the American Fisheries Society 89(1):35-52.

Wang, J., and N. Ryman. 2001. Genetic effects of multiple generations of supportive breeding. Conservation Biology 15(6):1615-1631.

Wang, S., J. J. Hard, and F. M. Utter. 2002. Salmonid inbreeding: A review. Reviews in Fish Biology and Fisheries 11:301-319.

Waples, R. S. 1999. Dispelling some myths about hatcheries. Fisheries 24(2):12-21.

Waples, R. S. 2004. Salmonid insights into effective population size. Pages 295-314 *in* A. P. Hendry, and S. C. Stearns, editors. Evolution illuminated: salmon and their relatives. Oxford University Press.

Waples, R. S., and C. Do. 1994. Genetic risk associated with supplementation of Pacific salmonids: Captive broodstock programs. Canadian Journal of Fisheries and Aquatic Sciences 51 (Supplement 1):310-329.

Waples, R. S., K. Hindar, S. Karlsson, and J. J. Hard. 2016. Evaluating the Ryman-Laikre effect for marine stock enhancement and aquaculture. Current Zoology 62(6):617–627.

Waples, R. S., K. A. Naish, and C. R. Primmer. 2020. Conservation and Management of Salmon in the Age of Genomics. 8(1):117-143.

Ward, B. R., and P. A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. Canadian Journal of Fisheries and Aquatic Sciences 45:1110-1122.

Waters, C. D., and coauthors. 2015. Effectiveness of managed gene flow in reducing genetic divergence associated with captive breeding. Evolutionary Applications 8(10):956-971.

WDFW. 2009. Fish and Wildlife Commission Policy Decision. Policy Title: Washington Department of Fish and Wildlife Hatchery and Fishery Reform. Policy Number: C-3619. Effective date: November 6, 2009. 3p.

Westley, P. A. H., T. P. Quinn, and A. H. Dittman. 2013. Rates of straying by hatchery-produced Pacific salmon (*Oncorhynchus* spp.) and steelhead (*Oncorhynchus mykiss*) differ among species, life history types, and populations. Canadian Journal of Fisheries and Aquatic Sciences 70:735-746.

Whitlock, M. C. 2000. Fixation of new alleles and the extinction of small populations: Drift, load, beneficial alleles, and sexual selection. Evolution 54(6):1855-1861.

Willi, Y., J. V. Buskirk, and A. A. Hoffmann. 2006. Limits to the adaptive potential of small populations. Annual Review of Ecology, Evolution, and Systematics 37:433-458.

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

Willoughby, J. R., and M. R. Christie. 2017. Captive ancestry upwardly biases estimates of relative reproductive success. Journal of Heredity 108(5):583–587.

Willoughby, J. R., and coauthors. 2015. The impacts of inbreeding, drift and selection on genetic diversity in captive breeding populations. Molecular Ecology 24(1):98-110.

Wipfli, M. S., J. P. Hudson, J. P. Caouette, and D. T. Chaloner. 2003. Marine subsidies in freshwater ecosystems: salmon carcasses increase growth rates of stream-resident salmonids. Transactions of the American Fisheries Society 132:371-381.

Withler, R. E. 1988. Genetic consequences of fertilizing chinook salmon (*Oncorhynchus tshawytscha*) eggs with pooled milt. Aquaculture 68:15-25.

Withler, R. E., M. J. Bradford, D. M. Willis, and C. Holt. 2018. Genetically based targets for enhanced contributions to Canadian Pacific Chinook salmon populations. DFO Canadian Science Advisory Secretariat Research Document 2018/019. xii+88p.

WWTIT, and WDFW. 2006. The Salmonid Disease Control Policy of the Fisheries Co-Managers of Washington State. Revised July 2006. 38p.

YKFP. 2008. Klickitat River Anadromous Fisheries Master Plan. Yakima/Klickitat Fisheries Project 1988-115-35. 188p.

Young, K. A. 2003. Evolution of fighting behavior under asymmetric competition: an experimental test with juvenile salmonids. Behavioral Ecology 14(1).

Young, K. A. 2004. Asymmetric competition, habitat selection, and niche overlap in juvenile salmonids. Ecology 85(1):134-149.