Do Pacific salmon hatchery programs work for their intended purpose?

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Abstract

Do Pacific salmon hatchery programs work for their intended purpose?

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Pacific salmon hatchery programs are used as a tool to increase the abundance, productivity, or probability of persistence of populations. Today, they are used throughout the North Pacific Rim. On the west coast of the United States they are used to conserve endangered or threatened populations (designated under the Endangered Species Act), fulfill tribal treaty rights and other legal requirements, provide ecocultural value, and enhance recreational and commercial fishing opportunity. To understand the breadth of hatchery programs and consider the extent to which they function as intended, twenty-two individual hatchery programs were reviewed across Alaska, California, Idaho, Oregon, and Washington. Principal selection criteria was for available management plans (to determine program purpose and objectives) and a combination of monitoring reports and independent evaluations (to determine outcomes). The question guiding the review was, “Do hatchery programs work for their intended purpose?” Through the review of programs, seven program purposes emerged (captive breeding, reintroduction, restoration, mitigation, supplementation, fill underutilized habitat, and optimum production) and were grouped together by the language embedded in management plans. These purposes demonstrated the range of applications that hatchery programs intend to provide; to intervene in the abundance of a targeted population on a continuum from extinct to abundant. Objectives were categorized as biological, ecological, economic, and social. The relationship between purpose and objectives was clear; programs focused on conserving salmon populations emphasized biological and ecological objectives while programs focused on providing

opportunity emphasized economic and social objectives. Outcomes were ranked as generally positive, generally negative, and mixed. Programs with management scale mismatches (e.g., federal oversight and tribal treaty rights) had generally negative outcomes, programs with adequate funding with capacity to adapt had generally positive outcomes, and programs that integrate policy reform (e.g., HSRG framework) had generally positive outcomes. Within the twenty-two programs reviewed, there is not a one-size-fits-all policy for hatchery programs; each works for its intended purpose when managers consider the social-ecological context of the program and design policy that is achievable to implement and adapt.

I. INTRODUCTION

Pacific salmon (*Oncorhynchus spp.*) and steelhead (*O. mykiss*) hatchery programs are numerous and widely distributed throughout the North Pacific, including extensive programs in the U.S., Canada, Japan, and Russia. Salmon are valued in human communities; for their cultural and spiritual significance for tribal nations (ecocultural value), recreational and commercial fishing opportunities (economic and social value), and role as a keystone species (ecological value) in freshwater and marine ecosystems. Hatchery programs are one tool to maintain these values and this tool has been applied across geographic areas, species, levels of abundance and management jurisdictions.

Pacific salmon are anadromous; they hatch and rear in freshwater, migrate to the ocean to grow to maturity, then return to freshwater to spawn. This complex and unusual life history trait presents management challenges in an era of widespread human populations within watersheds and marine systems because salmon require connected and suitable habitat (Kondolf et al. 2008), and are exploited in recreational and commercial fisheries in the ocean and some river systems as well. Additionally, system-wide biotic and biotic shifts change the composition of wild salmon and non-salmon species within the North Pacific ecosystem and lead to changes in salmon species produced in hatchery programs. For example, during a surge of hatchery development between the 1960’s and 1990’s an ocean regime shift occurred in the North Pacific (1976-77). Pink (*O. gorbuscha*) and sockeye (*O. nerka*) salmon abundance (hatchery + wild) increased while chum (*O. keta*) salmon relative abundance decreased. Prior to the regime shift (1950-1970), pink and sockeye salmon were generally declining in abundance while chum were relatively steady (Ruggerone 2011). Releasing large numbers of juveniles from hatchery production changes the structure of the North Pacific ecosystem through density dependence which affects marine growth rates, productivity, and abundance of salmon in the system (Kaeriyama et al. 2010). As human populations expanded in the North Pacific, so did the demand for resources, but at a cost to watersheds and salmon habitat. With expansion, wild salmon runs precipitously declined. The overall declines are largely attributed to a combination of overfishing and watershed alterations through hydroelectric projects, deforestation, agriculture, industry, and urbanization (NRC 1996). However, overuse of hatchery intervention as a 'magic bullet' tool has also led to declines in many salmon populations (Waples 2007, Naish et al. 2008; HSRG 2014).

Hatchery programs for Pacific salmon are permitted under existing regulatory and policy frameworks. Depending on the jurisdiction (federal, tribal, state, private) and value (social, ecocultural, legal) of the targeted salmon hatchery programs are required to implement different regulations and policies (e.g., water rights, land acquisition, state and federal fisheries permits, river habitat modifications, etc.). Programs produce legally binding documents which incorporate these regulations and policies. These documents are referred to as management plans. Within management plans there are stated program purposes and objectives to measure performance and maintain use. Programs also produce monitoring documents which outline outcomes annually, and define a regular program review period (e.g., 5-year programmatic review), or to restructure the program to incorporate changes in hatchery regulation and policy. Outside of program management structure and document deliverables - management agencies, scientific review panels, and research groups may also review outcomes of hatchery programs. These results identify additional gaps or concerns for how the program is managed including risks to wild salmon populations and associated social-ecological systems. Outcomes feed into restructuring management at multiple scales. Hatchery programs have evolved considerably since they were first established on the west coast through improved culturing practices, a better understanding of the salmon life cycle, and the need for efficiency in production. Program evolution is also demonstrated by reformed regulations and policy across jurisdictions, adoption of system-wide research, and recognition of the social-ecological systems in which programs exist.

I.II HISTORY OF SALMON HATCHERIES

History of salmon hatcheries demonstrates the breadth of program applications. From what is recorded in European history, salmon culturing began as early as 1420 in France. Dom Pinchon, a monk from the Abbey of Reome collected Atlantic salmon (*Salmo salar*), hand-fertilized eggs, then buried them in a mix of sand and gravel in wicker baskets set in a stream (Norris 1868; Pennell and Barton 1996). It wasn't until 1763 that the German naturalist Jacobi found Pinchon's records and replicated the culturing methods with some success (Forteath 2011). Methods used by Pinchon, then later Jacobi were adopted and expanded by Shaw in Scotland (1836) and Gehin and Remy in France (1852) with Atlantic salmon and brown trout (*S. trutta*), respectively. Shaw conducted experiments in ponds, successfully rearing salmon to the smolt life-stage (i.e., when the juveniles migrate to sea). Whereas Pinchon, Jacobi and Shaw were pursuing culturing because of a general interest in the salmon lifecycle. Gehin and Remy applied culturing techniques with the intent of augmenting depleted fish populations in France (Pennell and Barton 1996). A hatchery was built on the Rhine to culture brown trout, charr (*Salvelinus alpinus*), and huchen (*Hucho hucho*). This was the first recorded large-scale fish hatchery operation in Europe. Techniques were adopted from predecessors (e.g., Shaw in Scotland) and emerging industrial farming practices. Fish culturing was funded by the French government which also invested in shellfish farming to provide food sources in response to the growing human populations when urbanization and other alterations modified salmon habitats so they could not support native fish populations to the same degree (Forteath 2011).

Culturing techniques from Europe were adopted in North America as early as 1853 with the brook trout (*Salvelinus. fontinalis*) in Ohio. Atlantic salmon culturing began on the east coast as early as 1868 in New Hampshire (Forteath 2011). Pacific salmon culturing began on the west coast in 1872 with Chinook salmon (*O. tshawytscha*). Fertilized eggs were collected on the McCloud River, a tributary of the Sacramento River in California. The eggs were transplanted on the east coast in an effort to augment declining Atlantic salmon populations, but the transplant was unsuccessful. In the 1800's in North America, little was known about the difference between Atlantic and Chinook salmon, therefore, transplanting any salmon seemed like a logical decision (Pennell and Barton 1996). This was also about the same time that rainbow trout were transplanted to European streams and used for culturing (Pennell and Barton 1996). The use of fish culturing rapidly expanded throughout Europe and North America spurred by the prevailing theory that if eggs were cultured in a hatchery, more smolts would result, and more adults would return to the hatchery for harvest than without hatchery intervention, or in an unmodified system (Roppel 1982).

Canned fish were becoming a popular non-perishable protein source and hatcheries were a logical complement to meet demand. The U.S. government authorized canneries to construct and operate salmon hatcheries, incentivizing hatchery production by compensating for every 10 juvenile salmon released (Pennell and Barton 1996). Oregon and Washington began hatchery production in 1877 for Chinook salmon on the Clackamas River. The first project ran for eleven years but hatcheries did not have sufficient juvenile salmon releases and adult returns to fulfill production objectives. The first hatchery in Alaska began operating in 1891 for sockeye in Karluk on Kodiak Island. The hatchery was a collaborative effort between four canneries to produce more salmon for harvest. The hatchery did not last long because the four canneries could not decide on how much of the salmon each was allowed to harvest (Roppel 1982). At the time of hatchery expansion throughout the west coast of the U.S., goals were to maintain the supply of a valuable resource for the public without reducing fishing effort and losing revenue or an important food source. These sentiments were expressed by two U.S. Commissioners of Fish and Fisheries, Dr. Brown Goode in 1887 and George Bowers in 1913 (Roppel 1982). Most hatcheries developed between the late-1800's and mid-1900's were not successful in producing a meaningful yield of salmon to increase survivability from egg to smolt life stages (NRC 1996) or to compensate for overfishing (Roppel 1982). In the Columbia River Basin most facilities closed. In Alaska, facilities rarely lasted more than a few years and by the 1930's there were very few facilities left because the salmon were not increasing in response to hatchery intervention as hoped (Roppel 1982). Hatchery production lost popularity between 1930 and 1950 because the direct feedback of increased harvests was not significant, hatchery facilities had considerable disease problems, and high mortality rates. Additionally, effective culturing methods and salmon life-history requirements were not well understood at the time. Improvements in culturing emerged decades later once more was understood about the salmon life cycle, how to prevent disease, and how to more effectively feed juvenile salmon (NRC 1996).

Then, as the human population and economic growth expanded, new hydroelectric projects surged in number, deforestation continued, and irrigation needs expanded, all of which put pressure on watersheds and ecosystems throughout the region (NRC 1996). In response, hatchery production re-emerged as a way to mitigate mortality from dam operations and losses to previously accessible salmon habitat (Mahnken et al. 1998). Federal intervention through congressional action resulted in The Mitchell Act (1938) which provided funding for nearly forty hatcheries in the Columbia River Basin, many of which were built below dams and cultured high value species (e.g., Chinook and coho (*O. kisutch*)) with production losses to low value species (e.g., sockeye and chum) and distinct populations in the upper reaches of the Columbia River Basin (NRC 1996). Hatchery science, feed improvements, and new developments in technology drastically improved survival and reduced disease in facilities. Popularity of hatcheries increased as a tool to mitigate (NRC 1996) and also with the intention of countering natural fluctuations for the fishing industry. In Alaska, a surge of hatchery intervention in the mid-1970's provided more salmon for commercial and recreational harvest opportunity at a period of low abundance for valuable species (Stopha 2019). Through improvements in hatchery program efficiency (NRC 1996) and a bypass of natural mortality in wild salmon (Waples et al. 2007), nations throughout the North Pacific, including the U.S. significantly increased Pacific salmon hatchery production output as shown by the number of juveniles released.

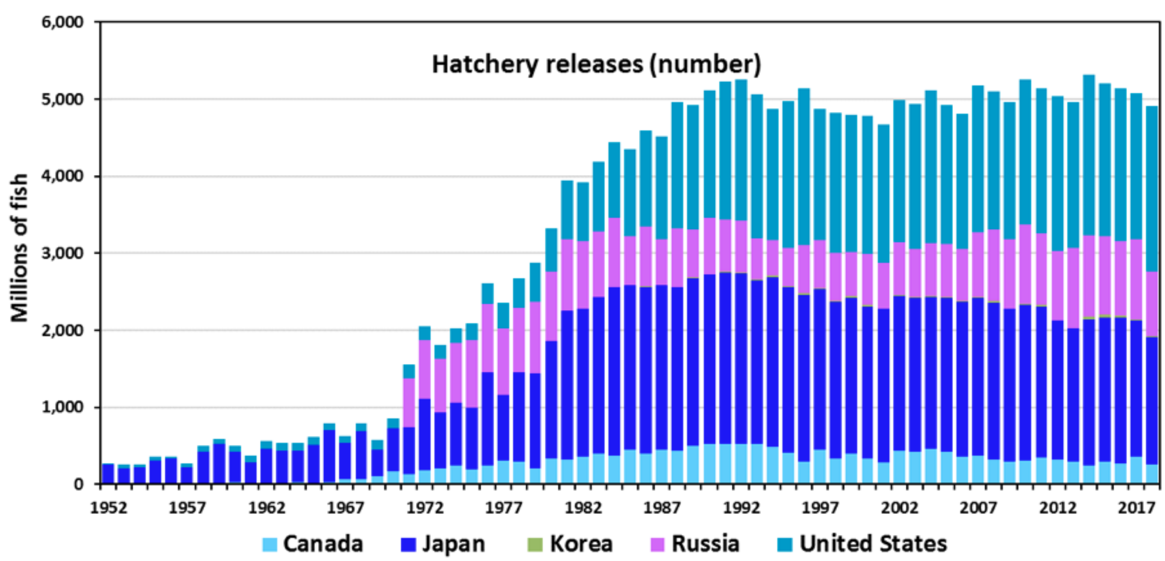

Figure 1. Pacific salmon hatchery releases from 1952 to 2018. Reproduced from NPAFC (2019) without alteration.

As hatchery production increased rapidly from the 1970's onward, concern for biological and ecological risks to wild populations began to emerge. This culminated in multiple reviews of these risks, which generally pointed to a lack of monitoring of impacts of hatchery fish on wild stocks (e.g., NRC 1996). In response, Congress established the Hatchery Scientific Review

Group (HSRG) to review hatchery programs throughout the Pacific Northwest. The HSRG succeeded in reviewing, recommending policy changes, and guiding programs to manage better through clear goal setting, scientific defensibility, and monitoring and evaluation in an adaptive management framework (HSRG 2014; Anderson et al. 2020). The HSRG framework is guiding new policy for hatchery programs throughout the west coast of the U.S. and represents progress in how hatchery programs are managed; from increasing survivability, to compensation for overfishing and mitigation for habitat loss, to optimization of fisheries and conserving valuable populations.

Since the inception of Pacific salmon hatchery programs on the west coast of the US, there has been considerable variance in program intentions for production and actual results. Additionally, the history of hatcheries as an intervention tool has been controversial, with concerns about overuse during different eras and as a widespread 'magic bullet' tool. Therefore, this review focuses on three elements of individual hatchery programs: purpose, objectives, and outcomes. These elements are indicators of program structure, how salmon are valued, and the social-ecological context in which each program was developed and continues to operate. The goal of this thesis is to review selected hatchery programs to illustrate variation in intended use (i.e., purpose and objectives) and results (i.e., outcomes) of programs since hatchery use rapidly increased in the 1970's (see Figure 1). The thesis goal and review elements are addressed through the guiding question, "Do Pacific salmon hatchery programs work for their intended purpose?"

II. METHODS

I reviewed agency literature (federal, tribal, state), program reports (e.g., management and monitoring documents), and peer-reviewed literature to gain a general understanding of how Pacific salmon hatcheries have been used as an intervention tool since the 1970s. Background research was guided the thesis question "Do Pacific salmon hatchery programs work for their intended purpose?" I estimate that I investigated more than 50 programs. From the background research I learned that a common way to differentiate hatchery programs is by the broad benefits they intend to provide, as conservation or harvest hatchery programs (see Anderson et al. 2020). Generalizing as two broad benefits oversimplifies what these programs intend to do and underwrites the complex social-ecological systems they are within. An alternative approach to differentiating hatchery programs is to define them as a tool to intervene in the status of a population where status can be defined by ‘threatened’ or ‘endangered’ under the Endangered Species Act (ESA). The status falls within a continuum that ranges from an extinct to stable population (Fraser 2008). This approach defines programs by type (e.g. captive breeding, harvest-supplementation, and supplementation) and suggests that the type of program can slide along the continuum by managing to prevent an extinct population to managing to maintain a stable population. I applied this continuum approach to seven Pacific salmon hatchery program purposes which are identified from background research. Programs transition between each purpose along the continuum to address population abundance instead of population status. For example, if a captive breeding program meets indicators to transition to the next phase then it will reintroduce the population, focus on restoration, and facilitate the population to a self-sustaining abundance, either with a plan to terminate (no hatchery program) or supplement (continued intervention). All of this depends on the condition of the environment and objectives as the program slides along the continuum. The continuum approach (Fraser 2008) addresses a limited band of population status from extinct to stable. A stable population would, by definition, not require hatchery intervention in order to maintain itself as a self-sustaining run. Therefore, the continuum is expanded from extinct-stable to extinct-abundant where the seven programs defined by their purpose are intervention tools in the abundance of a targeted salmon population, not the agency status (e.g., ESA listings) and not as either/or descriptions of the benefits they provide. The seven program purposes are described as follows:

1. Captive breeding - prevent extinction and preserve genetic and demographic diversity of the population(s) until external pressures (e.g., habitat) are addressed
2. Reintroduction - introduce population(s) of genetically similar salmon to an extirpated habitat for eventual establishment and local adaption
3. Restoration - restore a watershed through habitat improvements and use hatchery programs concurrently to restore a population to a specified abundance
4. Mitigation - minimize and mitigate for hydrosystem mortality and loss of habitat connectivity to maintain abundance
5. Supplementation - maintain or increase abundance

6. Fill underutilized habitat - enhance existing self-sustaining runs or introduce a new population previously unoccupied by salmon; either of which includes ecosystem enhancements
7. Optimum production - maximize abundance while minimizing negative biological and ecological effects to wild salmon

Based on the seven Pacific salmon hatchery program purposes, I selected 2-4 hatchery programs for each purpose which resulted in a review of 22 total programs to illustrate variability in how program purposes met their objectives based on outcomes. The principal criteria for selection of a hatchery program was adequate program documentations through available management plans (to determine program purpose and objectives) and monitoring reports and/or independent evaluations (to determine program outcomes). Hatchery programs do not have the same management structure, therefore the type of document to guide the program may range from a hatchery genetic management plan (HGMP) to a watershed management plan. If the program was guided by more than one document, multiple sources were documented in the review. If the outcomes were described in both monitoring data and independent evaluations, all sources are included in the review. Factors considered but not treated as principal criteria for selection are geography, species produced, and management. Geographic review is limited to west coast states of the U.S. because Pacific salmon are native to these states, hatchery programs are used throughout, and management plans and monitoring/evaluation documents are publicly accessible. Species reviewed are Chinook, chum, coho, pink, and sockeye (including kokanee). Steelhead trout (*O. mykiss*) are native to these states but excluded from the review. Management agency review includes federal, tribal, state, and private entities. The following is a detailed description of the review elements of purpose, objectives, and outcomes:

1. **Program purpose** – "What is the intended purpose of the program?" The purpose is defined from a statement of intent or mission embedded in the introduction or executive summary of management plans. The purpose is either explicitly stated or implied but the language fits within one the seven purposes defined by background research.

2. **Objectives** – "What metrics are developed to measure program performance and what mechanisms are in place to maintain the program?" Objectives are derived from the purpose and are stated as desired outcomes. Some management plans include indicators or triggers to measure performance and maintain the program across time. Objectives can be categorized as biological, ecological, economic, and social. Biological objectives consider the hatchery population and potential impacts to co-existing wild populations. Common examples of biological objectives may include: preserve genetic diversity, prevent fitness loss, and facilitate local adaptation. Examples of ecological objectives include consideration of habitat requirements, trophic interactions, ecosystem dynamics, and the culturing environment at the hatchery. Other common ecological objectives may include: conduct a baseline study of spawning habitat, restoration of habitat, and prevent disease and viruses at the hatchery facility. Economic objectives consider funding mechanisms and program responsibility such as the facility operation and improving efficiency. Common examples may include: adequately funding for the facility, operate the facility efficiently, and utilize a cost-recovery structure. Social objectives consider responsibility of management agencies, ecocultural value, recreational and commercial opportunity, tribal treaty rights, and other legal requirements. Common examples may include: collaboration between agencies, involvement of stakeholders, and fulfilling legal requirements. For the review (see Chapter III) biological, ecological, economic, and social objectives are notated as (B), (E), (Ec), and (S), respectively.

3. **Outcomes** – "Did the program work for its intended use?" Outcomes are the results of monitoring data (e.g., annual management reports) or independent evaluations (e.g., peer reviewed literature, agency review, state or federally mandated task force review) which provide information to compare against program purpose and objectives. Independent evaluations for hatchery programs are generally promoted by concern from the public and tribal nations (e.g., Tribal Treaty Rights at Risk (NWIFC 2011) and the scientific community (e.g., NRC 1996; HSRG 2009; HSRG 2014; HSRG 2020). For the results of the qualitative review (see Chapter III) biological, ecological, economic, and social outcomes are notated as generally positive (+), generally negative (-), and mixed (+/-) according to the corresponding objective (e.g., B+ or E-). Generally positive means that

the objectives are met. Generally negative means that the objectives are not met. Mixed means that the objectives are not met consistently across monitoring years (e.g., the management plan indicates an adult escapement goal while subsequent monitoring reports indicate that the adult escapement goal is met in some, but not all years).

The detailed summary of the review is organized in Microsoft excel (see Appendix A). Descriptors of program name, location, species, and management are included to provide distinct information for each hatchery program but the review elements of purpose, objectives, and outcomes are the focus of this thesis.

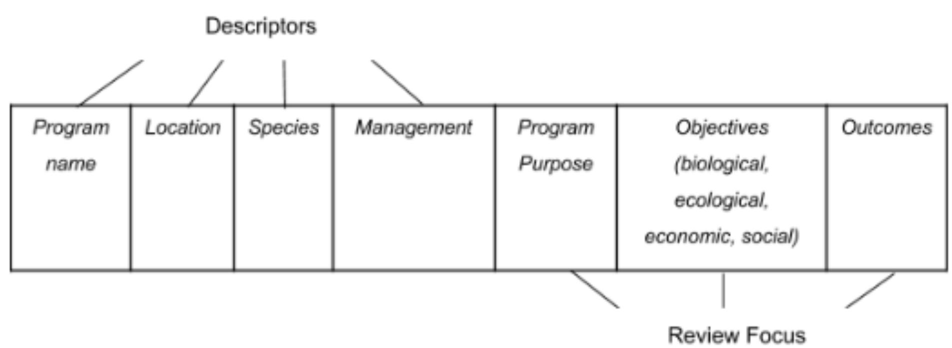

Figure 2: Conceptual diagram of review organization.

Folllowing review of programs (see Chapter III) using methods described above, findings are described as major themes to explain if programs work for their intended purpose and how evolution of system-wide management strategies is influencing individual hatchery programs (see Chapter IV).

III. REVIEW OF HATCHERY PROGRAMS AND OUTCOMES BY HATCHERY PURPOSE

This chapter provides an overview of the seven program purposes (captive breeding, reintroduction, restoration, mitigation, supplementation, fill underutilized habitat, and optimum production), and the 22 hatchery programs reviewed within each for objectives and outcomes.

Results of the review and other pertinent data for each salmon hatchery are summarized in Appendix A.

III.I HATCHERY PURPOSE: CAPTIVE BREEDING

The purpose of captive breeding programs is to prevent extinction and preserve genetic and demographic diversity of the population(s) until external pressures (e.g. habitat degradation or extreme overfishing) that caused the decline are addressed. Species and populations are targeted for captive breeding and gene banking programs are listed under the ESA as either ‘endangered’ or ‘threatened’ (16 U.S.C. § 1521). Captive breeding can be successful to boost population abundance because hatchery technology drastically increases the survival of egg-to-juvenile releases and juvenile-to adult returns (Kline and Flagg 2014; Bauer et al. 2019). However, there is limited empirical evidence that captive breeding programs can transition to successful reintroductions and self-sustaining populations because fitness loss is rarely countered by increases in abundance (Fraser 2008). One exception is the Redfish Lake sockeye where naturally producing smolt to adult returns were more than three times higher than hatchery returns, demonstrating rapid increases in fitness (Kline and Flagg 2014). Long-term management objectives of captive breeding programs are not always well defined because they are primarily focused on preventing extinction and eventual delisting of the ESU under the ESA by meeting recovery objectives. Instead of focusing on minimizing extinction risk it may be prudent to evaluate and assess genetic diversity, fitness, and feasibility of a long-term self-sustaining run to inform decision making (Fraser 2008), integrate HSRG recommendations and principles; the new standard for hatchery programs (HSRG 2009) into the development and reform processes for captive breeding programs (Kline and Flagg 2014). Effective evaluations and implementations are demonstrated by the Redfish Lake sockeye program which integrated a science-based collaborative approach during program development and continued to integrate best-hatchery practices as the program evolved (Kline and Flagg 2014). Two other captive breeding programs are reviewed to understand the variation in programs which may not integrate HSRG principles into initial program development and tailorings; Russian River Basin coho (California), and the Upper Klamath coho (California and Oregon).

Snake River sockeye (*O. nerka*) were the first salmon population listed as 'Endangered' and designated as an ESU under the ESA (Federal Register 1992). The listing was prompted by a petition from the Shoshone-Bannock Tribe in the early 1990's (USFWS 2011). Currently, the tribe, NOAA, IDFG, and Bonneville Power Administration (BPA) work together on the hatchery program. This population travels 1,448 km from the mouth of the Columbia to Redfish Lake in Sawtooth Valley, Idaho; the longest distance traveled by any current sockeye population. Their initial decline was due to increasing Columbia river fishing pressures in the mid 1800's. Subsequent declines were due to habitat loss and alterations from hydroelectric projects, agriculture, mining, and purposeful removal of sockeye in the Sawtooth Valley lakes for recreationally preferred species (i.e., rainbow trout). A captive breeding program began in the 1990's to preserve population genetics (Kline and Flagg 2014). The purpose of the captive breeding program was to prevent extinction, preserve population genetics, and facilitate self-sustaining runs (Maynard et al. 2012). The primary and short-term objectives were to maintain remaining genetic diversity and population heterozygosity (B). The secondary and long-term objectives were to facilitate a self-sustaining population to prompt delisting and create harvest opportunities for tribal and recreational use (S) by producing 1,000 naturally spawning adults (B) (Flagg et al. 2004). Biological objectives were formed for culturing methods (B), genetic preservation (B), and feasibility of recovery effort through genetic diversity (B). Social objectives identified interagency monitoring efforts and data requirements (S). The Stanley Basin Sockeye Technical Oversight Committee, an interagency working group guided program development (S). No habitat connectivity or restoration objectives were identified in the report to access historical spawning grounds or to improve migration corridors below Sawtooth Valley, although these were added as research components once the population was phasing into reintroduction (Kline and Flagg 2014). Without hatchery intervention it is clear that the Redfish Lake ESU would have gone extinct.

The captive breeding program began by collecting broodstock and rearing to spawning adults in captivity. The program phased into partial captivity over time as broodstock collection, egg survival, and juvenile to adult survival increased (B+) and fish health was maintained (E+). Broodstock, eggs, and juvenile fish were in excess of program needs, therefore, the captive breeding program was phased into a reintroduction program with partial captive breeding maintained (B+) (Kline and Flagg 2014). Initially the reintroduction program was developed as an experimental program. Additional restoration measures were added to facilitate successful reintroduction by evaluating the habitat and improving the ecosystem for better rearing outcomes (E+) (Flagg et al. 2004). Currently the program still functions as a partial captive breeding program (from broodstock collection to pre-smolt release). The program continues to evolve. The initial objectives of preserving genetic diversity and population heterozygosity were met (B+). As the program phases from reintroduction to successful recolonization then eventual self-sustaining runs, studies are underway to determine habitat capacity and rearing to fulfill the program purpose and objectives in the recovery (management) plan. Monitoring following the transition from captive breeding to reintroduction focused on egg survival, juvenile to adult survival, and broodstock abundance as measurements of program success (Johnson et al. 2017). Kline and Flagg (2014) determined that 1 million hatchery-reared smolts would produce 5,000 adults, of those, 1,600 would be naturally spawning. Since the inception of the program there have been varying numbers of returning adults (B+/-). There were no habitat connectivity or restoration goals highlighted at the inception of the program (Kline et al. 2003) and fish passage access continues to be a problem outside of the Sawtooth Valley Lakes (E-). The program evolved by considering HSRG management recommendations of using a sliding scale to determine broodstock, egg, and juvenile to adult requirement each year (HSRG 2009) (B+; E+; S+). The program will fully terminate as a captive breeding program when there are sufficient salmon returning to spawn. Hatchery intervention will remain to boost survival from the egg to the smolt stage. However, habitat concerns below the Sawtooth Valley Lakes were never addressed from the initial program development to now. Ocean productivity and climate change impact the future status of this population (Kline and Flagg 2014). Until managers recognize and address habitat limitations below Redfish Lake, hatchery intervention will likely remain.

There are two coho (*O. kisutch*) ESUs designated in California, the central California coast (CCC) ESU and the Southern Oregon/Northern California (SONCC) ESU. The Central California Coast (CCC) coho salmon in the Russian River basin of California, USA was listed in 1995 as ‘Threatened’ and relisted in 2005 as ‘Endangered’ (Federal Register 2005). For the CCC coho, a captive breeding program was developed for the purpose of preventing extinction, maintaining spatial distribution, restoring habitat connectivity, and creating future harvest opportunities for tribal, recreational, and commercial use. The regulatory purpose of the hatchery program was to delist the CCC ESU under the ESA. The recovery strategy identified five major objectives and methods for measuring success for the program including extinction prevention of distinct populations (B), restoration (E) population trends (B), spatial distribution (B), and habitat connectivity (E) (CDFW 2012).

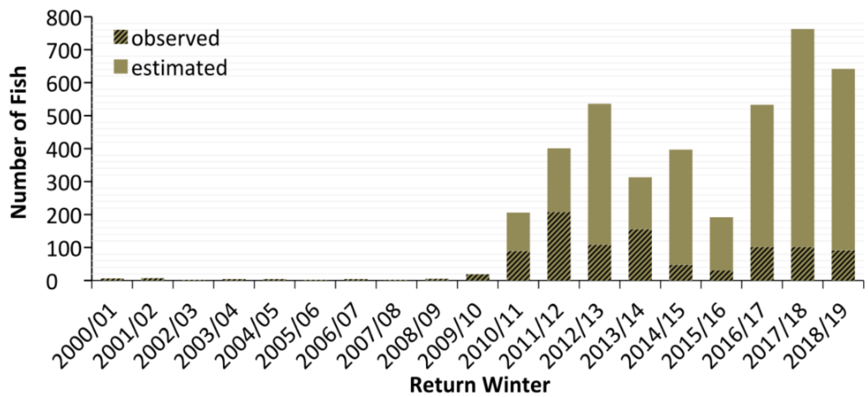

Figure 3. Adult coho salmon returns to the Russian River from 2000 to 2019. Reproduced from Bauer et al., (2019) without alteration.

Since the inception of the program, more than 50 restoration and fish passage projects occurred in the Russian River watershed (E+). The Russian River Coho Water Resource Partnership sought to improve water resources and habitat connectivity for coho recovery and work as a model for future watershed partnership programs. Watershed community connections were strong through partnership formation (S+) The program has been successful in meeting restoration and habitat objectives (E+) but outside restoration and captive breeding efforts coho salmon are still declining for all ESUs in the region (B-) (Bauer et al. 2019). Between 2004 and 2015 released juveniles increased from approximately 6,000 to 172,000 (CDWF 2012). Returning adults increased from <5 in the early 2000's to a maximum of 750 in the 2017/18 monitoring years (Bauer et al. 2019). The captive breeding program was successful in a relatively short timeline to increase releases and returns, as measured in abundance (B+; S+) (Figure 1). Monitoring and evaluation efforts are focused on outputs and returns on multiple spatial scales, however, there are still remaining genetic concerns (B-) for captive breeding populations throughout the watershed, therefore broodstock from an adjacent creek was integrated into the Russian River broodstock (Bauer et al. 2019). The CCC ESU hatchery program has not demonstrated that the population could be self-sustaining or that ESA recovery objectives will be met for delisting criteria.

The SONCC ESU listed as 'Threatened' in 1997 and relisted as 'Endangered' in 2005 (Federal Register 2005). A gene banking program was developed to protect genetic diversity and prevent extinction of the dwindling coho salmon of the Upper Klamath River (CDFW 2014; Williams et al. 2016). As part of the ESA recovery strategy for coho in California, management was developed as a phased program. The first phase of the program is gene banking and the phase will be maintained until the Iron Gate and mainstem Klamath River dams are removed and habitat connectivity can be addressed at a watershed scale. In the 2014-2024 HGMP, the program centered on biological objectives to preserve genetic diversity (B), abundance (B), and broodstock needs of the hatchery program (B) before any habitat issues are addressed. Reintroduction is the second phase of the program but will not be implemented until the dams are removed and habit requirements can be feasibly addressed (CDFW 2014). Under the Klamath River Renewal Definitive Plan, hatchery facility requirements and mitigation goals were addressed through terms of the settlement agreement which was a collaborative effort among user groups and stakeholders (S) in the Klamath Basin (Upper Klamath River Coho Salmon Workshop 2012). Funding for hatchery operations (Ec) and water needs prior to, during, and after dam removal will be provided by PacifiCorp (KRRC 2018). Monitoring and evaluation of the program has not yet been realized because the dam isn't scheduled for removal until 2022 (KRRC 2018). Preservation genetic diversity is the primary purpose of the program until the river can be restored. Because the Klamath dams have not been removed, there are no monitoring reports which would provide data to determine intermediate outcomes of the program. This hatchery program is included in the review because it demonstrates a purposefully phased program (S+) with consistent funding mechanisms (Ec+) but does not include any studies to determine habitat capacity or life stage requirements (E-) once the program is phased into the reintroduction stage.

III.II HATCHERY PURPOSE: REINTRODUCTION

The purpose(s) of reintroduction programs is to introduce population(s) of genetically similar salmon to habitat from which they were extirpated for eventual establishment and local adaptation. Populations from adjacent or nearby watersheds must be used to facilitate development of a new locally adapted population. Depending on the species, life history traits, and status of nearby populations a suitable broodstock population may be difficult to find and utilize. Reintroduction programs are either concurrent with existing hydrosystem projects (e.g., San Joaquin River spring-run Chinook; Yakima River coho), following removal (e.g., planned for 2022 Klamath River coho) or through relicensing (e.g., Deschutes River spring-run Chinook). Reintroduction programs are often prompted by a settlement or court agreement but can also be implemented to address overall population viability of a listed population (e.g., Chimacum Creek summer chum). Whereas captive breeding is focused on preventing extinction, reintroduction is focused on a population that is important to reintroduce for defined user groups (e.g., tribal treaty rights, recreational use, commercial use). Positive program outcomes often stem from settlement cases because well-defined objectives including biological, ecological, economic, and social criteria are required on short- and long-term scales before the program is even approved. Additionally, a funding mechanism is in place to reassure long-term monitoring and evaluation and collaborative approaches between groups are used to come to an agreement. Unsuccessful program outcomes stem from competing management goals (e.g., ESA recovery objectives vs. program objectives) and lack of funding, infrastructure, and habitat considerations. To understand the variation in reintroduction hatchery programs. four programs were reviewed: San Joaquin River Chinook (California), Deschutes River spring-run Chinook (Oregon), Yakima River coho (Washington), and Chimacum Creek chum (Washington).

For reintroduction of spring-run Chinook salmon in the San Joaquin River (SJR), California, USA, the development of the San Joaquin River Restoration Program (SJRRP) was a result of a settlement case (Natural Resources Defense Council (NRDC), et al., v. Kirk Rodgers, US Bureau of Reclamation, et al. 2003). The settlement conditions created a set of well-defined objectives that targeted hatchery management and restoration efforts with the purpose of reintroducing runs and creating a self-sustaining population in the SJR. Five objectives were developed by the Restoration Administrator and the Fisheries Management Working Group (FMWG). Two genetic objectives were developed by FMWG. National Marine Fisheries Service

(NMFS) Performance metrics were developed to measure the outcome of the program against objectives and the program purpose (Bork et al. 2018). Clear objectives were defined for biological, ecological, and social dimensions but no economic objectives were specified other than funding mechanisms (Bork et al. 2018). The program is ongoing; therefore, outcomes are preliminary. In the most recent annual report, the self-sustaining population goal was met. Natural spawners increased through time for captive bred hatchery releases (B+) (SJRRP 2018) and hatchery juvenile releases (B+), however reports did not describe fitness or demographic shifts through monitoring efforts (B-). Social objectives were met through a variety of successful outreach and education programs (S+) and consensus-based management decisions for concurrent restoration programs targeting habitat connectivity (E+; S+).

The reintroduction of spring-run Chinook salmon in the Deschutes River in Oregon was prompted by the Federal Energy Regulatory Commission (FERC) relicensing of the Pelton Round Butte (PRB) Dam, associated hydrosystem projects, and a settlement agreement. The settlement conditions included a fish passage plan (FERC Project No. 2030-036 2005). The initial plan informed program purpose to include habitat connectivity (E) and reintroduction elements (B), and facilitation of a self-sustaining population (B) (ODFW and CTWS 2008). A risk-benefit framework was used to categorize performance metrics and guidelines for monitoring and evaluation efforts (ODFW 2017). Because the fish passage plan was the main objective of the program there was less of an emphasis on biological objectives and genetic criteria in collaborative recovery plans (ODFW and CTWS 2008) than subsequent HGMPs (ODFW 2017). The secondary objective of reintroducing spring-run Chinook salmon above the PRB dam generally addressed biological and ecological criteria but did not provide specific metrics. Objectives highlighted consider the risk the hatchery population poses to the wild population and other native fish populations in the Deschutes River (ODFW 2017). Objectives were to reduce straying (B), synchronize run timing and life history characteristics (B), assess intra- and interspecific competition (E), prevent disease in the hatchery facility (E), consider harvest impacts (S), and incidental harvest (S). All objectives in the risk framework identified concerns on other fish populations but did not highlight any biological, ecological, economic, or social indicators for the hatchery population specifically. Outcomes in the HGMP highlighted numeric goals of juvenile releases and harvest (S+) but did not highlight any returning spawner goals for stock management and genetic effects on fitness of the hatchery population (B-) (ODFW 2017). There is a tribal fishery for Chinook salmon on the Deschutes River (S+). The reintroduction plan was developed by a combined state and tribal effort (S+). There are other hatcheries on the Deschutes operated by tribes and for tribal use (e.g., Warm Springs Hatchery). There is also a recreational fishery on the Deschutes for other anadromous species. Incidental mortality from recreational fishing is a concern for out-migrants (E-; S-) (ODFW and CTWS 2008). Objectives do not include a comprensive list of ecosystem indicators (E-) and are centered on smolt releases without considering genetic risk (B-).

Reintroduction of coho salmon in Yakima River in Washington was prompted by a tribal treaty court case (USA, et al. v. Oregon et al. 1985). Conditions of the settlement centered on harvest objectives and reintroduction of a historic coho salmon population. In the planning process, the program was divided into four phases including a short-term feasibility study to see if reintroduction was possible by out-of-basin stock (Phase 1) and a long-term program to increase capacity of spawning and enhance local adaption without using out-of-basin stock (Phase II, III, IV). An integrated program was developed to reintroduce coho above Prosser Dam to create a self-sustaining population for conservation and future harvest benefits (E, S). A segregated program was developed below the Prosser Dam to meet harvest goals for tribal treaty rights and recreational angling interests (S). Performance objectives and monitoring requirements highlighted harvest (S) and population viability objectives (B) (Blodgett 2003). The risk-benefit framework outlined local adaption (B), harvest (S), and conservation (E) objectives to identify indicators of success for both the segregated and integrated programs. Phase I objectives were met through successful reintroduction of coho salmon above the Prosser Dam by seeing returning spawners (B+), and no negative ecological impacts (E+) i.e., predation, competition, disease to other native species in the basin through field observations. Phase II objectives were met by the continued increasing number of observed adult returns and redds observed (69% increase) since the program began (B+). Phase I and II resulted in measurable outcomes and facilitated the development of an adaptive management framework for Phase III and IV (S+). The revised goal of the overall program is to reduce out-of-basin stock used for hatchery production and increase in-basin stock for both the integrated and segregated programs for the purpose of increased harvest (Yakama Nation 2012). Phase III and IV addressed production through harvest for both the integrated and segregated programs in the Yakima River. The independent scientific review panel (ISRP), which is a review panel funded by the BPA to make recommendations on fish and wildlife projects reviewed the program four times between 2012 and 2020, highlighting a lack of compliance in meeting and revising harvest and conservation objectives. The panel found outstanding issues of a lack of indicators to transition between program phases (S-), harvest and spawning escapement concerns (B-; S-), uncertainty associated with ecological criteria (E-), and how to effectively monitor the project as the program expands (S-) (ISRP 2020). There is no future plan to remove the Prosser Dam. Any recovery effort for the Yakima River coho must consider the habitat limitations and the impact on survival with the dam in place.

Summer chum in Chimacum Creek were extirpated in the mid-1980's due to harvest and habitat pressures (Johnson and Weller 2003). They were designated under the Hood Canal summer chum ESU listed in 1999 (Federal Register 1999). The reintroduction program began prior to ESA listing in 1996 with adjacent Salmon Creek broodstock. The program objectives were defined within ESA recovery objectives; need in a larger context to preserve genetic diversity and demographics (B), restore habitat (E), and reduce harvest rate from an average of 54.7% over 1980-1991 to an average of 9.8% over 1992-2004 (S). The first adults returned in 1999 and the program was suspended in 2003 after two generations returned as adult spawners because the adult spawner recovery goal was exceeded prior to the third generation (B+; E+; S+).

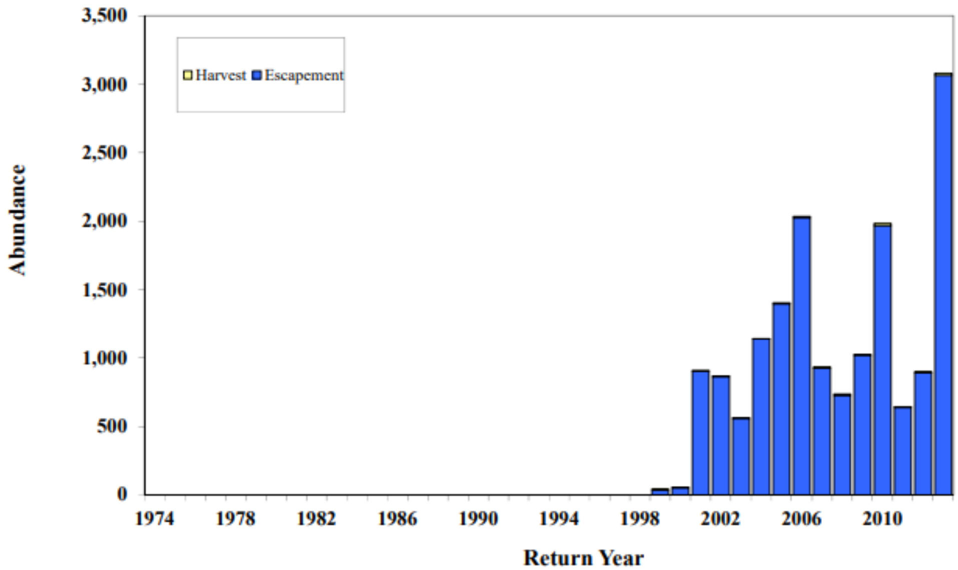

Figure 4: Summer chum annual abundance as a combined escapement and harvest value for Chimacum Creek from 1974 to 2013. Reproduced from Point No Point Treaty Tribes and WDFW (2014) without alteration.

The program successfully created a self-sustaining run in Chimacum Creek which continues to maintain itself today. Adult spawners continue to return to the creek well after the termination of the program (Point No Point Treaty Tribes and WDFW 2014; Anderson et al. 2020). The success of the program working for its intended purpose was met through clearly defined objectives which integrated ESA recovery objectives, harvest reductions, and habitat restoration. Although the summer chum ESU is still listed, the population in Chimacum Creek is thriving without hatchery intervention.

III.III HATCHERY PURPOSE: RESTORATION

The purpose of restoration programs is to restore a watershed through habitat improvements and use hatchery programs concurrently to restore a population to a specified abundance. Salmonids require baseline ecosystem connectivity for survival (Kondolf et al. 2008). Some programs are designed to restore an entire watershed designated as suitable habitat whereas others are designed to restore select areas of a migratory corridor or spawning grounds to increase the probability of survival. Hatchery production is a component of restoration programs. Dissimilar to mitigation or supplementation programs, restoration focuses on habitat improvements primarily and uses hatchery production secondarily to fulfill former ecosystem functions. The difference between full restoration and partial restoration depends on existing hydrosystem projects and the ability to restore an entire watershed. Programs are termed as 'phased restoration' because initial program development includes a number of stages which have a defined timeline with specific objectives for each. To understand the variation in restoration program management two cases were explored: the Elwha River multi-species restoration program (Washington) and the Lake Sammamish kokanee restoration program (Washington).

The Elwha River Fish restoration effort considered restoration of the Elwha River through dam removal and habitat improvements concurrent with hatchery production. The Elwha River Ecosystem and Fisheries Restoration Act "Elwha Act" (Public Law 102-495) was a 1992 Congressional action for river restoration through complete removal of both dams in place at the time. Federal action stemmed from an issue within a FERC license renewal process where the Elwha dams failed safety inspections and could not be effectively upgraded to meet current energy standards. From this, a funding mechanism for dam removal was established (Ec) and interagency collaboration designed a restoration plan for the Elwha River. The Elwha River Restoration Plan detailed a phased program through adaptive management, objective setting, monitoring, and evaluation metrics. Two objectives focused on maintaining genetic diversity (B), one objective focused on maintaining fish health (E), and the final objective focused on ecosystem recovery (E) (Ward et al. 2008). The program was reviewed in 2012 by the HSRG. Their review indicated that management and monitoring objectives were not clear in the management plan. Additionally, the review identified concern for extensive hatchery influence in the Elwha River watershed, and likelihood of failure to meet program objectives and recolonize salmon after dam removal (HSRG 2012). The approach used in the initial plan was action-based (S-) while hatchery reform prefers biological-based approaches within a risk-benefit framework (HSRG 2012; Anderson et al. 2020). The turbulence continued for the Elwha River restoration with a court case between the Wild Fish Conservancy and the National Park Service (NPS). The plaintiff brought forth compelling evidence for the need to restore the river without hatchery influence because of concerns over prolonged hatchery influence (B-), genetic effects (B-), and ill-defined endpoints in the restoration plan (E-), all of which were also identified by the HSRG review. The NPS and tribes in favor of the hatchery program confirmed that the program could be managed without any negative genetic effects and would operate in an adaptive management framework. Further, using hatchery production to preserve, reestablish, then facilitate self-sustaining runs would maintain a federal mandate and uphold tribal treaty rights (S+) (Wild Fish Conservancy et al. v. NPS et al. 2012). The Elwha River restoration program is complex and requires collaboration to ease HSRG and others concerns over using a hatchery program to intervene for the salmon populations.

The Lake Sammamish kokanee restoration program is in the Sammamish Basin, WA. The program's purpose is to prevent extinction by boosting population abundance and facilitate self-sustaining runs for eventual harvest while concurrently restoring salmon habitat (Berge and Higgins. 2013). Hatchery intervention objectives are defined in short-term timeline (3 years) and a long-term timeline (12 years). The short-term objectives are to prevent extinction (B), maintain genetic diversity, distribution, abundance, and demographics (B) of the remaining population. The long-term objectives are to increase abundance, demographics, genetic diversity through facilitating a self-sustaining run (B) within a three-generation timeline. If self-sustaining runs are viable without continued hatchery intervention (B) the program will be analyzed to assess recreational and tribal fisheries impacts on the population (S) (Berge and Higgins. 2013). The habitat restoration component of the program is driven by an agency and user group collaborative process which formed a working group for the program (i.e., Lake Sammamish Kokanee Working Group (KWG) (S+), determined habitat restoration projects (E+), developed outreach and education materials (S+), and secured funding mechanisms (Ec+) (KWG 2014). Managers identified an expected timeline for meeting program goals. The timeline initially set has since been revised to reflect monitoring and evaluation results. In years of higher population abundance, the returning hatchery spawners were a small proportion of the total population (including hatchery and wild spawners) (7% for 2012-13 and 2015-16). In years of low population abundance, the returning hatchery spawners were a high proportion of the abundance (41% for 13-14 and 28% for 2014-15). A recent ecological assessment indicated that the supplementation program was not working as predicted, “the goal of this conservation strategy is not being realized as intended, and implementation is both costly and time intensive.” (KWG

2017). The contribution to overall population abundance is sporadic (B+/-) and the predicted ratio of contributing hatchery spawners is rarely met (B-). For years of low abundance, the hatchery proportion is important to maintain overall population abundance (B+) but the overall hatchery program is costly without consistent, long-term benefits (B-; Ec-; S-). Boosting population abundance through hatchery influence was not effective. Although the primary purpose to prevent extinction was met (B+) the population with hatchery influence is not increasing in abundance towards a self-sustaining run (B-). Habitat goals are continually achieved (+) though without a sufficient population to utilize the habitat the population could not be self-sustaining or support recreational and tribal fisheries. Modification of hatchery culturing techniques and assessing ecosystems was recommended as high priority to continue the program (KWG 2017). Since the program operates within an adaptive management framework (KWG 2014) there is room for modifications and improvements in the future. The program continues to operate. It is possible that the program will not realize its intended use because the purpose and objectives were optimistic given the status of the population and the initial timeline defined by managers. There are additional ecological pressures in Lake Sammamish including non-native predation on juvenile kokanee and changes in temperature regimes which affect species composition for prey availability and physiological processes (e.g. heat stress) (E-). Until the larger scope of the program is taken into consideration and objectives are redefined it is likely that the feasibility of program success will remain low.

III.IV HATCHERY PURPOSE: MITIGATION

The purpose of mitigation programs is to use hatchery production to minimize and mitigate for hydrosystem mortality and loss of habitat connectivity to maintain abundance. Mitigation programs are generally structured on an indefinite timeline or as long as hydroelectric projects are not slated for removal. Mitigation programs are phasing out as a recovery tool (e.g., Pahsimeroi River summer Chinook) because they address an endpoint goal (e.g., minimum threshold of adult returns, egg takes, smolt releases) but do not consider the larger watershed impacts of a hydroelectric project and changes in capacity due to hydrosystem alterations over time. Additionally, considering endpoint objectives meets the basic requirement of mitigation programs which is to mitigate for losses because of altering a watershed. Although, baseline habitat requirements are essential for salmon, without an understanding of how the habitat has changed overtime due to hydrosystem developments, limits a hatchery program to effectively intervene and meet objectives. Because most mitigation programs are funded by power companies and agencies that own and operate hydroelectric projects, programs that are costly and serve a limited purpose may be suspended in favor of producing another species in the watershed that is in greater need of hatchery intervention (e.g., Wenatchee Lake sockeye and steelhead). To understand the variation in mitigation programs three programs were reviewed: Pahsimeroi River summer Chinook (Idaho), Lake Wenatchee sockeye (Washington), and Chelan Falls/Turtle Rock Chinook (Washington).

The hatchery program for summer Chinook salmon in Pahsimeroi River is operated as a mitigation program under the Hells Canyon Complex FERC license. The Pahsimeroi Fish Hatchery was constructed in the late 1960's by the Idaho Power Company (IPC) as a mitigation facility for native Chinook salmon and steelhead affected by the construction and future operations of the dam (reviewed by HSRG 2009). Summer Chinook are a designated population of the Snake River ESU listed threatened under the ESA in 1992 (Federal Register 1992). Prior to listing the program was designed as a harvest-oriented program then shifted to a conservation-oriented program following hatchery reform. Under a harvest-oriented program, objectives were based on smolt releases and adult returns (B, S) (Garlie 2003). Neither smolt releases or adult return minimum thresholds were met annually (B-; S-), therefore the program was restructured as an integrated conservation and supplementation program (as designated by the HSRG 2009) on a sliding scale which means to use relative returns to determine wild-origin and hatchery-origin broodstock needs and smolt release expectations instead of minimum or maximum values (B+) (HSRG 2009; IDFG 2017).

Sockeye salmon in the Wenatchee basin were under a supplementation-mitigation program which is one of three hatchery program types defined and managed by collaborative agency effort and funded by Chelan and Grant Public Utility Districts (PUDs). Lake Wenatchee was used as a sockeye salmon hatchery-origin rearing site beginning with the Grand Coulee Fish Maintenance Project (GCFMP) concurrent with the construction of the Grand Coulee Dam (GCD) in the 1930's (Cates 2006 *USFWS unpublished report*). This review focuses on the last phase of the program which ran from 1989 to 2011. The program was defined as a safety-net program: to harvest in high abundance years and to act as a reserve for the natural spawning population in low abundance years (Hillman et al. 2018). The primary purpose of the program was to mitigate hydrosystem mortality from the Rock Island Dam (WDFW and USFWS 2016). The secondary purpose was to supplement the wild population without adversely affecting productivity, abundance, and fitness from hatchery influence (Hillman et al. 2018). The Lake Wenatchee sockeye salmon program was terminated after 22 years of operation. Smolt releases into Lake Wenatchee exceeded the production goal 11 of 22 years (B+/-; S+/-) and all viable salmon population (VSP) criteria was met (B+; E+) for the majority of years. None of the program outcomes violated the primary purpose, secondary purpose, or objectives. Instead, the program was terminated because steelhead trout were prioritized over sockeye for hatchery production with the same funding source (S+/-) (Hillman et al. 2018).

The Chelan Falls/Turtle Rock summer Chinook are under an augmentation-mitigation program, one of the three hatchery program types managed by collaborative agency effort and funded by Chelan and Grant PUBS. The program is a No Net Impact (NNI) compensatory program to mitigate hydrosystem mortality for the Rocky Reach Dam in Wenatchee, WA. The primary purpose of this program type is to provide harvest opportunities lost to hydrosystem mortalities (WDFW and USFWS 2016). The secondary purpose is to segregate hatchery origin salmon from the wild origin salmon (Hillman et al. 2018; WDFW and USFWS 2016). Objectives for both the Lake Wenatchee sockeye and Chelan Falls/Turtle Rock summer Chinook (as determined by WDFW) were determined by minimum production thresholds and VSP criteria. Objectives were centered on genetic criteria (B), population demographics (B), spatial distribution (E), and ecosystem impacts (E). Funding mechanisms for the program were provided through a combination of Chelan and Grant PUDs (Ec) as part of the mitigation program in the upper Columbia River watershed (WDFW and USFWS 2016).

The Chelan Falls/Turtle Rock summer Chinook salmon program continues after 25 years of operation. During a FERC relicensing of the Rocky Reach Dam the Chelan Falls Hatchery was built to expand production capacity, augment limited rearing habitat, and address straying concerns stemming from the facility location and limitations of the Turtle Rock Hatchery

(Chelan PUB 2010). For the 1995-2017 monitoring years, egg take threshold, sub-yearling release thresholds were not met for any monitoring years (B-). Smolt release thresholds were met for the majority of years when the release target was 200,000 (S+/-) (1995-2009) and for none of the years when the release target was bumped to 600,000 (S+/-) (2009-2015). Monitoring efforts indicated that fecundity and fertilization rates were lower than predicted which prevented smolt release thresholds from being met (B-). Straying percentages were monitored for streams outside of Chelan River. In the accelerated yearling release program between 1995-2009 an average of 29.3% strayed outside of Chelan River (B-). For hatchery strays in the non-accelerated yearling release program between 1995-2004 an average of 59.9% (B-) and between 2005 and 2011 an average of 14.3% (B-) strayed outside of Chelan River. A reduction in straying outside of Chelan River was likely due to changing production facilities from the lower Turtle Rock to the upper Chelan Falls (Hillman et al. 2018). For Columbia River fisheries, the proportion of adults harvested was 74.2% (S+) (Hillman et al. 2018) though the contribution to total Columbia River fisheries was not indicated. The Chelan Falls/Turtle Rock hatchery program will be maintained with adequate funding sources set aside for the population. Unless priorities change, the program will be maintained because it provides important harvest opportunities for tribal, recreational, and commercial users.

III.V HATCHERY PURPOSE: SUPPLEMENTATION

The purpose of a supplementation program is to maintain or increase abundance. Contrary to mitigation programs which provide salmon through hatchery intervention because of losses due to hydrosystem projects, this program type targets populations that may not need intervention to prevent the status from sliding to extinction or extirpation. The general purpose is to enhance for harvest while minimizing effects to the wild population. Generally, supplementation programs are developed to maintain or increase abundance of the targeted wild population (Naish et al. 2008) and continue to provide harvest opportunities for different user groups (i.e., tribal, recreational, and commercial). Supplementation programs are widely used throughout the west coast of the U.S. While well intended to boost a population, supplementation programs that are integrated, where the wild and hatchery populations rear and spawn concurrently, may affect the fitness of proximate wild populations and as a result are rarely successful in maintaining wild population abundance after program suspension (reviewed in Anderson et al. 2020). In addition, Integration of wild and hatchery salmon also leads to challenges in monitoring, evaluation, and escapement estimates over time (Amoroso et al. 2017; Fraser 2008). However, closely monitored supplementation programs can boost population abundance by preventing fitness losses to the concurrent wild population (Janowitz-Koch 2019). To understand the variation in supplementation hatchery programs, three programs were reviewed: Big Quilcene River summer chum salmon (Washington), Stillaguamish Chinook (Washington), and Salmon River Chinook (Oregon).

Summer chum salmon in Hood Canal and the Strait of Juan de Fuca were listed as Threatened under the ESA in 1999 (Federal Register 1999). The Summer Chum Salmon Conservation Initiative (SCSCI), a collaborative agency effort between WDFW and Point No Point Treaty Tribes identified Big Quilcene River chum as an ideal population for a supplementation program. Other chum populations of Hood Canal were extirpated and were identified as ideal subpopulations for reintroduction programs (e.g., reintroduced Chimacum Creek summer chum). The purpose of the program was to facilitate recovery of the ESU and provide harvest opportunities for tribal, recreational and commercial users. Objectives outlined to aid recovery were hatchery production (B), reducing interactions of hatchery and wild spawners (B, E), addressing habitat limitations (E), identifying habitat restoration potential (E), and reducing harvest pressure (S). Prior to supplementation, voluntary harvest reductions were used to reduce pressure on the stock (S+/-) by the Point No Point Treaty Tribes. Effort was instead focused on collecting broodstock for hatchery culturing (B+). During program development the major issue identified was degraded habitat (E-) (WDFW and Point No Point Treaty Tribes 2000). In 1992 the 5-year average (1989-1994) for adult escapement was 12 fish (B-; S-). After implementing the supplementation program in 1992 and reducing harvest pressure, the 4-year average (1995-1998) for adult escapements (mixed wild and hatchery stocks) was 5,523 fish (B+; S+) (Adicks et al. 2005). The program was reviewed in 2003 following separation of hatchery and wild returns by clipping the adipose fin of juvenile hatchery salmon. For 2001 and 2002 returns of natural origin spawning adults there were 2,300 and 2,700 salmon, respectively (B+; S+) (Johnson and Weller 2003). Self-sustaining objectives were met between 1995 and 2002 (B+). The initial escapement threshold was 2,607 hatchery and natural origin spawners. The runs continue to exceed the minimum escapement threshold and are a self-sustaining run. Supplementation programs in Hood Canal are limited to three generations or meeting escapement thresholds (Kostow 2012). The Big Quilcene River supplementation program met and exceeded escapement thresholds and has also exceeded three generations. In 2002 managers discussed scaling the program back but did not identify a strategy to end the supplementation program (Johnson and Weller 2003) despite meeting all escapement goals and running the program past 3 generations (B+/-; S+/-). In 2009 the USFWS reviewed the program using the HSRG framework and recommended a preferred alternative to scale back production. This alternative was a compromise to maintain harvest opportunities while addressing underlying biological and ecological concerns with surplus salmon (straying, disease etc.) (B+/-; S+/-) (USFWS 2009).

The Stillaguamish River Chinook salmon is a designated population segment of the Puget Sound Chinook ESU and an escapement indicator stock (Chinook Salmon Technical Committee (CTC), Pacific Salmon Commission (PSC), Gray et al. 2016). Hatchery programs have been utilized in the Stillaguamish Watershed since the early 1950's (Gray et al. 2016). A supplementation specific recovery program began in the 1980's and a refined program was initiated in the early 2000's to address harvest and habitat concerns. The watershed-wide recovery plan addressed the Stillaguamish Chinook generally while the hatchery management plan addressed the population specifically. Under the hatchery management plan, the program purpose was to facilitate a self-sustaining run of Chinook in the North Fork of the Stillaguamish River for future tribal, recreational, and commercial fishing opportunities through increasing abundance, spatial distribution, and genetic diversity (STAG 2000). The plan recommended three strategies to achieve recovery: hatchery production, future harvest potential, and habitat restoration. The plan outlined biological, ecological, social, and economic recommendations to guide the hatchery program and to ensure integration with harvest and habitat recovery strategies (STAG 2000). The program fell under an adaptive management framework which allowed for reform and restructuring as new information became available. The program also recommended an adult-spawner escapement objective of 2,000 (B). Biological recommendations were to limit interaction amongst wild-origin and hatchery-origin salmon to prevent genetic impacts through domestication, straying, and integration (B). Ecological recommendations were to design a risk assessment to guide facility operations and integrate habitat and hatchery goals through understanding predation, competition, resource use, and habitat requirements (E). Economic recommendations were to ensure quality and cost-effective programming by innovating the facility, rearing techniques, and efficiency (Ec). Social recommendations were to integrate hatchery management and harvest goals to ensure a future harvest opportunity for multiple user groups (S) (STAG 2000).

Under the watershed wide recovery plan, the program purpose was to facilitate self-sustaining runs and increase population abundance and likelihood of survival through hatchery production. The primary objective was to preserve in the short term (B) and enhance in the long term (S) to maintain and increase the population for future harvest opportunities. The secondary objective was to use the program to provide data about the Stillaguamish stocks for U.S. and Canada fisheries (S). Under the habitat strategy, three objectives were identified to increase habitat connectivity through reducing fragmentation, increase connectivity, protect, and restore essential habitat (E) for the population (SIRC 2005). The program also recommended an adult-spawner escapement goal of 2,000 despite escapement data indicating that combined hatchery and wild escapement only exceeded the threshold once between 1974 and 2002. To determine habitat and hatchery limitations, maximum habitat and escapement potential was explored through modeled scenarios over a 100-year timescale. If habitat conditions were improved, and hatchery production continued, escapement numbers would increase approximately 200% (SIRC 2005).

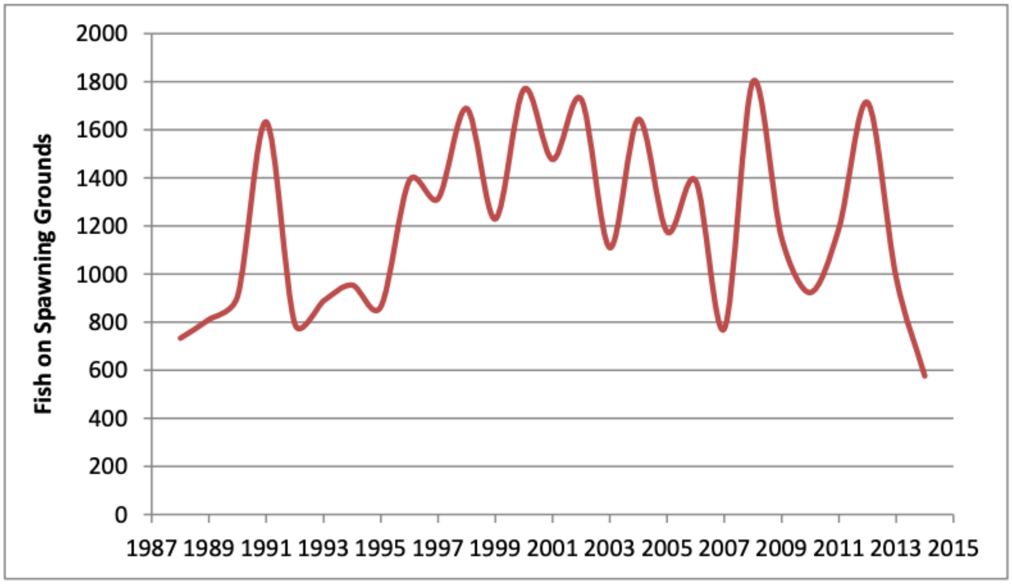

Figure 5: Stillaguamish River Chinook salmon escapement from 1988 to 2014. Reproduced from Gray et al., (2016) without alteration.

Despite an optimistic outlook for an integrated harvest and hatchery recovery program (S+), the North Fork Stillaguamish River Chinook salmon did not rebound or maintain abundance (B-). 1988 to 2014 escapement data indicated a max escapement of ~1800 adult spawners (B-) (Figure 3). To better understand the limitations of the program, the Stillaguamish Tribe of Indians Natural Resource Department conducted a study of regulation, enforcement, and capacity of the recovery program (Gray et al. 2016). In the report they identified that the program continues to fail to meet habitat objectives (E-), "habitat remains a considerable limiting factor, and habitat protection and restoration efforts are possibly the most important actions that can be taken to recover these fish." (Gray et al. 2016). Public process, private landowners, and developers are conflicting with treaty rights and the recovery of this population (S-). The program succeeded in preserving genetic diversity of the population in the short term through hatchery production (B+) (Anderson et al. 2020), however the program has failed in meeting escapement goals for harvest despite the tribe voluntarily forgoing harvest (S-) (SIRC 2005, Gray et al. 2016, Anderson et al. 2020), and habitat goals for the long-term survivability of the population (E-) (Gray et al. 2016).

The Salmon River Chinook salmon is a designated population segment of the listed Oregon Coast Coho Salmon ESU. Hatchery production began in the late 1970's to support harvest opportunities for the Oregon production area and later for the Oregon Coast Coho Salmon ESU listed in 1998 (Jones et al. 2018). Coho salmon objectives were initially defined in terms of smolt releases and spawner abundance including hatchery to wild spawner proportions (B). Monitoring for Salmon River coho was conducted by annual smolt release and spawner surveys. Data are available in agency-published reports. Monitoring data indicates a significant proportion of hatchery to wild spawners and strays (B-) prompting a unit-wide review of all coastal coho and concurrent hatchery programs. Five population viability criteria were developed as an assessment tool for hatchery programs in the unit. Criteria included spawner abundance (B), productivity (B), long-term stability (B), distribution (B), and genetic diversity (B). The Salmon River coho salmon failed all five criteria, indicating that hatchery production was the main reason for the decline in the river's wild salmon (B-) (Chilcote et al. 2005). The assessment prompted the suspension of hatchery releases and initiated an experimental recovery program without the use of supplementation through hatchery production, "to explore whether an independent population of coho salmon can recover from a prolonged period of very low abundance following removal of the primary factor limiting productivity" (Jones et al. 2009). Later studies indicated that the total adult abundance did not decrease but was maintained after hatchery production was suspended (B+; S+) (Jones et al. 2018).

III.VI HATCHERY PURPOSE: FILL UNDERUTILIZED HABITAT

The purpose of fill underutilized habitat programs is to enhance existing self-sustaining runs or introduce a new population previously unoccupied by salmon; either include ecosystem enhancements. Programs are developed to (i) increase carrying capacity and suitability of a rearing site for salmonids then use hatcheries to enhance the populations (e.g., Bear Lake/Resurrection Bay coho and sockeye) or (ii) assume the ecosystem can handle more salmonids and increase hatchery production for planting in suitable rearing sites, determined to be underutilized habitat (e.g., Tustumena Lake and Chelatna Lake sockeye). The habitats may be historically void (e.g., no access, owing to a natural barrier such as a waterfall) or have a limited number of salmonids because, for example, spawning area is limited but feeding area is not.

Ecosystem engineering mechanisms for increasing carrying capacity are predator extermination, nutrient additions, removing natural barriers for fish passage, and fertilizing for salmonid preferred prey. To understand the variation in ecosystem engineering program management, four cases were explored: Bear Lake/Resurrection Bay coho and sockeye (Alaska), Tustumena Lake sockeye (Alaska), and Chelatna Lake sockeye (Alaska).

In Alaska there is a history of altering lakes and tributaries with the intent to improve rearing habitat for important salmonid species and using hatcheries to boost survival or develop a founding population, e.g., Lower Cook Inlet Lakes Project (LCILP). These programs were managed by Alaska Department of Fish and Game (ADFG) and later incorporated by the private non-profit (PNP) regional association; Cook Inlet Aquaculture Association (CIAA). CIAA now manages four hatcheries throughout Cook Inlet as one program. The program's purpose is centered on self-sustaining runs, habitat, and optimizing salmon as a common property resource per the Alaska's Constitution (CIAA 2015). Objectives are to participate in the public process for salmon habitat concerns (S) and harvest interests (S), enhance runs for the purpose of harvest (S), evaluate projects and advance research for production (B, S), and ensure fiscal responsibility (Ec). Objectives are based on CIAA needs but do not have defined performance indicators. They are consistent with the mission, which emphasizes maximizing self-sustaining runs, the importance of the program from a public perception perspective, and responsible resource development and stewardship (CIAA 2015). The association is funded through a cost-recovery system, commercial user tax, and outside grants (Ec). Four programs managed by CIAA were reviewed which included elements of predator extermination, lake fertilization, and enhancement for commercial and recreational use in state lands and federally designated wilderness areas.

In Seward, Alaska, Bear Lake/Resurrection Bay coho and sockeye salmon hatchery programs were developed to enhance fishing opportunity by engineering the ecosystem to better suit sockeye and coho rearing habitats. Historically, Bear Lake was not conducive to sockeye and coho rearing because of abiotic (water chemistry and nutrient availability) and biotic (predation, density dependence, prey availability) conditions. Both programs were developed to increase harvest opportunities for commercial and recreational users in Resurrection Bay. Bear Lake was chosen as a suitable site because of its proximity to the Bay and potential for accessibility to find and improve rearing habitat. Bear Lake/Resurrection Bay coho are an integrated population from Kodiak, Southeast Alaska, Oregon, and Kenai River coho populations first cultured in 1962. Rotenone was used three times between 1963 and 1971 to eliminate non-salmonid predacious species and facilitate coho smolt survival (B, E) (Stopha 2012 and references therein). A fertilization project was initiated in 1979 by adding liquid ammonium-nitrate to change the chemistry of the lake and facilitate growth of prey species for rearing coho (B, E) (Stopha 2012 and references therein). The fertilization project continues today in other CIAA managed rearing lakes (CIAA 2019) and is considered successful in facilitating rearing conditions for coho and sockeye because there are abundant adult returns for recreational and commercial harvest. Bear Lake/Resurrection Bay sockeye are an integrated population from Bear Lake, Upper Russian River, and Big River first cultured in 1990. The broodstock chosen for the program had early-run timing life history traits which aligned with the desired run timing of sockeye as to not conflict with the coho sport fishery in the Bay (Stopha 2012 and references therein). The program was developed by the Division of Fisheries Rehabilitation Enhancement and Development (FRED) prior to the creation of Alaska's Finfish Genetic Policy (1985) and was acquired by CIAA. If the program was proposed today it would likely not be approved by ADFG because it used non-local broodstock (B-), increased disease in wild-origin salmonids (E-), and eradicated non-valuable native species and salmon predators (e.g. stickleback (*Gasterosteidae spp*.)) for the benefit of a recreational and commercially valued population (E-), all of which are a violation of current ADFG policies.

The Tustumena Lake Sockeye Salmon project in the Kenai National Wildlife Refuge on the Kenai Peninsula of Alaska was developed in 1972 to enhance a self-sustaining run of sockeye rearing in the lake and to use the same broodstock to enhance other sockeye populations in the Lower Cook Inlet Lakes Project (Stopha 2012). Social and biological objectives centered on threshold values of egg collection, smolt releases, adult returns - all for increased harvest opportunities (S) (Dodson 2003). The major biological objective was to use local stock for propagation (B). The lake is on the Kenai National Wildlife Refuge, designated as a Wilderness area under the 1964 Wilderness Act (16 U.S.C. § 1131). The Alaska National Interest Lands Conservation Act (ANICLA) was passed in 1980 which designated management authority to Alaska to protect resource interests of residents affected by the Wilderness Act in Alaska (16

U.S.C §§ 3101-3233). ANICLA allowed continuation of gamete collection from the lake under a special use permit as a research project initially then an operational permit jointly filed by ADFG and CIAA. The permit was approved by the United States Fish and Wildlife Service (USFWS) although a commercial operation was not compatible or supportive of the purpose of the refuge to "protect and preserve the wilderness character" (16 U.S.C. § 1131). The project was a conflict of state, federal, and user group resource management (S-). The enhancement program was developed with the intent to increase harvest opportunity for commercial and recreational users in Cook Inlet (Ec; S+), however, there was no indication that the population was depressed. The program was suspended because it violated the fundamental purpose of the Wilderness Act (S-) (Wilderness Society. v. US Fish and Wildlife Service. 2003).

The Chelatna Lake sockeye salmon program was developed to enhance an already self-sustaining run in the Susitna River Watershed in Alaska under the LCILP. An assessment of 24 lakes within the watershed indicated the highest euphotic volume for Chelatna Lake. Euphotic volume was calculated by measuring light penetration (Kyle et al. 1994 and references therein) which was the criterion for choosing lakes in which to rear hatchery salmon. ADFG developed objectives through a basic management plan and reported monitoring data through annual management plans. Gamete collection (B), smolt releases (S), and the use of local stock (B) were highlighted as major goals for the program (Stopha 2012 and references therein). The lake was surveyed for zooplankton between 1984-1993 (E). Between the years surveyed, zooplankton species composition changed, which limited prey to sockeye rearing in the lake (E-) (Kyle et al. 1994) The program violated the gamete collection maximum threshold five out of six years of operation (B-) and used Hewitt Cove donor stock for one program year which is an out-of-basin stock (B-) (Stopha 2012 and references therein). Lake studies and monitoring efforts ended because funding ran out (Ec; S-) (Kyle et al. 1994). The program was suspended by ADFG in 1996 (Fox 1998).

III.VII HATCHERY PURPOSE: OPTIMUM PRODUCTION

The purpose of optimum production programs is to maximizes the number of salmon produced while minimizing negative biological and ecological effects to wild salmon. Although most hatchery programs highlight a harvest goal in their management plan, harvest is a secondary or tertiary goal and is not a significant aspect of the program until there are sufficient salmon to harvest. In Alaska, precipitous declines in commercial salmon harvests prompted hatchery development in the early 1970's (Botz and Russell 2017). In response to low abundance and subsequent low harvests there was a State Constitutional Amendment, formation of FRED, and legislative action to authorize private non-profit corporations (PNPs) regional associations to manage hatchery programs;

> "It is the intent of this Act to authorize the private ownership of salmon hatcheries by qualified nonprofit corporations for the purpose of contributing, by artificial means, to the rehabilitation of the state's depleted and depressed salmon fishery. The program shall be operated without adversely affecting natural stocks of fish in the state and under a policy of management which allows reasonable segregation of returning hatchery-reared salmon from naturally occurring stocks." (Alaska Legislature 1974)

These programs, through PNPs, were specified as segregated programs and designed to increase harvest opportunities without negatively impacting wild stocks (Stopha 2019). PNP regional associations were required to develop objectives in line with genetic policies (e.g., *Genetic Policy,* Davis et al. 1985), health and disease policies (e.g., Meyers 2014), and fisheries policies (5 AAC 39.222). ADFG evaluated hatchery programs through the guidance of these policies (e.g., Stopha 2015; Stopha 2017; Stopha 2019). Since the inception of hatchery production, regional associations have succeeded in increasing harvest potential for commercial salmon fisheries throughout Alaska (Figure 4) though not without added complexities. Empirical evidence identifies negative ecological and biological interactions due to hatchery production in PWS and SE Alaska (B-; E-). Further, the substantial addition of hatchery fish complicated stock assessments (Amoroso et al. 2017). Management of large-scale hatchery programs is complex. To understand variation in optimum production programs three cases were reviewed: Prince William Sound pink salmon production through the Prince William Sound Aquaculture Corporation (PWSAC) (Alaska), chum salmon production through the Northern Southeast Regional Aquaculture Association (NSRAA) (Alaska), and chum salmon production through the Southern Southeast Regional Aquaculture Association (SSRAA) (Alaska).

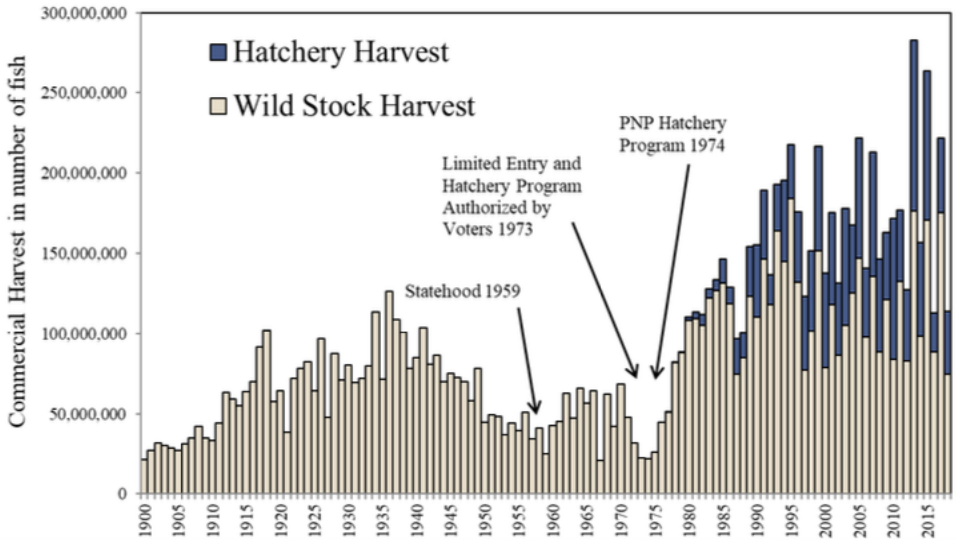

Figure 6: Commercial salmon harvest in Alaska from 1900 to 2018. Reproduced from Stopha (2019) without alteration.

Hatchery programs for pink salmon in PWS were developed to achieve optimum production on a sustained yield basis. Sustained yield within the fisheries context is to harvest without impacting population abundance and regeneration. The purpose was to develop economically viable hatcheries, paid for by cost recovery from the fisheries that they enhanced, without negatively impacting wild populations for sustained and consistent harvest. The objectives considered wild escapement thresholds (B), 2% hatchery proportion in wild spawning streams (B), density dependent growth rate in hatchery population (E), predation in hatchery population (E), and cost effectiveness (Ec) (PWS CRRPT 1994). Additionally, broodstock collection, egg take, and culturing practices were to be in compliance with the state genetic policy (B) (Lewis et al. 2009) and the hatchery facility should guide culturing practices through the health and disease policies (Meyers 2014). Monitoring reports from ADFG and independent reviews highlighted biological and ecological concerns with broodstock collection and source (-) (Habicht et al. 2000), violations of genetic policy (-) (Lewis et al. 2009), and exceedance of straying threshold throughout the region (B-; E-) (Knudsen et al. 2016; Brenner et al. 2012; Joyce and Evans 1999; Sharr et al. 1995). In the latest straying study (2013-2015) the average estimated range for all streams in PWS was 4-10% for odd years and an average of 14% for even years (Knudsen et al. 2016). Additionally, ADFG review noted a general lack of compliance with regulations and monitoring requirements (S-). The cost recovery structure was not successful in meeting the economic objective (Ec-); the PWSAC took out multiple loans to continue facility operation and production (Lewis et al. 2009). Further, there was concern that hatchery production replaced rather than enhanced returns and skewed escapement estimates (B-; E-) (Amoroso et al 2017; Hilborn and Eggers 2000).

Permitting of hatchery production for Southeast Alaska was activated by approval of the Comprehensive Salmon Plan (CSP) Phase I in 1981 which determined objectives for programs managed by NSRAA and SSRAA. Objectives were written in part, by input from recreational users, commercial harvesters, and processors (S, Ec). Hatchery production stabilized the supply and limited uncertainty between years of important populations (e.g., Bright Fall Chum) enhanced for commercial harvest (Ec+; S+) (Stopha 2017). CSP Phase II and III redefined goals and objectives to better align with state policies, "enhance the salmon fishery while minimizing the impact on wild stocks" (CSP Phase III). Objectives in CSP Phase III were to minimize impact on concurrent wild populations (B, E), maintain hatchery production using hatchery and wild populations (S, Ec), and manage hatchery production in compliance with state policies and regulations (CSP Phase III). Subsequent permits for expansion and consolidation of facilities were approved for Phase II and III of salmon management in SE AK.

Hidden Falls Hatchery in Southeast Alaska is jointly managed by ADFG and NSRAA. Hatchery chum production began in 1977 to partially fulfill harvest objectives stated in the CSP (Ec, S) (Stopha 2015). Funding mechanisms for NSRAA are through cost recovery commercial harvests and ex-vessel tax for any salmon species harvested in SEA AK (Ec) (McDowell Group 2018). Monitoring and evaluation of hatcheries in SE AK includes annual reviews from ADFG and independent reviews when there are concerns of the effect of hatchery influence. Fish health at the hatchery did not violate the state health and disease policies. Staff at the facility worked collaboratively with state pathologists to address any health and disease concerns (E+). Broodstock collection, egg take, and releases did not exceed permitted thresholds (B+). Any compliance concerns were timely addressed by the hatchery (S+) (Stopha 2015). Neets Bay Hatchery is jointly managed by ADFG and SSRAA. Hatchery chum production began in 1986 to partially fulfill harvest goals in CSP Phase I. Funding mechanisms for SSRAA are through cost recovery commercial harvests and ex-vessel tax for any salmon species harvested in SE AK (Ec) (McDowell Group 2018). No transport permit was held for egg take at the time of review (B-). No disease or long-term health impacts were noted by the state pathologist and any health-related issues were coordinated with ADFG (E+) (Stopha 2017). Region-wide straying studies in Southeast Alaska (Piston and Heinl 2012; Knudsen et al. 2016) indicated a variation of straying proportions from <5% to 41% hatchery salmon (B-) in all streams surveyed.

To address straying concerns for both PWS pink and SE AK chum programs, a research project was implemented to assess population structure, spatial distribution of hatchery straying across multiple years, and impact of fitness on wild populations due to straying (ADFG 2011). Research design was a collaborative effort led by ADFG. A science panel of PNPs, NMFS, and non-governmental scientists (S) was formed; Alaska Hatchery Research Project (AHRP). Funding was provided through a series of outside grants (NOAA Saltonstall-Kennedy; North Pacific Research Board), legislative funds, Department funds, PNPs, Seafood Processors Association, and spearheaded by the PWS and Sitka Sound Science Centers (S+) (ADFG 2019). For PWS pink salmon, preliminary findings of population structure for even and odd-year populations indicated greater variation in odd-year than in even-year runs. Across time, genetic structure of odd-year populations was similar between samples in the 1990's and samples in 2013; 2015 (B+). For the even-year historic genetic comparison the assessment report has yet to be released (ADFG 2019). Findings for the straying studies across 2013-2015 indicated hatchery origin spawners in all streams analyzed for PWS pink and SE AK chum. These findings are not informing Department recommendations and hatchery management adaptations (B-; E-; S-). ADFG reviewed the PWS pink production program and recommended it align with state policies. Specifically, the program should review the *Genetic Policy* (Davis et al. 1985) and update the management plan by defining terms such as 'significant stocks', 'unique stocks', and 'remote release sites' (Evenson et al. 2018). Interaction of hatchery and wild spawners becomes a concern if they interbreed *and* there are fitness losses in subsequent generations of the locally adapted wild population, thus negatively impacting the wild population.

The term 'conservation' as interpreted by the Alaskan constitution is management of a resource for use without overuse (Meacham and Clark 1994). These guiding principles formed Constitutional Amendments, legislative actions (e.g., Alaska State Legislature 1974), and override policies for hatchery management. The purpose of optimum production programs is to maximize economic and social benefits while minimizing biological risk. The AHRP is studying biological and ecological risks for hatchery production in two regions: PWS and SE AK. However, in this case, the evidence of risk does not reform management. Collaborative science and stakeholder cooperation are imperative to providing funding for research and long-term monitoring, however without initiative to integrate data into management changes it is unlikely that the risk of straying will be adequately addressed.

IV FINDINGS

Seven program purposes emerged from background research and twenty-two programs were selected for review. Each program prioritized objectives across biological, ecological, economic, and social categories differently depending on the purpose. The most common objectives are summarized below:

Table 1: summary of the most common objectives of the review

Purpose	Biological	Ecological	Economic	Social
Captive Breeding	Preserve genetic diversity[1]	Healthy culturing environment	Adequately fund	Collaborate
Reintroduction	Local adaption[1]	Restore Habitat[1]	Adequately fund	Collaborate
Restoration	Maintain genetic diversity	Restore Habitat[1]	Adequately fund	Develop partnerships
Mitigation	Integrate or segregate	Healthy culturing environment	Species-specific funding priority	Opportunity*[1]
Supplementation	Integrate or segregate	Healthy culturing environment	Production efficiency	Opportunity*[1]

Underutilized Habitat	Local adaption	Enhance habitat	Adequately fund	Expand fishing opportunities[1]
Optimum Production	Minimize negative genetic effects	Efficient culturing environment	Operation and production efficiency[1]	Stability[1]

*may include tribal treaty rights and identity, ecosystem services, and recreational and commercial fishing
[1]represents prioritized objective or objectives for each program purpose

While there are many objectives across hatchery programs they are rarely weighted equally. In Table 1, the prioritized objective for each program purpose is noted. While captive breeding, reintroduction, and restoration programs generally focus biological and ecological objectives, Mitigation, supplementation, underutilized habitat and optimum production programs generally focus on economic and social objectives. These may change over time as management adapts or the program transitions along the continuum of purposes for salmon hatchery intervention.

Outcomes also varied for each program based on how well objectives were met. There are three broad assessment ranks from generally positive (+), to generally negative (-), and to mixed (+/-) outcomes. This is not a measure of program success or failure, it is a method to qualify if hatchery programs work for their intended purpose. Additionally, programs are tools to address the abundance of a targeted salmon population and management strategies are continuously evolving. Three themes emerged following review of the programs to further describe if hatchery programs work for their intended purpose. These themes are illustrated through hatchery programs reviewed in Chapter III of this thesis. The first two themes are described generally as findings to explain if hatchery programs work for their intended purpose: management alignment and mismatch and adequacy of funding. The final theme describes recent evolution for system-wide hatchery influence where reform and science-based recommendations are driving improvements in how individual hatchery programs are structured within the context of social-ecological systems.

IV.I MANAGEMENT ALIGNMENT AND MISMATCH

Management is aligned when the program structure of purpose and objectives consider all applicable agency policies and laws (federal, tribal, state), social-ecological context of the program (salmon, human communities, ecocultural value, opportunity), life history requirements (rearing, migrating, spawning), scale of impact (natal stream to the North Pacific ecosystem), program production (small to large), and the capacity to implement, enforce, and adapt policy for managers and individual hatchery programs. Alignment is demonstrated through some captive breeding (Snake River sockeye) and reintroduction (San Joaquin River; Chimacum Creek) programs. Management is mismatched when any of these are not aligned and is demonstrated through some mitigation (Yakima River coho), supplementation (Stillaguamish River Chinook), underutilized habitat (Tustumena Lake sockeye), and optimum production (Prince William Sound pink and Southeast Alaska chum) programs.

The captive breeding program for Snake River sockeye (ID) demonstrates alignment between agency policies, social-ecological values, and objectives. The program has realistic objectives with achievable indicators, interagency cooperation and monitoring efforts between the Shoshone-Bannock tribe (who prompted the ESA listing by petition), NOAA, IDFG, and BPA. All are working together on the hatchery program and it has since phased to reintroducing sockeye while providing a safety-net if the abundance declines (Kline and Flagg 2014). The reintroduction program for San Joaquin River Chinook (CA) demonstrates alignment between agency policies (NMFS recovery goals) and objectives. All objectives were created by interagency cooperation and include performance metrics directly from NMFS recovery goals (Bork et al. 2016). The reintroduction program for the Chimacum Creek chum (WA) demonstrates alignment between agency policies (NMFS recovery goals), life history, scale, and objectives. NMFS recovery goals were embedded in objectives, there was sufficient baseline data about the population and habitat, and harvest pressure was significantly reduced for the duration of the program. As for outcomes, all NMFS recovery goals, program objectives were met and exceeded in a two-generation timeline (Point No Point Treaty Tribes and WDFW 2014). Therefore, the program was suspended.

The mitigation program for Yakima River coho (WA) demonstrates a mismatch between management recommendations and objectives. Recommendations were made four different times between 2012 and 2020 by the ISRP, identifying indicators designed to move onto the next phase of the program were not well defined or realistic, inadequate baseline information about the ecosystem and population, and general issues with escapement and harvest data (ISRP 2020). The supplementation program for the endangered Stillaguamish Chinook (WA) demonstrates a mismatch out outcomes and tribal treaty rights. While the program succeeded in preserving genetic diversity of the population (prioritized biological objective) there remains considerable conflict with habitat restoration and the actual number of salmon returning to the Stillaguamish. This conflict is mostly with private landowners and developers in the watershed (Grey et al. 2016). The Stillaguamish tribe and other Western Washington tribes report disparate standards for harvest and habitat for federal oversight. This is a failure to protect tribal treaty rights (NWIFC 2011). The underutilized habitat program in Tustumena Lake (AK) demonstrated a mismatch between federal laws and program structure including purpose and objectives. The program permit was approved by a federal agency, the USFWS. However, the lake was in a designated wilderness area under the Wilderness Act of 1964. In a case elevated to the 9th circuit court of appeals, the program was found to be incompatible with, and threaten the purpose of the wilderness area (Wilderness Society. v. US Fish and Wildlife Service. 2003). Additionally, the program provided no benefit to a stable population. The intended benefit of the program was to provide more salmon for fishing opportunities (Stopha 2012). The optimum production programs in Prince William Sound and Southeast (AK) demonstrate a mismatch between existing policy (e.g., *Genetic Policy,* Davis et al. 1985), management plans that align with the policy (e.g., PWS CRRPT 1994) and incentives for managers to enforce policy. As program size increases it is more difficult to manage biological and ecological risks to wild salmon. Managers (ADFG) did not require these programs to comply with the state genetic policy. This resulted in a major deviation from the state genetic policy for broodstock collection and straying issues. Although straying studies indicate significant biological and ecological risk to wild populations (e.g.. Knudsen et al. 2016) managers have not yet identified a path to restructuring or adequately enforcing the state genetic policy, which has not been revised since 1985, or how to incentivize compliance through individual program management revisions.

IV.II ADEQUATE FUNDING

Adequate funding is a major priority to meet objectives, though sometimes the funding mechanism dictates how the program is structured (Lake Sammamish kokanee), what the priorities are (Lake Wenatchee sockeye), and the duration of the program (Chelatna Lake sockeye). For the restoration program for Lake Sammamish kokanee (WA) there was purposeful design with extensive interagency collaboration and restoration efforts for adaptive management. However, the program is very costly for the yield of spawning adults. This does not indicate an unsuccessful program outcome but encourages a restructuring and reprioritizing. The program has the capacity to do so because it is adaptively managed (KWG 2014). The mitigation program for Wenatchee Lake sockeye (WA) funding was provided by the utility districts. Although the program was successful in meeting all objectives with mostly generally positive and mixed results, the same funding source was re-appropriated for steelhead, a higher priority species for the funders (Hillman et al. 2018). The underutilized habitat program for Chelatna Lake sockeye (AK) was suspended because funding was inadequate for lake studies and long-term monitoring efforts to determine if they should continue the program (Kyle et al. 1994).

IV.III IMPLEMENTATION OF HATCHERY REFORMS

Hatchery reform through the HSRG began in 1999. HSRGis a congressionally established and funded scientific review panel formed through a collaborative process. Its initial purpose was to review hatchery programs in Washington. It works one-on-one with hatchery facilities to make individual recommendations and analyze different scales of hatchery programs to make system-wide recommendations. It has created useful tools for facilities and managers, many of which have been adopted by hatchery programs and other agencies such as the USFWS and Washington Fish and Wildlife Commission (WFWC):

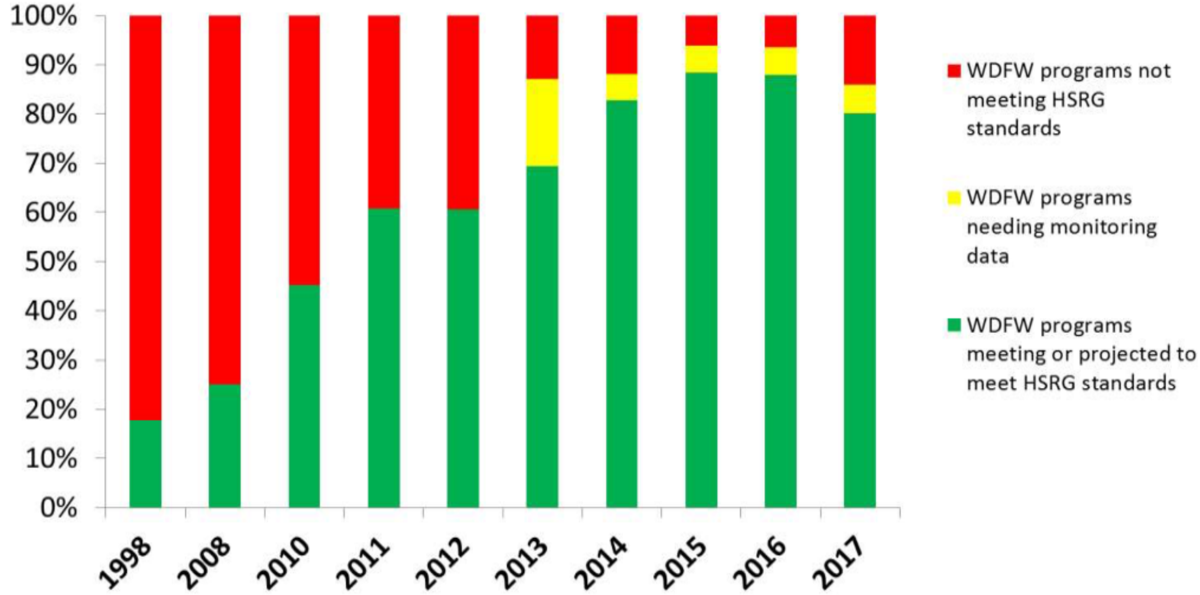

Figure 7: Integration of WFWC Hatchery and Fishery Reform Policy for WDFW Hatchery Programs. Reproduced from WFWC (2018) without alteration.

As of 2017, approximately 80% of the 168 WDFW hatchery programs are meeting or projected to meet HSRG standards through policy developed by the WFWC. In general, the HSRG tools and recommendations are designed to minimize biological and ecological risk. According to the WFWC policy, significant progress has been made to integrate HSRG recommendations and tools. It is up to program and agency managers to consider social and economic factors for hatchery programs. Many of the programs reviewed in this thesis in Washington, Oregon, and Idaho integrate HSRG tools and are meeting standards. The mitigation program for the Pahsimeroi River Chinook (ID) was reviewed by the HSRG and restructured on a sliding scale using relative returns for each year's salmon released and used for broodstock (IDFG 2017; HSRG 2009). The supplementation program for Salmon River coho (OR) had a high proportion of hatchery stays in wild-spawning streams. This program was a major factor in a USFWS review of all coastal coho programs in Oregon using HSRG principles. The program failed all five VSP criteria (Chilcote et al. 2005) and it was determined that hatchery intervention was the primary cause of decline in the population (Jones et al. 2009) The program was suspended in favor of allowing the population to recover without hatchery intervention.

V RECOMMENDATIONS AND CONCLUSIONS

Hatchery programs are intervention tools to address underlying pressures that affect the abundance Pacific salmon populations throughout the North Pacific. Programs have been utilized on the west coast of the U.S. since the late 1800's. Their application provides benefits to conserve populations and provide harvest opportunities (see Anderson et al. 2020). They also fulfill tribal treaty rights, provide ecocultural value, and enhance recreational and commercial opportunities. These are economic and social benefits which must be considered because they influence why hatcheries are used and the variation in outcomes that result. Although, over time their use has proved to be a controversial topic. For example, the HSRG (2014) wrote, "the widespread use of traditional hatchery programs has actually contributed to the overall decline of wild populations. The historical use of artificial propagation for harvest mitigation has frustrated the successful integration of management directive and created regional economic inefficiencies" (HSRG 2014). This review demonstrates that managing hatchery programs is complex. Do they work for their intended purpose? They can if they are implemented with management alingments through clearly defined purposes and objectives that consider the individual facility and the system-wide context of producing salmon including social and ecocultural values that Pacific salmon provide to human communities. There must be adequate and specific funding mechanisms with capacity to monitor the status of the population during and after (if applicable) the program is complete. For hatchery programs that are primarily used to fulfill economic and social objectives (e.g., fill underutilized habitat and optimum production) it is important to assess the trade-offs as the benefits they provide and the biological and ecological risk that increases with production. Hatchery programs are not the only tool to intervene in maintaining the abundance of Pacific salmon populations, nor is there one policy solution to address the problems of hatchery programs. Hatchery reform through the HSRG demonstrates progress in managing hatchery programs. Effective collaborative efforts to address system-wide issues are imperative to redefining the variable roles that hatchery programs play to address Pacific salmon abundance.

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Appendix A: Review Organization

Program Name	Location	Species	Management	Purpose	Objective: Biological	Objective: Ecological	Objective: Economic	Objective: Social	Outcomes
Snake River Sockeye ESU Hatchery Program	Redfish Lake, ID, USA	Sockeye	NOAA, IDFG, SBT (tribal), BPA (power administration)	Prevent extinction, preserve population genetics, facilitate self-sustaining run	1. Culture broodstocks from wild-spawning stock through facility development, genetic matrix, genetic effect, cryopreserved archives (if need be), adaptive management 2. recovery analysis by determining if hatchery produced contribute to overall recovery of salmon 3. population and life history characteristics within basin 4. maximize integrated population and identify individual genetic characteristics through sampling 5. produce 1,000 naturally spawning adults	1. parasite, viral, and fungal infections were monitored for multiple lifestages and releases stages of the program	Funding mechanisms: settlement agreement	1. work with Shoshone-Bannock Tribe and monitor impact of recreational fishing on recovery 2. public information and transparency to meet data requirements of state, tribal, and federal entities through the technical oversight committee	(B+) genetic matrices and release success for multiple life stages, survivability of eggs, juvenile, and adults increased over time (B+) broodstock, eggs, and juveniles exceeded program needs for captive breeding, eventual phase into reintroduction (B+/-) variable number of returns throughout program (E+) no viral pathogens, some bacterial infections were treated with antibiotics, some presence of whirling disease but not from hatchery operations (E+) restructured program with restoration initiatives for better hearing outcomes (E-) fish passage issues outside of Sawtooth Valley (B+, E+, S+) HSRG principles integrated
California Central Coast Coho ESU Hatchery Program	Russian River, CA, USA	Coho	CDFW, NOAA, USACE	1. Protect genetic integrity to delist the ESU unit and prevent extinction of and facilitate distinct populations and cohorts 2. maintain and increase spawning 3. maintain historic spatial distribution 4. maintain essential habitat 5. increase and restoration of historic habitat Self sustaining and abundant enough for future harvest opportunities for tribal, recreational, and commercial use	1. genetic diversity 2. determine populations for ESU's, where could they be established, how to facilitate population growth 3. determine adult population abundances and trends through time 4. determine spatial distribution	1. fish health 2. determine viable or essential habitat requirements for all life stages 3. develop habitat quality index (HQI) and monitor habitat through restoration phases	Funding mechanisms: settlement agreement and collaborative agencies	Future harvest for tribal, recreational, and commercial users following delisting of two separate ESU's	(E+, S+) 50+ habitat restoration and fish passage projects with the intent of improving coho habitat (an underlying factor of recovery) (B+) significant juvenile release increases from 6k to 172k between 04 and 12 (B+) significant increases in adult returning abundance since 2001 (2-6 between 2001-2009 and 205 in 2012) (B-) genetic concerns with the population, therefore the russian river coho are cross bred with Olema Creek coho in an effort to min founder effect and max diversity (B-) declining abundance for all ESU's in region, unlikely delisting criteria will be met (S+) 08-09 partnership to focus on habitat connectivity for coho recovery. Mainly focused on water and habitat resource goals but looking to act as a model for other watersheds looking to implement a recovery program
Southern Oregon/Northern California Coho ESU Hatchery Program	Klamath River, CA, USA	Coho	CDFW, NOAA	- Protect genetic resources, reintroduce population after dam is removed or fish passage is implemented, local adaptation and self sustaining run	Phase 1: 1. maintain high abundance of returning spawners because natural spawner abundance is ~7 fish, very low abundance 2. protect species diversity 3. reduce demographic risks 4. HOR, NOR broodstock source 5. once broodstock needs are met the remaining fish will be equally distributed between Klamath River and Bogus Creek 6. 75,000 smolt release threshold Phase 2: recolonization Phase 3: local adaption	1. fish health 2. Prior to decision making habitat requirements were not sufficient to support a self sustaining population, therefore, phase 2 will include habitat improvements in order to allow for recolonization	In order to meet mitigation and recovery goals funding mechanisms are in place from PacifiCorps mandated by settlement terms	Collaborative management and conflict resolution of DOI, DOC, California, Oregon, associated counties, tribal groups, water user groups, conservation groups, fishing groups, PacifiCorp, licensee	(S+) purposefully phased program (E-) no studies indicated presently to address habitat capacity or life stage requirements as program phases

San Joaquin River Restoration Program	San Joaquin River, CA, USA	Chinook (Spring run)	CDFW SCARF (Salmon Conservation and Research Facility in construction) interim SCARF in operation	Reintroduce runs and maintain a population that transition into self-sustaining and natural spawning population and manage water project impacts from restoration projects	1. selection and collection of broodstock 2. min domestication, max effective population size in experimental and integrated populations 3. self sustaining, naturally spawning 4. PNI >.67 5. segregate spring-run experimental population from fall-run population 6. phase out if pHOS is <15% by 2032	1. min disease and pathogens 2. legal requirements for effluent, water diversion and quality 3. Restore flow regime and provide habitat connectivity 4. flow during migration periods 5. suitable habitat for holding, spawning, rearing, and migration 6. water quality 7. predation reduction by suitable habitat increases 8. restore complexity of habitat and watershed	Funding mechanisms through settlement agreement (NRDC v. Kirk Rodgers, US Bureau of Rec. 2003)	1. legal requirements 2. public outreach on program Harvest: none planned for recreational or commercial harvest through entire reintroduction period. Development of an in-river recreational fishery may occur if minimum returns are met in the reintroduction period	(S+) Program extended to 2040 (B+) captive breeders released into the restoration area naturally spawned (2017, 2018). Returning spawners released from hatchery as juveniles and reared in the ocean returned to the restoration area (2019) (B-) no note of fitness or demographic shifts (S+) legal requirements met throughout program duration to date (E+, S+) habitat goals and projects are notified through coordinator to access habitat through private land and a consensus-based process is used to communicate with community about project and negotiations. There are also tours and transparency through project updates and media
Deschutes River Chinook Program	Deschutes River, OR, USA	Chinook (Spring run)	ODFW, FERC, CTWS	1. Self-sustaining reintroduction and future harvest opportunities 2. Reconnect habitat that is impeded by dam through hydrological improvements and fish passage	1. reduce straying 2. synchronize run timing and life history characteristics 3. juvenile releases	1. assess intra and interspecific competition 2. prevent disease in facility	Performance standards, objectives, M&E: Benefits and Risks	1. tribal fishery 2. combined state and tribal reintroduction plan	Management Concerns (E-) Limited ecosystem indicators and program indicators (B-; S-)Incidentally mortality in recreational fishery for out migrating juveniles (B-)numeric goals centered around smolt releases (B-) genetic impacts not identified
Yakima River Coho Program	Yakima RIver, WA, USA	Coho	Columbia River Treaty Tribes WDFW BPA	1. Increase harvest opportunity pursuant to tribal treaty rights and confirmed by US v. Oregon 1969 (segregated) 2. reintroduction of coho to establish natural spawning (integrated)	1. local and heritable adaptation 2. indicators include RRS of integrated and segregated and life history traits.	1. Interactions - minimize negative effects to other species in targeted area 2. Predation - minimize losses of coho to predators 3. Indicators include ecosystem interactions, trophic interactions and contributions 4. conservation benefits	1. effective production and distribution 2. production improvements 3. long term facility requirements	Indicators of harvest benefits for productivity with a goal of sustainable and consistent harvest potential for survival of fish, fisheries contribution, angler goals, and cultural needs	(E+) sampled through residual proportions and predation. Residual coho through sampling period was not significant, nor is there a concern for negative ecological interactions. Predation on listed spring and fall chinook is minimal and not significant in comparison with bass predation. No competition for space and resources was noted for native trout species. (B+) natural origin returns (NOR) increased from 0.142% to 0.456% for the 1998-2001 time period for the lower portion of the river. Independent Review: (S-) lack of indicators to transition between phases (B-; S-) spawning and escapement concerns (E-) uncertainty of ecological criteria
Summer Chum Salmon Conservation Initiative	Chimacum Creek	Summer Chum	NOAA WDFW Point to Point Treaty Tribes	Recovery of Hood Canal Summer Chum ESU through reintroduction	1. Larger population objectives of preserving Hood Canal chum ESU 2. Abundance and Escapement (NOR, natural origin abundance and escapement below threshold) 3. Productivity (NRS >= 1.6 over eight years and NRS may not < 1.2 for 2/8 years) 4. Diversity (rebuild populations naturally and artificially for abundance and recovery thresholds)	Habitat restoration projects to increase production capacity and productivity of runs	Funding mechanisms through recovery program	1.Reduce harvest rate (54.7% 1980-1991, 9.8% 1992-2004) 2. Watershed wide stock management and exploitation expectations categorized as Strait of Juan de Fuca (8.8%) and Hood Canal (10.9%) 3. habitat protection and recovery through interagency collaboration	(B+, E+, S+) Program terminated after reaching adult return thresholds. Program was terminated ahead of schedule (2 generation instead of 3 generation) because it was exceeding goals ahead of time

Elwha River Fish Restoration Program	Elwha River, WA, USA	multi-species	NOAA, FERC, OP tribes	1. preserve population during dam removal through gene banking of every year class (as identifiable) as a 'safe haven' approach during dam removal 2. then, facilitate recolonization of historically used salmonid habitat for self sustaining runs	Selecting stocks and culture 1. population size at time of evaluation 2. genetic ID 3. phenotypic traits, life history traits 4. life history (run timing) 5. how easy to access and collect broodstock M&E objectives: 1: recolonize, consider spatial distribution, variance in spawners, productivity, abundance 2: genetic diversity, population integrity, run and spawn timing, genetic, phenotypic variation	M&E objectives: 1: disease and pathogen risk 2: Landscape level ecosystem recovery	Funding mechanism through FERC	1. Self sustaining runs for tribal treaty rights 2. interagency collaboration for recovery plan	HSRG Review: (B-) excessive and prolonged hatchery influence (B-) fitness, delayed restoration, reduced harvest opps (B-) hatchery and wild interactions in a resource limited system (S-) capacity issues w/ M&E leading to poor management decisions, responses, field of knowledge (B+, S+) support ESUs (B+) preservation through and after removal (E+) ecosystem benefits of spawning, carcasses (B+) spawning habitat availability and disruption of sediment (S+) harvest
Lake Sammamish Kokanee Restoration Program	Lake Sammamish, WA, USA	Sockeye (kokanee)	Lake Sammamish Kokanee Working Group	Prevent extinction, facilitate self sustaining runs for harvest opportunities, concurrently restore salmon habitat	1. Generation - 12 year, 3 generations limits genetic effects for specific populations (within and between) (S. Phelps, WDFW, pers. comm., April, 1998 cited in WDFW and Point No Point Treaty Tribes 2000). After 2 generations it will reevaluate to see if the program should continue with the third generation for egg takes. Allow for program increase if it is not successful after 3 generations and/or if habitat is not suitable to sustain or increase population. Evaluation allows for program to shift to gene pool conservation or captive breeding if not successful. 2. Run size objective - not specified, determined at later date 3. Early termination criteria - not specified, determined at later date	1. time release 2 weeks before hatchery coho release into lake sammamish to reduce predation 2. release into creeks to encourage stream imprinting 3. release when zooplankton are increasing in lake but before peak (mid-April) 4. release after emergence and will not extend enhancement. They will only be kept until there are optimal conditions at release sites that do not conflict with above statements	Funding mechanisms from working group	1. ecocultural value 2. eventual harvest opportunity 3. volunteer restoration work and educational opportunity 4. collaboration between groups	(B-; Ec-; S-) Supplementation program is not providing sufficient or consistent hatchery returns to develop a self sustaining run and assess as a harvest fishery (B-) contribution varies and predicting rate of wild spawner not met (B+) when abundance is generally low, hatchery proportion is met (B-) when abundance is generally high, hatchery proportion is not met (B+) prevented extinction (E+) habitat goals achieved (E-) larger ecological considerations - predation, climate change etc.
Pahsimeroi River summer Chinook Program	Pahsimeroi River, Salmon River Basin, Idaho	Summer Chinook	IDFG FERC mandated to mitigate for Hells Canyon Dam IPC	**Pre 2007 -** harvest oriented **Post 2007 -** Conservation of wild salmon through integration, Harvest of hatchery salmon through segregation	Pre 2007 - smolt release goals and adult returns Post 2007 - use relative returns to determine broodstock needs	No ecological objectives indicated	Funding provided through mitigation (IPC)	Harvest opportunities	Did not meet adult returns or subsequent smolt release minimum thresholds consistently, therefore the program transitioned into a conservation-supplementation program with a sliding scale.
Wenatchee Lake Sockeye Program	Wenatchee, WA, USA	Sockeye	WDFW USFWS Chelan and Grant PUDs	1. provide harvest opp. lost to hydrosystem mortalities 2. segregate hatchery origin from wild origin	1. VSP criteria 2. production minimum Genetic objectives: variation within and between, population size, straying and spawner composition within targeted population and outside targeted population, run and spawn timing, distribution of spawning, size, and age Demographic objectives: spawner abundance, NOR, NRR, juvenile per redd ratio, RRS, HRR	Disease, NTTOC abundance, size, and distribution	Funding Mechanisms: Chelan, Douglas, Grant Public Utility Districts	Harvest opportunities	(S+/-) Program terminated in 2012 and funds/effort transitioned to steelhead - First broodstock collected in 1989, last broodstock collected in 2011 (B+; S+; Ec+) production goal met 11/22 years w/average 208,271 parr released into Lake Wenatchee for rearing (B+; E+) All VSP criteria were met for the majority of monitoring years.
Chelan Falls/Turtle Rock Summer Chinook Salmon Program	Chelan Falls/Turtle Rock, WA, USA	summer Chinook	WDFW USFWS Chelan PUBs	1. provide harvest opp. lost to hydrosystem mortalities 2. segregate hatchery origin from wild origin	1. VSP criteria 2. production minimum Genetic objectives: variation within and between, population size, straying and spawner composition within targeted population and outside targeted population, run and spawn timing, distribution of spawning, size, and age Demographic objectives: spawner abundance, NOR, NRR, juvenile per redd ratio, RRS, HRR	Disease, NTTOC abundance, size, and distribution	Funding Mechanisms: Chelan, Douglas, Grant Public Utility Districts	1. Harvest augmentation program for sport fishery 2. Could be used as a fail-safe for other declining sockeye fisheries in CRB	(B-) egg take threshold, sub-yearling release, and smolt releases were not met for the majority of years (B-) Fecundity and fertilization rates were lower than predicted which lowered smolt releases (B-) Straying percentages outside of Chelan River were very high (S+) Contribution to fisheries was substantial

Summer Chum Salmon Conservation Initiative	Big Quilcene River, Hood Canal, WA, USA	Chum	NOAA WDFW Point no Point Treaty Tribes	Facilitate recovery and provide harvest opportunities for tribal, recreational, and commercial users	1. production thresholds 2. minimize interaction between hatchery and wild salmon	1. address habitat limitations 2. identify habitat restoration potential	Funding mechanisms through SCSCI	1. Reduce harvest pressure 2. Voluntary tribal effort to reduce harvest and focus on collecting broodstock	(E-) degraded habitat (B+; S+) escarpments increased over time (B+/-; S+) despite meeting objectives hatchery production continues (B+/-; S+/-) revisions under way after review using HSRG principles
Stillaguamish River Chinook Program	North Fork Stillaguamish, WA, USA	Chinook	NOAA WDFW Puget Sound Tribes U.S. and Canada	Hatchery management plan: facilitate self sustaining run for harvest opp Watershed Recovery plan: facilitate self sustaining runs and increase population abundance and likelihood of survival through hatchery production	HMP: 1. risk assessment guides facility goals 2. genetic management considered impact on wild origin spawners 3. limit impact to wild origin spawners 4. innovation to limit domestication and maintain segregation 5. marking and tagging 6. research for determining productivity and abundance for wild runs (as an integration metric) 7. separation of wild and hatchery salmon Watershed: preserve genetics then increase population abundance	HMP: 1. research to determine current habitat capacity of stillaguamish chinook (as an integration metric) 2. improve hatchery facility to mimic natural rearing conditions (as an integration metric) 3. survivability, predation risk 4. outmigration food sources (as an integration metric and salmon recovery metric for ecosystem considerations and general habitat considerations) Watershed: 1. reduce habitat fragmentation 2. increase connectivity 3. protect and restore essential habitat	HMP: 1. quality and cost effective programming 2. innovation to improve efficiency of survival, release, and returns 3. hatchery operation plans Watershed: none	HMP: - tribal treaty rights - sustainable fisheries and a research driven process SIRC 2005: - tribal treaty rights - escapement goals for future harvest - data for U.S. and Canada Watershed: 1. enhance for harvest	(B-; S-) has not met escapement goal of 2,000 fish but once between 1974 and 2016 (S-) no enforceability and not meeting tribal treaty rights (E-) not meeting habitat objectives (B-; S-) not meeting escapement objectives
Salmon River Coho (Oregon Coast Coho ESU) Program	Salmon River, OR, USA	Coho	Salmon River Hatchery	Production to meet harvest demands and ESU goals	Pre review objectives: 1. smolt release minimum 2. spawner abundance including hatchery to wild proportions Post review VSP criteria: 1. spawner abundance 2. productivity 3. long-term stability 4. distribution 5. genetic diversity	None	Harvest potential for recreational and commercial sectors	Maintain or increase harvest opportunities	(B-) Failed all five criteria (B-) hatchery production primary reason for population decline (B+; S+; E+; Ec+) following termination of program abundance increased and was maintained
Bear Lake/Resurrection Bay Hatchery Program	Bear Lake/Resurrection Bay, Alaska, USA	Sockeye	Owned: ADFG Operated through contract: CIAA	Enhance fishing opportunity for commercial and recreational users in Resurrection Bay	1. integrated population from Bear Lake, Upper Russian River, Big River (1990) 2. production threshold 3. integrate broodstock that also has a life history characteristic of early run timing so the stock does not conflict with coho sport fishery	1. rotenone used to eliminate non-salmonid predacious species and facilitate survival 2. fertilization project initiated to facilitate growth of prey species for rearing 3. fertilization project continues for other CIAA managed rearing lakes	1. fiscal responsibility 2. maintain facilities for effective operations and in compliance with state regulations and statues 3. maximize value	1. habitat protection through public discourse 2. participate in regulatory process and changes as they pertain to self-sustaining and maximizing value goals 3. prioritize research and technology developments in hatchery production 4. harvest interests 5. educate public about salmon and association interests 6. legal requirements - in compliance with state regulations and statutes 7. design program so that it does not conflict with resurrection sport fishery	(B-) 1985 Genetic Policy: broodstock collection does not align with state genetic policy but the program was developed prior to the policy (E-) disease in wild origin (E-) eradicated non-valuable fishery species (S-) violated ADFG policies
Bear Lake/Resurrection Bay Hatchery Program	Bear Lake/Resurrection Bay, Alaska, USA	Coho	Owned: ADFG Operated through contract: CIAA	Enhance fishing opportunity for commercial and recreational users in Resurrection Bay	1. integrated population from Kodiak, SE AK, Oregon, Kenai River 2. production threshold	1. rotenone used to eliminate non-salmonid predacious species and facilitate coho survival 2. fertilization project initiated to facilitate growth of prey species for rearing coho 3. fertilization project continues for other CIAA managed rearing lakes	1. fiscal responsibility 2. maintain facilities for effective operations and in compliance with state regulations and statues 3. maximize value	1. habitat protection through public discourse 2. participate in regulatory process and changes as they pertain to self-sustaining and maximizing value goals 3. prioritize research and technology developments in hatchery production 4. harvest interests 5. educate public about salmon and association interests 6. legal requirements - in compliance with state regulations and statutes 7. design program so that it does not conflict with resurrection sport fishery	(B-) 1985 Genetic Policy: broodstock collection does not align with state genetic policy but the program was developed prior to the policy (E-) eradicated non-valuable fishery species (S-) violated ADFG policies

Tustumena Lake Sockeye Salmon Project	Tustumena Lake, Alaska, USA	Sockeye	ADFG CIAA Crooked Creek Hatchery ->TLH Lower Cook Inlet Lakes Project	Enhance self sustaining population and stock other lakes in lower cook inlet lakes project	1. threshold values for: egg collection, smolt releases, adult returns 2. use local stock for propagation	None	Harvest potential for recreational and commercial sectors	1. increase local stock for harvest opportunities 2. LCILP	(Ec+; S+) increased harvest opp (B-; S-)diversions from permit, violation (B-) Reared stock for increasing production of lake but also used broodstock for main LCI lakes project broodstock (S-) In violation of the 1962 Wilderness Act (9th Circuit Court of Appeals) ordered project terminated (Stopha 2012)
Lower Cook Inlet Lakes Project: Chelatna Lake Sockeye Salmon Program	Chelatna Lake, Alaska, USA	Sockeye	ADFG CIAA Trail Lake Hatchery	Increase production in an underutilized habitat for a population that is already self sustaining	1. use local stock 2. not to exceed 2 million egg takes 3. 1.6 increasing to 2 million juvenile releases	habitat studies	1. Harvest potential for recreational and commercial sectors 2. funding mechanisms through ADFG on a limited cycle	Increase for harvest opp	(B-) Exceeded egg take numbers 5/6 years of program (B-) Did not meet or exceed juvenile release permitted numbers (B-) Used Hewitt Cove as donor stock in 1990 (BMP) (E-) prey species composition changed over time (S-) program suspended
Prince William Sound Copper River Regional Planning Team: Comprehensive Salmon Plan	Prince William Sound, Alaska, USA	Pink	Private non-profit PWSAC	Segregated: optimum production on a sustained yield basis; increase harvest opp without negatively impacting wild stocks	1. wildstock escapement goals 2. 2% straying threshold	1. density independent growth rate in early marine period 2. abundance of predators independent of abundance of salmon	Supplement for economic benefit Cost recovery, vessel tax	Supplement for public benefit benefit all user groups	(B-; S-; Ec; E-) ADFG did not require compliance with approved practices over time which accumulated in a major deviation (application and enforcement inconsistent) (B-; S-; Ec; E-) Not in compliance with permit or BMP including standards set out in 5 AAC 40.860 (B-) Straying violates genetic management plan and ecological, biological wild systems, allocation plan, and hatchery CR (B-) Broodstock violates regulatory standards by roe-stripping moreso and egg-take less (B-; S-; Ec; E-) Few if any consequences for lack of compliance but there are few solutions because they don't want to disrupt commercial fishing and would be in violation of management and allocation plan (5 AAC 24.730, PWS allocation plan) (Ec-; S-) cost recovery and economic structure is not meeting goals. They've taken out additional loans
Comprehensive Salmon Plan: SE AK Chum	Southeast, Alaska, USA	Chum	Private non-profit NRSSA Hidden Falls Hatchery	Optimum production of wild and enhanced salmon stock on a sustained-yield basis for max social and economic benefit to all communities and all user groups of SE Alaska	1. minimize impact on wild stocks 2. adhere to state genetic policy	1. minimize impact on wild stocks 2. adhere to health and disease policy	1. long-term: 75% CPH, 25% CR 2. Provide resource to maintain economy and provide more opportunities	1. public benefit through increased salmon, consistent, stable. 2. community stability	(B-) straying issues (E+) fish health and disease policies were met (B+) broodstock and egg take met state policies (B+; E+)compliance concerns were addressed by hatchery
Comprehensive Salmon Plan: SE AK Chum	Southeast, Alaska, USA	Chum	Private non-profit SRSSA Neets Bay Hatchery	Optimum production of wild and enhanced salmon stock on a sustained-yield basis for max social and economic benefit to all communities and all user groups of SE Alaska	1. minimize impact on wild stocks 2. adhere to state genetic policy	1. minimize impact on wild stocks 2. adhere to health and disease policy	1. long-term: 75% CPH, 25% CR 2. Provide resource to maintain economy and provide more opportunities	1. public benefit through increased salmon, consistent, stable. 2. community stability	(B-) straying issues (E+) fish health and disease policies were met (B+/-) broodstock and egg take met state policies except a transport permit was not held for one area of egg take (B+; E+) compliance concerns were addressed by hatchery