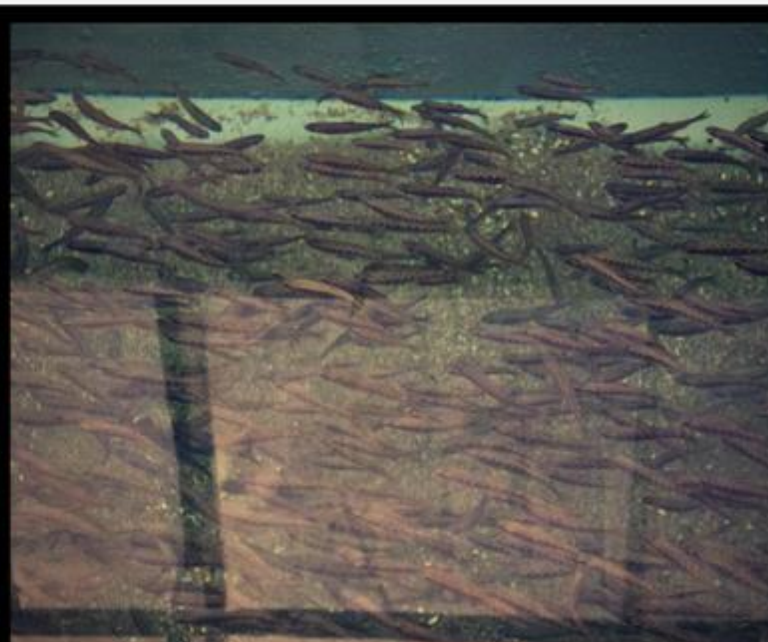
UPPER COLUMBIA SALMON RECOVERY BOARD

HATCHERY

BACKGROUND SUMMARY



Compiled by:
Greer Maier
greer.maier@ucsrb.org

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December 5, 2017

Dear Reader,

The Upper Columbia Salmon Recovery Board (UCSRB) coordinates implementation of *the Upper Columbia Spring Chinook and Steelhead Recovery Plan*. As part of this role, the UCSRB is compiling background data and information related to each management sector of salmon and steelhead – habitat, harvest, hatcheries and hydropower (referred to as “All-H”). These background summaries are not intended to be decision documents, but to provide a starting point for shared learning and discussions among partners working across the different management sectors.

The intention of this Hatchery Background Summary is to compile into one document information on:

- The purpose of Upper Columbia hatchery programs.
- The status of hatchery programs in the region.
- How hatchery programs have changed over the years.
- Current hatchery data, information gaps, and uncertainties.

The UCSRB is interested in engaging and collaborating with hatchery managers and partners on any challenges and possible solutions that could accelerate integrated recovery, and move the region towards the ultimate goal of delisting.

Sincerely,

Douglas County Commissioner Steve Jenkins
UCSRB Chair

UCSRB.ORG

11 Spokane Street, Suite 101, Wenatchee, WA 98801 | 509-662-4707 | info@ucsrb.org

Upper Columbia Salmon Recovery Board | Chelan, Douglas and Okanogan Counties, Colville Confederated Tribes, and the Yakama Nation

Contents

Acknowledgements

Integrated Recovery Technical Advisory Group

Casey Baldwin - Colville Confederated Tribes
Jennifer Johnson - Washington Governor's Salmon Recovery Office
Matt Cooper- U.S. Fish and Wildlife Service
Jeremy Cram - Washington Dept. of Fish and Wildlife
John Crandall - Confluence Aquatics
Peter Graf- Grant Public Utility District
Tom Kahler- Douglas Public Utility District
Andrew Murdoch - Washington Dept. of Fish and Wildlife
Keely Murdoch - Yakama Nation
Matt Cooper - U.S. Fish and Wildlife Service
Mike Tonseth - Washington Dept. of Fish and Wildlife
Justin Yeager- NOAA National Marine Fisheries Service
Catherine Willard- Chelan Public Utility District

Additional Reviewers

Greg Mackey- Douglas PUD
Todd Pearsons- Grant PUD
Alene Underwood- Chelan PUD
Steve Parker- Yakama Nation
Michael Humling- U.S. Fish and Wildlife Service
Greg Fraser- U.S. Fish and Wildlife Service
Bill Gale- U.S. Fish and Wildlife Service

Staff

This document was compiled and developed (analysis, writing, coordination) by Greer Maier with assistance from Mary Sutton Carruthers, Melody Kreimes, Jean Evans, James Fletcher Healey, and James White.

Data and Information

Data and information in this report was compiled from a variety of sources including peer-reviewed literature and reports. Much of the data on hatchery programs was compiled from research and monitoring funded and implemented by US Fish and Wildlife Service, Washington Department of Fish and Wildlife, Colville Confederated Tribes, Yakama Nation, Bonneville Power Administration, Bureau of Reclamation, Douglas PUD, Grant PUD, and Chelan PUD.

Key Points

The key points covered in more detail in this summary are:

- Hatchery supplementation has been used across the Upper Columbia to meet mitigation, harvest, and conservation goals since the early 1900's.
- Currently, CPUD, DPUD, GPUD, WDFW, USFWS, The Yakama Nation, and The Colville Tribes manage and operate 21 hatchery programs in the Upper Columbia, producing spring Chinook, summer/fall Chinook, coho, sockeye, and steelhead. Over half of these programs raise and release listed spring Chinook and steelhead in the Wenatchee, Methow, and Okanogan subbasins.
- Conservation hatchery programs play a role in helping depressed populations avoid extinction and depensation. They can also help supplement natural-origin runs and may play a role in recovering listed populations to a point at which they can be de-listed.
- Hatchery programs are supported by extensive research and monitoring programs that help managers adapt their programs to best meet their goals.
- Between 2010-2015 an average of 9.6 million hatchery-origin fish were released annually in the Upper Columbia. Of those releases, 2.3 million were ESA-listed spring Chinook and steelhead.
- From these releases, thousands of hatchery-origin adults return to the Upper Columbia each year. These returning fish contribute to fisheries and to total spawner escapement. In years of low natural-origin returns, hatchery-origin adults can buffer the natural population against short-term extinction risk.
- Hatchery-origin adults returning to the region are managed based on permit requirements and the goals of the program from which they originate. In some cases, to avoid undesirable genetic consequences, this management entails the intentional removal of hatchery-origin adults from the population to prevent them from spawning.
- There is a growing body of scientific studies that suggest both positive and negative hatchery effects on natural populations, specifically related to adult returns, productivity, reproductive success, and genetics, among others.
- There is still considerable uncertainty related to the influence of hatchery programs (both past and present) on the genetics and productivity of Upper Columbia populations. Hatchery managers and researchers continue to ask and answer questions that will help better identify and address risks to listed species.
- Total spawner abundance of salmon and steelhead in the Upper Columbia has increased over the past decade. Hatchery programs have played a role in that increase but it is less clear what role they have played in the trends seen in natural-origin returns and what role they may play in recovery.

Introduction

Hatcheries play a major role in replacing and recovering salmon and steelhead in the Columbia basin. Roughly 80% of the anadromous salmonids in the Columbia basin originate in hatcheries, and virtually all salmon and steelhead harvested in recreational fisheries are produced in hatcheries (BPA 2010; Figure 1). Most of the hatchery-origin fish in the Upper Columbia region are produced to compensate for fish lost due to the operations of hydroelectric dams and the loss of harvest opportunities as result of the dams. Since the first Endangered Species Act (ESA) listing of Columbia River salmon in 1991, hatchery programs have increasingly focused on supporting recovery of listed stocks. Hatchery-origin fish produced to aid in the conservation of listed species are often themselves listed under the ESA because they are the progeny of natural-origin fish and are genetically similar and share similar life history and ecological characteristics (NOAA 2005).

In 2016 over 50% of all salmon and steelhead released from hatcheries in the Columbia Basin were listed under the ESA. In contrast, 15 year ago less than 3% were listed since some species had not yet been listed and/or many programs were not focused on conservation (DART- Columbia River Data Access in Real Time 2016). The year 2006 represented a big upturn in the number and percent of ESA-listed hatchery fish released in the Columbia Basin after a large number of ESA listings in the Lower Columbia and Snake River basin. Hatchery production is widespread across the Columbia basin and use of hatcheries to supplement listed populations occurs in all listed Ecologically Significant Units (ESUs) and Distinct Population Segments (DPSs) (Figure 2).

Hatcheries in the Upper Columbia have been releasing fish since the late 1890's. Currently, all major subbasins of salmon and steelhead in the Upper Columbia (Wenatchee, Entiat, Methow, and Okanogan) are supplemented with hatchery-origin fish. Hatchery production occurs for all species and runs of salmon and steelhead in the Upper Columbia region (summer Chinook, spring Chinook, steelhead, coho, sockeye). Between 2010-2015 an average of 9.6 million hatchery-origin fish were released annually in the Upper Columbia. Of those releases 2.3 million were listed under the ESA (Columbia River DART 2016). The majority of returning adult coho, spring Chinook, and steelhead in the Upper Columbia are of hatchery-origin (SASI 2016). Because of the long history of hatchery releases in the region, and the extent of the practice today, it is important to consider the potential effect of hatchery programs on recovery of ESA-listed species.

Hatchery programs in the Upper Columbia fall under different artificial propagation strategies that address the different goals. **Conservation programs** primarily focus on increasing the natural production of fish in tributaries. Conservation programs generally use a high proportion of natural-origin fish for broodstock to maximize genetic similarities between hatchery- and natural-origin fish. A similar term often used is supplementation, which is a strategy by which hatcheries are used to produce fish from wild stocks that are introduced into the natural environment to become naturally spawning fish. In this way they are meant to "supplement" natural production. Some conservation programs have sister **safety-net programs** (sometimes called "stepping-stone programs") intended to function as reserve capacity to prevent extinction, preserve genetic integrity, and ensure adequate broodstock during years of low escapement. Safety-net programs in the Upper Columbia use first generation (F1) hatchery returns from their sister conservation program as broodstock so that the progeny are closely related to the conservation program stock. **Reintroduction programs** are intended to re-establish extirpated populations in areas where they have been extirpated. **Harvest programs** focus on increasing or restoring harvest opportunities.

Based on the goals of the program, hatchery programs are generally managed as either integrated or segregated from natural-origin fish. The HSRG (2009) defined an integrated hatchery program as one where 1) the naturally spawning and hatchery produced fish are considered components of a single population, and 2) the adaptation of the combined population is driven more by the conditions of the natural environment than the hatchery. Although these two traits are not common to all integrated programs they provide a basis for understanding the nature of programs that intentionally integrate the hatchery component of the populations with the natural component. Segregated harvest programs may be managed differently from integrated conservation programs. The intent of a segregated hatchery program is to maintain a genetically distinct hatchery stock, distinct from natural-origin fish. The segregated approach uses only hatchery-origin fish for broodstock and results in a population that is adapted to the hatchery environment and managed to avoid spawning between hatchery-origin and natural-origin fish (HSRG 2009). Harvest programs can be either segregated or integrated with the natural spawning population. **Segregated** harvest programs only use hatchery-origin fish in the broodstock while **integrated** harvest programs use some natural-origin fish in their broodstock. Conservation programs (supplementation, safety-net, and reintroduction) are generally integrated with the natural spawning population.

Since spring Chinook and steelhead were listed in the Upper Columbia in the late 1990's, hatchery science has informed managers as to how programs can maximize their benefits to listed species while minimizing their risk. This learning and adaptation continues today. This summary is intended to gather information about current hatchery programs and their goals, potential risks and benefits, and to summarize what actions have occurred that directly address risk factors or recovery actions identified in the *Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan* (Recovery Plan) and hatchery reviews that occurred after adoption of the recovery plan (e.g. HSRG and HRT). It is expected that programs will continue to evolve in the future and this summary does not conjecture what those changes may be, but rather summarizes current programs and provide the context of past hatchery management.

Hatchery programs across the Upper Columbia, and across the world, have been in a state of evolution since their inception. As more is learned about hatchery and wild populations, including development of new technologies and tools, and as goals for these programs change the programs are refined. Originally envisioned to produce fish for harvest, many programs have transitioned to the role of supporting the conservation of ESA listed species. Programs in the Upper Columbia have been guided by different laws, agreements, plans, and recommendations over the years. The *Recovery Plan*, CPUD and DPUD's Mid-Columbia HCPs, GPUD's Settlement Agreement, Biological Opinions, HSRG and HRT Reviews, ongoing research, and other processes have either mandated, or provided guidance and information on hatchery programs in the region.

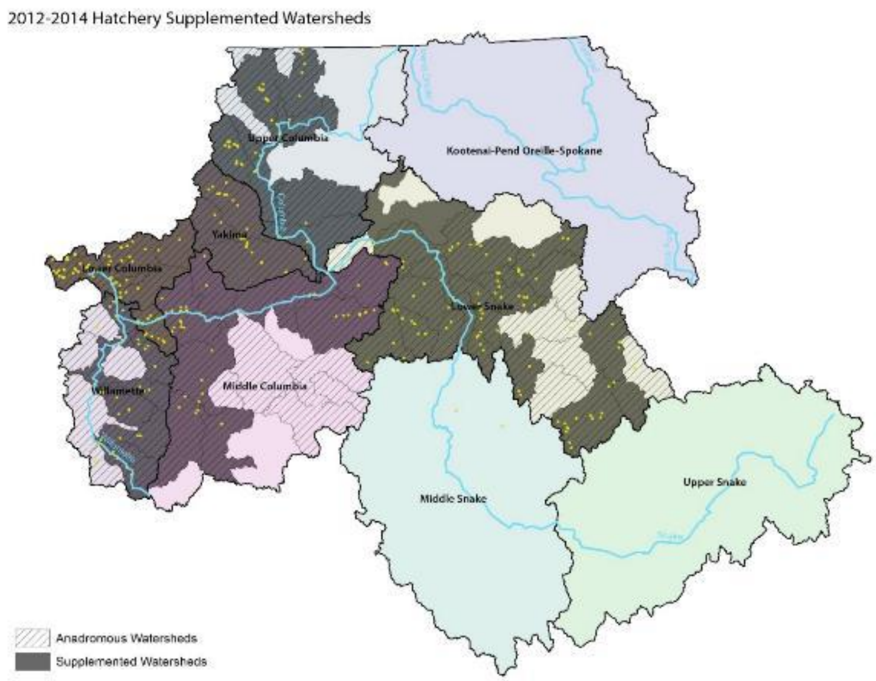


Figure 1. Map of Columbia River Basin showing hatchery supplementation in watersheds (based on data from 2012-2014).

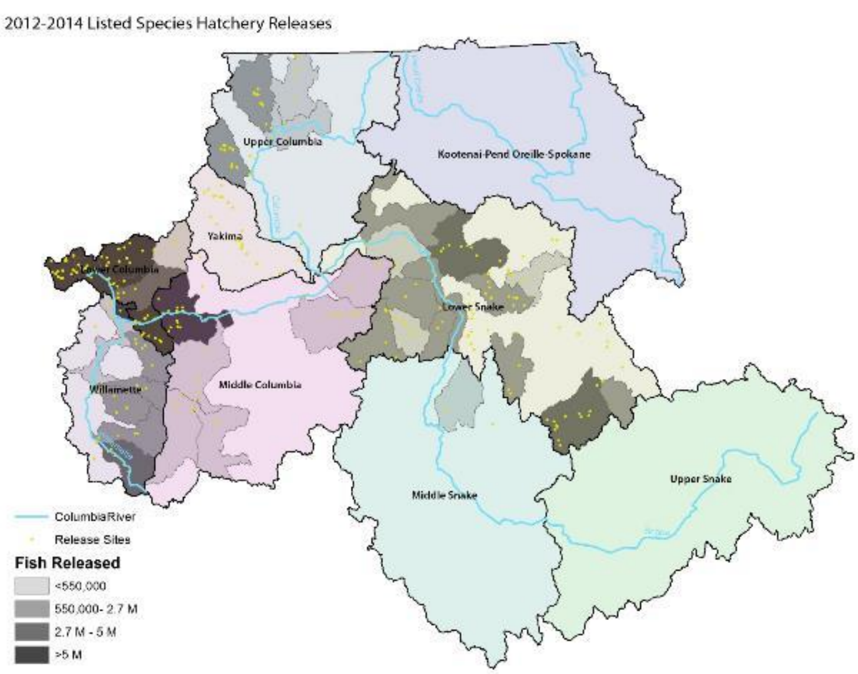


Figure 2. Map of Columbia River Basin showing hatchery supplementation of listed species in watersheds (based on data from 2012-2014).

This summary is largely based on outcomes of hatchery programs that are researched, monitored and reported on by local PUDs and the Fish and Wildlife Service. Hatchery programs and their associated infrastructure can influence the demographics, genetics, life history, and habitat of populations. Despite an extensive body of literature that has documented risks or failed to prove harm associated with hatchery-origin fish, the benefits associated with hatchery programs are not well understood. In several cases hatchery programs have helped to avoid extinction (e.g. Snake River sockeye) and can be a way to maintain minimum abundance in a population during a survival bottleneck (e.g. poor ocean conditions such as those seen in the 1990's). Most of the consequences of hatchery activities are difficult to assess because supplementation has been ongoing for so many years and has changed frequently over that time. In addition, it is difficult to find suitable reference populations within or outside the Upper Columbia with which to compare.

In addition to the uncertainties related to hatchery science, there is on-going debate about the appropriate use of hatcheries. Whether and/or how to properly use hatcheries in the recovery of ESA-listed species is the subject of technical debate and policy contention throughout the Columbia Basin. The great complexity of debated issues can be tied to fundamental decisions about balancing the perceived biological risks of hatcheries against varying levels of risk acceptance, the existence of alternatives to hatchery intervention, and the demand for fishery benefits. The relative importance of these factors may be weighted differently by entities having different technical perspectives, management objectives, and public policy responsibilities. Accordingly, it is difficult to objectively judge the merits of various management policies that attempt to strike their own balances between the risks and benefits of hatchery intervention in salmon recovery.

The *Hatchery Background Summary* is part one of a series of documents summarizing the major management programs and their reported outcomes related to management and recovery of listed Upper Columbia salmon and steelhead. These documents are intended to support "All-H" collaboration and can be used: a) to improve integrated decision-making; b) as a communication and outreach tool; c) to identify key uncertainties and gaps in knowledge and understanding; and d) to better track and understand progress toward integrated recovery. These documents are based on scientific information and data compiled from a variety of entities working within each sector. The first document in this series was the *UCSRB Habitat Report*, released in the Fall of 2014 and available at www.ucsrb.org. This summary provides background and information on hatchery programs in the region, with a focus on programs that release listed steelhead and spring Chinook.

The development of these "All-H" background summaries is part of a larger Integrated Recovery Approach that the UCSRB adopted in 2017. The first goal of this larger effort is to achieve recovery of Upper Columbia spring Chinook salmon and of Upper Columbia steelhead, which will require coordinated actions in all of the management sectors affecting salmon. The second goal is to engage and collaborate with managers in finding and implementing solutions to identified issues. The background summaries are an integral part of this process as a vehicle for compiling and synthesizing complex information that can be used to inform dialogue and progress toward achieving these overarching goals.

Species Status and Trends

NOAA periodically reviews the status of viable salmonid parameters (VSP) parameters to assess the viability of listed species. These parameters are defined in terms: *abundance, productivity (population growth rate), spatial structure, and diversity*. A viable evolutionary significant unit (ESU) is **naturally** self-sustaining, with a high probability of persistence over a 100-year period. Recent risk trends published by the NOAA indicate improving conditions for steelhead and stable conditions for spring Chinook in the Upper Columbia region; however, both species are still considered high risk for extinction (NOAA 2016).

Viability criteria for Upper Columbia populations were developed in the *Recovery Plan* based on recommendations by the Interior Columbia Technical Review Team (ICTRT). The ICTRT (2007) established four categories for populations based on *intrinsic potential*: basic, intermediate, large, and very large. The ICTRT then assigned species-specific minimum abundance and productivity thresholds associated with these four categories. In the Upper Columbia, the population-viability criteria for each population of spring Chinook salmon and steelhead are shown in Table 1. Populations within the ESU must meet each of these thresholds to achieve the de-listing criteria.

Table 1. Recovery thresholds (UCSRB 2007) and status of Upper Columbia spring Chinook salmon and steelhead based on NOAA's VSP parameters (see above).

ESU	Independent Population	Minimum Adult Abundance Threshold[a,b]	Current Adult Abundance[c]	Productivity Threshold	Current Productivity[c]	Spatial Structure/ Diversity (SS/D) Risk Threshold	Current SS/D Risk[c]
Upper Columbia Summer Steelhead DPS	Wenatchee	1,000	1,025	1.1	1.207	Moderate	High
	Entiat	500	146	1.2	0.434	Moderate	High
	Methow	1,000	651	1.1	0.371	Moderate	High
	Okanogan[d]	500	189	1.2	0.154	Moderate	High
Upper Columbia Spring Chinook ESU	Wenatchee	2,000	545	1.2	0.60	Moderate	High
	Entiat	500	166	1.4	0.94	Moderate	High
	Methow	2,000	379	1.2	0.46	Moderate	High
	Okanogan	Not defined (extinct)					

[a] *From UC Recovery Plan (UCSRB 2007)*

[b] *Viability criteria for Okanogan steelhead are for the U.S. portion of the population only.*

[c] *10-year geometric mean of natural-origin adult returns in each subbasin from NOAA (2016)*

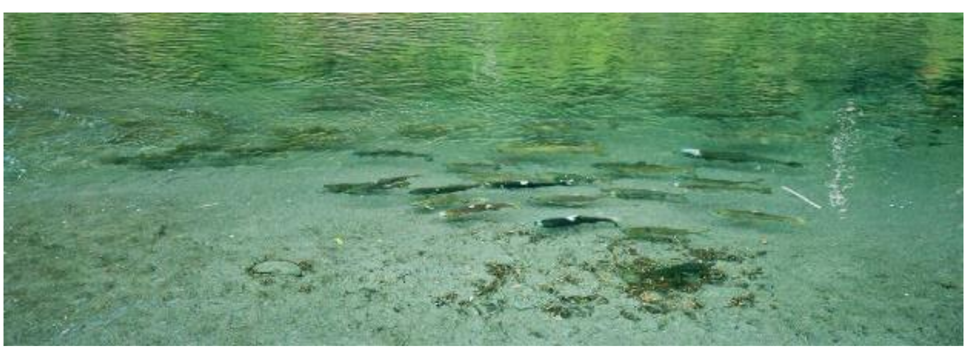
[d] *US portion of Okanogan*

Aside from the Wenatchee steelhead population, none of the populations met their abundance or productivity threshold, and none of the three spring Chinook or four steelhead populations met the spatial structure and diversity risk threshold. Therefore, the ESU and DPS remain at high risk for extinction. Recent observed abundances of returning natural-origin spring Chinook (average 1996-2016) are less than 25% of those estimated historically (1960-1980) (WDFW SaSI Database 2017). Comparing the geometric mean from 2011-2015 to 2006-2010, however, there has been a recent increase in natural-origin adult returns in the Wenatchee and Entiat populations (105% and 33%, respectively), and no change in the Methow population (WDFW SaSI Database 2015). The trend in total natural-origin adult returns since 1999 has been positive for the Entiat and Wenatchee populations and neutral for the Methow spring Chinook population (NOAA 2015).

Steelhead abundance shows overall trends similar to spring Chinook, but with increased five-year geometric mean abundance and increased total natural-origin adult returns in all four populations. Across the region, steelhead natural-origin adult returns increased 47% from 2011-2015 compared with returns from 2006-2010, with the Entiat population showing the greatest increase (135% increase) (WDFW SaSI Database 2015).

Despite recent upward trends in abundance, population growth rates for spring Chinook and steelhead remain well below replacement levels. Long-term trends indicate swings within the Upper Columbia populations between times of high productivity and low productivity. NOAA's updated metrics indicate improved productivity for Wenatchee and Entiat spring Chinook populations, and no change in the Methow population since the last review. Steelhead productivity has remained the same (Wenatchee, Methow, and Okanogan) or declined (Entiat) since the last review. Productivity is influenced by both freshwater tributary egg-to-emigrant survival, out-of-basin smolt-to-adult return (SAR), and adult pre-spawn mortality.

The *2016 NOAA Five-Year Status Review*, like the *2011 Review*, rated all Upper Columbia spring Chinook and steelhead populations at high risk based on diversity metrics. The main factor influencing the diversity of Upper Columbia populations is the chronically high number of hatchery spawners in natural spawning areas and the lack of genetic diversity among natural-origin spawners (NOAA 2016). Over the past ten years, Upper Columbia natural spawning areas for both spring Chinook and steelhead averaged 65% hatchery-origin spawners with a range between 45-80% during those years (WDFW SaSI Database 2017; NOAA SPS Database 2017).



Upper Wenatchee

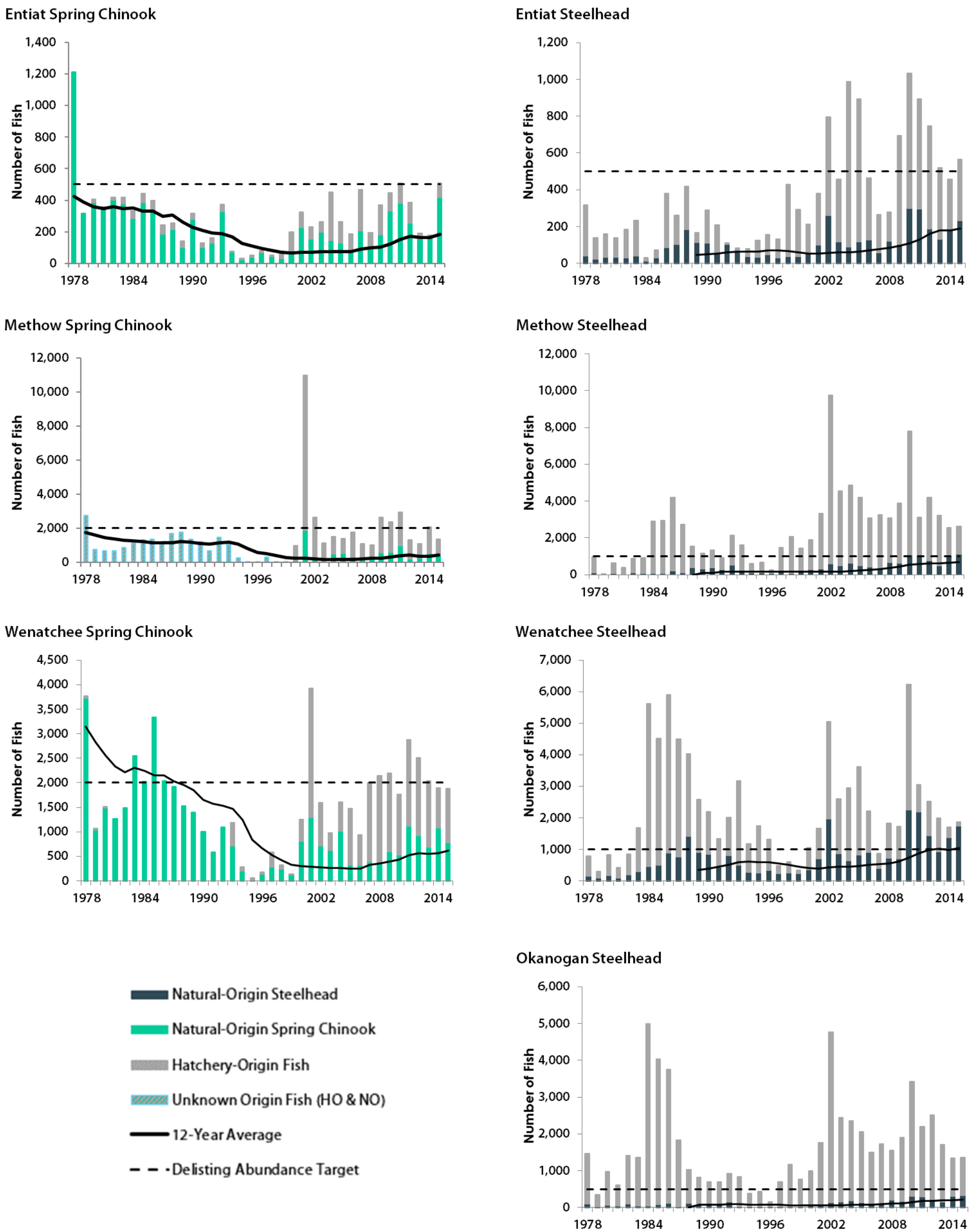


Figure 3. Returns of spring Chinook and steelhead to Upper Columbia tributaries with 12-year geometric means of abundance and delisting abundance targets indicated for each population. Source: NOAA Salmon Population Summary database and Washington Department of Fish and Wildlife Salmonid Stock Inventory database. 2016.

Upper Columbia Salmon and Steelhead Recovery Strategy- Hatcheries

The *Recovery Plan* incorporates actions from several different regional implementation strategies. Habitat actions were selected from other plans (e.g., *Northwest Power and Conservation Council Subbasin Plans*, watershed plans, *Wy-Kan-Ush-Mi Wa-Kish-Wit* [Spirit of the Salmon], The Tribal Fish Recovery Plan, and the U.S. Fish and Wildlife Services *Bull Trout Draft Recovery Plan*), modeling, public input, and the best available science. These actions are believed to represent a sound scientific approach based on available information and tools, address the range of known threats, and are feasible within the known constraints of the Upper Columbia.

The list of hatchery goals and objectives in the *Recovery Plan* summarized below are intended to reduce the threats associated with hatchery production while meeting other obligations (UCSRB 2007). The list was not intended to be all-inclusive. Also, included in the *Recovery Plan* are specific recommendations for actions related to hatchery programs. These actions were selected based on the best available science and from existing hatchery and genetic management plans (HGMPs), biological opinions, and the Habitat Conservation Plans (HCPs).

Progress has been made to address these objectives with the continuation of hatcheries to maintain populations and expand production to unused or underutilized areas while reducing or mitigating risks of those programs. Adult management including conservation fisheries have been implemented to reduce the proportion of hatchery-origin fish on spawning grounds, and most programs now use local broodstock or are in the process of transitioning to a local broodstock. Stray rates are being examined and hatchery practices (e.g. acclimation and rearing/release strategies) have reduced straying of hatchery-origin fish. Hatchery programs continue to evolve to best meet mitigation and conservation goals. This progress is more thoroughly discussed later in this summary.

The *Recovery Plan* recognizes the need to balance recovery objectives with legal obligations and mandates for hatchery programs under HCPs, Biological Opinions, GPUD settlement agreement,the Mitchell Act, federal government and tribal agreements, HGMPs, *U.S. v. Oregon*, and FERC project relicensing agreements. For example, recovery objectives are consistent with the *Biological Assessment and Management Plan: Mid-Columbia River Hatchery Program* (BAMP) (Bugert 1998) developed by parties negotiating the HCPs for Chelan and Douglas Public Utility Districts (PUDs). The Upper Columbia recovery objectives are also sensitive to The Mitchell Act, which calls for conservation of the fishery resources of the Columbia River; establishment, operation, and maintenance of one or more hatchery stations; and the conduct of necessary investigations, surveys, stream improvements, and stocking operations for these purposes. The objectives also consider agreements between tribes and federal agencies.

Upper Columbia Salmon and Steelhead Recovery Plan (UCSRB 2007)

Short and Long-Term Hatchery Objectives:

Short-Term (0-15 years)

- Continue to use artificial production to maintain critically depressed populations in a manner that is consistent with recovery and avoids extinction.
- Use artificial production to seed unused, accessible habitats.[1]
- Use artificial production to provide for tribal and non-tribal fishery obligations as consistent with recovery criteria.
- Use harvest or other methods to reduce the proportion of hatchery-produced fish in naturally spawning populations (see Section 5.2).
- To the extent possible use local broodstock in hatchery programs.
- To the extent possible, integrate federal, state, and tribal-operated hatchery programs that use locally derived stocks.[2]
- Reduce the amount of in-basin straying from current hatchery programs.

Long—Term (50-100 years)

- Phase out the use of out-of-basin stock in the federal programs at Leavenworth and Entiat National Fish Hatcheries if continued research indicates that the programs threaten recovery of listed fish and those threats cannot be minimized through operational or other changes.
- Help develop ongoing hatchery programs that are consistent with recovery.

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[1] Hatchery-origin fish should not be introduced into unused habitat unless the habitat is suitable for spawning and rearing of the fish. Therefore, the habitat in degraded streams needs to be restored or improved before hatchery-origin fish are introduced into the stream (UCSRB 2007).
[2] Because state and federal hatchery programs have different objectives and obligations, the programs cannot be fully integrated. However, they can develop common broodstock protocols and production levels that optimize recovery of naturally produced fish (UCSRB 2007).

Policies Governing Hatcheries in the Upper Columbia

Most hatchery programs in the Upper Columbia were developed to mitigate for fish losses caused by the construction and operation of mainstem Columbia dams. The PUDs and federal government are the primary entities responsible for funding the hatchery programs based on binding mitigation agreements associated with past and ongoing losses. Federally-funded programs undergo ESA Section 7 consultation and non-federal programs use Section 10 consultation to maintain consistency with recovery of listed species.

In 1988, under the authority of *U.S. v. Oregon*, the states of Washington, Oregon, and Idaho, federal fishery agencies, and the treaty tribes agreed to the *Columbia River Fish Management Plan* (CRFMP), which was a detailed harvest and fish production process. The CRFMP expired in 1998 and these entities currently operate under an interim agreement. The fish production section reflects current production levels for harvest management and recovery purposes.


Nason Creek Hatchery Facility

Included in the Upper Columbia Federal Energy Regulatory Commission (FERC) licenses are separate Anadromous Fish Agreements and HCPs (Rock Island, Rocky Reach, and Wells Hydroelectric Projects) and the Salmon and Steelhead Settlement Agreement (Priest Rapids Hydroelectric Project), detailing the long term adaptive management of Plan Species and their habitats as affected by the Projects. Parties to these agreements include: Federal agencies (USFWS, NOAA), Washington Department of Fish and Wildlife (WDFW), Tribal governments (Confederated Tribes of the Colville Reservation and The Confederated Tribes and Bands of the Yakama Nation) as well as Grant, Chelan, and Douglas PUDs. Section 8 of the Chelan and Douglas HCPs and section 13 of the Grant PUD Settlement Agreement detail the objectives, responsibilities, and mitigation requirements of hatchery programs.

The overriding goal of the HCPs and the Settlement Agreement is to achieve “no net impact” (NNI) on anadromous salmonids for Wells (Douglas PUD), Rocky Reach, Rock Island (Chelan PUD), Wanapum, and Priest Rapids (Grant PUD) dams. The NNI obligations are met through a combination of fish protection and mitigation measures, tributary enhancement, and hatchery programs, using a long-term adaptive management strategy to manage NNI obligations. For these purposes, the HCPs and Settlement Agreement established Hatchery Compensation Plans and Artificial Propagation Plans with initial hatchery production levels and created Hatchery Committees (comprised of representatives from each of the HCP/Settlement Agreement parties) to oversee development, implementation, and monitoring of the hatchery elements of the HCPs and Settlement Agreement.

The PUDs hatchery program obligations are implemented through an adaptive management process set forth in agreements and overseen by the HCP Hatchery Committee and Priest Rapids Coordinating Committee Hatchery Subcommittee (PRCC HSC). Specifically, the Committees adjust PUD hatchery production levels following periodic survival studies that change compensation obligations for NNI production, and automatically every 10 years based primarily on changes in abundance of fish entering project areas, smolt to adult returns (SARs), and juvenile passage survival. They make program modifications to achieve program objectives, including changes to facilities, release methods, and rearing strategies. Program modification may occur more frequently than adjustments of hatchery mitigation levels based on the analytical reports and adaptive management. The fish resource management agencies initially developed the following general goal statements for each hatchery program, which were adopted by the HCP Hatchery Committees and the PRCC-HSC:

> *(1) Support the recovery of ESA listed species by increasing the abundance of natural adult populations, while ensuring appropriate spatial distribution, genetic stock integrity, and adult spawner productivity.*
>
> *(2) Increase the abundance of the natural adult population of unlisted plan species, while ensuring appropriate spatial distribution, genetic stock integrity, and adult spawner productivity. In addition, provide harvest opportunities in years when spawning escapement is sufficient to support harvest.*
>
> *(3) Provide salmon for harvest and increase harvest opportunities, while segregating returning adults from natural tributary spawning populations.*

Salmon and steelhead hatchery programs that operate in regions with ESA-listed populations are evaluated and permitted through the federal government to ensure consistency with the ESA. As part of the ESA permitting process for hatchery programs, the HCP Hatchery Committees, PRCC-HSC, Colville Confederated Tribes, and U.S. Fish and Wildlife Service have been working over the past decade to develop HGMPs for each of their hatchery programs in the Upper Columbia. To date, HGMPs have been developed and submitted for all Upper Columbia hatchery programs. HGMPs describe the composition and operation of each individual hatchery program with the goal of describing biologically-based artificial propagation management strategies that ensure the conservation and recovery of ESA-listed salmon and steelhead populations. NOAA is in the process of reviewing the submitted HGMPs and permitting Upper Columbia programs. Table 2 below provides a summary of major laws and policies governing management of hatcheries in the region.

Table 2. Summary of major laws and policies governing management of hatcheries in the Upper Columbia.

Policy	Description	Link to Hatchery Management
U.S. vs. OR *Columbia River Fish Management Plan*	Decisions reached in the U.S. vs. OR case are implemented under the Columbia River Fish Management Plan (CRFMP). The plan governs management of some hatchery and harvest programs in the Columbia River basin.	Adopts and recommends current production levels for harvest management and recovery for some hatchery programs.
Endangered Species Act (ESA)	Hatchery programs that operate in regions with ESA-listed populations and have the potential to affect listed species or critical habitat are evaluated and permitted through the federal government to ensure consistency with the ESA. There are different processes in the ESA that can be followed to allow for this evaluation, depending on the hatchery operator and the federal listing designation; ESA Section 4(d) or Section 10a (1)(A) are common processes used for artificial production programs.	NOAA and USFWS permit operation and maintenance of hatchery programs. Through this process various permit requirements are implemented to reduce or eliminate impacts to listed species.
Hatchery Genetic Management Plans (HGMP)	HGMPs are technical documents that thoroughly describe the composition and operation of each individual hatchery program. The primary goal of an HGMP is to describe biologically-based artificial propagation management strategies that ensure the conservation and recovery of ESA-listed salmon and steelhead populations. NOAA Fisheries Service and U.S. Fish and Wildlife Service uses the information provided by HGMPs to evaluate impacts on listed species. Completed HGMPs may also be used for regional fish production and management planning by federal, state and tribal resource managers.	HGMPs provide management strategies for hatchery programs to reduce or eliminate risks to listed species. They may be used in permitting under ESA.
Habitat Conservation Plans (HCPs)	An HCP is a required part of an application for an Incidental Take Permit, a permit issued under the Endangered Species Act to private entities undertaking otherwise lawful projects that might result in the destruction of a listed species. The overriding goal of the HCPs for Wells, Rocky Reach, and Rock Island dams is to achieve “no net impact” (NNI) on anadromous salmonids. These agreements provide DPUD and CPUD with Endangered Species Act coverage for continued operations and maintenance of these dams.	“No net impact” commitments relate directly to hatchery production levels for PUD hatchery programs. The HCPs also prescribe monitoring and adaptive management of hatchery programs through the Coordinating and Hatchery Committees (which are comprised of signatory parties to the HCP). The HCP also constitutes the parties' terms, conditions and recommendations for Plan Species under Sections 10(a), 10(j) and 18 of the Federal Power Act, the Fish and Wildlife Conservation Act, the Essential Fish Habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act, the Pacific Northwest Electric Power Planning and Conservation Act, and Title 77 RCW of the State of Washington.
Priest Rapids Salmon and Steelhead Settlement Agreement (SSSA) and NOAA Biological Opinion	The GPUD settlement agreement and NOAA Biological Opinion similarly fulfills ESA and regulatory requirements for FERC relicensing of Grant PUD’s Wanapum and Priest Rapids Dams. The SSSA intends to achieve and maintain “no net impact” from the Priest Rapids Project on spring, summer, and fall Chinook salmon, sockeye salmon, steelhead, and coho salmon through a combination of fish passage measures, fish passage survival performance standards, hatchery propagation, implementation of the Hanford Reach Agreement, and contributions to the habitat and no net impact funds.	The substantive requirements of the SSSA were incorporated into the water quality certification, NOAA and FWS's Section 18 prescriptions under the Federal Power Act, NOAA's terms and conditions under Section 7(b) of the ESA and 305(b)(2) of the Magnuson-Stevens Fishery Conservation Act.

Hatchery Research, Monitoring, and Evaluation

The goal of hatchery research, monitoring, and evaluation (RM&E) is to determine if the programs are performing properly as outlined in the HCPs, HGMPs, Settlement Agreements, and ESA Section 7 and 10 consultations. PUDs, USFWS, and tribes are primarily responsible for monitoring the progress and success of hatchery programs in the Upper Columbia basin. For PUD programs, an extensive monitoring program evaluates hatchery performance and natural production. The PUD monitoring and evaluation program is described in detail in the *Monitoring and Evaluation Plan for PUD Hatchery Programs: 2017 Update* (Hillman et al. 2017). The *Monitoring and Evaluation Plan* reflects evaluation of data collection methods, and M&E results, along with shifting management paradigms affecting M&E needs, all of which have occurred under advancing fish culture and monitoring techniques. This document was a result of a five-year review intended to expand on and coalesce previous M&E documents (BAMP 1998; Cates et al. 2005; Murdoch and Peven 2005; Hays et al. 2006; Pearsons and Langshaw 2009a, 2009b) with inclusion of new information. The *Monitoring and Evaluation Plan* is updated every five years and is adaptively managed to address recommended improvements. Data reports resulting from M&E are compiled annually; statistical reports are compiled every five years; and comprehensive reports are compiled every ten years. The data presented in this summary is a compilation of the monitoring data that has resulted from the extensive hatchery RM&E effort over the past several decades.

Monitoring is used to determine if hatchery programs are meeting the intended management objectives. As stated in Hillman et al. 2013, objectives for hatchery programs are generally grouped into three categories of performance indicators: 1) **Risk Assessment Indicators** ("Does the program pose risks to other populations?"); 2) **In-Hatchery Indicators** ("Is the program meeting the hatchery production objectives?"); and 3) **In-Nature Indicators** ("How do fish from the program perform after release?"). For conservation programs RM&E, focuses on how the program affects target population abundance and productivity, and how the program affects target population long-term fitness. For safety-net programs RM&E focuses on how the program affects target population long-term fitness. For harvest augmentation programs RM&E focuses on evaluating if the program provides harvest opportunities. Productivity indicators are the primary metrics used to assess if conservation and safety-net program goals have been met, while harvest rates and effects on non-targeted populations are used for harvest programs.

Conservation programs are evaluated with a sequential, logical series of steps based on the program objectives and associated indicators described in Table 3 below. One of the indicators used in Hillman et al. (2013) is at a minimum, a conservation hatchery program must be able to produce more adults per spawner than would occur in the natural environment. Should the program fail this test, hatchery operations should be evaluated to determine whether improvements can correct the problem. If a program successfully replaces the required number of adults, it is then evaluated against a reference population or condition, if available, to determine if: 1) the overall number of naturally-spawning fish has increased (including both hatchery- and natural-origin adults), 2) the number of natural-origin spawners has increased, and 3) productivity of the population has changed. When these targets are met, the program is considered successful. When the targets are not met, monitoring indicators may infer why the program is not achieving its goals.

The goal of safety-net programs is to provide a demographic and genetic reserve for a population being supplemented by a conservation program. Therefore, the monitoring for these programs and other program types focuses on estimating the number of fish that escape to spawn naturally, stray rates, and in-hatchery performance evaluation. The primary goal of a harvest augmentation program is to increase harvest opportunities. Harvest opportunity, survival rates, and stray rates are important indicators for assessing the success of harvest augmentation (Hillman et al. 2013). The U.S. Fish and Wildlife Service conducts monitoring for their hatchery programs at the three Leavenworth Complex federal fish hatcheries (Leavenworth National Fish Hatchery (NFH), Entiat NFH, and Winthrop NFH) according to their own *Hatchery Evaluation Plan* (Cooper et al. 2017). The USFWS's Mid-Columbia Fish and Wildlife Conservation Office (MCFWCO) program uses RM&E results to assist the Leavenworth Complex in effectively meeting both its mitigation and ESA responsibilities. Monitoring objectives are outlined and supported in the Complex's governing documents, including each facility's HGMP, Washington State Department of Ecology permits, NOAA Fisheries and the USFWS's BiOp's. All research, monitoring, and evaluation are conducted with the goal of optimizing performance while minimizing risk for each program. Monitoring by the FWS is complementary to that done by the PUDs and focuses on the specific goals of each program. Specific monitoring objectives for USFWS programs can be found in Cooper et al. 2017.

Spawner surveys in the Wenatchee River.

Table 3. Productivity and monitoring indicators based on program objectives, indicators, and goals for conservation hatchery programs (also applies to safety-net programs when used to support a conservation program) and harvest augmentation programs. Table from Hillman et al. 2013.

	Objective	Indicator	Target	Program goals		
				Rebuild natural populations	Maintain genetic diversity	Opportunity for harvest
Conservation Program Productivity indicators	Determine if the program has increased the number of naturally spawning adults	Abundance of natural-origin spawners	Increase	✓		✓
		Adult productivity (NRR)	No decrease	✓		
	Determine if the proportion of hatchery-origin fish affects freshwater productivity	Residuals vs. pHOS	No relationship	✓		
		Juveniles per redd vs. pHOS	No relationship	✓		
Conservation Program Monitoring indicators	Determine if run timing and distribution meets objectives	Migration timing	No difference	✓	✓	
		Spawn timing	No difference	✓	✓	
		Redd distribution	No difference	✓	✓	
	Determine if program has affected genetic diversity and population structure	Allele frequency (hatchery vs. wild)	No difference		✓	
		Genetic distance between populations	No difference		✓	
		Effective population size	Increase		✓	
		Age and size at maturity	No difference		✓	

	Objective	Indicator	Target	Rebuild natural populations	Maintain genetic diversity	Opportunity for harvest
	Determine if hatchery survival meets expectations	HRR	HRR > NRR	✓		
		HRR	HRR ≥ Goal	✓		
	Determine if stray rate of hatchery-origin fish is acceptable	Out of basin	≤ 5%	✓	✓	
		Within basin	≤ 10%	✓	✓	
	Determine if hatchery-origin fish were released at program targets	Size and number	= Target	✓		
	Provide harvest opportunities when appropriate	Harvest	Escapement goals			✓
Harvest Program Monitoring Indicators	Determine if hatchery survival meets expectations	HRR	HRR > NRR			✓
		HRR	HRR ≥ Goal			✓
	Determine if stray rate of hatchery-origin fish is acceptable	Out of basin	≤ 5%		✓	
		Within basin	≤ 10%		✓	
	Determine if hatchery-origin fish were released at program targets	Size and number	= Target			✓
	Provide harvest opportunities when appropriate	Harvest	Escapement goals			✓

Hatchery Reviews

When salmon and steelhead were listed in the 1990s, most hatcheries were producing fish for harvest and supplementation to mitigate for past habitat loss and hydroelectric development. These hatchery programs generally were not considering the effects on natural spawning populations. A few innovative hatchery programs were constructed to determine how hatchery technology could enhance wild populations while minimizing deleterious hatchery effects. Once species were listed under the ESA, conservation of salmon became a high priority and the need for hatchery reform became apparent because of the potential risks and benefits of these programs to listed species. Congress and federal agencies responded by implementing a series of review processes in the early 2000's. In addition to these large-scale reviews, all hatchery programs in the Upper Columbia undergo periodic technical review to ensure that their operations do not impede the recovery of ESA-listed species. Recommendations from these reviews have been implemented over the past 10 years and results from these changes are still being evaluated. A brief description of past large-scale reviews follows.

Artificial Production Review and Evaluation - 2003

In 2003, Congress directed the Northwest Power and Conservation Council (NWPCC) to conduct a review of all federally-funded hatchery programs in the Columbia basin. The resulting Artificial Production Review and Evaluation (APRE) process was based on the Hatchery Scientific Review Group (HSRG) process that had been implemented in Puget Sound and the Washington Coast from 2001-2003. The APRE explored a range of issues, including whether more strategic use of hatchery-origin fish could better accommodate ecological and social goals, and how many hatchery-origin fish should be released each year. The APRE report was used as the basis for an issues paper that helped delineate the NWPCC's approach to hatchery reform. The goal was to gather information, evaluate programs against their stated goals, and promote reporting and accountability. The full basin report can be found at https://www.nwcouncil.org/media/28959/2004_17.pdf

U.S. Fish and Wildlife Service Hatchery Review Process - 2007

In 2004, the USFWS concluded that its twelve National Fish Hatcheries in the Columbia basin should undergo an internal hatchery review. This review was largely spurred by the positive success of the HSRG evaluation involving Puget Sound Hatcheries. The resulting process was like that of the HSRG and focused on making federal programs consistent with the best available science and responsive to new scientific information and changing regional priorities. The review also focused on ensuring that federal programs were consistent with ESA-protection and recovery plans. USFWS formed a Hatchery Review Team (HRT), which evaluated federal programs and prepared recommendations intended to increase benefits and/or reduce risks of the current programs. The HRT also assessed several possible alternatives to the current programs. Recommendations for the Upper Columbia Leavenworth Fisheries Complex (Leavenworth, Entiat, and Winthrop NFHs) covered all areas of fish culture and hatchery management (HRT 2009). Links to the HRT reports can be found at https://www.fws.gov/pacific/Fisheries/Hatcheryreview/Reports/leavenworth/LeavenworthComplexReview_19April2007_FINAL.pdf.

Following completion of these reviews the USFWS held a number of formal meetings with co-managers (YN, CCT, and WDFW) to evaluate the review findings and determine which recommendations and alternatives should be implemented. Notable changes include the development of plans to transition the Winthrop NFH steelhead program to locally sourced broodstock (rather than co-mingled Wells stock), improved fish passage at Leavenworth NFH, new marking schemes to better differentiate hatchery origin fish and reduce straying into natural spawning areas, and transition of the Entiat spring Chinook salmon program to a summer Chinook salmon program.

The goal of the USFWS 2009 hatchery review was to ensure that all federal hatcheries are operated in accordance with best scientific principles, and contribute to sustainable fisheries and the conservation of naturally-spawning populations of salmon, steelhead and other aquatic species. The HRT considered four characteristics of each salmonid population or stock within hatchery influenced watersheds, including: biological significance, population viability, habitat conditions, and harvest goals or contributions. The HRT used both short- (10-15 years) and long-term (50–75 years) goals, as identified by the fishery co-managers, as a foundation for assessing the benefits and risks of the hatchery programs. Likewise, their recommendations for current programs addressed short-term needs while their recommended alternatives to existing programs addressed long-term goals.

The HRT found that of the three Leavenworth Complex hatcheries in the Upper Columbia (Leavenworth NFH, Entiat NFH, and Winthrop NFH), the spring Chinook program at the Leavenworth NFH is the only program that was providing significant fishery benefits. Notably, the Entiat spring Chinook program was found to provide little or no measurable benefits and, following the HRT recommendation, the USFWS and co-managers terminated the program in 2007 with the last adults returning in 2010. Other risks, opportunities, and alternatives identified by the HRT for federal programs in the Upper Columbia at the time of their review are summarized below (HRT 2007).

Leavenworth NFH – The HRT review of the Leavenworth NFH spring Chinook program found that the program provided significant harvest benefits. Risks that were identified included water use and fish passage issues associated with the hatchery facility as well as genetic risks associated with using a non-native stock (note: at the time of the review LNFH fish were not uniquely marked and could spawn naturally, but are generally isolated to a three-mile reach of Icicle Creek). A variety of alternatives were explored from termination of the program to continuance of the existing production program. One alternative proposed was to continue the existing spring Chinook program until the water intake system for the hatchery was replaced; then consider transition to a native spring Chinook broodstock that is integrated genetically with an existing Wenatchee River ESA recovery hatchery broodstock using a safety-net ("stepping stone") model. Further, the HRT recognized that a change of this magnitude would require discussion and approval of the co-managers and may not be practical due to other considerations.

Entiat NFH –The Hatchery Review Team concluded in their review that the spring Chinook program represented a threat to the Entiat population because of the non-local broodstock of the program and the large number of hatchery fish spawning in the river (e.g. high potential for interbreeding with the local stock). The HRT believed this was just cause for termination. Alternative use of the hatchery could include the propagation of species of high conservation or harvest importance, or making the Entiat a “reference stream” for assessing ESA hatchery recovery efforts by prohibiting any releases in the subbasin. NOTE: This program was terminated in 2007 and replaced with a summer Chinook program as a result of the HRT review.

Winthrop NFH- The Winthrop NFH spring Chinook program conservation and mitigation goals were determined to be inadequate at the time of the HRT review. Adult trapping facilities pose a genetic and demographic risk to the listed populations of spring Chinook and steelhead. Alternatives include a) modification of the present broodstock strategies for spring Chinook at the Winthrop and Methow hatcheries including the establishment of an integrated conservation program and a second broodstock at the Winthrop NFH that is genetically integrated with the Methow Hatchery broodstock according to the “stepping stone” model and b) reducing the number of spring Chinook released from the Winthrop NFH to the degree they are not needed to meet in-basin conservation objectives.

For the Winthrop steelhead program, recommendations included development of an integrated program from returns to the Methow River, no longer releasing steelhead from Wells Dam origin into the Methow, and improvement of adult collection facilities. It was also recommended to increase the size of the program to a minimum of 100 adults (50% natural-origin) to meet minimum broodstock genetic guidelines, resulting in a program size of 200,000 smolts.

Hatchery Reform Project - 2009

The Hatchery Reform Project was established by the U.S. Congress in 2000 because of a recognition by scientists and policy-makers that while hatcheries play a role in meeting harvest and conservation goals for salmon and steelhead, the hatchery system needed comprehensive reform (HSRG 2009). This project was initially limited to an evaluation of hatchery programs in Puget Sounds and Coastal Washington. The scope was later expanded to include the Columbia River Basin. As part of the Hatchery Reform Project, the HSRG, an independent scientific review panel, was created. The HSRG was charged by Congress with reviewing all state, tribal and federal hatchery programs as part of a comprehensive hatchery reform effort to conserve wild genetic resources, assist with recovery of populations, provide sustainable fisheries, and improve the quality and cost-effectiveness of hatchery programs.

After the HSRG reviewed programs in Puget Sound and Coastal Washington in 2004, Congress directed NOAA’s National Marine Fisheries Service (NOAA Fisheries) to replicate the process in the Columbia basin. The Columbia basin review was based on a new, ecosystem-based approach founded on the idea that harvest goals are sustainable only if they are compatible with conservation goals. As such, the HSRG analytical approach focused on: 1) well-defined goals, 2) scientific defensibility, and 3) informed decision-making.

The USFWS HRT and the HSRG both reviewed hatchery programs, but with different perspectives and objectives. The HSRG used the “All-H Analyzer,” a population modeling tool to evaluate alternative hatchery strategies. The HSRG recommendations focused on: (1) re-sizing hatchery programs, (2) managing spawning escapement of hatchery-origin fish, and (3) genetic management of hatchery broodstocks to meet conservation goals while retaining harvest benefits. The USFWS review focused on fish culture protocols, facilities, and "on-the-ground" management of hatchery-origin fish. In the end, recommendations of the two review groups were very similar, but their approaches were quite different and complementary.

The HSRG's analysis of the 178 Columbia basin hatchery programs and 351 salmon and steelhead populations resulted in principles, recommendations, tools and procedures that provide a foundation for managing hatcheries more effectively into the future (HSRG 2009). The full report can be found at http://hatcheryreform.us/hrp/reports/system/welcome_show.action.

All populations in the Upper Columbia were designated as "primary" populations except for spring Chinook in the Okanogan (classified as "stabilizing). The HSRG had guidelines for integrated hatchery programs in primary populations. For these programs, the HSRG believes that the proportion of natural-origin adults in the broodstock (pNOB) should exceed the proportion of hatchery spawners (pHOS) by at least a factor of two, corresponding to a PNI (proportionate natural influence) value of 0.67 or greater, and that pHOS should be less than 0.30. Upon completion of the 2009 HSRG review, it was determined that none of the Upper Columbia programs met these standards.

The HSRG noted that options for improving **spring Chinook** integrated hatchery programs were somewhat limited by the low number of natural-origin fish. Contribution to conservation could be improved for Wenatchee spring Chinook (and its sub-populations) by improving broodstock collection and limiting hatchery-origin fish on the spawning grounds. For the Entiat population, the HSRG recommended better control of out-of-basin hatchery-origin fish. In the Methow subbasin, the HSRG looked at various hatchery scenarios that could improve productivity of the sub-populations, but could not significantly increase abundance of natural-origin spawners because of limited habitat quality (productivity) and quantity (capacity).

Options for improving **steelhead** integrated hatchery programs were possible but also limited by the low number of natural-origin fish. The HSRG found that contributions to conservation can be improved in the Wenatchee and Methow by improving broodstock collection and limiting hatchery-origin fish on the spawning grounds. In the Entiat and Okanogan subbasins, the HSRG analyzed various hatchery scenarios that could improve productivity of the subpopulations, but could not significantly increase abundance of natural-origin spawners under current habitat conditions. This is generally the result of limitations in habitat quality (productivity) and quantity (capacity).

HSRG recommendation across all programs included:

1. ***Sliding Scale Management-*** Manage hatchery-origin spawning (pHOS) and natural-origin broodstock (pNOB) on a "sliding scale", in order to balance the demographic risk (low overall abundance) against genetic risks (too much hatchery influence), while still assuring that PNI and pHOS objectives are met on average over generations. In low abundance years,

more of the appropriate stock is allowed to reach the spawning grounds. In high abundance years, more hatchery-origin fish are removed through adult management. Similarly, the number of natural-origin broodstock is determined by the natural run size any given year.

2. ***Harvest-*** Increase harvest opportunities by selectively targeting excess hatchery-origin fish.
3. ***Habitat Improvement-*** Increase the effectiveness of habitat actions by combining with hatchery and harvest reforms. Unless hatchery and harvest reforms are implemented, the potential benefits of current or improved habitat cannot be fully realized.
4. ***Broodstock Management-*** Manage hatchery broodstocks to achieve proper genetic integration with, or segregation from, natural populations and promote local adaptation of natural-origin and hatchery-origin fish.
5. ***Safety-Net Programs-*** Use safety-net ("stepping stone") programs to allow managers to use returning excess hatchery adults from integrated conservation programs to provide additional harvest and meet broodstock and escapement during years of low natural returns. Overall, the HSRG found that options for improving the integrated hatchery programs are possible but limited by the low number of natural-origin fish.

The HSRG recommendations were intended to provide scientific guidance for managing each hatchery more effectively in the future. These recommendations have led to standards for developing new hatchery programs, and helped make existing programs more consistent with resource goals and current science. Each of the above recommendations have been incorporated in some way into the new HGMPs that followed the HSRG process.

Historic Hatchery Programs

Salmon and steelhead hatchery programs have evolved since their beginnings in the early 1900s. This history is important because current populations are, in part, shaped by past artificial production. Although changes in hatchery programs and local adaptation work to revert populations to a more natural condition, the legacy of hatchery programs can influence populations for generations (e.g. Christie et al. 2011).

The first hatcheries to release salmon in the Upper Columbia began operation in 1899 in the Wenatchee River on Chiwaukum Creek and in the Methow River near the confluence of the Twisp River. These hatcheries were built to boost salmon runs that had been nearly eliminated due to harvest and habitat loss and degradation. Almost 8 million fry were planted per year in the Wenatchee River and up to 3 million in the Methow River. Most the fish released were coho with only small, sporadic releases of steelhead and Chinook. Hatchery programs used a combination of local (Upper Columbia) and non-local (outside the region or outside the Columbia basin) stocks. The release of fry from these early programs probably contributed little to adult returns (Chapman et al. 1995).

A large-scale fish production program was initiated in response to the loss of fisheries resources resulting from the construction of the Grand Coulee Dam without fish passage. This mitigation program, the Grand Coulee Fish Maintenance Project maintained from 1939 through 1943, collected adult salmon and steelhead at Rock Island Dam and randomly mixed them to create a common broodstock. Resulting smolts were released into Upper Columbia tributaries. Adults were also trapped, transported and then released into a few tributaries to spawn naturally. Transported adults often failed to spawn. The last brood year of natural-origin fish to return to their natal stream to spawn naturally during this time was in 1938. For a more comprehensive record of activities conducted under the Grand Coulee Fish Maintenance Project see Chapman et al. (1995).

Several hatcheries were built as part of the GCFMP and began operation in the 1940s at Leavenworth, Entiat, and Winthrop NFHs (now called the Leavenworth Fisheries Complex). These programs were authorized in 1938 as part of the Mitchell Act (952 Stat. 345) and the three hatcheries were built to relocate populations of salmon and steelhead that previously migrated upstream of Grand Coulee Dam. The hatcheries used varied broodstock sources over the years (Lower Columbia. McKenzie River (Oregon), Rock Island Dam trapping, and within-basin returning adults) and Leavenworth Fisheries Complex has raised and released several species of salmon since it was built. All three national fish hatcheries have over the years raised and released spring Chinook using "Carson" stock that originated at Carson NFH in the Lower Columbia. Entiat NFH began producing spring Chinook in 1974 and within a few years the broodstock was 100% local returns. In 2000 Winthrop NFH hatchery transitioned their broodstock to the listed Upper Columbia river stock of spring Chinook. Leavenworth NFH still raises and releases "Carson" stock although the hatchery hasn't transferred fish from the lower river since 1985 (Potter 2016). Historic survival of fish released from these programs was generally low (<1%), likely because of the mixed broodstock origin and disease issues (Chapman et al. 1995).


Leavenworth National Fish Hatchery construction in 1940. Photo courtesy of USFWS.

Currently, WDFW is contracted by Chelan and Grant PUDs to operate several hatcheries in the Upper Columbia to compensate for losses at publicly-owned hydroelectric projects (Grant PUD - Priest Rapids Project, Chelan PUD - Rock Island and Rocky Reach Projects). Most of these hatcheries began operations either after the dams were completed in the 1960s, or prior to listing in the late 1980s and early 1990s in response to the Federal Energy Regulatory Commission (FERC) settlements and relicensing agreements.

In 2004, HCP agreements for Chelan PUD and Douglas PUD formalized hatchery compensation for HCP species (spring Chinook, summer Chinook, fall Chinook, sockeye, coho, and steelhead). The HCP agreements among Chelan PUD, Douglas PUD, NOAA Fisheries, USFWS, WDFW, the Colville Tribes, and The Yakama Nation allowed for continued operation of both the hatchery programs initiated in the 1960s, and the relatively newer programs started in 1989 and 1991. The Hatchery Committees for each HCP were tasked with overseeing the development of recommendations for implementation of the hatchery elements of the HCP that Douglas PUD and Chelan PUD are responsible for funding. Similarly, a settlement agreement and NOAA Biological Opinon with Grant PUD has proposed additional artificial propagation within the Upper Columbia basin. Hatchery releases of spring Chinook and steelhead have varied over the years with peaks in hatchery production in the region in the 1980s (Figure 4).

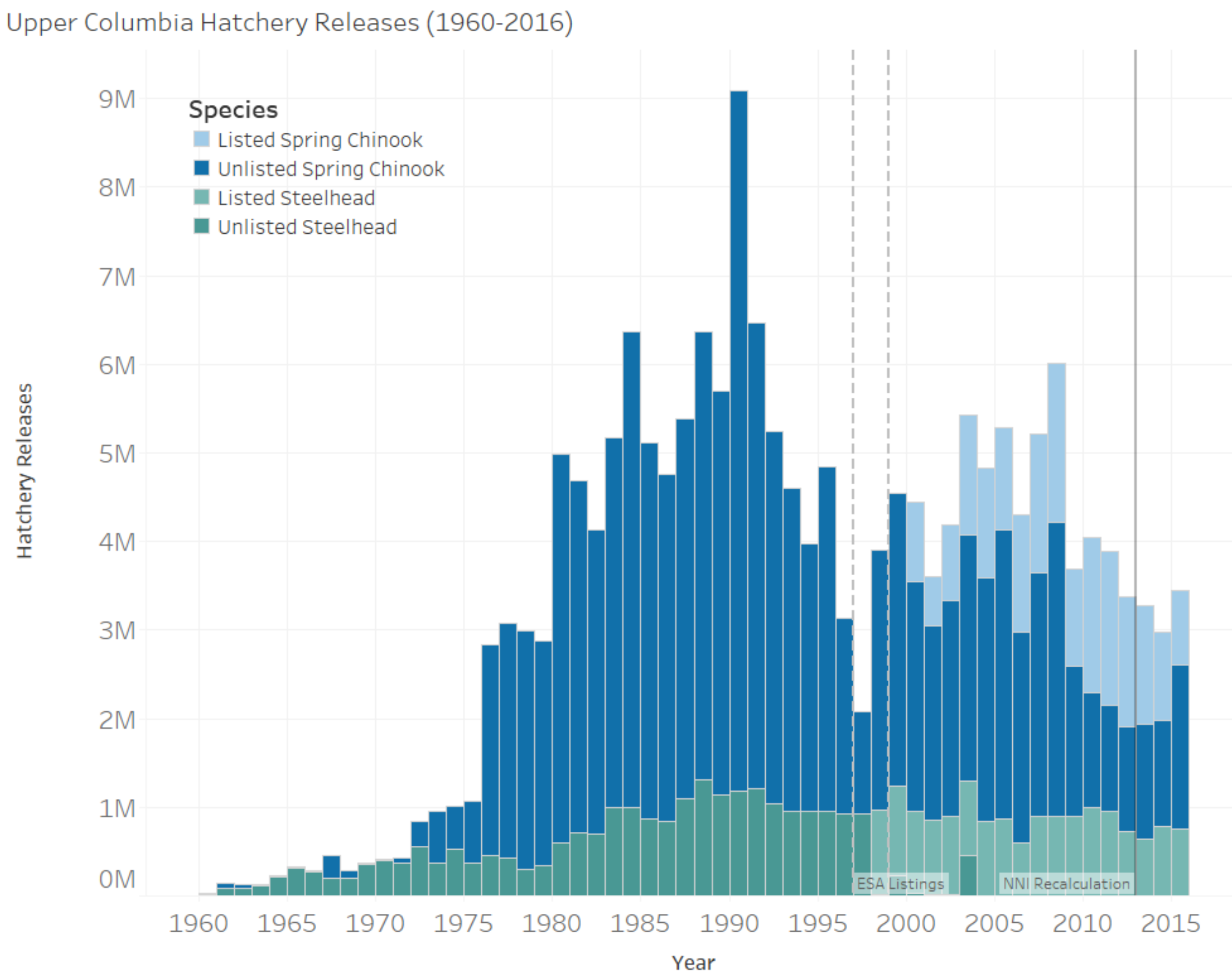


Figure 4. Historical spring Chinook and steelhead hatchery releases in the Upper Columbia (1960-2016). Data from Fish Passage Center (2017).

Hatchery production for supplementation and harvest began in the late 1930's and continues today. After listings, there was an additional push to supplement depressed runs of listed species, and some hatchery programs shifted management toward supplementation of depressed populations to aid in recovery (Figure 5; Figure 6). Current programs reflect a shift toward conservation-oriented goals and are the product of decades of changes based on negotiation, permitting, species status, scientific findings, and funding among other reasons.

Figure 5. Timeline of hatchery programs in the Upper Columbia 1890’s to present.

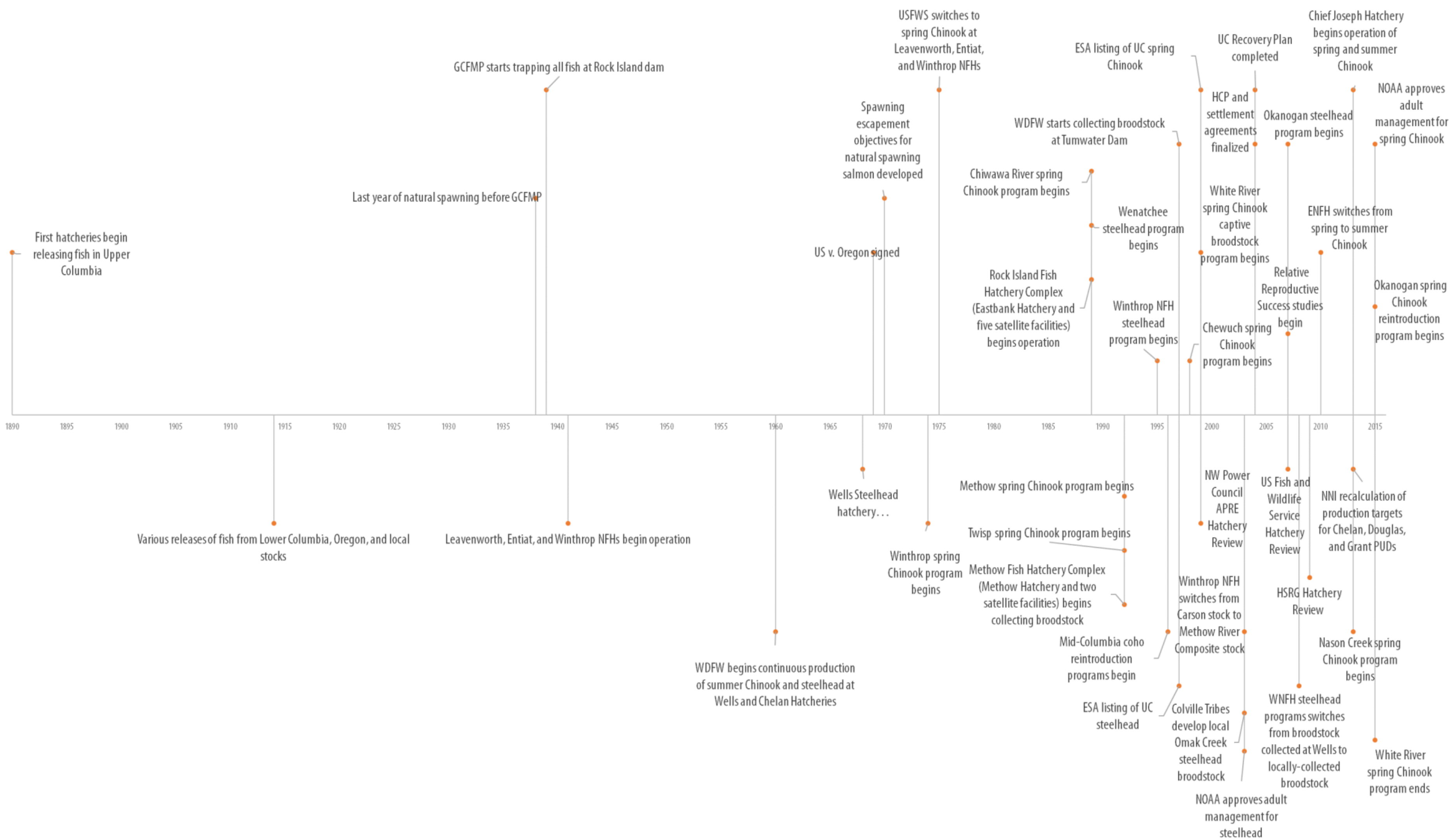


Figure 6. Timeline with dates of important hatchery program changes in the Upper Columbia.

Year	Event
1890	First hatcheries begin releasing fish in Upper Columbia
1914	Various releases of fish from Lower Columbia, Oregon, and local stocks
1938	Last year of natural spawning before GCFMP
1939	GCFMP starts trapping all fish at Rock Island dam
1941	Leavenworth, Entiat, and Winthrop NFHs begin operation
1960	WDFW begins continuous production of summer Chinook and steelhead at Wells and Chelan Hatcheries
1968	Wells Steelhead hatchery program begins
1970	Spawning escapement objectives for natural spawning salmon developed
1975	USFWS switches to spring Chinook at Leavenworth, Entiat, and Winthrop NFHs
1969	US v. Oregon signed
1974	Winthrop spring Chinook program begins
1989	Rock Island Fish Hatchery Complex (Eastbank Hatchery and five satellite facilities) begins operation
1989	Chiwawa River spring Chinook program begins
1989	Wenatchee steelhead program begins
1992	Methow Fish Hatchery Complex (Methow Hatchery and two satellite facilities) begins collecting broodstock
1992	Methow spring Chinook program begins
1992	Twisp spring Chinook program begins
1995	Winthrop NFH steelhead program begins
1996	Mid-Columbia coho reintroduction programs begin
1997	ESA listing of UC steelhead
1997	WDFW starts collecting broodstock at Tumwater Dam
1998	Chewuch spring Chinook program begins
1999	White River spring Chinook captive broodstock program begins
1999	ESA listing of UC spring Chinook
1999	Winthrop NFH switches from Carson stock to Methow River Composite stock
2003	NW Power Council APRE Hatchery Review
2003	Colville Tribes develop local Omak Creek steelhead broodstock
2003	NOAA approves adult management for steelhead
2004	HCP and settlement agreements finalized
2004	Okanogan steelhead program begins
2007	UC Recovery Plan completed
2007	US Fish and Wildlife Service Hatchery Review
2009	HSRG Hatchery Review
2010	ENFH switches from spring to summer Chinook
2007	Relative Reproductive Success studies begin
2008	WNFH steelhead programs switches from broodstock collected at Wells to locally-collected broodstock
2013	NNI recalculation of production targets for Chelan, Douglas, and Grant PUDs
2013	Chief Joseph Hatchery begins operation of spring and summer Chinook
2013	Nason Creek spring Chinook program begins
2015	Okanogan spring Chinook reintroduction program begins
2015	White River spring Chinook program ends

Current Hatchery Programs

Hatchery mitigation for conservation and harvest is spread throughout the four major subbasins of the Upper Columbia Region as well as in the mainstem Columbia at a series of hatcheries. Currently, CPUD, DPUD, GPUD, WDFW, USFWS, The Yakama Nation, and Colville Tribes manage and operate 21 hatchery programs in the Upper Columbia, producing spring Chinook, summer/fall Chinook, coho, sockeye, and steelhead. Eleven of these programs raise and release listed spring Chinook and steelhead in the Wenatchee, Methow, and Okanogan subbasins. Current (2015-2016) hatchery programs in each of the major subbasins, as well as the mainstem Columbia, are summarized below.

Wenatchee Subbasin

- 7 hatchery programs (4 conservation, 1 reintroduction)
- 3.3 million smolt target (LISTED- 367,696 spring Chinook, 247,300 steelhead)

There are currently seven hatchery programs releasing four stocks of fish (steelhead, spring Chinook, summer Chinook, and coho) in the Wenatchee subbasin. Fish are released to the mainstem Wenatchee (Dryden acclimation pond and Blackbird Island Pond), Icicle Creek (Leavenworth NFH), and from Nason Creek (Nason Creek acclimation facility and Rolfing's pond), Chiwawa acclimation facility, and various locations throughout the subbasin. Coho (1,000,000 smolt target) are released throughout the watershed as part of a reintroduction program in the Wenatchee (and Methow) subbasins. Summer Chinook (500,000 smolt target) are released from Dryden acclimation pond as part of an integrated harvest program. Steelhead (247,300 smolt target) are planted or released into the Chiwawa River, to the mainstem Wenatchee, and to Nason Creek as part of a safety-net (Hatchery x Hatchery) and conservation (Wild x Wild) program. Spring Chinook (1,567,696 smolt target) are released from the Leavenworth NFH, Chiwawa acclimation facility, and the Nason Creek acclimation facility as part of a harvest, safety-net, and two conservation programs. The 1.2 million spring Chinook released from the Leavenworth NFH are reared and released for harvest mitigation and are unlisted.

Several changes have occurred in hatchery programs in the Wenatchee subbasin. The overall number of spring Chinook and steelhead released today is a reduction from past years because of NNI recalculation for the PUD programs beginning with brood-year 2013. The effort to establish separate spring Chinook programs for the White River, Chiwawa River, and Nason Creek spawning aggregates has also been modified over time. The White River captive broodstock program began in 1999 and ended in 2015 and a new Nason Creek spring Chinook hatchery program was started in 2013. This modification was due, in large part, to local opposition to hatchery facilities and the potential habitat degradation the facilities might have incurred. Adult management (removing hatchery-origin fish at weirs, dams, or through selective fisheries) of hatchery spring Chinook at Tumwater dam was permitted starting in 2016. Adult management occurs according to a permitted proportion of natural influence (PNI) sliding-scale management scheme that decreases the proportion of hatchery-origin fish on the spawning grounds and increases use of natural-origin fish in the broodstock (Jones 2015). Adult management and broodstock collection at Tumwater Dam was permitted for steelhead starting in 2003. More information about programs that release hatchery fish in the Wenatchee subbasin can be found below.

Chiwawa Hatchery Spring Chinook

Artificial propagation of Chiwawa River spring Chinook began in 1989 as mitigation for Rock Island Dam. The program is an integrated conservation program using local broodstock collected in the Chiwawa River and Tumwater Dam (previously PIT-tagged natural-origin smolts). A weir is used to collect natural-origin adult broodstock from the Chiwawa River. Tumwater Dam on the Wenatchee River is used to collect returning hatchery-origin fish for broodstock if the number of natural-origin broodstock targets are not achieved. The program is intended to increase the number of adults on the spawning grounds and subsequently lead to an increase in natural production. The program is funded by Chelan PUDs and operated by WDFW. The current production goal is 144,026 smolts.

Nason Hatchery Spring Chinook

The Nason Creek program began in 1997 as a captive broodstock program. Improvements in adult escapement in Nason Creek have reduced the near-term risk of extinction and therefore the captive-broodstock program was discontinued. Supplementation began with the collection of broodstock in 2013. The first releases of the program occurred from the Nason Creek Acclimation Facility in the spring of 2015. The program is intended to be an integrated conservation program using locally derived spring Chinook returning to the Upper Wenatchee and Nason Creek. The program goal is to increase the number of adults on the spawning grounds and thereby leading to an increase in natural production. The Nason Creek spring Chinook program consists of a conservation (WxW broodstock) and safety-net (HxH broodstock) component. The program is funded by Grant PUD and operated by WDFW. The current production goal is 125,000 smolts for conservation and 98,670 smolts for safety-net.

White River Hatchery Spring Chinook (ended in 2015)

Artificial propagation of White River spring Chinook began in 1997 as a captive-broodstock program started from eyed-eggs were collected from redds in the White River (Petersen and Dymowska 1999). The first yearling smolt release occurred in the spring of 2001. The White River was always the only source for eggs used as brood fish. The White River program released its last fish in 2015 and this production obligation was temporary shifted to the Nason Creek program while data is being collected and an expert panel review in 2026 to determine whether a new hatchery program should be restarted in the White River.

Leavenworth National Fish Hatchery Spring Chinook

Leavenworth NFH has released spring Chinook into Icicle Creek since 1940. The program is a segregated harvest program and is intended to mitigate for the construction of Grand Coulee Dam by providing salmon for harvest, primarily in the Columbia River and in Icicle Creek. Chinook released from the LNFH are not part of the spring Chinook ESU. Broodstock were originally collected from commingled upriver stocks and later from other Columbia River hatcheries including Carson NFH. Since 1985, broodstock have consisted solely of Leavenworth program adult returns that volunteer into the hatchery on Icicle Creek. Program broodstock are segregated from the natural spawning population in the Wenatchee River basin. The program is funded by the

Bureau of Reclamation and operated by the US Fish and Wildlife Service. The current production goal is 1.2 million smolts.

Wenatchee Hatchery Steelhead
The Wenatchee steelhead conservation program has been in place since 1989 and is currently intended to be an integrated supplementation program. The program is an integrated conservation program and uses local Wenatchee broodstock and releases fish in the Chiwawa River, mainstem Wenatchee, and Nason Creek. The Wenatchee steelhead program consists of a conservation (WxW broodstock) and safety-net (HxH broodstock) component. The program is funded by Chelan PUD and operated by WDFW. The current production goal is 247,650 smolts for conservation and 123,650 smolts for safety-net. Prior to the current program, Wenatchee River received smolt plants starting in 1965 from the Chelan and Turtle Rock programs, using broodstock collected at Wells Dam for most years, but also including some Skamania stock in the 1980s.

Mid-Columbia Hatchery Coho
The Mid-Columbia coho program is a reintroduction program started in 1996 to re-establish naturally spawning coho populations to harvestable levels in tributaries of the Wenatchee and Methow basins. The program originally used Lower Columbia stock to start the program but has been shifting to local broodstock as returns have increased. The program releases fish at various acclimation sites throughout the Methow and Wenatchee subbasins. The current production is 1.5 million smolts (1 million in Wenatchee and 500,000 in Methow). The Methow could increase to 1 million but this increase would only be for one coho generation then there will be a subsequent ramping down of release numbers by 30%. After that release numbers will continue to decline every 2-3 generations as phased goals are achieved. The goal is to eventually ramp down hatchery production as natural production ramps up. The program is funded by BPA, DPUD, GPUD, CPUD and operated by the U.S. Fish and Wildlife Service and the Yakama Nation.

Wenatchee Hatchery Summer Chinook
The goal of the Wenatchee Summer Chinook program, established in 1989, is to mitigate for loses at Rock Island Dam, Wanapum, and Priest Rapids dams by producing fish for harvest and conservation. The program is an integrated harvest program and uses local Wenatchee broodstock and releases fish from Dryden pond in the mainstem Wenatchee. The program is funded by Chelan and Grant PUDs and operated by WDFW. The current production goal is 500,000 smolts.

Entiat Subbasin

- 1 hatchery program (0 conservation)
- 400,000 smolt target (LISTED- none)

The Entiat subbasin has had several hatchery programs over the years for steelhead and Chinook. Currently there is just one hatchery program for summer Chinook at the Entiat NFH. The U.S. Fish and Wildlife Service has been raising and releasing Chinook from the Entiat Hatchery since 1940 when it was built. In 2007 the USFWS stopped stocking unlisted spring Chinook in response to hatchery reform recommendations that suggested the risk to wild Entiat River spring Chinook was too high. The USFWS transitioned to summer Chinook with local broodstock and has been releasing summer Chinook from the Entiat NFH since 2009 to help meet Grand Coulee Dam mitigation obligations. The Entiat River was also stocked with 40,000 steelhead smolts from the Chelan/Turtle Rock program from about 1965 until sometime around 1999. Although there are no hatchery programs for listed species, hatchery-origin steelhead and spring Chinook from other subbasins stray into the Entiat River and spawn naturally each year (Fraser and Hamstreet 2016). More information about programs that release hatchery fish in the Entiat subbasin can be found below.

Entiat Hatchery Summer Chinook
The Entiat summer Chinook harvest program began in 2009 after the spring Chinook program ended. The program was initiated with eggs from Wells Hatchery and transitioned to using local Entiat broodstock. The goal of the program is to maintain a segregated harvest program. Fish are released directly from the hatchery. The program is funded by the Bureau of Reclamation and operated by the U.S. Fish and Wildlife Service. The current production is 400,000 smolts.

Methow Subbasin

- 7 hatchery programs (5 conservation, 1 reintroduction)
- 1,671,765 smolt target (LISTED- 623,765 spring Chinook, 348,000 steelhead)

There are seven hatchery programs that release fish in the Methow subbasin. These programs release four stocks (Steelhead, spring Chinook, summer Chinook, and coho). Fish from these programs are released in the mainstem Methow River and Twisp River and from the Methow Hatchery, Winthrop NFH, and the Carlton and Chewuch acclimation facilities, as well as several other small acclimation facilities. Coho (500,000 smolt target) are released throughout the subbasin as part of a reintroduction program in the Methow (and Wenatchee) subbasins. Summer Chinook (200,000 smolt target) are released from the Carlton acclimation facility on the mainstem Methow. Steelhead (348,000 smolt target) in the Methow are released as part of two conservation programs at Winthrop NFH and the Twisp River, and one safety-net program at the Methow Hatchery. Spring Chinook (623,765 smolt target) are released as part of a safety-net program at the Winthrop NFH (400,000 smolts) and a conservation program in the Methow, Twisp, and Chewuch Rivers (223,765 smolts).

Recent changes in Methow programs include a decrease in steelhead and spring Chinook program sizes and the start of a Methow-stock steelhead conservation program with 2-year old smolts at the Winthrop NFH. The Methow coho program could shift to a 1 million smolt production level in the next few years as they enter a new phase of reintroduction but that level of production will not persist. More information about programs that release hatchery fish in the Methow subbasin can be found below.

Methow Hatchery Spring Chinook
The Methow Hatchery Spring Chinook conservation program provides mitigation for Douglas PUD, Grant PUD, and Chelan PUD. The program is currently funded by the three PUDs and operated by DPUD. The Methow spring Chinook program began in 1992 with broodstock collected from adult returns in the Methow, Chewuch, and Twisp Rivers. A transition to rearing the Methow Composite stock, which is a combination of Chewuch River and Methow River stocks, began in 1998 for the

releases to the Methow and Chewuch rivers. The Methow Hatchery spring Chinook program is an integrated conservation program intended to enhance the natural production of spring Chinook in the Chewuch, Methow, and Twisp rivers. The current production goal is 223,756 smolts.

Winthrop National Fish Hatchery Spring Chinook

The WNFH released spring Chinook in the Methow River from 1942 to 1962, then again from 1976 until present. The program's goals are to compensate for a portion of lost fish production due to the construction of Grand Coulee Dam while minimizing impacts on naturally-spawning spring Chinook. The program was a segregated harvest program using unlisted "Carson" stock (originating from the Carson NFH) until 2000 when it switched to local broodstock. This transition linked the program with the local population according to the "stepping-stone" concept described by the Hatchery Scientific Review Group (HSRG 2009). Within this context, the program operates as the safety-net program to the Methow Hatchery spring Chinook conservation program using Methow Hatchery returns as broodstock. Accordingly, returns from this program are 100% externally-marked and available for selective harvest fisheries when deemed appropriate by fisheries co-managers, but available to support natural spawning and broodstock needs in years of low escapement. The current production goal is 400,000 but 200,000 additional eggs are transferred and used for the reintroduction of spring Chinook into the Okanogan (see below).

Twisp Hatchery Steelhead

The Twisp Steelhead conservation program began in 1997 and is an integrated conservation program. Smolts are raised at the Wells Hatchery (see below) and released at the Twisp acclimation ponds. Broodstock is collected in the Twisp River. The program is funded and operated by DPUD. Currently the production goal is 48,000 smolts.

Winthrop National Fish Hatchery Steelhead

In 1995, the Leavenworth NFH steelhead program was relocated to WNFH. A consistent goal of the program has been to compensate for a portion of lost fish production due to the construction of Grand Coulee Dam. Since the 1997 ESA listing, the program has evolved towards aiding recovery of this stock. Beginning in 2008, the program transitioned from a more traditional harvest augmentation program to an integrated conservation program. This transition was completed by 2015 and included transition to locally-collected, primarily natural-origin broodstock to reduce domestication selection on the spawning grounds while supporting the number of naturally-spawning fish on the spawning grounds. This programmatic shift linked the program with the local population according to the "stepping-stone" concept described by the Hatchery Scientific Review Group (HSRG 2014). Within this context, the program operates as the primary integrated broodstock generator which is subsequently supported by a safety-net program at Wells hatchery. Returns from this program are 100% externally-marked and are able to be managed when deemed appropriate by fisheries co-managers, but available to support natural spawning and broodstock needs in years of low escapement.

Methow Hatchery Steelhead

The Methow Safety Net program releases 100,000 smolts from Wells Hatchery into the Methow River. The program operates as a safety-net program for the Winthrop Hatchery Steelhead conservation program and uses WNFH returns for broodstock. The program is funded and operated by Douglas PUD.

Mid-Columbia Coho

The Mid-Columbia Coho program is a re-introduction program targeted at re-establishing naturally-produced coho in the Methow and Wenatchee subbasins (see more info in Wenatchee programs). The current production target for the Methow is 500,000 smolts. The program is funded by BPA, DPUD, GPUD, CPUD and operated by the U.S. Fish and Wildlife Service and the Yakama Nation.

Methow Hatchery Summer Chinook

The Methow Summer Chinook program is an integrated harvest program. Broodstock is collected from the run-at-large at Wells Dam. Beginning in 2012 the collection goal was reduced by more than half based on updated NNI goals. The program is funded by Grant PUD and operated by WDFW. Currently, the program has a release goal of 200,000 smolts.

Okanogan Subbasin

- 4 hatchery programs (3 conservation, 1 reintroduction)
- 3,100,000 smolt target (LISTED- 100,000 steelhead, 200,000 spring Chinook)

There are four hatchery programs in the Okanogan subbasin releasing sockeye, spring Chinook, summer Chinook, and steelhead. Summer Chinook (1.2 million smolt target) are released from the Okanogan River and the Similkameen River for harvest and conservation. A total of 200,000 spring Chinook are transferred from the Winthrop NFH safety-net program as part of an ESA Section10j reintroduction program in the Okanogan. Steelhead (100,000 smolt target) are reared at Wells Hatchery and acclimated and released as part of a conservation program from the Okanogan River, Similkameen River, and Omak, Salmon, Aeneas, and Antoine creeks. Sockeye fry are released into Skaha Lake and Lake Osoyoos in Canada (1.6 million smolt mitigation target).

In recent years, there has been a large increase in hatchery Chinook smolt releases in the Okanogan subbasin because of the completion of Chief Joseph Hatchery and the start of its summer Chinook program. Also, the Okanogan River steelhead program has been increasing its use of natural-origin fish collected in the Okanogan Basin, and is working to develop local broodstock for the program. More information about programs that release hatchery fish in the Okanogan subbasin can be found below.

Okanogan Hatchery Steelhead

The Okanogan Steelhead program is an integrated conservation program that rears juveniles at Wells Hatchery and releases smolts in the mainstem Okanogan and Similkameen rivers and in Omak Creek, Salmon Creek and several other smaller tributaries. Broodstock collection has recently shifted from 20% Omak Creek and 80% run at large at Wells Dam, to 100% within the Okanogan

Basin. Currently the production goal is 100,000 smolts. The program is funded and operated by and the CCT and DPUD.

Chief Joseph Hatchery Spring Chinook

The Chief Joseph Hatchery spring Chinook program consists of a reintroduction program in the Okanogan River and a segregated program at Chief Joseph Hatchery. The reintroduction program uses within-ESU origin spring Chinook from the Methow River (WNFH safety-net program) as stock for this designated "experimental" reintroduced population within Upper Columbia spring Chinook historic range. The program is funded by BPA, Chelan, Douglas, and Grant PUDs and operated by the Colville Confederated Tribes. Currently, the reintroduction program has a production goal of 200,000 yearlings.

Chief Joseph Hatchery Summer/Fall Chinook

The Chief Joseph summer/fall Chinook program in the Okanogan is an integrated program with conservation and harvest objectives. The program is funded by BPA, Chelan, Douglas, and Grant PUDs and operated by the Colville Confederated Tribes and WDFW (Similkameen Acclimation Pond). This program has a production goal of 1.2 million smolts.

Okanogan Sockeye

Production from the Okanogan sockeye program began in 2004 at the Shuswap Hatchery. Production moved to the new hatchery in Penticton in 2014. The goals of this program are reintroduction and harvest and is funded by Chelan and Grant PUDs and operated by the Okanogan Nation Alliance. The program has a production goal of 1.6 million smolts but is subject to change according to the findings of the monitoring programs.

Mainstem Columbia

- 7 hatchery programs (1 conservation)
- 13. 94 million smolt target (LISTED- 160,000 steelhead)

There are six major hatcheries on the mainstem Columbia in the region and five programs that release steelhead and spring, summer, and fall Chinook directly into the mainstem Columbia. Mainstem hatcheries provide most mitigation production for the region. In addition, Wells, Eastbank, and Chief Joseph hatcheries also serve as the spawning and rearing facility for various conservation and safety-net programs throughout all four subbasins. Upriver bright fall Chinook (10.8 million smolt target) are released for harvest from Priest Rapids Hatchery and Ringold Springs Hatchery at the southern extent of the region. Summer Chinook (2.28 million smolt target) are released for harvest from Chelan Falls Hatchery, Wells Hatchery, and Chief Joseph Hatchery. Unlisted spring Chinook (700,000 smolt target) are released for harvest from Chief Joseph Hatchery. Steelhead (160,000 smolt target) are released from Wells Hatchery as a safety-net program.

One of the biggest changes in mainstem Columbia hatchery production in the Upper Columbia has been the completion and implementation of the Chief Joseph Hatchery and its programs. This hatchery significantly increased mainstem production for harvest. Another change was the closing of Turtle Rock Hatchery and the move of those releases to Chelan Falls Hatchery. The re-programming of safety-net hatchery steelhead from Methow Basin to Wells Hatchery and the Columbia River is also a recent change. More information about programs that release hatchery fish in the mainstem Columbia can be found below.

Chief Joseph Hatchery Spring Chinook
The Chief Joseph Hatchery has a spring Chinook segregated program that releases into the mainstem Columbia and a spring Chinook reintroduction program in the Okanogan River (see above). The segregated program is funded by BPA CPUD, DPUD, and GPUD and operated by the Colville Confederated Tribes. The program uses unlisted Leavenworth stock and currently has a production goal of 700,000 yearlings released into the Columbia River.

Chief Joseph Hatchery Summer/Fall Chinook
The purpose of the Chief Joseph Hatchery summer/fall Chinook program is to increase harvest The program has both a segregated component for harvest and an integrated component for restoration and conservation purposes. The segregated program will be a "stepping stone" program, striving to only use first generation returns from the integrated program. This program is funded by BPA, CPUD, DPUD, and GPUD, and operated by the Colville Confederated Tribes. It has a production goal of 900,000 smolts which are released into the mainstem Columbia from the hatchery.

Wells Hatchery Steelhead
The Wells Hatchery steelhead program provides inundation mitigation for Douglas PUD. The safety-net program is operated by DPUD and releases 160,000 inundation-comp fish into the Columbia River from Wells Hatchery. The program uses broodstock from Methow Safety-Net and Wells returns. Adult returns support recovery goals and, during years of high abundance, provide harvest opportunities.

Wells Hatchery Summer Chinook
The Wells summer Chinook program is a harvest augmentation program. Broodstock collection is typically from the Wells Hatchery volunteer channel trap and may include Wells Dam fishway trapping if needed. Up to 10% of the broodstock is of natural origin. The program is funded and operated by Douglas PUD. The production goal is 804,000 smolts released into the Columbia River at Wells Hatchery.

Chelan Falls Hatchery Summer Chinook
The Chelan Falls Summer Chinook program is a harvest augmentation program. Originally the program released both sub-yearling and yearlings; however, this was changed in 2010 to entirely yearlings. Currently broodstock is collected at the Chelan Falls Canal Trap located at the Chelan River, prior to that broodstock collection was at the Eastbank Hatchery Outfall (2013 to 2015), and at Wells Dam and/or Wells Hatchery. The program is funded by Chelan PUD and operated by WDFW. The production goal of 576,000 yearling smolts which are released into the Chelan River at the Chelan Falls Hatchery.

Priest Rapids Fall Chinook
The Priest Rapids fall Chinook program is at the southern extent of the Upper Columbia region. The Priest Rapids program is an integrated harvest program which began operations in 1963 and currently has a release goal of 7.3 million sub-yearling smolts. Broodstock for this integrated program is collected at Priest Rapids Hatchery; beginning in 2010, unmarked adults from Priest Rapids Dam were also collected to integrate more natural-origin fish. The program is funded by Grant PUD and the Army Corps of Engineers and operated by WDFW.

Ringold Springs Fall Chinook
The Ringold Springs fall Chinook program is at the southern extent of the Upper Columbia region. The Ringold program is an integrated harvest program. Broodstock is collected at Priest Rapids and Ringold hatcheries. The program is funded by the Army Corps of Engineers and operated by WDFW. The program currently releases 3.5 million smolts but the program has a proposed target of 10.4 million fall-Chinook releases into the mainstem Columbia, pending facility upgrades.

Egg sorting at Leavenworth NFH.

Table 4. Current (2016) Hatchery programs in the Upper Columbia region.

Species	Program	Subbasin(s)	Program Component(s)	Goals	Production Goal	Operator	Funding Entity[a]
Spring Chinook	Wenatchee Spring Chinook	Wenatchee	Nason, White[b], Chiwawa	Conservation	269,026	WDFW	C, G
	Wenatchee Spring Chinook	Wenatchee	Nason	Safety-Net	98,670	WDFW	G
	Methow Spring Chinook	Methow	Methow, Twisp, Chewuch	Conservation	223,765	DPUD	C, D, G
	Winthrop Spring Chinook	Methow		Safety-Net	400,000	FWS	BOR
	Leavenworth Spring Chinook	Wenatchee		Harvest	1,200,000	FWS	BOR
	Chief Joseph Spring Chinook	Okanogan		Harvest	700,000	CCT	BPA, C, D, G
	Chief Joseph Spring Chinook	Okanogan		Reintroduction	200,000	CCT	BPA, C, D, G
Steelhead	Wenatchee Steelhead	Wenatchee		Conservation	123,650	WDFW	C
	Wenatchee Steelhead	Wenatchee		Safety-Net	123,650	WDFW	C
	Wells Steelhead	Methow, Columbia	Methow, Wells	Safety-Net	260,000	DPUD	D
	Twisp Steelhead	Methow	Twisp	Conservation	48,000	DPUD	D
	Winthrop Steelhead	Methow		Conservation	200,000	FWS	BOR
	Okanogan Steelhead	Okanogan		Conservation	100,000	DPUD, CCT	G
Coho	Mid-Columbia Coho	Wenatchee, Methow	Wenatchee, Methow	Reintroduction	1,500,000	YN	BPA, C, D, G
Summer/Fall Chinook	Priest Rapids Fall Chinook	Columbia		Harvest	7,300,000	WDFW	G, ACE
	Ringold Springs Fall Chinook	Columbia		Harvest	3,500,000	WDFW	ACE
	Chelan Falls Summer Chinook	Columbia		Harvest	576,000	WDFW	C
	Wells Summer Chinook	Columbia		Harvest	804,000	DPUD	D
	Wenatchee Summer Chinook	Wenatchee		Harvest	500,000	WDFW	C, G
	Entiat Summer Chinook	Entiat		Harvest	400,000	FWS	BOR
	Methow Summer Chinook	Methow		Harvest	200,000	WDFW	G
	Chief Joseph Summer/Fall Chinook	Columbia		Harvest	900,000	CCT	BPA, C, D, G
	Chief Joseph Summer/Fall Chinook	Okanogan		Conservation/Harvest	1,200,000	CCT	BPA, C, D, G
Sockeye	Okanogan Sockeye	Okanogan		Reintroduction/Harvest	1,600,000	ONA	C, G

D-Douglas PUD, G-Grant PUD, C-Chelan PUD, BPA- Bonneville Power Administration, ACE- Army Corps of Engineers, BOR- Bureau of Reclamation

[b]*The last release of juveniles from the captive brood program occurred in 2015.*

Smolt Production

Hatchery production in the region takes place at the eight hatcheries and ten rearing and acclimation facilities. Total artificial production targets in the Upper Columbia River exceed 22 million juveniles annually, nearly 2 million of which are listed species (Table 5). Of the 22 million smolts, 10.3 million upriver bright fall Chinook are reared and released at Priest Rapids Hatchery and Ringold Spring Hatchery at the lower extent of the region and up to 1.6 million hatchery sockeye fry are released into the Okanogan subbasin from the the k] cpə'lk' stim' Salmon Hatchery in Canada.

Programs in the Upper Columbia fall under several different artificial propagation strategies that address the different goals of the program: reintroduction, conservation, and harvest. In the Upper Columbia 85% of smolts released are produced for harvest. The remaining 15% of production is for conservation, reintroduction, and safety-net production (Table 5).

Table 5. Current hatchery production and primary program goals in the Upper Columbia.

	Goal*				
Species	Conservation	Harvest	Reintroduction	Safety-Net	Grand Total
Spring Chinook	492,791		200,000	498,670	1,191,461
Steelhead	471,650			383,650	855,300
Unlisted Spring Chinook		1,900,000			1,900,000
Summer/Fall Chinook		15,380,000			15,380,000
Coho			1,500,000		1,500,000
Sockeye		1,600,000			1,600,000
Grand Total	964,441	18,880,000	1,700,000	882,320	22,426,761

** Some programs have more than one goal (such as the Okanogan summer Chinook program which produces fish for conservation and harvest.).*

In-hatchery rearing strategies are designed to maximize survival of eggs, fry, and juveniles and improve hatchery fish performance within the hatchery to improve performance in the natural environment. Measures such as those implemented to reduce precocious maturation, improve juvenile swimming performance, and meet biologically-based size targets have been researched heavily and implemented in many programs to improve hatchery outcomes. These approaches have the potential to increase survival, reduce ecological interactions, and mimic variables of natural origin fish such as size-at-maturity (e.g. Beckman et al. 2017; Berejikian et al. 2016; Johnson et al. 2015). Where it is reported, in-hatchery survival from unfertilized egg to release has been between 60-90% with most listed programs having set permit requirements for in-hatchery survival (Snow et al. 2016; Hillman et al. 2016; M. Humling 2017, pers com.).

Since 1999, there has been steady production of listed spring Chinook and steelhead in all four subbasins of the Upper Columbia (Figure 7). The recent exception is the Entiat River steelhead releases stopped in the late 1990's and spring Chinook releases stopped in 2007 (Figure 7). Leavenworth NFH has consistently released over a million unlisted spring Chinook in the Wenatchee over the past two decades. Leavenworth NFH has produced 32% of all spring Chinook hatchery fish in the region over the past 10 years. Hatchery production of spring Chinook in general is greatest in the

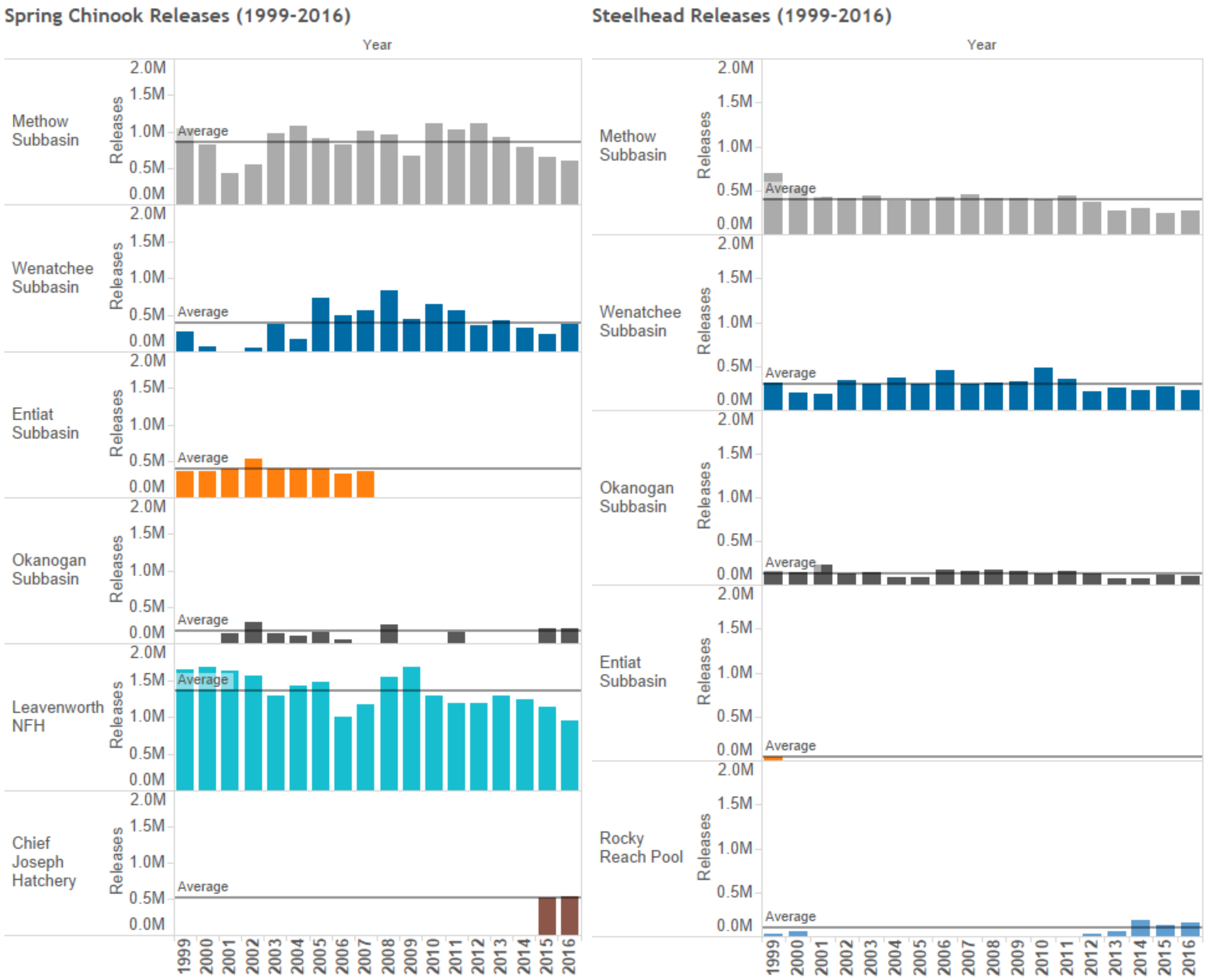
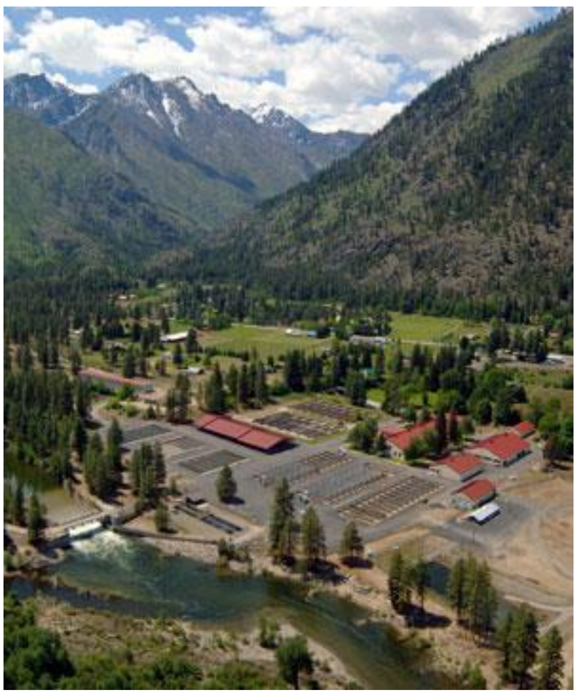


Figure 7. Releases from hatchery programs in the Upper Columbia region based on hatchery release data from Fish Passage Center (August 1, 2017). Wenatchee spring Chinook releases do not include LNFH (which are graphed separately). Spring Chinook releases from LNFH and CJH are from unlisted harvest programs.

Wenatchee subbasin because of LNFH releases. Releases of listed spring Chinook are greatest in the Methow (45% of all listed spring Chinook releases from 2006-2016) followed closely by the Wenatchee with 43% of listed spring Chinook releases between 2006-2016. Spring Chinook releases in the Wenatchee subbasin were low after ESA listing due to broodstock contraints then peaked in 2008. Recent changes in production targets have decreased hatchery releases in all subbasins since 2013, mostly due to recalculated mitigation obligations (NNI) for the PUD programs. Leavenworth NFH also decreased production targets for spring Chinook from 1.625 million to an interim 1.2 million in 2010 in an effort to maintain optimum fish health and rearing parameters until such time infrastructure repairs and water quality improvements are realized.

Steelhead hatchery production in the Upper Columbia is relatively low compared with spring Chinook releases. Since 1999 an average of 846,386 steelhead smolts have been released per year from tributaries (Figure 7). Steelhead originally were released from all four subbasins but steelhead production in the Entiat stopped in 1999 when the Entiat NFH transitioned to a spring Chinook program. Over the past 10 years (2006-2016) steelhead hatchery production has primariy occurred in the Methow subbasin (42% average) and Wenatchee subbasin (36% average). A smaller portion or hatchery releases occur in the Okanogan subbasin (15%) and from Wells Hatchery in the Rocky Reach pool of the Columbia River mainstem (13%). Similar to spring Chinook, steelhead production in the region has decreased since 2013, mostly due to recalculated mitigation obligations (NNI) for the PUD programs. A protion of safety-net hatchery production in the Methow was trasferred to Wells hatchery starting in 2012.



Leavenworth National Fish Hatchery on Icicle Creek.

Hatchery programs release smolts from hatcheries in the mainstem and from hatcheries and acclimation facilities in the four major tributaries in the region (Figure 8). Most major hatchery facilities are located on the mainstem Columbia River but the three Leavenworth complex hatcheries (Leavenworth, Entiat, and Winthrop NFHs) as well as the Methow Hatchery are in spawning and rearing areas for spring Chinook and steelhead. Acclimation facilities are intentionally located in spawning areas. Broodstock collection facilities (Tumwater Dam, Dryden Dam, and the Chiwawa, Twisp, and Okanogan weirs) are located on migratory pathways and/or in spawning and rearing areas. Hatcheries in tributary habitat operate year-round and have the potential to affect habitat through water withdrawals, instream structures, floodplain and bank alteration, and hatchery effluent discharge. Acclimation facilities are only operational for part of the year but can impact habitat in similar ways. Some acclimate sites use natural ponds and are only used for a very short time period. These types of sites likely have minimal to negligible habitat impacts. Dams and channel-spanning weirs can block or delay migration and can impact habitat both upstream and downstream through water impoundment and increased velocities. In most cases, NOAA Fisheries or Washington Dept. of Ecology outline standards and guidelines for operation and maintenance of these facilities. Some activities are permitted under various laws and regulations. However, some hatcheries were constructed decades ago and have facilities that need to be updated. Many of these updates are currently underway. Leavenworth NFH and Tumwater Dam were identified in the *Recovery Plan* as having potential adverse effects on habitat (UCSRB 2007). The UC Biological Strategy (UCRTT 2013) notes several habitat-related factors associated with Leavenworth NFH, Okanogan acclimation sites, and Tumwater Dam.

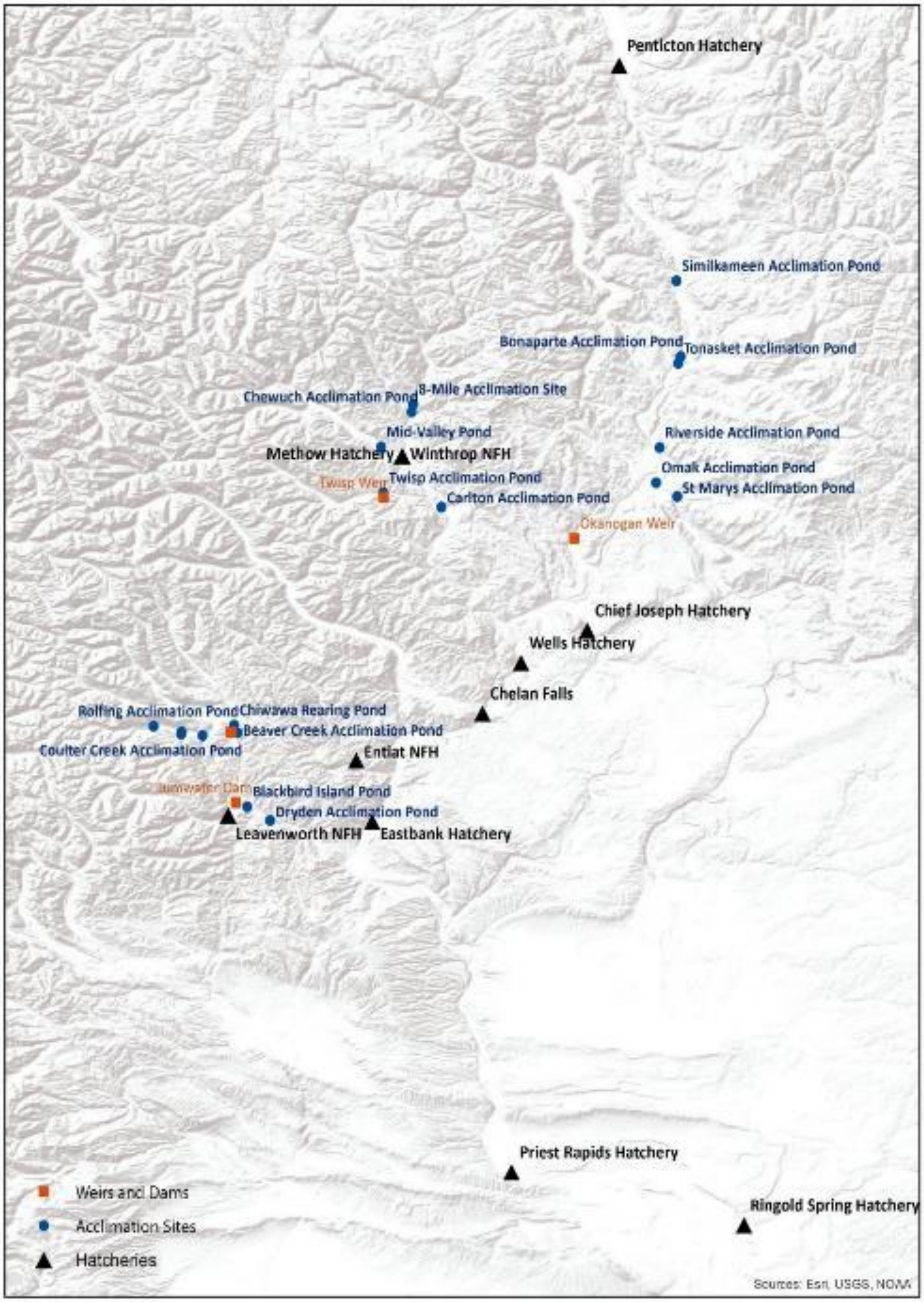


Figure 8. Hatchery facilities in the Upper Columbia including weirs and dams, acclimation facilities, and hatcheries.

Smolt Survival

Although hatchery-origin fish experience a much greater survival advantage in the hatchery during the egg-to-emigrant life stage, they can have a reduced survival rates as smolts once they leave the hatchery environment. These differences in survival rates between hatchery- and natural-origin smolts, when they exist, are thought to be related genetic differences between hatchery and natural-origin fish and differences between hatchery and natural environments. These differences manifest themselves in certain biological and behavioral characteristics, generally referred to as phenotypic traits. Phenotypic traits describe the suite of behaviors that largely determine the likelihood of survival in natural conditions, and certain hatchery-induced traits may reduce the survival of hatchery fish after release from a hatchery. Some phenotypic traits have a genetic basis and are inherited by each new generation, while others may be the result of environmental (including hatchery) conditions that are not heritable (HSRG 2009).

Smolt-to-adult survival rates (SARs) are calculated as the ratio of adult returns to smolt numbers released by hatcheries or produced in the wild. Research suggests that hatchery-origin fish can potentially have a lower ocean survival due to the constrained migration timing and comparatively poor foraging and predator avoidance in the natural environment (e.g. Beamish 2011). Based on recent hatchery monitoring in the region (Hillman et al. 2016; Snow et al. 2016; C.; Baldwin pers. comm.) of survival from juvenile release to return at Bonneville Dam between 2004-2010, SARs were approximately 0.4% (program range 0.36%-0.52%) for hatchery spring Chinook and 0.9% (program range 0.47%-1.68%) for hatchery steelhead. This means that in recent years approximately 4 spring Chinook adults and 9 steelhead adults have returned for every 1,000 smolts produced in the region. Compared to recent (2008-2015) estimates of natural-origin SARs from Rocky Reach to Bonneville Dam (0.76% for spring Chinook and 2.4% for steelhead) from the Fish Passage Center (McCann et al. 2017) hatchery-origin fish SARs are a quarter to a third of that of their natural counterparts. There does not appear to be a trend in SARs for most programs based on available data (Hillman et al. 2016; Snow et al. 2016).

A recent CPUD report (Hillman et al. 2016) noted that some of the variation between programs and years could be related to release location, type of release, and rearing scenario. This report noted that on average, steelhead released in the Chiwawa River appeared to have higher survival rates to McNary Dam than did steelhead released in the lower and upper Wenatchee River or Nason Creek. For steelhead released into Nason Creek and the Wenatchee River, fish released from circular tanks had higher survival rates than those released from raceways. This relationship between survival and performance of smolts and hatchery rearing and release strategy has been explored in several studies over the past decade and appears to be related to factors such as the size, growth, and phenotypic characteristics of the smolts produced by differing rearing strategies (e.g. Beckman et al. 2017; Berejikian et al. 2016; Johnson et al. 2015). Winthrop National Fish Hatchery has transitioned their hatchery steelhead program to a local brood-sourced conservation program requiring a 2-year hatchery rearing strategy. Tatara et al. (2017) showed similar, or better, survival for steelhead reared for two years in the hatchery rather than one, allowing for a hatchery program that better-protects local stock structure.

Adult Returns

Each year thousands of hatchery steelhead and spring Chinook return to the Upper Columbia. The number of returning adults is driven by hatchery releases in prior years, post-release survival rates of smolts (smolt-to-adult or SAR rates), adult survival, and stray rates. These returning hatchery-origin adults contribute to fisheries and to total spawner escapement (ISAB 2003; Bugert 1998; Reisenbichler 2004; Baumsteiger et al. 2008). The foundation of this desired effect is in the survival advantage for early life stages in the hatchery environment, which is expected to generate a number of hatchery-origin adults returning that is larger than would have resulted from natural spawning by the same number of parents (ISAB 2003). In years of low natural-origin returns, hatchery-origin adults can buffer the natural population against short-term extinction risk. In years of high natural-origin returns, hatchery-origin fish are often removed through adult management (see Adult Management section below) to meet permit requirements by managing the influence of hatchery-origin fish on natural-origin spawners.

Steelhead and spring Chinook hatchery-origin escapement to the Upper Columbia (at Priest Rapids Dam) is not easily summarized because not all hatchery-origin fish are externally marked (e.g. adipose fin-clipped) in a way that they could be counted at mainstem fish ladders. Grant PUD does count the number of adults that pass upstream of Priest Rapids Dam into the Upper Columbia. The PUD records the number of adipose-present fish (mixed natural-origin and hatchery-origin) and the number of adipose-clipped (hatchery-origin) fish. Between 2008-2016 an average of 15,457 ad-clipped hatchery-origin fish passed above Priest Rapids Dam. This represented about 75% of the average total run of 20,158 adult steelhead (Hillman et al. 2017).

Fish are identified and counted at Tumwater Dam and on spawning grounds but the number of fish that return to the region but do no spawn (e.g. because of pre-spawn mortality) is less well known. This total escapement is important to help understand how many of the smolts that are released in the region return to the region as adults. Hatchery-origin steelhead are now counted and tracked using PIT tag expansions from fish tagged and identified at Priest Rapids Dam and monitored at mainstem dams and PIT tag arrays but this monitoring effort has not been expanded to spring Chinook (see data gaps section).

Returning Chinook in the Wenatchee River. Photo by Russ Rickets.

Spring Chinook escapement can be estimated using various methods. WDFW uses radio telemetry (English et al. 2001, 2003) to estimate the run size into each tributary. U.S. Fish and Wildlife Service also tracks the number of Leavenworth NFH adult spring Chinook that return using sport harvest creels, estimated tribal harvest, spawning ground survey estimates, and LNFH fish ladder returns (Potter 2016). Using these data, the estimated average run escapement between 2011-2015 of hatchery-origin spring Chinook was 18,068 adults (min=12,145, max=20,096) (Figure 9). Of the hatchery-origin spring Chinook returning to the region, the majority are adults from the Leavenworth NFH Program (average 7,413 adults annually), followed by the Methow safety-net and conservation programs (average 7,106 adults annually), and the Upper Wenatchee safety-net and conservation programs (average 3,460 adults annually) (WDFW data 2017; Potter 2016). Hatchery-origin adult escapement into the Entiat subbasin can be estimated based on spawning survey data and an estimate of pre-spawn mortality (10%) (WDFW SASI database 2017). Approximately 90 hatchery-origin adult spring Chinook returned on average between 2011-2015 as strays from other areas.

As Chief Joseph Hatchery spring Chinook harvest program ramps up over the next several years it is expected that it will also contribute hatchery-origin adults (2,500-5,000 adults) to the region. All hatchery-origin spring Chinook returns to the Entiat subbasin are strays from programs in other areas. The nearby Eastbank Hatchery facility is used for rearing the Wenatchee River supplementation stock prior to transfer to the Chiwawa acclimation pond. It is possible that some of the returns from that program are homing on the Eastbank facility and then straying into the Entiat River, the nearest spawning area (NOAA 2016).

Steelhead escapement is estimated by WDFW using a similar methodology. Based on these estimates, the average hatchery-origin steelhead run size between 2011-2015 was 9,776 adults (min=5,872, max=10,537) returning to the Wenatchee, Entiat, Methow, and Okanogan (WDFW PIT tag escapement data 2017). Adult hatchery-origin steelhead also return to Wells Hatchery on the mainstem Columbia (up to several hundred some years), and to other smaller tributaries on the Columbia but data were not available to include them in these estimates. Most hatchery-origin steelhead adults return to the Methow from the Methow Hatchery safety-net and Winthrop NFH conservation steelhead program (average 3,972 annually), followed by the Okanogan steelhead conservation program (average 2,219 annually), and the Wenatchee steelhead conservation and safety-net programs (average 1,521 annually) (WDFW data 2017; Potter 2016) (Figure 9). A small number of hatchery-origin adults (360 average) return to the Entiat subbasin as strays from other watersheds.

Hatchery-origin spawners that return to the region are intentionally managed to meet a variety of goals. Some are caught in fisheries, some are removed through adult management, some collected for broodstock, and some return to spawn in the wild. The ultimate fates of returning adults largely depends on: 1) the purpose or goal for which they were produced; 2) considerations such as permit regulations; 3) the hatchery and natural spawning escapement in any given year; 4) the broodstock targets for hatchery programs; and 5) adult management facilities and policies. Adult returns from conservation programs are managed differently from safety-net or harvest programs. The intent of segregated harvest programs is to remove hatchery-origin adults from the population to the extent possible to prevent introgression with the natural spawning population. Adults from safety-net programs are sometimes removed through broodstock collection and/or adult management when they are not needed to meet escapement goals. The fate of adults from conservation programs depends on a variety of factors discussed later in this document (see "Adult Management" section).

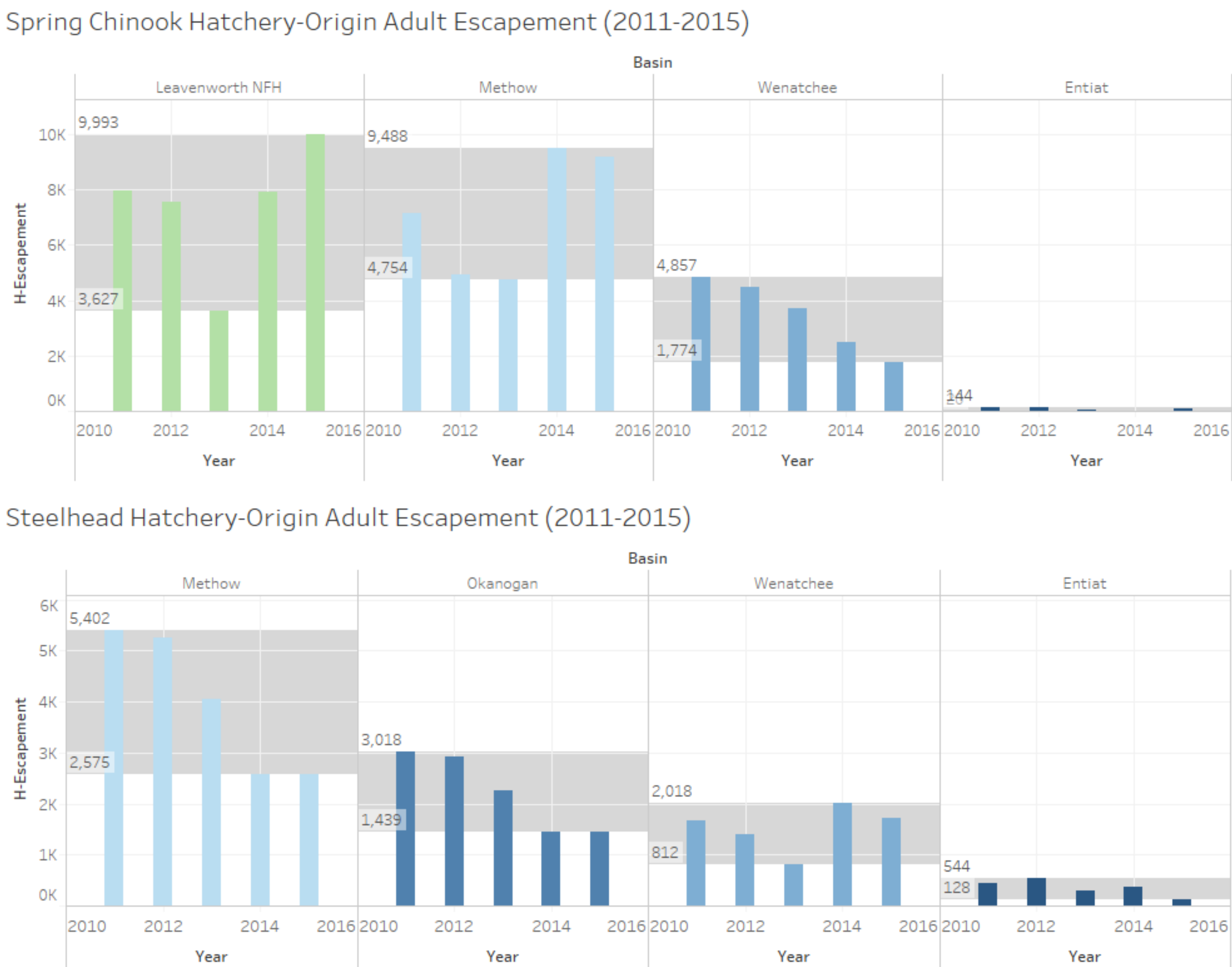


Figure 9. Hatchery-origin adult escapement estimates to Upper Columbia tributaries before tributary fisheries, broodstock collection, adult management, and spawning (Potter 2016; WDFW PIT tag escapement data 2017). Spring Chinook hatchery returns to the Entiat subbasin are strays. Error bars are from WDFW PIT tag escapement estimates.

Phenotypic characteristics such as migration timing, spawning distribution, age and size at maturity, sex ratio, and fecundity and egg size are monitored to assess how similar the hatchery-origin fish are to natural-origin fish. Hatchery- and natural-origin fish appear to be similar in most characteristics, but differ in terms of their spawning distribution in some areas and their age at maturity (Hughes and Murdoch 2017; Hillman et al. 2016; Murdoch et al. 2016). There can also be differences in the age at which hatchery-origin juveniles are released compared with the range in out-migration timing of natural-origin juveniles. Many of these differences in life history and phenotypic traits are the result of hatchery practices that have led to differences in the survival and reproductive success of hatchery- and natural-origin fish as described in the relative reproductive success studies and the annual hatchery reports (Hillman et al. 2016; Snow et al. 2015; Goodman et al. 2016; Murdoch et al. 2015; Ford et al. 2015). Hatchery managers carefully monitor these traits of hatchery-origin fish and modify their practices to reduce differences between hatchery- and natural-origin fish.

Adult Survival

As noted earlier, hatchery-origin fish can have different survival rates than natural-origin fish. Survival rates of adults can be different due to physical traits, behavioral traits, as well as different management of hatchery-origin adults. Hatchery-origin adults are exposed to mark selective fisheries during ocean residency and upriver migration and therefore have higher mortality than unmarked hatchery- or natural-origin fish. Marked hatchery-origin fish may also be exposed to different handling in monitoring or research programs depending on the goals and permit requirements of those studies.

Hatchery-origin fish could also experience differential predation rates if they exhibit different phenotypic or behavior traits that predispose them to predation. Hatchery-origin spring Chinook could experience differential predation rates if they exhibit earlier migration timing than their natural-origin counterparts based on recent monitoring in the Columbia River estuary. Sorel et al. 2017 found that timing of river entry had a strong effect on population-specific survival rates. Hatchery-origin fish such as Leavenworth spring Chinook could experience higher predation rates due to their migration timing (Sorel unpublished data). Most hatchery-origin spring Chinook in the region appear to have similar migration timing (Snow et al. 2017; Hillman et al. 2017) and therefore likely experience similar predation rates.

Some studies have indicated a difference in the pre-spawn mortality rates of hatchery-origin adults in tributaries (e.g. Bowerman et al. 2017; Schroeder et al. 2007; Young and Blenden 2011) and may be related to factors such as increased spawner density, spawning location, greater competition, elevated fishery effort, or phenotypic differences between natural- and hatchery-origin fish. In some hatchery populations, phenotypic traits can rapidly diverge from wild genetic stock (Weber and Fausch 2003; Knudsen et al. 2006), potentially resulting in trait differences that could lead to higher mortality of hatchery adults. Life history or behavior traits (e.g. migration timing or holding locations) can also make hatchery-origin adults more susceptible to mortality. The relative reproductive success study of spring Chinook in the Wenatchee will provide more information about the differences in pre-spawn mortality between hatchery- and natural-origin adults and the causes for those differences within the next 5 years.

Adult Straying

Based on passive integrated transponders (PIT tags), some proportion of adults detected at Bonneville Dam are subsequently not detected at Rock Island Dam (PTAGIS 2016). Some of these fish die or are intercepted in fisheries before reaching the Upper Columbia but at least some portion of these fish stray into non-target watersheds outside the Upper Columbia. Once reaching the Upper

Columbia, fish may also stray into non-target watersheds within the region. Straying is defined as those individuals that return to spawn in locations other than their natal spawning grounds or hatchery. Straying can within the same subbasin (within-basin straying) or to other subbasins within the ESU or DPS (out-of-basin straying) and each is viewed differently by managers. Straying is considered a desirable and natural characteristic of salmon, and is critical to genetic resilience, demographic stability, and range expansion into unexploited habitats (Keefer and Caudill 2012). However, the stability of salmonid population structure can be undermined by increased hatchery-origin strays. Such increases can lead to gene flow above natural levels and be counterproductive to recovery efforts within listed ESUs because of hatchery adaptations or domestication (Epifanio et al. 2003, Waples and Drake 2004), losses of genetic variability through supportive breeding (Ryman and Laikre 1991, Wang and Ryman 2001), and erosions of natural population structure such as homogenization (Utter 2005). The ultimate impact of these increases in gene flow is dependent upon the duration of the increase, the proportion of exogenous spawners, and the origin of those spawners (ICTRT 2007). The Interior Columbia TRT (ICTRT 2007) risk criteria associated with spawner composition that considers hatchery-origin straying.

Straying may result from proximate causes such as a failure to home resulting from incomplete learning of odors during juvenile stages, inability to retain odor memories, failure to detect or respond to odors as adults, or physical incapacity to reach the home site, among other reasons. Alternatively, straying may represent adaptive behavior patterns, allowing colonization and buffering against environmental change (Westley et al. 2013). Rates of straying in natural populations vary between species and populations and can be highly variable (Keefer and Caudill 2014). Although some level of straying is natural to these populations, hatchery-origin fish can, in some cases, stray at a higher rate than what is expected from natural-origin fish (Ford et al. 2015). Hatchery programs are managed, within the confines of facilities and policies, to limit straying so that spawners return to their target hatchery or tributary.

Ford et al. (2015) found large variation in spring Chinook salmon stray rates in the Wenatchee subbasin that were related to origin (hatchery vs. natural) and location. Hatchery-origin fish released from the Chiwawa acclimation facility had higher stray rates than natural-origin fish produced from the same river. Progeny of hatchery-origin fish that spawned in nature had higher rates of straying than progeny of natural origin fish that spawned in nature. The results of the study were inconclusive on the causes for observed differences but the authors suggested that the difference in stray rates between origins could be a genetic effect. They further speculated that variation in spawning location may be partially explained by the quality of spawning habitat, with poor spawning habitat (e.g. the upper Wenatchee and lower Chiwawa River) related to high stray rates. Based on a sample size of 2,248 natural-origin and 1,1594 hatchery-origin fish, the authors estimated that the rate of homing to natal tributaries by natural-origin fish ranged from 0% to 99% depending on the tributary. Hatchery-origin fish released in one of the five tributaries homed to that tributary at a far lower rate than the natural-origin fish on average (71% compared to 96%) (Ford et al. 2015).

In terms of its relevance to hatchery management, straying of hatchery-produced fish and the subsequent interactions between stray hatchery-origin fish and natural-origin fish on the spawning grounds has been cited as a concern in some cases (Araki et al. 2008; Kostow 2009; Brenner et al. 2012). The level of concern for stray rates is related to the degree of relatedness between the hatchery- and natural-origin fish in a watershed. Hatchery fish derived from a local population may be allowed to stray into natural production areas at higher rates than those having out-of-basin ancestry. Low stray rates can maximize hatchery benefits and minimize hatchery risks by helping maintain local adaptation and genetic variation between stocks (Hillman et al. 2012). Hatchery practices (e.g. rearing and acclimation, broodstock selection, release strategies and locations) can influence stray rates of hatchery-origin fish through genetic and phenotypic mechanisms (HSRG 2009).

The most recent PUD monitoring and evaluation plan (Hillman et al. 2017) identifies three stray rate metrics; brood-year stray rate, among population return-year stray rate, and within population return-year stray rate. The PUDs have targets for return-year stray rate targets based on the ICBTRT (2005) and Upper Columbia Spring Chinook Salmon and Steelhead Recovery Plan (2007), which are linked to extinction risk. That is, hatchery strays from other populations cannot make up more than 5% of the spawning escapement within a non-target, recipient population. In addition, hatchery strays from other spawning aggregations within a population (e.g., Chiwawa spring Chinook) cannot make up more than 10% of the spawning escapement within a non-target, recipient spawning aggregate (e.g., White River). Brood-year stray rates are tracked to determine if hatchery operations affect the homing and straying of specific brood years. These data support the return-year stray metrics and are used to inform possible changes in genetic variation among stocks.

Currently there are only a few estimates of out-of-basin return-year stray rates are available because of the difficulty in calculating this metric (especially for steelhead where carcasses are not available to determine origin). U.S. Fish and Wildlife Service used coded-wire tag recoveries and PIT tags to estimate their return-year stray rates for the Winthrop NFH steelhead conservation program and spring Chinook safety-net program. Between 2011-2016 they found that less than 10 adults strayed each year and most years between 0 and 2 adults strayed outside their target subbasin. CPUD and GPUD reported that hatchery-origin Chiwawa spring Chinook have strayed into the Methow and Entiat basins at variable rates over the past few decades straying has been tracks (Hillman et al. 2017). In 6 of the past 10 years Chiwawa spring Chinook have made up more than 5% of the spawning escapement in the Entiat River basin. In three years, Chiwawa spring Chinook hatchery fish made up more than 20% of the spawning escapement in the Entiat River basin. In 2014 and 2015 the percentage of strays was <5% (Hillman et al. 2017). It is expected that more information about return-year straying will be available in the next few years as methods for estimating this metric are developed and improved.

Concerns have been raised about LNFH unlisted spring Chinook since it originated from a non-native stock (HRT 2007). Based on data from 2002-2016, the USFWS used coded-wire tag recoveries from returning fish (6,300 average) to estimate straying and found that approximately 5% of LNFH spring Chinook do not return to the hatchery and are not caught in fisheries (Potter

2016). These fish instead remain in Icicle creek or stray to other hatcheries or tributaries. Some adults stray into the Upper Wenatchee and are either removed at Tumwater Dam or escape to Upper Wenatchee tributaries. USFWS estimates some adult strays into the Upper Wenatchee in 2015 (estimated 20 adults) and in 2010 (estimated 20 adults) but none between 2012-2014. This equates to approximately 1% of total spring Chinook spawner escapement in the Upper Wenatchee in those years (Potter 2016). Overall, escapement of Leavenworth NFH hatchery-origin adults into the major spawning areas for spring Chinook appears to be very low (Potter 2016).

Broodstock Collection

A portion of returning adults are collected for hatchery broodstock each year to meet production goals at the various programs. The number of broodstock collected and the type of broodstock collected (hatchery or wild) are driven by the goals of the program, the production targets of the program, and the number of returning adults (Table 6). Conservation programs aim to preserve the genetic characteristic of the target population and therefore attempt to use an integrated broodstock where only local, natural-origin fish are used. This method is intended to maximize reproductive potential of natural-origin fish while minimizing genetic divergence between the hatchery- and natural-origin fish. Reintroduction programs use hatchery and/or natural-origin broodstock from closely-related populations. Safety-net programs have a goal of providing a "back-up" of broodstock in years when insufficient broodstock return from the conservation program. Therefore, these programs generally use hatchery returns from the associated conservation program. Harvest programs can be either segregated or integrated with the natural spawning population. *Segregated* harvest programs only use hatchery-origin fish in the broodstock while *integrated* harvest programs use some natural-origin fish in their broodstock.

Broodstock collection at Wells Hatchery.

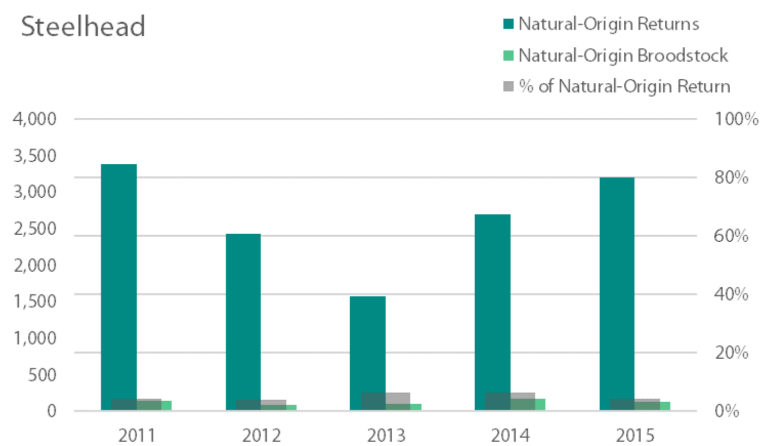
Table 6. Current (2016) broodstock collection goals for Upper Columbia spring Chinook and steelhead hatchery conservation programs.

Species	Program	Target NOB[a]	Target HOB	Target pNOB	Source
Spring Chinook					
	Chiwawa Conservation	80	0	100%	Tumwater Dam and Chiwawa Weir
	Nason Conservation	70	0	100%	Tumwater Dam and Nason Creek
	Nason Safety-Net	0	72	0%	Chiwawa/Nason Conservation Program
	Methow Conservation	122	0	100%	Methow Chewuch Composite, Twisp
	Winthrop Safety-Net	0	264	0%	Methow Hatchery Program
	Okanogan Reintroduction	0	132	0%	Winthrop Safety-Net Program
TOTAL		272	470		
Steelhead					
	Wenatchee Conservation	68	0	100%	Wenatchee
	Wenatchee Safety-Net	0	70	0%	Wenatchee Conservation Program
	Twisp Conservation	26	0	100%	Twisp River, Wells Dam, Methow River
	Winthrop Conservation	110	0	100%	Methow River
	Methow Safety-Net	0	156	0%	Winthrop Safety-Net Program, Wells Dam
	Okanogan Conservation	58	0	0%[b]	Okanogan Basin and Wells Dam
TOTAL		262	226		

[a]Not to exceed 33% of NOR population

[b]The goal is 100% pNOB for programs, but provisions exist to collect known Okanogan hatchery-origin fish if shortfalls of natural-origin fish occur.

An average of 187 natural-origin spring Chinook were collected each year for broodstock between 2011-2015 (WDFW 2016; Table 6). Within an individual subbasin, this equates to between 6-31% of spring Chinook runs between 2011-2015 in the Methow and Upper Wenatchee (average 22.3% for the Methow and 12% in the Upper Wenatchee). An average of 130 natural-origin steelhead were collected each year in the Upper Columbia which equates to between 2-9% of steelhead runs during this time period (average 6.5% Methow, 3.4% Okanogan, and 4.5% Wenatchee) (WDFW 2016; WDFW SaSI 2016; Figure 10).



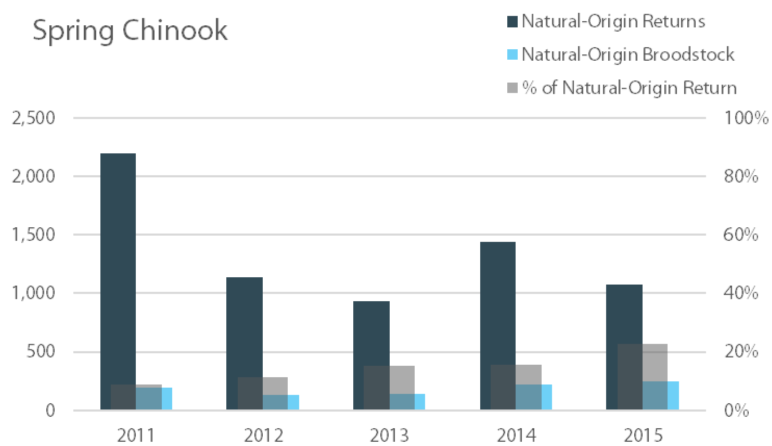


Figure 10. Number of natural-origin returns and natural-origin broodstock collected (and % of natural-origin run collected for broodstock) between 2011-2015 in Upper Columbia subbasins supplemented with listed steelhead and spring Chinook.

In the past, most hatchery programs have been operated in a manner that prevented the natural selection of population characteristics adapted to the local environment because they did not use local broodstock and did not manage hatchery returns. Proper integration or segregation of hatchery programs is the recommended means to minimize adverse effects of hatcheries on local adaptation of populations. Local adaptation of hatchery-origin fish is achieved by using local broodstock and avoiding transfer of hatchery-origin fish among watersheds. Local adaptation maximizes the viability and productivity of the population and maintains diversity within and between populations. Local adaption is also important to enable populations to adapt to changing environmental conditions (HSRG 2009). Most programs can collect broodstock from local sources and some composite broodstocks using multiple spawning aggregates have been developed to integrate natural-origin fish and meet recovery and mitigation goals (Table 6). Programs may use natural-origin broodstock (NOB) and/or hatchery- origin broodstock (HOB) depending on their goals. The percent natural-origin broodstock (pNOB) is used by hatchery managers to track the proportion of a hatchery broodstock composed of natural-origin adults. It is also used by some managers in calculations to assess genetic risks (see PNI discussion below).

Collecting enough natural-origin broodstock to meet production goals can be a challenge for conservation programs in years of limited natural escapement, and the permit restriction for collecting natural-origin returns based on run sizes any given year. Many programs follow some type of sliding-scale management goals based on natural-origin escapement (see individual Biological Opinions for program variations). These goals help minimize the risks of hatchery programs by minimizing use of natural-origin fish while maintaining an adequate infusion of natural genotypes into the broodstock.

Broodstock collection goals minimize removal of natural-origin fish for broodstock when natural-origin escapement is low to allow most or all natural-origin fish to spawn. At high natural-origin escapement the goal is to maximize natural-origin broodstock to maximize broodstock integration (pNOB) (see example in Table 7). Programs are almost always limited in collection of NOB to no more than 33% of the natural-origin run based on permit requirements. In some years, low returns of natural-origin spawners and broodstock collection constraints have resulted in mitigation goals not being met for some conservation hatchery programs.

Table 7. Example of sliding scale management goals at different natural-origin escapement levels (adapted from T. Cooney presentation).

Natural-Origin Returns (percentile)	Natural-Origin Broodstock Goals	Hatchery-Origin Spawner Goals	Proportion of Natural Influence (PNI) Goals	Overall Goal
Low (<10%)	Minimize	Maximize	Any PNI	Maximize escapement overall
Moderate (50%)	Extract no more than 33% of NOR run	Control for PNI	>0.5	Maximize natural escapement
Large (>75%)	Maximize but extract no more than 33% of NOR run	Minimize	>0.67	Minimize hatchery escapement

In addition to direct collection of adults for broodstock the handling of adults during broodstock collection and monitoring can lead to additional adult mortality. Some programs collect their broodstock from fish entering the hatchery, typically into a fish ladder and holding pond, while others sort through the run at-large, usually at a weir, ladder, or sampling facility or through angling techniques. The more a hatchery program accesses the run at-large, the greater the number of fish impacted indirectly. Although rare, unused natural-origin fish are returned to the river to spawn. Unused hatchery-origin fish may be culled or released into terminal fishery areas with no connection to anadromous waters. In the case of steelhead, recent hatchery practices allow natural-origin females to be live-spawned and returned directly to rivers or reconditioned in captivity to enhance repeat spawning.

Most programs have been more successful in recent years at collecting natural-origin broodstock and the need for NOB has decreased along with production goals. The WNFH steelhead, Methow spring Chinook, Twisp spring Chinook, and Chiwawa spring Chinook programs have each achieved a pNOB of 100% at least one of the last three years. During years of high natural-origin returns broodstock goals may be met while during years of low natural-origin returns broodstock goals may not be met (Hillman et al. 2016; Snow et al. 2016). Factors that can influence hatchery manager's ability to meet pNOB goals include low natural escapement, permit limitations, and production goals.

Hatchery adult returns produced from broodstock collected can be evaluated using a metric of hatchery replacement rate (HRR). HRR is the hatchery adult-to-adult returns and is calculated as the ratio of hatchery-origin returns (HOR) to the number of parent broodstock collected. Natural replacement rates (NRR) is the natural-origin adult-to-adult returns and is calculated similarly to HRR except using natural-origin returns and spawners.

The HRR of hatchery programs should be greater than the NRR (given their survival advantage in the hatchery) and should be equal to or greater than the program-specific HRR expected value based on estimated survival rates listed in Appendix 2 in Hillman et al. (2013). In almost all years and across all programs HRR>NRR meaning that hatchery-origin fish had a survival advantage over natural-origin fish. In most years hatchery return rates were a factor of 10-20 greater than natural return rates for spring Chinook and a factor of 30-60 greater for steelhead (Hillman et al. 2017; Snow et al. 2017) (Table 8).

Table 8. Hatchery and natural return rates reported by hatchery program. Spring Chinook RRs are calculated from brood years 2006-2010 (BY06-10) except for Winthrop NFH (BY04-08). Steelhead RRs are calculated from BY08-12 except for Twisp (BY11-12) and Winthrop NFH (BY08-10) (Hillman et al. 2017 and Snow et al. 2017).

			(Harvest Included)		
		Years Assessed	HRR	NRR	Hatchery Survival Advantage
Spring Chinook					
	Chiwawa	BY06-10	8.7	0.9	10
	Twisp	BY06-10	5.7	1	6
	Methow	BY06-10	6.7	0.37	18
	Chewuch	BY06-10	5.4	0.66	8
	Winthrop NFH	BY04-08	4.58	0.4	11
Steelhead					
	Wenatchee	BY08-12	15	0.5	30
	Wells	BY08-12	21.9	0.33	66
	Twisp	BY11-12	19.7	0.33	
	Winthrop NFH	BY08-10	15.3	0.3	51

A viable salmonid population that includes naturally spawning hatchery-origin fish should exhibit sufficient productivity from naturally-produced spawners to maintain population abundance at or above viability thresholds in the absence of hatchery subsidy (McElhany et al. 2000). For the natural population to remain stable or increase, the NRR must be at a level where parents are being replaced by their offspring as spawners in the next generation (Hillman et al. 2017). It is possible to affect an increase in natural-origin spawners through supplementation with a stable or decreasing NRR, however, if the NRR is below replacement (NRR<1.0), termination of the supplementation program will result in a declining natural population should that state of NRR persist (Hillman et al. 2017). In general, NRR across all Upper Columbia populations of spring Chinook and steelhead does not exceed 1.0 meaning that naturally-spawning adults did not replace themselves in the next generation (Hillman et al. 2016; Snow et al. 2016).

Most programs can collect broodstock from local sources although some composite broodstocks have been developed because of the need to integrate natural-origin fish and meet production goals. Collecting brood (hatchery- or natural-origin) from a location downstream of multiple populations results in mixing fish from 2 or more populations. This 'compositing' was common in past hatchery practices but has been greatly reduced or eliminated from the broodstock protocols for ESA-listed programs in the Upper Columbia. The ICTRT identified composited broodstock as a high-risk factor for diversity for Okanogan steelhead, due to the collection of brood at Wells Dam (ICTRT 2008). As of 2014, the Okanogan steelhead program has stopped using composite collections of broodstock at Wells Dam and now collect 100% within the Okanogan basin or at Wells Dam but only use fish if they are positively identified as having originated from the Okanogan program (through CWT reading during the spawning process) (Casey Baldwin pers. comm.).

Adult Management

Hatchery adult fish that return to the Upper Columbia are intentionally managed to meet the goals of the program and reduce risks to natural-origin fish. This "adult management" is defined as the intentional allocation of returning adult hatchery-origin adults to directly influence the number and origin composition of fish on spawning grounds. The primary goal of "adult management" is to enhance the numbers and success of naturally spawning adults. The primary objective of adult management is to achieve a target proportion of natural origin (NOR) adults on the spawning grounds, while concurrently achieving an optimum spawning escapement goal and retaining appropriate numbers of broodstock. Other adult management objectives include the social benefits through existence values and harvest opportunities, supplementation of other waters, and nutrient enhancement in basin tributaries (WDFW 2010).

Adult management is implemented pursuant to an adult management plan, developed under an HGMP, and permitted under the ESA. Managers use estimates of returning adults and origin composition to implement these measures in a way that allows them to influence the proportion of naturally spawning adults. Removal of hatchery-origin adults can occur through a variety of management tools including conservation fisheries, hatchery outfall trapping, and trapping at weirs or dams. Each of these measures can impose risks on natural-origin spawners, such as hooking mortality in catch-and-release conservation fisheries or handling stress associated with trapping.

Tagging and marking strategies are an important part of tracking and managing hatchery-origin fish. Most smolts released from hatcheries in the region are "ad-clipped" meaning their adipose fin is removed. This marker is used in some fisheries (mark-selective fisheries) to distinguish between hatchery- and natural-origin fish. Hatchery reared smolts are also marked with coded-wire tags (CWTs) which are also used in hatchery programs and are inserted into the snout of smolts before release. These tags are used in fisheries management and help distinguish hatchery-origin fish in adult management, spawning surveys, and other studies. Passive Integrated Transponder (PIT) tags are often used in a proportion of the smolts released from hatcheries to help answer a variety of question such as survival and movement of hatchery-origin fish. In some cases, other tagging methods such as floy tags, otolith marks, or genetic markers are used to answer specific questions. Tagging strategies are carefully developed by hatchery managers depending on the goals of the program and specific information needs.

Adult management for steelhead began in the Okanogan and Methow in 2003 with a conservation fishery (intended as a tool for adult management) for listed, hatchery-origin fish, and a weir at Omak Creek and several small tributaries in the Okanogan. In the Wenatchee, it began in 2007 with a fishery and then more intensively in 2010 with adult removal at Tumwater Dam. Adult management for spring Chinook began in 2013 with limited removal of fish at Tumwater Dam. A spring Chinook conservation fishery in the Wenatchee began the following year. In the Methow, adult management for spring Chinook began in 2010 (WNFH) and 2015 (both WNFH and Methow Hatchery) with removal at traps and weirs. There is currently not a permit for a spring Chinook conservation fishery in the Methow. Conservation fisheries have been restricted or eliminated in the Upper Columbia in recent years due to poor hatchery- and natural-origin returns.

The level of adult management in the Upper Columbia is often driven by sliding-scale management goals (Table 7). This means that when natural returns are low, the goal is to maintain the population and allow returning hatchery-origin fish to spawn (demographic management). When natural returns are high, the goal is to remove hatchery-origin fish to maximize natural-origin spawning and reduce genetic risks while still meeting escapement targets (see next section).

Between 2008-2015, a total of 60,000 or 20% of all hatchery-origin spring Chinook and steelhead returning to the Upper Columbia have been removed through adult management (including conservation fisheries in the mainstem Columbia [RI, RR, and Wells pools] and tributaries and direct removal of hatchery-origin fish at hatcheries, weirs, dams, and in-river) (Figure 11). This equates to an average of 5,000 hatchery-origin adults removed each year. The number and percent of hatchery-origin fish removed varies dramatically by species, year, and by watershed because of the timing of permitting for adult management activities and the presence of control points (e.g. dam or weir to catch adults). In some years, as much as 65% of the run has been removed to control the number of hatchery-origin fish that spawn. In other years, to meet escapement goals no hatchery-origin fish were removed (WDFW 2015; Figure 11). Between 2011-2015 the largest number of hatchery-origin adults removed through adult management was Methow spring Chinook (3,390 adults average 2011-2015), followed by Methow steelhead (1,451 adults), Wenatchee steelhead (821 adults), Wenatchee spring Chinook (427 adults); and Okanogan steelhead (462 adults). In addition, an average of 1,430 steelhead were caught in mainstem conservation fisheries between 2011-2015 in Rock Island (63 adults), Rocky Reach (187 adults), and Wells pool (724 adults) (WDFW data 2017). Given the location of these fisheries and the results of coded-wire tag recoveries, hatchery-origin adults from the Methow and Okanogan are most often removed in mainstem conservation fisheries (WDFW data 2017).

An analysis for the Winthrop NFH spring Chinook HGMP (USFWS 2012) showed that some years, like 2015, when natural runs are moderate or good, upwards of 80% of Methow Hatchery returns and 90% of Winthrop NFH returns may need to be removed from the population to help meet pHOS and PNI goals for the population. The ability to remove hatchery-origin fish through adult management is a challenge in some areas like the Methow due to the lack of an appropriate control point (e.g. dam or weir) at which to remove hatchery-origin fish from the run at large. The ability to meet pHOS and PNI goals for a population is a challenge most years in the region because of the low natural-origin returns.

Conservation programs generally release fish that are the progeny of a higher component of natural-origin broodstock and, therefore, fish from these programs are prioritized for natural spawning over adults from safety-net programs, which generally release fish that are the progeny of hatchery-origin broodstock. Adults from safety-net programs are meant to be removed from the population unless needed to meet broodstock or escapement goals.

Steelhead conservation fishery on the Wenatchee.

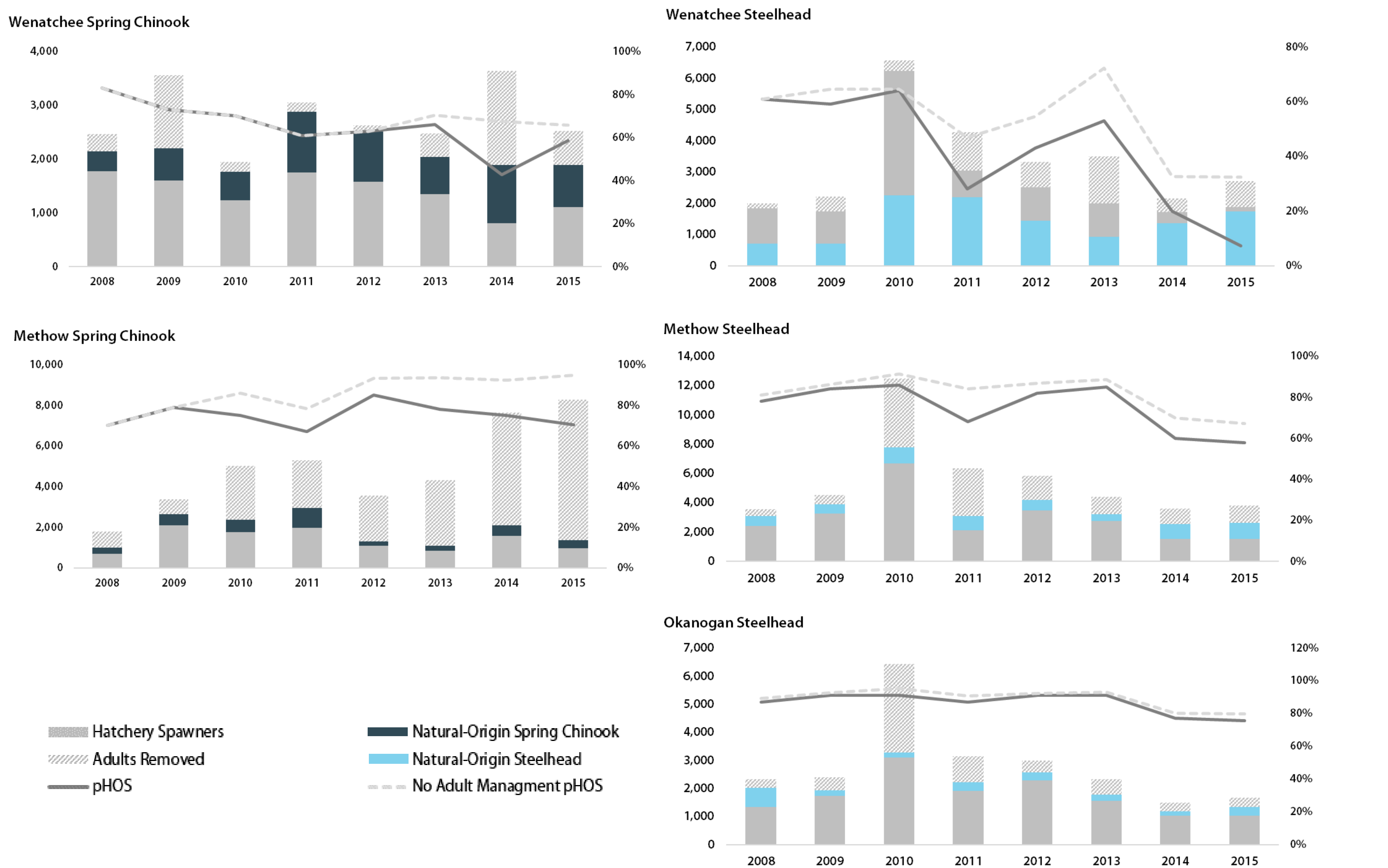


Figure 11. Adult management of spring Chinook and steelhead hatchery between 2008-2015 as well as pHOS with adult management and predicted pHOS without adult management (surplus and conservation fishery) (WDFW 2015; Snow et al. 2017). Additional steelhead adults are caught in mainstem Columbia conservation fisheries but cannot be assign to a population. Spawner escapement and resulting pHOS are from NOAA SPS and WDFW SASI databases (NOAA SPS 2017; WDFW SASI database 2017).

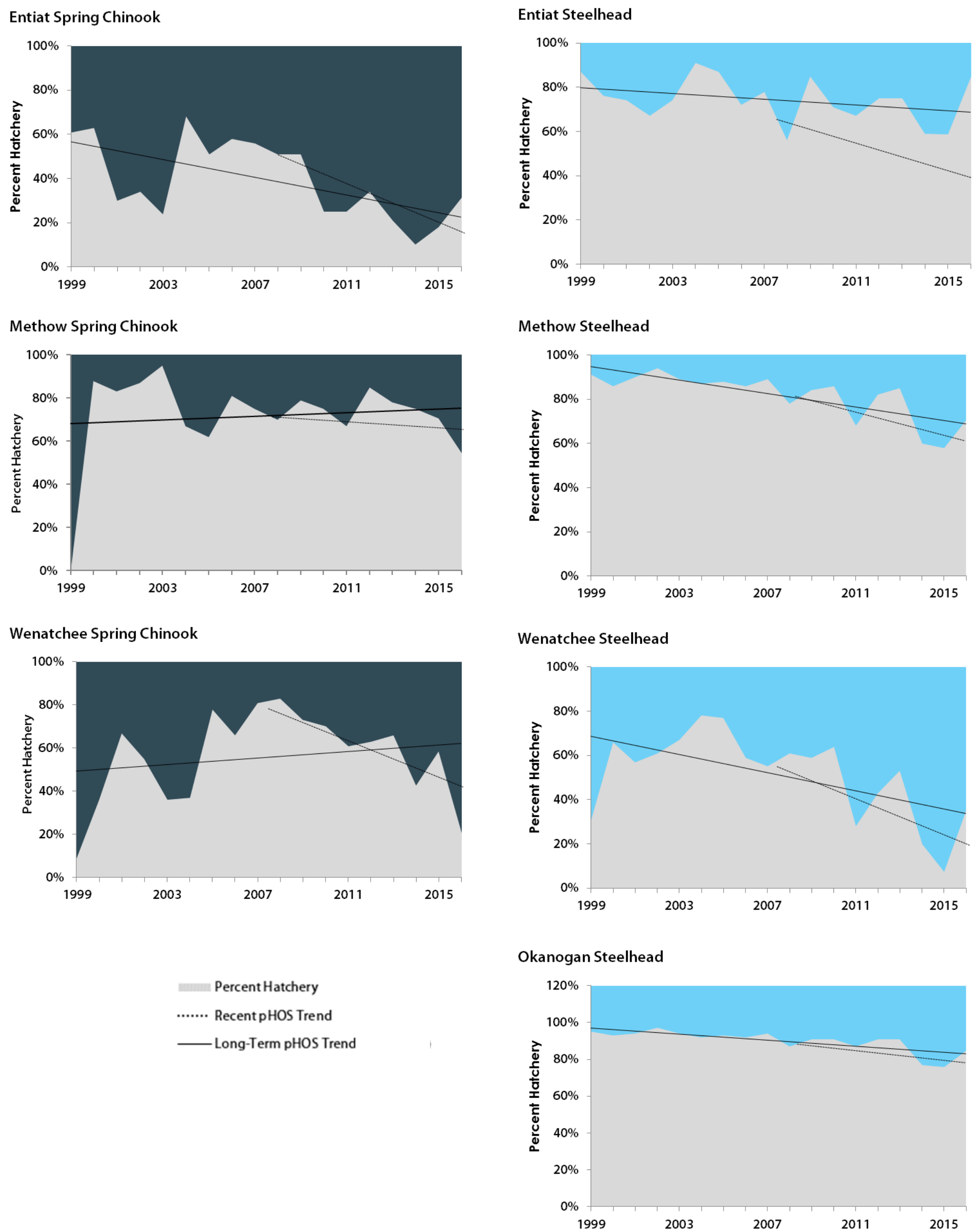
Hatchery Spawners

The goal of segregated harvest programs is to prevent natural spawning through removal of hatchery-origin fish through harvest and adult management. The goal of conservation hatchery programs is to have some proportion of adult returns spawn and contribute to future returns of natural-origin fish. This goal of maximizing spawning populations with hatchery returns is balanced with the need to control risks associated with hatchery-origin fish spawning in the wild. Recent changes in hatchery production (e.g. reduced production and changes in release locations), and the addition of adult management and conservation fisheries, has reduced the number of hatchery-origin fish returning to and spawning in some areas (e.g. Fraser and Hamstreet 2016). In some years as much as 50-80% of listed hatchery-origin spring Chinook and steelhead are removed through adult management and broodstock collection, or die prior to spawning (WDFW unpublished data 2017). On average Wenatchee steelhead and spring Chinook hatchery-spawners, and to a lesser extent Okanogan and Methow steelhead hatchery-spawners, have decreased over the past 10 years. Methow spring Chinook hatchery spawners have not changed substantially over this time (WDFW 2016).

Hatchery spawners make up a substantial proportion of the spawning adults in the Wenatchee, Methow, and Okanogan. In the Entiat, hatchery spawning by strays from other watersheds is common but happens at low levels. The percent of spawners that is comprised of hatchery-origin fish (# hatchery spawners/# natural-origin spawners) is an important metric in hatchery management. This metric (percent hatchery-origin spawners or pHOS) can vary by year and location based on program release numbers, release location, adult management (removal) of hatchery-origin fish, and natural-origin returns. The number and/or percent of hatchery spawners is greatest in supplemented watersheds near release locations but can be considerable in unsupplemented watersheds if stray rates of hatchery-origin fish into that watershed are high. The percent of hatchery-origin spawners can also be high in watersheds or reaches where the number of natural-origin spawners is low. In most tributaries in the region, at least half the spawners are hatchery-origin (Figure 12). Only a small number of tributaries and reaches have spawning populations dominated by natural-origin fish (e.g. steelhead in Peshastin Creek).

Until recently, conservation hatchery-origin adults were not removed except through broodstock collection and harvest. One outcome was hatchery-origin fish in natural areas at rates relative to their abundance, which at times could lead to high levels of pHOS. As described above, adults are now managed in many areas to control the number of hatchery spawners. Because of this, and because of changes in hatchery- and natural-origin returns, the pHOS has decreased or remained the same in most populations over the past decade (Figure 12). Current levels of pHOS are expected to continue to change across the region in the future due to recent decreases in production and the implementation of adult management.

Figure 12. Percent hatchery-origin spawners for Upper Columbia spring Chinook and steelhead populations from 1999-2016 with short (2008-2016) and long-term (199-2016) trend lines over that time period. The Entiat Subbasin is not currently supplemented with spring Chinook or steelhead but does recieved stray hatchery adults from other populations (WDFW SaSI data 2017).



The spring Chinook pHOS averages 52% across the Upper Columbia region, ranging from 75% in the Methow to 24% in the Entiat (WDFW SaSI data 2016). Approximately 57% of steelhead spawners are hatchery-origin, ranging from 84% in the Okanogan to 30% in the Wenatchee. In the case of the Entiat all steelhead hatchery-origin spawners are out of basin strays. Spring Chinook hatchery-origin spawners are entirely out- of- basin strays since the Entiat NFH program stopped releasing spring Chinook.

Values of pHOS vary by species, location, and year, and the scale at which it is measured is important to consider (population versus reach) (Figure 13). Based on spawning surveys by WDFW, most hatchery-origin spring Chinook tend to spawn within a few kilometers of their release site (usually an acclimation or hatchery facility) (Figure 13). Natural-origin fish generally exhibit greater spatial spawning diversity compared to their hatchery-origin counter parts (e.g. Hughes and Murdoch 2017; WDFW 2016). Depending on the locations of release sites relative to suitable spawning habitat, hatchery- and natural-origin spawning distributions may or may not overlap. This affects the interpretation of pHOS values calculated for a watershed. Although the calculated pHOS may be high or low, sometimes the natural and hatchery-origin fish distribute themselves in a way in which the actual pHOS is much different. For example, the watershed pHOS may be high but if the hatchery- and natural-origin fish occupy different spawning habitat a low proportion of hatchery- and natural- origin fish may be spawning together than what could be inferred from the calculated pHOS (e.g. Hughes and Murdoch 2017).

Steelhead spawning in the Okanogan subbasin. Photo courtesy of Brian Miller, CCT.

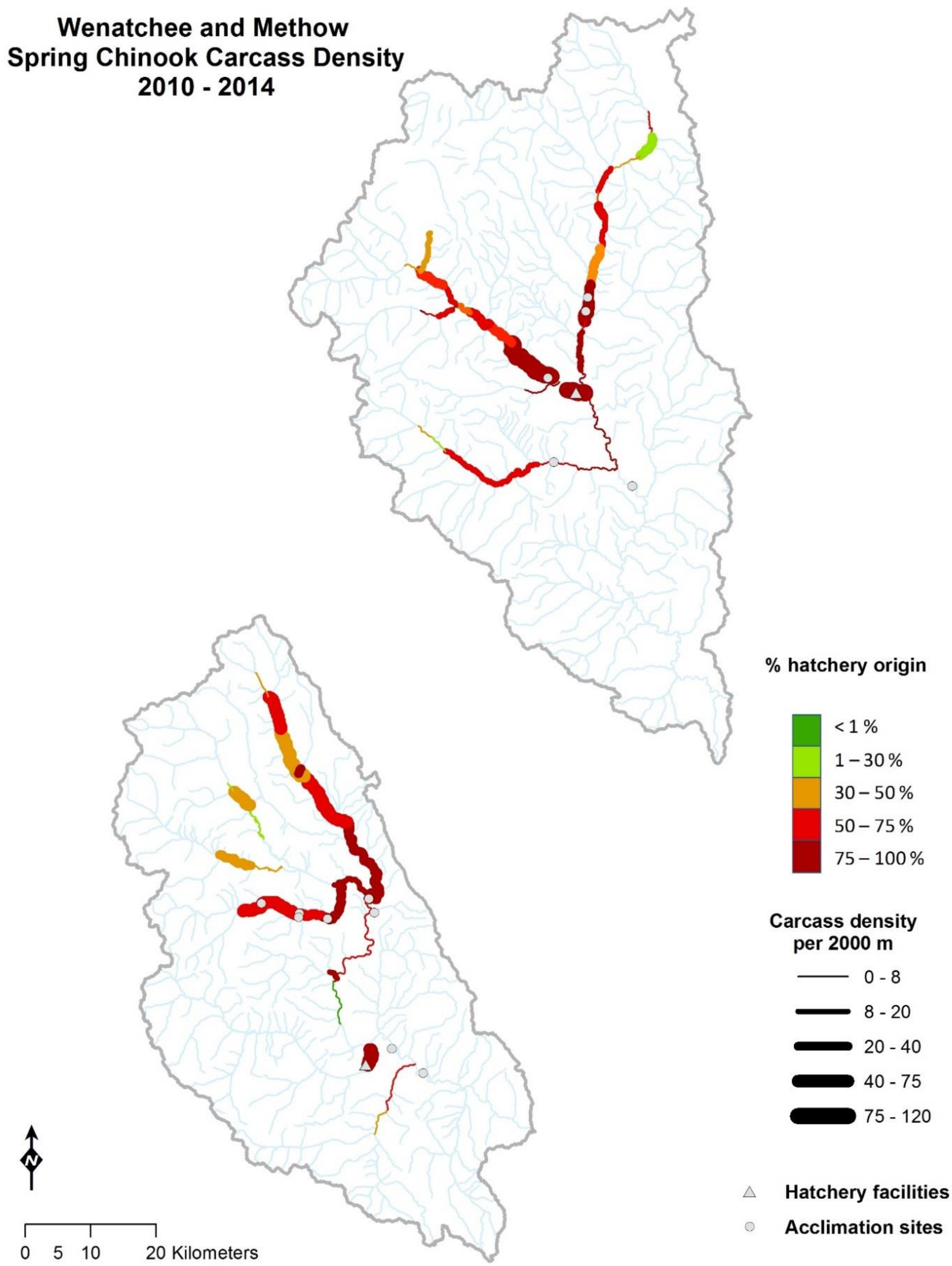


Figure 13. Density and pHOS of spring Chinook hatchery spawners in the Methow and Wenatchee subbasins (2010-2014) with the locations of hatchery release sites noted for reference. Data from WDFW (2015).

In addition to the number of hatchery spawners, the origin of hatchery spawners is also important to consider. Hatchery-origin fish on the spawning grounds of one tributary can originate from smolts released in that tributary (natal hatchery-origin fish), from smolts released in another tributary in that watershed (within-basin hatchery stray), or as strays into the watershed from another area (out-of-basin hatchery stray). According to recent PUD reports, hatchery spawners in the Wenatchee and Okanogan largely originate from smolts released in that area. Over the past five years in the Methow, some portion in each spawning area originate from other areas (Snow et al. 2016; Figure 14). In the mainstem Methow this could be the result of fish homing to their natal hatchery (Methow Hatchery or Winthrop NFH), regardless of where they were acclimated. Although the Entiat River does not have a spring Chinook or steelhead hatchery program there are hatchery spring Chinook and steelhead that return to the Entiat subbasin. Based on PIT-tag detections, these hatchery-origin adults in the Entiat are strays from the Wenatchee, Methow, Okanogan, and from other populations in the Columbia River (PTAGIS 2016).

Spring Chinook Spawner Composition in the Methow Major Spawning Areas (2011-2015 Averages)

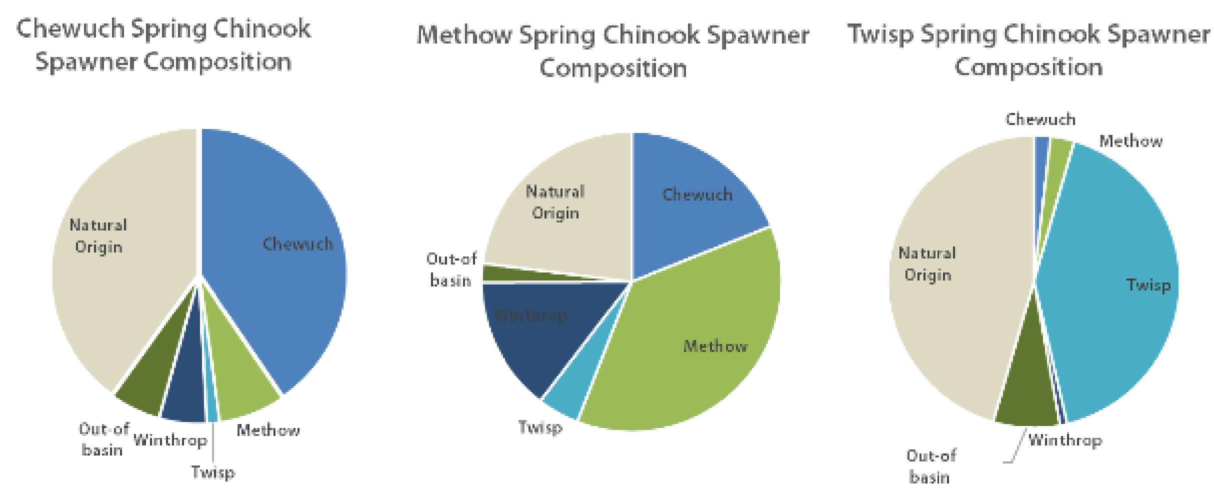


Figure 14. Average spawning escapement (%) of spring Chinook spawners by hatchery release group in the Methow major spawning areas between 2011-2015 (Snow et al. 2016). Gray color indicates natural-origin

When hatchery-origin fish spawn in the wild there is the potential to have a genetic effect on the natural-origin population. This is because hatchery-origin fish can be genetically different than their natural counterparts. The process of rearing fish in hatcheries can inadvertently impose selection pressures, eliminate natural selection of traits essential for natural reproduction, and reduce the genetically effective number of breeders (Campton 2004, 2005; Quinn 2005). Selection pressures in and out of the hatchery have a significant effect on behavior and phenology and can affect smolt-to-adult survival of hatchery-origin fish after release. Some effects such as release size can provide a selective advantage in the wild (Reisenbichler et al. 2004), while other domesticated traits (e.g. foraging behavior and predator avoidance) can have a detrimental effect on survival (see Reisenbichler and Rubin 1999). Some studies showed selection alone can be a sufficient explanation for differences in fitness between hatchery- and natural-origin fish (Araki et al. 2008).

Although these effects are documented, they are difficult to detect in the population because they are manifested over multiple generations and/or are confounded with other factors that can reduce productivity (e.g., habitat degradation, incidental harvest of natural-origin fish in fisheries targeting hatchery-origin fish, etc.) (see Christie et al. 2011, 2014).

Many traits potentially have very different optimal values for hatchery and wild fish, especially traits subject to selective breeding by hatchery personnel (e.g., return and spawn dates of fish selected for broodstock), and traits related to natural reproduction that are relaxed in the hatchery environment (Quinn 2005). Segregated programs often result in optimal traits for the hatchery and reduce spawning of segregated fish in the wild. With integrated programs the mean phenotypic values of hatchery- and natural-origin fish is often intermediate to some degree to the phenotypic optima in the hatchery and wild environments. Although current hatchery programs are managed to minimize domestic selection, the current populations are the direct result of decades of hatchery supplementation in which programs operated with little to no regard for genetic impacts (e.g. historic out-of-basin transfers, inbreeding, no attempts to prevent hatchery fish from spawning in the wild, etc.).

Segregated programs aim to minimize genetic effects on natural spawning populations. Integrated programs are designed to encourage natural breeding of hatchery-origin and natural-origin fish and therefore have a high potential for genetic implications. To mitigate any potential negative genetic effects, segregated programs try and avoid or minimize straying and natural spawning, use entirely hatchery-origin local broodstock, and select for traits that maximize success in the hatchery environment. The Leavenworth NFH spring Chinook segregated program has relatively low rates of straying and natural spawning (see Adult Straying section above) and therefore have a low risk of interbreeding with natural-origin spawners (Potter 2016). The Chief Joseph Hatchery spring Chinook segregated program is expected to have a low risk of spawner interactions given its location and this will be evaluated once more adults begin to return from this program (CCT 2008).

Conservation programs seek to use 100% natural-origin broodstock (pNOB=1) and try to minimize selection pressures resulting from the hatchery program (e.g. collect broodstock across the entire run, spawn various age-classes, implement multiple crosses of parents). They also try to control the percentage of hatchery-origin spawning in the wild. Additionally, conservation programs try to limit straying of returning hatchery adults to maintain local adaptation of populations. Most programs are required by permit to operate per standards established for levels of natural-origin broodstock and hatchery spawning to minimize genetic risks to naturally spawning populations.

The likelihood that hatchery and natural-origin fish spawn together is largely driven by the two-groups' overlap in spawning distribution, and by the percent of hatchery-origin fish on the spawning grounds. To minimize any potential risks, the HSRG recommends that for integrated conservation programs, pHOS levels should be no greater than 30% (HSRG 2009). Although pHOS is used to guide management of hatchery-origin fish it is not a direct measure of interactions between hatchery and natural-origin fish. The pHOS metric also does not describe the degree of similarity or dissimilarity between hatchery and natural-origin fish that could potentially spawn together and the risks are difficult to detect and describe. Therefore, most hatchery managers have adopted the Proportionate Natural Influence (PNI) model as a tool to assess relative hatchery influence on a population and explain the potential genetic effects of a hatchery program (Ford 2002). According to this model and its assumptions, PNI is calculated as *pNOB/ (pNOB + pHOS)* with the larger the ratio (PNI), the greater the strength of selection in the natural environment relative to that of the hatchery environment. For the natural environment to dominate selection, PNI should be greater than 0.50, and integrated populations should have a PNI of at least 0.67 (HSRG/WDFW/NWIFC 2004). Although this model may be useful in managing some supplemented populations, some populations are at greater risk for extinction (e.g. low natural return rates (<500 NOR)) and have a need to supplement the population at a high rate to maintain runs at levels that prevent depensation. In these cases, managing for genetic risks and PNI may be less important that avoiding demographic extinction.

Twisp weir used to manage hatchery programs.

Based on PNI values reported in the most recent PUD reports (average BY2010-2015), supplemented spawning areas in the Upper Columbia have had a calculated PNI that is less than or roughly equal to 0.50. This could suggest that the hatchery environment has a greater influence on adaptation than does the natural environment. Spawning areas in the Methow and Okanogan have the lowest average PNI values (<0.40) and Wenatchee spawning areas have had the highest average PNI values in the region (≥0.50) (Snow et al. 2016; Hillman et al. 2016) (Figure 15). The PNI metric is driven by both the percent of hatchery-origin fish spawning in these tributaries (pHOS) and the percent of natural-origin broodstock in the hatchery programs (pNOB). Like pHOS, the calculated PNI value may not accurately reflect the true hatchery influence in the population if the spatial distributions of hatchery- and natural-origin spawners do not overlap or overlap very little. In such a case, there is little or no chance of interbreeding and gene flow even if the PNI value calculated for the tributary population suggests otherwise.

Adult management at Tumwater Dam allows managers to control hatchery spawning in the Wenatchee and this may contribute to higher PNI values in spawning areas upstream as compared with the Methow and Okanogan. Natural-origin returns have also been higher in the Wenatchee, contributing to lower pHOS values overall (Figure 3).

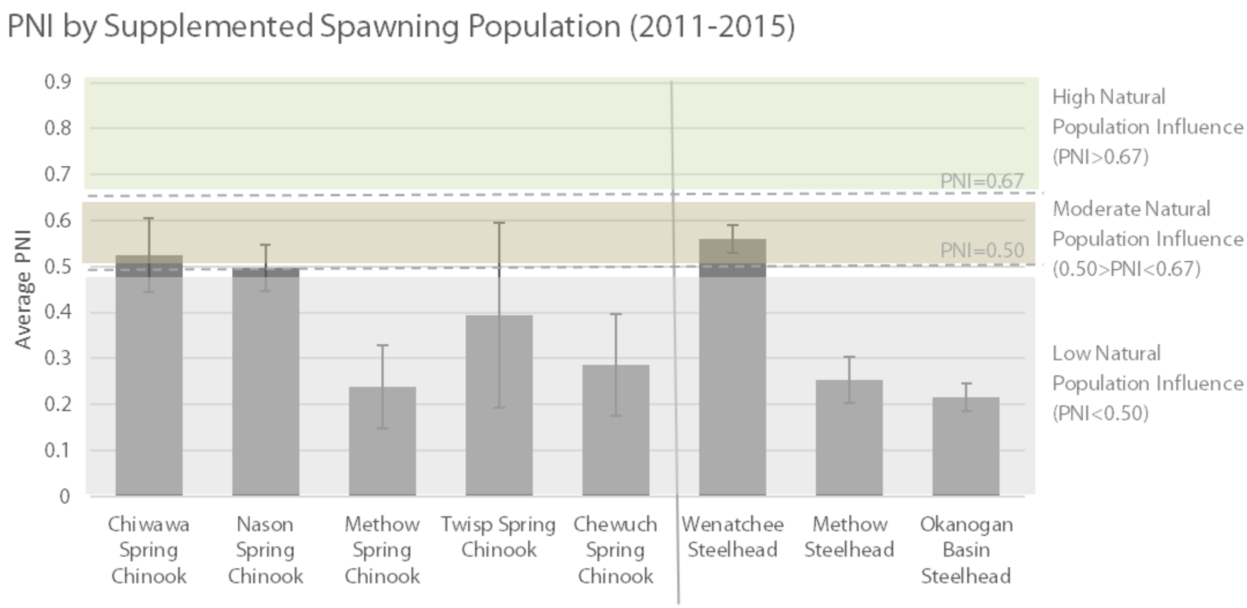


Figure 15. Proportionate natural influence (PNI) of tributaries in the Upper Columbia for 2010-2014. See Snow et al. (2016) and Hillman et al. (2016) for data and methods for calculating PNI.

In addition to intraspecific (same species) genetic risks there is also the risk of imposing interspecific (between species) risks. A recent study by USFWS found evidence of hybridization between spring and summer Chinook species in the Entiat (T. Degroseillier 2017, pers comm.). The extent or degree of hybridization is unknown at this time.

Hatchery Progeny

The most basic of the intended objectives of supplementation is to provide an increase in the number of returning adults that will eventually lead to an increased abundance of natural-origin adults in the target salmon or steelhead population. To realize this benefit, hatchery spawning must increase the total number of progeny that then augment the natural-origin population in future generations. (ISAB 2003; Bugert 1998; Reisenbichler 2004; Baumsteiger et al. 2008). The production of offspring by hatchery-origin spawners, their progeny's survival to adulthood, and the number that return to contribute to fisheries, conservation, and recovery is determined by the fitness of the spawners, the genetic and biological characteristics of the offspring, and the habitat conditions that affect their offspring's survival through each life stage.

Phenotypic traits in hatchery-origin fish having a genetic basis can be inherited by offspring of hatchery and natural-origin adults when they spawn together on the spawning grounds. Of principle interest to managers is distinguishing which of the phenotypic traits are potentially heritable and which are non-heritable by the offspring of hatchery and natural-origin parents. Efforts to integrate natural-origin fish in the broodstock and reduce the selection pressure by the hatchery environment help reduce divergence between the hatchery- and natural-origin fish (HSRG 2009).

The latest five-year (2006-2010) reports on Chelan and Douglas PUD hatchery programs (Hillman et al. 2012; Murdoch et al. 2012) summarized the effects of these programs on the demographics of the target populations. During the period reviewed, the trends for supplemented populations were not significantly different from trends for unsupplemented populations. The one exception was Okanogan steelhead which did experience an increase in both total spawners and natural-origin returns, although without reference populations the authors could not determine whether those increases resulted from the hatchery program or from out-of-basin factors. The report noted that although hatchery programs in the region have returned hatchery origin adult spawners, it is unclear if their progeny have contributed to increased natural-origin adults. The PUDs are currently updating these results in a new 5-year review of their programs (expected 2020). The updated report will reflect changes made to the hatchery programs including reduced production and adult management.

The recently completed Idaho Supplementation Study (ISS) evaluated multiple hatchery programs over 23 years and showed that hatchery programs can increase: (1) total redd numbers, (2) natural-origin juvenile emigrants and smolts, and (3) returning natural-origin adults (Venditti et al. 2015; Venditti et al. 2017). The results of supplementation were shown to vary by population and by life stage. Supplementation provided the greatest increase to redds, juveniles, and smolts but only a small increase in natural-origin adult returns. As part of the study design, some hatchery programs were stopped and the researchers found that the benefits of supplementation also stopped at that point (e.g. the benefits did not perpetuate after the program stopped). The study concluded that there are short-term population benefits with supplementation, with a low cost to natural fish productivity, and that supplementation can be a valuable tool for managing populations. Similar findings were made by the Independent Scientific Review Board (ISAB) in their 2003 review of salmon and steelhead supplementation (ISAB 2003) and in other studies across the region (Hess, et al 2014; Yakima-Klickitat Fisheries Program).

The success of hatchery-origin spawners in producing offspring that can survive and return to contribute to recovery is dependent on several factors. Genetic fitness, biological characteristics (e.g. run timing, spawning distribution, size, age, etc.), and habitat conditions and capacity all can contribute to spawner success (e.g. Ford et al. 2016; Murdoch et al. 2015; ISAB 2003). In some cases, hatchery programs can lead to relatively high spawner abundances, such that capacity is exceeded and density-dependent mortality of both hatchery- and natural-origin offspring occurs (ISAB 2016). There is evidence for density-dependence in the Upper Columbia in areas where it has been evaluated (ISAB 2016; Hillman et al. 2016).

WDFW and DPUD have been studying the differences in reproductive success (termed the relative reproductive success) of hatchery and natural-origin fish since 2010 in the Methow and Wenatchee rivers (Ford et al. 2015; Murdoch et al. 2015; Goodman et al. 2016). These studies provide information on the relative contribution of hatchery-origin fish to subsequent generations of natural-origin fish, and the overall productivity of the population in which they spawn. One goal of the relative reproductive success (RRS) studies is to determine the degree to which any differences between hatchery and wild reproductive success can be explained by genetic and measurable biological characteristics. These questions are fundamental to understanding the contribution of hatchery programs to recovery of listed populations.

Results from these local studies suggest that productivity of hatchery-origin fish in the natural environment, at both the smolt and adult life stages, is significantly lower than that of naturally-produced fish. These results are consistent with those reported in others RRS studies outside the Upper Columbia (e.g. Ford et al. 2015; Berntson et al. 2011; Araki et al. 2007). Both male and female hatchery-origin adults produce about half the juvenile or adult progeny per parent when spawning than did same-age natural-origin adults. Reductions are greatest when hatchery-origin fish spawn with other hatchery-origin fish (Ford et al. 2015).

The studies have found that the reasons for reduced reproductive success of hatchery-origin spring Chinook in the Wenatchee subbasin appear to be related to the spawning densities and the locations of hatchery redds in sub-par habitat in the lower reaches of the Chiwawa River and Nason Creek (Williamson et al. 2010; Hughes and Murdoch 2017; Figure 16). Hatchery-origin fish are likely spawning in sub-par spawning areas because they are closer to the acclimation areas where they were released and are prevented from passing upstream of the Chiwawa weir some years. In areas where there was greater overlap in the spawning distribution of hatchery and natural-origin (Little Wenatchee and White rivers), there was a two-fold increase in the RRS of hatchery-origin fish. Hatchery-origin spring Chinook in the Upper Wenatchee had the lowest RRS (~0), primarily because of the poor spawning habitat. This difference may not apply to the progeny of hatchery-origin fish, who appear to redistribute to higher quality spawning habitat upstream (Ford et al. 2015).

Hatchery steelhead in the Twisp and Wenatchee rivers also showed a lower reproductive success than their natural counterparts. In these populations broodstock origin strongly influences natural spawning success of hatchery steelhead. Progeny produced from hatchery spawning of two natural-origin parents (W x W hatchery-origin fish) had similar reproductive success to natural-origin fish. In contrast, the reproductive success of hatchery-origin fish produced from two hatchery parents (H x H hatchery-origin fish) was extremely low (<0.20). The strong influence of broodstock origin on reproductive success suggests a genetic basis for the low reproductive success of hatchery steelhead. However, other factors affecting reproductive success of hatchery-origin fish, including fish size, return time, age, and spawning location, cannot be entirely ruled out (Ford et al. 2016).

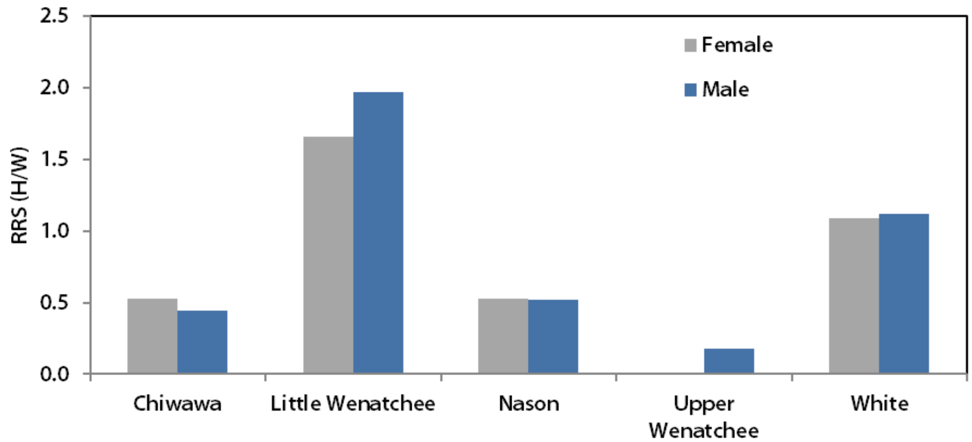


Figure 16. Relative reproductive success of hatchery male and female spring Chinook in the Upper Wenatchee. Figure courtesey of A.Murdoch (WDFW 2016).

Understanding the mechanisms that contribute to the reported lower reproductive success of hatchery-origin fish (e.g., Hughes and Murdoch 2017; Ford et al. 2016; Williamson et al. 2010) is important for mangers to determine what can be done to improve the fitness and productivity of hatchery-origin fish in rivers where hatchery production is identified as a strategy for rebuilding natural spawning populations (Hughes and Murdoch 2017).

Ecological Interactions

Several recent studies highlight the potential importance of the ecological interactions of hatchery and natural-origin fish (Naish et al. 2008; Pearsons 2008; Nickelson 2003; Weber and Fausch 2003). Factors including duration of hatchery-origin fish and natural-origin fish cohabitation, relative body size, prior residence, location, and species differences all influence competitive interactions, with fish density in relation to habitat carrying capacity likely exerting the greatest influence (Tatara and Berejikian 2012). Predation and disease risk can also be a factor depending on the two species and the timing of overlap (e.g. Naman and Sharpe 2012). Additionally, the risk of density dependent effects occurs whenever there is competition for limited resources, which can occur at any life stage within and among species (ISAB 2015). Risks can be evaluated based on a variety of factors and mitigated to some extent through hatchery rearing practices (see Pearsons and Hopley 1999). The PUDs developed a non-target taxa of concern (NTTOC) ecological risk assessment as a regional objective that would addressed ecological interactions on non-target taxa. Non-target taxa include species, stocks, or components of a stock with high value (e.g., stewardship or utilization) that may suffer negative effects because of a hatchery program (Hillman et al. 2017). These risks were evaluated for Upper Columbia hatchery programs and the results published in a 2014 report titled *Ecological Risk Assessment of Upper-Columbia Hatchery Programs on Non-Target Taxa of Concern* (Mackey et al. 2014).

Predation and Competition

Hatchery and natural-origin smolts may differ in their early marine behavior and life histories but may still compete for resources during their seaward migration. However, little is known about competition and predation in the mainstem Columbia River and the Columbia River estuary.

Furthermore, there remains substantial uncertainty regarding the habitat overlap between hatchery- and natural-origin fish during their early life history in the marine environment. Returning natural-origin and hatchery-origin adults can also overlap in their migratory and holding habitat in the Columbia River and Upper Columbia tributaries leading to potential for interactions and competition.

A recent Independent Scientific Advisory Board (ISAB) report (2015) showed that many salmon populations throughout the interior Columbia basin are experiencing density dependence (limitations in survival and growth due to population density) at levels that may constrain their recovery The ISAB found that strong density dependence at current abundance levels suggest that freshwater habitat capacity has been diminished or that it was lower than previously thought. The ISAB also concluded that hatchery releases may create unintended density effects. The risk of density dependent effects occurs whenever there is competition for limited resources, which can occur at any life stage within and among species. Without knowing the capacity of the habitat, it is difficult to determine the full effect of hatchery programs on listed populations. It is commonly accepted that when habitat capacity is limited, the increased population densities caused by hatchery programs can exacerbate density dependent effects. With the large numbers of hatchery-origin fish released in the upper Columbia basin, it is possible that the survival and productivity of natural origin fish have been reduced (Hillman et al. 2012). The updated M&E Plan for the PUDs outlines methods for estimating carrying capacity (Appendix 1 in Hillman et al. 2017). This information can be valuable in helping hatchery managers inform supplementation programs.

Other noted ecological effects of hatchery programs have been the superimposition of spring Chinook redds by hatchery summer Chinook redds. From 2013-2015 between 14-28% (20% average) of spring Chinook redds in the mainstem Entiat were superimposed by summer Chinook. However, to date most superimposition is done by natural-origin Chinook (94% on average) with only a small proportion done by hatchery-origin Chinook (Fraser and Hamstreet 2016). Recent studies also indicate the potential for hybridization between summer Chinook (hatchery- and natural-origin) and spring Chinook in the Entiat (Degrosslier pers comm.) although the occurrence and implications of this hybridization are not known.

Residualization of released hatchery steelhead and spring Chinook (e.g. juvenile fish that fail to migrate seaward after release) has also been reported and is a potential risk to listed species (Ford et al. 2015; Snow et al. 2013; McMichael et al. 1999; Hausch and Melnychuk 2012; Larsen et al. 2004; Harstad et al. 2014). Size, time, age, location and method of release of hatchery-origin fish can affect the severity of this risk. Residual hatchery-origin fish compete with natural-origin conspecifics as well as other native species (McMichael et al. 1997, 1999; McMichael and Pearsons 2001). Larger-sized residual hatchery-origin fish may also prey on natural-origin fry (Hawkins and Tipping 1999; Naman and Sharpe 2012). Release strategies now being utilized have been shown to reduce the occurrence of residualism in some cases (Snow et al. 2013).

Hatchery Contributions to Viable Salmonid Populations

The influence of improved hatchery practices and performance on natural-origin spawners or natural productivity has yet to be determined although some studies are underway across the Northwest. Various research and monitoring programs will contribute information on the effects of current hatchery programs and the potential for future hatchery programs to contribute to recovery. In addition, modeling can be used to evaluate different hatchery management options and outcomes. These outputs can help us understand how hatchery programs can potentially influence progress toward recovery. A life cycle modelling approach can be used to evaluate what effect hatcheries can have on the viability of a population. Currently, life cycle models in the Upper Columbia are under development.

The Recovery Plan focuses on the viable salmonid population (VSP) criteria as the core measures used to gauge progress toward recovery. Hatcheries affect all four criteria – abundance, productivity, spatial structure, and diversity. Conservation programs are intended to contribute to the natural ***abundance*** of the population without negatively affecting the ***productivity***. In some cases, they are intended to maintain or expand population ***spatial structure***. Lastly, hatchery influence is a direct component of the ***diversity*** metric of VSP.

Abundance

Current Abundance Risk: High (NOAA 2016)

Intended Hatchery Contribution: (conservation hatchery programs should contribute or maintain natural-origin abundance)

Hatchery programs contribute spawners to Upper Columbia spawning populations. During years of extremely low natural returns the addition of these spawners helps prevent depensation in the population. This important role can be critical to prevent extinction of populations. Current average natural-origin returns remain well below NOAA's minimum threshold levels. Beyond just avoiding extinction, conservation programs have the potential to add natural-origin spawners to the population in the future when hatchery-origin fish produce natural progeny that replace or exceed removal for broodstock.

Productivity

Current Productivity Risk: High (NOAA 2016)

Intended Hatchery Contribution: (the productivity of the combined hatchery and natural-origin population should be positive)

Population growth rate (productivity) provides information about how well a population is performing, how well it can respond to low survival periods, and determine its future abundance. According to McElhany et al. (2000), a population should, at a minimum, replace itself, and a viable salmon population that includes naturally spawning hatchery-origin fish should exhibit sufficient productivity from naturally-produced spawners to maintain population abundance at or above viability thresholds in the absence of a hatchery subsidy.

Hatchery programs have the potential to affect productivity because hatchery-origin fish can have reduced survival and reproductive success, and because they can increase density-dependent mortality in a population.

A large number of fish produced by hatcheries may result in density-dependent mortality that could result in a replacement of natural origin fish by hatchery-origin fish (ISRP 2016). Hatcheries are unlikely to benefit productivity except in cases where the natural spawner population's small size is a limiting factor itself (NOAA 2004). Hatchery reform actions implemented over the last 10 years, along with those planned in the next several years, are intended to reduce spawner densities and improve the reproductive success of hatchery fish and therefore the overall productivity of the combined population of hatchery- and natural- origin spawners.

Spatial Structure

Current Spatial Structure Risk: High (NOAA 2016)

Intended Hatchery Contribution: hatchery programs should not negatively affect spatial structure and can expand population spatial structure through reintroduction programs)

A population's spatial structure is made up of both the geographic distribution of individuals in the population and the processes that generate that distribution. A population's spatial structure depends fundamentally on habitat quality, access, spatial configuration and dynamics as well as the dispersal characteristics of individuals in the population. The geographic distribution of production within an ESU/DPS and within a population can be both positivity and negatively affected by hatchery programs. Hatcheries can be used to expand the range of a species and maintain source production areas.

Diversity

Current Diversity Risk: High (NOAA 2016)

Intended Hatchery Contribution: (hatchery programs should not affect population diversity and can help maintain diversity if populations are in decline)

Actions that affect patterns of mutation, selection, drift, recombination, and migration all have the potential to reduce or alter adaptive patterns of diversity. Diversity in a population or ESU is especially important because it is difficult to replace once it is lost. Much of the diversity within a population comes from local adaptation to a particular environment over many generations. Hatchery programs have the potential to inadvertently influence diversity and therefore rapidly erode the adaptive fit between an ESU or population and its environment, thereby increasing its risk of extinction. This influence occurs through the removal of fish from their natural environment and domestication of individuals to the hatchery environment. Conversely, hatcheries can temporarily support populations that might otherwise be extirpated or suffer severe bottlenecks, and have the potential to increase the effective size of small populations. All spring Chinook and steelhead populations in the Upper Columbia are at high risk for diversity, driven primarily by chronically high proportions of hatchery-origin spawners in natural spawning areas and lack of genetic diversity among the natural-origin spawners (ICTRT 2008). Hatchery reform actions have been implemented that could reduce the diversity risk level by the: 1) removal of hatchery fish to achieve a lower pHOS in the spawner composition, 2) cessation of compositing broodstock from multiple populations (e.g., former collection of Okanogan and Methow broodstock at Wells Dam), and 3) elimination of releases of non-local hatchery stocks (e.g., past spring Chinook programs Entiat and Winthrop NFH).

Uncertainties and Data Gaps

Despite the wealth of hatchery science that has developed over the past several decades there remain uncertainties and data gaps related to the risks and benefits of hatcheries. Populations affected by hatchery programs are inherently dynamic and complex and therefore some level of uncertainty is unavoidable. However, these uncertainties can pose a significant challenge to hatchery managers trying to maximize mitigation and conservation goals. As Waples (1999) noted, although it is easy to identify risks that hatcheries pose for populations, it is not so easy to predict whether deleterious effects will occur in any given situation or, if they do, how serious the consequences will be. Furthermore, the studies of hatchery effects often do not agree on the nature and severity of the risks hatcheries pose and ways to minimize them. Identifying areas of uncertainty related to hatchery science and hatchery management is an important part of understanding these programs.

The *Recovery Plan* identified several key uncertainties related to hatcheries including: 1) the interaction between hatchery and naturally produced fish, 2) the relative reproductive success of hatchery-origin spawners, and 3) whether hatchery programs increase the incidence of disease and predation on natural-origin fish. Progress has been made to address some of these questions but they remain important issues for study. Additionally, the Regional Technical Team's Monitoring and Data Management Committee (MaDMC) includes in its *Regional Data Gaps List* (MaDMC 2017) relative reproductive success of hatchery-origin spawners.

Below is a summary of several other areas of uncertainty and data gaps related to Upper Columbia hatchery programs that have been identified as important. Many of these areas of interest are currently being reiterated, expanded, and/or acted upon by the local HCP Hatchery Committees and PRCC Hatchery Sub-committee and other hatchery managers.

Natural-origin and hatchery-origin fish movement and returns

One of the most important information needs is basic data on hatchery and natural returns at the population and tributary scale. Although good information is available on spawning escapement, the only information on adult returns prior to spawning is dam counts which are reliant on external markings to track hatchery-origin adults. Not only is total hatchery escapement important to be able to track progress, but it helps us understand and identify issues such as smolt-to-adult returns, pre-spawn morality, and straying. Improving methodologies to increase the accuracy of both run escapement and spawning escapement was a recommendation in the 2012 PUD's Five-Year Report (Hillman et al. 2012 and Murdoch et al. 2012). In the last few years PIT tags have been used to estimate natural and hatchery steelhead escapement at various spatial scales in the Upper Columbia. This effort could be expanded to include spring Chinook as well as other species (summer Chinook and Coho). Expanded use of external marking could also be used to better track and assess hatchery-origin fish.

Causal mechanisms for differences between hatchery and natural-origin

The reduced productivity of hatchery-origin fish is well documented. It is now vitally important to determine why hatchery-origin fish have lower reproductive success in the wild. Answers to that question will help fisheries managers improve hatchery practices and programs. Relative reproductive success studies are one approach to understanding this difference. Other studies to evaluate differences between hatchery- and natural- origin fish and determine their causal mechanisms will help improve hatchery management.

Unsupplemented reference streams to understand baseline and impacts

As previously noted, there are almost no unsupplemented watersheds in the Upper Columbia. Reference streams are critical for distinguishing hatchery program effects from other effects such as habitat improvements. Annual monitoring data from unsupplemented streams could be as equally important as in supplemented streams.

Capacity of production areas and life stage survival bottlenecks

Hatchery supplementation for conservation purposes is intended to fill underutilized capacity in a watershed. Estimates of capacity at various life stages within production areas and populations would help determine the optimum escapement level for supplemented spawning areas. However, the identification of life stage-specific habitat capacity remains a significant data gap in some areas and may limit the effectiveness of hatchery programs if populations are at their carrying capacity at the spawning or rearing life stages. Estimation of carrying capacity is important because hatchery managers use it to inform supplementation programs, harvest managers use it to set appropriate harvest and escapement levels, modelers use it in life-cycle models to predict the effects of different recovery scenarios, and restoration practitioners use it to guide restoration actions.

Interactions between hatchery and natural-origin fish

To ensure hatchery programs are not having unintended consequences on populations it needs to be understood how hatchery-origin fish are interacting with natural-origin fish. The interactions between unlisted hatchery programs as well as their impact on listed species habitat capacity has been raised as an important question in the literature cited in this summary. Other important questions to consider are the benefits of hatchery-origin fish as sources of nutrients to headwater streams and their impact on predator prevalence and behavior in the mainstem Columbia (e.g. sea lions in the Columbia River Estuary).

Effects on hatchery-origin fish on bull trout

The ecological effects of hatchery-origin fish on bull trout are little known. Hatchery-origin fish have the potential to act as predators and competitors of bull trout. This data gap is listed on the Upper Columbia Monitoring and Data Management Committee's (MaDMC's) data gaps list.

Predation

The effect of hatchery production on predator populations and predation rates is unknown. Hatchery-origin fish could be supporting greater numbers of predators and therefore potentially increasing predation rates on listed species. Conversely, they could be providing a prey resource for predators as a substitution for listed species and therefore reducing predation rates. It is likely that both factors may be contributing to predator dynamics and more information would help clarify how these relationships work. Given the recent rates of avian and pinniped predation on Upper Columbia listed spring Chinook and steelhead (UCSRB 2014) this would could be an important data gap.

Summary

In 2015, an estimated 60,000 hatchery adult fish returned to the Upper Columbia. This accounted for 80% of the total salmon and steelhead run to the region. Almost 5,000 of those fish were listed steelhead and spring Chinook produced to support recovery of those species. Currently, there are 22 hatchery programs in the Upper Columbia and 11 of these hatchery programs raise and release listed spring Chinook and steelhead. The Entiat spring Chinook and steelhead populations are the only listed populations without an associated conservation hatchery program. Total artificial production targets in the Upper Columbia River exceed 22 million juveniles annually, nearly 700,000 of which are ESA-listed species for conservation.

Large-scale supplementation efforts in the Okanogan, Methow, and Wenatchee Rivers are implemented to mitigate mainstem hydropower losses and counter short-term demographic risks given the current low survival and high extinction risks of the natural populations. Hatchery programs can provide short-term demographic benefits such as increases in abundance during periods of low natural abundance. They also can help preserve genetic resources until limiting factors can be addressed. However, recent scientific studies indicate potential risks of hatchery programs to natural productivity and diversity. The magnitude and type of the risk can depend to some extent on the status of affected populations and on specific hatchery program practices. Changes in hatchery programs paired with other recovery actions can be critical to boosting natural populations. Many hatchery reform actions have been implemented in the last 10 years in the Upper Columbia and more are planned in the near future. These hatchery reform actions are lowering the risk levels for diversity in some populations and are intended to contribute to the conservation of the species over time. It is unclear how much more would need to be done to achieve moderate or low risk for diversity metrics outlined in the Salmon Recovery Plan.

Returning hatchery-origin fish contribute to fisheries, broodstock for future production, natural spawning, and ecological processes within and outside the Upper Columbia. Conservation programs are one type of program intended to have a direct beneficial effect on the abundance of listed species through the addition of spawners to the population. Harvest programs are intended to provide harvestable hatchery-origin fish with neutral or minimal impacts to listed species.

Hatchery-origin fish returning to the Upper Columbia can be caught in a fishery, return to their hatchery of origin, die prior to spawning, or spawn in natural areas. For harvest programs in the

Upper Columbia, the goal and intended outcome of the program is to provide mitigation, contribute to fisheries, and generally minimize or avoid natural spawning. For conservation programs, the goal is to allow some proportion of those hatchery adults to spawn in the wild within a tributary where supplementation is needed to aid in recovery of the species.

Hatchery programs can influence the demographics, genetics, life history, and habitat of populations. Each year up to 272 natural-origin spring Chinook and 165 natural-origin steelhead are removed from the populations for broodstock. The production from the resulting smolt releases provides substantial adult returns to the region which can be used to meet escapement goals. Each year between 50-90% of spawners are hatchery-origin. Although hatchery programs in the region have returned hatchery origin adult spawners, it is not clear to what extent their progeny have contributed to increased natural origin adults. At the very least, the survival advantage from the hatchery (i.e., egg-to-smolt) and the productivity of the returning hatchery-origin adults must be sufficient to produce a greater number of returning adults than if broodstock were left to spawn naturally.

Genetic differences between hatchery and natural-origin fish and differences between hatchery and natural environments have been shown to manifest themselves in phenotypic traits. Phenotypic traits in hatchery-origin fish having a genetic basis can be inherited by offspring of hatchery and natural-origin adults when they spawn together on the spawning grounds. Of principle interest to managers is distinguishing which of the phenotypic traits are potentially heritable and which are non-heritable by the offspring of hatchery and natural-origin parents. Efforts to integrate natural-origin fish in the broodstock and reduce the selection pressure by the hatchery environment help reduce divergence between the hatchery- and natural-origin fish (HSRG 2009).

Ecological effects of hatchery programs have been debated over the past two decades. Where overlap exists between listed species and unlisted hatchery-origin fish there is the potential for negative associations between the numbers of hatchery-origin fish released and natural origin salmon survival rates because of ecological interactions (e.g. predation and competition). Lastly, hatchery facilities affect habitat for listed species to varying degrees. Within the major spawning and rearing areas of spring Chinook and steelhead populations there are several hatcheries and weirs to collect broodstock as well as multiple acclimation facilities. The value of these facilities to prevent extinction, monitor populations, collect broodstock and manage adult fish must be weighed against sometimes competing habitat values or objectives.

Originally envisioned as a means to produce fish for harvest, many programs have transitioned to the role of supporting the conservation of listed species. Several hatchery review processes have resulted in numerous recommendations for changes to programs for the benefit of listed species conservation. Programs are now in the process of implementing those recommendations and finding better ways to manage hatcheries based on the best science and information.

Given the changes that have been implemented in Upper Columbia hatchery programs in the last 10 years and the emerging information in hatchery science there is likely to be future progress in hatchery programs that will positively impact our progress toward recovery. Although difficult to evaluate, this anticipated future progress is important to consider given that hatcheries are one tool that is used to avoid extinction and boost natural production of listed salmon and steelhead in the region.

At this time, it is challenging to evaluate and agree what future production should look like to best meet legal obligations and salmon recovery needs. Upper Columbia hatcheries are some of the most well-run, intensively evaluated, and costly hatcheries in the world. Hatchery managers and decision-makers continue to use science to evaluate their outcomes and adaptively manage their programs to best meet their program needs. The Chief Joseph Hatchery annual program review is one example of how the Colville Confederated Tribes is using information and partner input in a transparent way to adaptively manage their programs. There is broad agreement that hatchery programs can be improved and they will continue to evolve as we learn more about how best to use them in the context of their role in mitigation and conservation. As part of a coordinated strategy across all management sectors, hatchery management is critically important to the future of salmon in the Upper Columbia.

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Glossary

Assessment Unit - Comprised of either a portion of a primary sub-watershed or the entire sub-watershed, and, if the former, are used to categorize that sub-watershed into smaller units.

Adult Management- The intentional allocation of returning adult hatchery origin adults to directly influence the number and origin composition of fish on spawning grounds

BiOp - Biological Opinion

Carrying Capacity - The maximum population size of the species that the environment can sustain indefinitely, given the food, habitat, water and other necessities are available in the environment.

CWT - Coded-Wire Tag

Donor population - Hatchery group being evaluated; grouped by species, brood, and release location.

EDT - Ecosystem Diagnosis and Treatment

EIS - Environmental Impact Statement

ESA - Endangered Species Act

ESU - Ecologically Significant Unit

FCRPS - Federal Columbia River Power System

FHMP - Fisheries and Hatchery Management Plan

FPS - Fish Passage Survival

FTC - Fisheries Technical Committee

FWP - Columbia Basin Fish and Wildlife Program (Northwest Power and Conservation Council)

GSI - Genetic Stock Identification

HGMP - Hatchery and Genetics Management Plan

HOB - The number of hatchery-origin fish used as hatchery broodstock.

HOR - Refers to a mature returning fish of hatchery origin. When used as a variable, it is the total number of Hatchery-Origin Recruits from a hatchery program (the sum of HOS, HOB, and hatchery-origin fish intercepted in fisheries).

HOS - The number of hatchery-origin fish spawning naturally.

HSRG - Hatchery Scientific Review Group

HRT - Hatchery Review Team (U.S. Fish and Wildlife Service)

ICTRT - Interior Columbia Technical Review Team

IDFG - Idaho Department of Fish and Game

In-basin homing - Fish homed to its release stream (population).

In-basin stray - Fish strayed to another population within its release basin.

Integrated hatchery program- The HSRG (2009) defined an integrated hatchery program as one where 1) the naturally spawning and hatchery produced fish are considered components of a single population, and 2) the adaptation of the combined population is driven more by the conditions of the natural environment than the hatchery. In an integrated harvest program, there is no implied intent to allow hatchery-origin fish to spawn naturally.

ISAB - Independent Scientific Advisory Board

ISRP - Independent Scientific Review Panel

Life Cycle Model - A model that incorporates multiple production areas, juvenile life-history diversity, hatchery effectiveness, and numerous out-of-basin effects and reports population trajectories, extinction risk, and life-stage-specific survival bottlenecks under various future scenarios for freshwater habitat, ocean conditions, and other factors.

LSRCP - Lower Snake River Compensation Plan

MDN - Marine-Derived Nutrients

M&E - Monitoring and Evaluation

Natural-Origin - Synonymous with "wild." Some studies also use the term "wild" to mean natural-origin.

NMFS - National Oceanic and Atmospheric Administration—National Marine Fisheries Service

NOAA - National Oceanic and Atmospheric Administration

Non-target taxa of concern (NTTOC)- Species, stocks, or components of a stock with high value (e.g., stewardship or utilization) that may suffer negative effects because of a hatchery program.

NOR - Refers to a mature returning fish of Natural-Origin (a product of natural spawning). When used as a variable, it is the total number of Natural-Origin Recruits from a population (harvest plus escapement).

NOS - The number of natural-origin fish spawning naturally.

NOB - The number of natural-origin fish used as hatchery broodstock.

NWPCC - Northwest Power and Conservation Council

Out-of-basin stray - Fish strayed to a population in a different release basin.

pHOS - Mean proportion of natural-origin spawners in a watershed or stream composed of hatchery-origin adults each year.

PIT tag - Passive Integrated Transponder tag

PNI - Proportionate Natural Influence on a composite hatchery-/natural-origin population. Can also be thought of as the percentage of time the genes of a composite population spend in the natural environment. Calculated as pNOB/(pNOB + pHOS).

pNOB - Mean proportion of a hatchery broodstock composed of natural-origin adults each year.

Recipient population - Spawning population of species being evaluated; may be at the tributary (e.g., Methow, Twisp, Chewuch), or basin scale (e.g., Entiat, Wenatchee).

R/S - Recruits per Spawner

SAR - Smolt-to-Adult Return ratio

SaSI - Salmonid Stock Inventory (Washington Department of Fish and Wildlife database)

Segregated Hatchery Program- The intent of a segregated hatchery program is to maintain a genetically distinct hatchery stock, distinct from the natural spawning population. The segregated approach uses only hatchery-origin fish for broodstock and results in a population that is adapted to the hatchery environment and managed to avoid spawning between hatchery-origin and natural-origin fish (HSRG 2009).

SPS - Salmon Population Summary (National Oceanic and Atmospheric Administration database)

Supplementation- a strategy by which hatcheries are used to produce fish from wild stocks that introduced into the natural environment to become naturally spawning fish. In this way they are meant to “supplement” natural production.

UCSRB - Upper Columbia Salmon Recovery Board is a coalition of three counties (Douglas, Chelan and Okanogan) and two tribes (Yakama Nation and Colville Confederated Tribe).

VSP - Viable Salmonid Population