Evaluation and Assessment of Hatchery and Wild Salmon Interactions in WRIA 9

Prepared for:
WRIA 9 Steering Committee

GREEN/DUWAMISH AND CENTRAL PUGET SOUND WATERSHED

Funded by:
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Prepared by:
Anchor Environmental
and
Natural Resources Consultants, Inc.

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EVALUATION AND ASSESSMENT OF HATCHERY AND WILD SALMON INTERACTIONS IN WRIA 9

Prepared for

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EXECUTIVE SUMMARY

Conservation planning in the Water Resource Inventory Area (WRIA) 9 watershed has been ongoing since Puget Sound Chinook salmon was listed as threatened under the Endangered Species Act (ESA). When evaluating the status of Puget Sound Chinook salmon, effects of hatchery-origin salmon on natural-origin Chinook salmon were identified by the National Marine Fisheries Service (NMFS) as a key issue. In WRIA 9, the Soos Creek Hatchery, located in the Green/Duwamish basin, began operation in 1901; it is one of the most productive hatcheries in Puget Sound. Additionally, the Keta Creek Hatchery and several smaller facilities support hatchery production in WRIA 9. In order to facilitate conservation planning in WRIA 9, this report:

1. Briefly summarizes recent literature on interactions between hatchery- and naturally-produced salmon
2. Reviews Hatchery and Genetic Management Plans (HGMPs) and recommendations of the Hatchery Scientific Review Group (HSRG)
3. Reviews investigations of hatchery- and naturally-produced Chinook salmon in WRIA 9 (primarily the Green/Duwamish River)
4. Identifies uncertainties and research priorities associated with hatchery-origin salmon

A review of literature indicates hatcheries may adversely affect naturally-produced salmon in a variety of ways, including:

- Interbreeding with natural-origin salmon, which leads to altered genetic composition and associated traits that promote survival
- Competing for food and space in freshwater, estuarine, and marine environments
- Preying on juvenile salmon
- Over-harvesting of natural stocks in mixed-stock fisheries
- Masking of decreased productivity of natural stocks in response to habitat degradation and climate change.

New approaches are being developed in order to minimize the effects of hatchery-origin salmon on natural-origin salmon. These approaches often involve either integration or segregation of hatchery- and natural-origin salmon. These two approaches to hatchery management have important consequences for natural-origin salmon populations. All review studies on hatcheries cited the need for additional, focused research to better understand the effects of hatchery-origin salmon on wild salmon populations.

HGMPs for WRIA 9 typically contained descriptive rather than quantitative information. While it is important to have a document that provides common information on hatchery programs, the HGMPs provided little explanation as to why the hatcheries were operated the way they were, and the ecological and genetic consequences of hatchery protocols. HGMPs did not discuss the Viable Salmon Population (VSP) concept or how the hatchery may contribute to or adversely affect the VSP of natural populations.

The HSRG report provided a comprehensive and systematic evaluation of salmon hatcheries in Western Washington. In WRIA 9, the HSRG identified and reviewed 11 hatchery programs, of which only four had a stated goal that included conservation as one of their purposes: Green River fall Chinook, Green River coho, Green River chum, and Green River winter steelhead. The HSRG did not evaluate the key question of whether the stated hatchery goals were appropriate goals. Surprisingly, HSRG recommendations did not address VSP criteria. To the extent that hatchery programs were expected to contribute to conservation and recovery, it would have been useful if the HSRG had addressed the question of how hatchery production was expected to support the conservation and recovery goal—and explicitly how hatchery production was expected to affect abundance, productivity, biological diversity, and spatial distribution. Despite the absence of the VSP analysis, the HSRG made several important recommendations that have the potential to make the Green River hatcheries operate in a more efficient and effective manner.

Hatchery Production

Approximately 7 million hatchery-origin salmon and steelhead are released into WRIA 9 each year. In 2003, approximately 3.7 million Chinook salmon were released into the Green River basin, including approximately 3 million hatchery-origin fingerlings released into Soos Creek, 0.4 million fry released above Howard Hanson Dam, and 0.32 million yearlings released from Icy Creek ponds. Additionally, the hatcheries released 1.5 million coho salmon (including fish released at Elliott Bay net pens near Myrtle Edwards Park), 1.2 million chum salmon, and 263,000 steelhead. Additional WRIA 9 coho and chum salmon were released outside the Green River basin, including about 30,000 coho fry and 50,000 chum fry into Vashon Island creeks, 160,000 coho fry and 15,000 coho yearlings into Burien-area creeks, 25,000 coho yearlings at Des Moines net pens, and about 100,000 chum fry and fingerlings released in Elliott Bay from the Seattle Aquarium (HSRG 2003). Since 2000, the hatcheries have attempted to mass mark (adipose fin clip) all Chinook salmon and steelhead, but many coho salmon and all chum fry are not marked. Researchers have expressed concern about accuracy of mark estimates. Accurate mark estimates are essential for evaluations of natural-origin salmon abundance, migration timing, growth, and habitat use.

Juvenile Studies

Several studies have recently examined interactions between hatchery- and natural-origin juvenile Chinook salmon in the Green/Duwamish watershed. These studies relied upon identification of hatchery-origin Chinook salmon through observation of adipose fin clips and the presence of coded-wire-tag (CWT). The studies demonstrated that the release of subyearling hatchery-origin Chinook salmon occurred when natural-origin Chinook salmon were relatively abundant in the Duwamish River and Estuary.

In 2003, growth of natural-origin juvenile Chinook salmon declined 76 percent immediately after release of 3 million subyearling Chinook salmon, then recovered soon after most hatchery-origin salmon migrated to Puget Sound. Likewise, growth of natural-origin Chinook salmon that were sampled in off-channels of the lower Duwamish River during 2002 and 2003 declined approximately 60 percent after release of hatchery-origin Chinook salmon. These studies relied upon weekly changes in salmon length, which could have been influenced by migration patterns of salmon in addition to interactions with hatchery-origin salmon.

Residence time of hatchery- and natural-origin Chinook salmon were examined in restored Duwamish River off-channels using mark and recapture techniques (in 2003) and in the Duwamish estuary using otolith chemistry and daily growth rings (in 2002). In restored off-channel habitats, residence time of natural-origin Chinook salmon declined from 1.6 days prior to the release of 3 million hatchery-origin subyearlings in late May to 0.1 days after the release, suggesting that hatchery-origin salmon may have displaced natural-origin Chinook salmon from the off-channel habitats. Residence time of hatchery-origin Chinook salmon in marine waters prior to their capture at the mouth of the Duwamish River averaged 9.5 fewer days than that of natural-origin Chinook salmon (20 to 28 days) during late May to early June. However, residence time of hatchery-origin Chinook salmon captured in Elliott Bay (Piers 90/91) averaged 20 more days than natural-origin salmon captured in this area, which indicated that natural-origin salmon quickly dispersed from the Duwamish River area.

Predation by yearling hatchery-origin salmon on natural-origin salmon was evaluated at the WDFW trap on the Green River and in the Puget Sound marine nearshore. Predation rates on juvenile salmon at the trap were very low. Predation rates on salmon in the nearshore marine areas of King County were also very low, but sampling did not include the pre-April period when smaller Chinook fry may have been available.

A key finding in the nearshore marine area was that hatchery-origin fish from many hatcheries in Puget Sound utilize that nearshore habitat within WRIA 9. Salmon from WRIA 9 rapidly disperse to other areas of Puget Sound.

Adult Chinook Salmon

Recent mass-marking of Chinook salmon and analysis of CWT Chinook indicated that 60 percent of the Chinook salmon spawning in the mainstem Green River were hatchery-origin during 1989 and 1999. Approximately 42 percent of the Chinook salmon recovered at the Soos Creek Hatchery rack were natural-origin salmon, providing evidence that the Soos Creek Hatchery is an "integrated" hatchery. Genetic analyses indicated no significant differences between natural spawners in Newaukum Creek and salmon recovered at the Soos Creek Hatchery, a finding that is consistent with the observed exchange of hatchery- and natural-origin salmon. The effect of interbreeding on the fitness of these Chinook salmon is unknown, but some researchers suggest that interbreeding effects are likely minimal for salmon reared in hatcheries for short periods prior to release. Hatchery production in the Green River has contributed significantly to the harvests of salmon. If, however, the Green/Duwamish population of Chinook is expected to contribute to recovery of Puget Sound Chinook, then hatchery broodstock represents a major uncertainty that needs to be carefully evaluated.

NMFS evaluated the productivity of natural-origin Chinook salmon after considering two assumptions. When only natural-origin Chinook were examined in the analysis, the annual population growth rate was approximately 2 percent, indicating a relatively stable spawning population. However, when hatchery-origin strays were included and assumed to have reproductive success equal to natural spawners, the annual population growth rate of the natural populations declined to 0.70 percent, indicating a precipitous decline in the natural population that was considerably lower than any other Chinook population in Puget Sound. This estimate reflects the high percentage of hatchery-origin spawners on the spawning grounds. NMFS noted that the actual population growth rate is likely between the two extreme-case estimates shown above.

A key factor contributing to the great numbers of hatchery-origin Chinook salmon on the spawning grounds is the inability of sport, commercial, and tribal fishermen to harvest surplus hatchery-origin Chinook salmon in order to conserve natural spawning salmon. During 1997 through 2003, approximately 9,026 surplus hatchery-origin fish entered the Green River each year, composed of approximately 5,726 hatchery-origin fish returning to the river, and approximately 3,300 hatchery-origin fish returning to the hatchery. If live-capture gear was employed by commercial and Tribal fishermen, then unmarked natural-origin salmon could be live-released and more marked hatchery-origin fish could be harvested. The selective fishery approach could lead to more efficient use of hatchery-origin fish, greater harvests, reduced straying of hatchery-origin fish to the spawning grounds, and potentially greater escapements of natural-origin Chinook salmon.

The proposed reintroduction of salmon and steelhead in the Upper Green River was reviewed. Upstream passage facilities are in place, but full scale operation will not begin until the juvenile downstream migration facility is constructed. Agencies have yet to determine which species and stocks and numbers of fish will be allowed to pass upstream.

Research Priorities

Research priorities were identified and the research projects included:

- Evaluate fitness of hatchery-origin fish spawning naturally
- Evaluate predation by yearling salmon that were planted above the dams as fry and that successfully migrate downriver
- Evaluate interactions between hatchery- and natural-origin salmon in the transition zone
- Evaluate adequacy of spawning habitat in the Green River given the large numbers of stray hatchery-origin salmon
- Develop accurate estimates of natural recruitment and productivity

- Identify numbers of marked versus unmarked hatchery-origin salmon annually
- Develop methods to improve attractiveness of hatcheries to returning salmon
- Evaluate the feasibility of non-lethal harvest techniques to enable selective fisheries

Recommendations

Any recommendations regarding alternative management regimes for the Green/Duwamish River and the WRIA 9 watershed planning area are highly dependent on the long-term goals for the watershed. Our review of existing literature, HGMPs, and most importantly, the HSRG recommendations reveals that the big picture questions about the role and goals of hatcheries, given the wild fish conservation efforts in the Puget Sound evolutionary significant unit (ESU), have yet to be answered (or posed). If, for the purposes of ESA delisting and recovery, NMFS requires that the Green/Duwamish River supporst a naturally reproducing, self sustaining population of fall Chinook salmon population, then this suggests one set of future conditions and use of one type of artificial production strategy. Compared to the current situation in the Green/Duwamish River, such a future might include greatly minimized hatchery production, and lower abundance, greater life history diversity, and more spatially-distributed spawning and rearing of natural-origin fish. Alternatively, if the long-term goal for the watershed is to maximize production and maintain high harvest opportunity, then the future hatchery management regime would probably be quite similar to today's regime. This would include continued reliance on high levels of hatchery production and acceptance of the negative interactions between hatchery- and naturally-produced fish.

1 INTRODUCTION

The use of hatcheries to enhance the abundance of Pacific salmon dates back to the latter half of the 19th century, and the arrival of Euro American settlers, who were attracted to the bountiful natural resources of the Pacific Northwest. Among those natural resources were the anadromous fish, with literally millions of adult salmon and steelhead returning to spawn in coastal waters each year. Salmon had long been the cultural and spiritual focus of Native American tribal life and customs, and they rapidly became a major source of nutrition for the early settlers.

As the human population increased in the Pacific Northwest, salmon became an increasingly important staple of the newcomers diet. In addition, advances in canning and other preservation technology fueled major increases in harvest as salmon became an international commodity. The new settlers' quest for precious metals, timber, and agricultural products increased as well and, as pursued, led to widespread destruction of salmon habitat. All of these events put enormous pressure on salmon populations, and hatcheries were envisioned as a solution to all of these pressures (Lichatowich 2001). When the dam building era began in the 1930s, salmon populations throughout the Pacific Northwest were already greatly reduced from historic levels, and the damming of northwest rivers became yet another major threat. Whether the action was logging, mining, or dam building, the term "salmon hatcheries" came to be used interchangeably with mitigation.

The first Pacific salmon hatchery on the West Coast was established by Livingston Stone on the McCloud River in California. Within 5 years, the technology was transferred to the Oregon Territory with establishment of a hatchery on the Clackamas River, a tributary of the Columbia River. In subsequent years, hatcheries spread throughout the Oregon and Washington Territories, with numerous facilities located in the Puget Sound basin.

Although hatcheries have a documented history of increasing the abundance of Pacific salmon for harvest, they have done so with little regard for the integrity of locally adapted salmon populations (Levin and Schiewe 2001). The primary culprit in this regard has been the indiscriminate transfer of stocks from hatchery-to-hatchery, watershed-to-watershed, and state-to-state, in an effort to "balance" and maximize production. As early as 1877, after a flood destroyed the Clackamas hatchery's first egg take, Livingston Stone ordered replacement eggs from the McCloud Hatchery in California. This practice of transferring eggs among hatcheries became so commonplace over the next 100 years that few populations have been untouched by this practice. Unfortunately, it has only been recently recognized that this practice is a major source of risk to the integrity of population structure and biodiversity of Pacific salmon. Indeed, today when fishery biologists refer to the major risks facing Pacific salmon, they often refer to "the four H's"—harvest, habitat, hydropower, and hatcheries.

In Washington state, the salmon recovery effort is organized around Water Resource Inventory Areas, or WRIAs. WRIA 9, which includes the Green/Duwamish River and the Maury/Vashon Island planning areas, is located in one of the more urbanized environs of the Puget Sound basin. From its headwaters in the Cascade Mountains about 30 miles north of Mount Rainier, the Green River flows 93 miles through a mosaic of forests, agricultural land, and urban development before entering Elliott Bay through the highly industrialized Duwamish Waterway. Historically, the Green River was home to robust native populations of Chinook, coho, and chum salmon, but no quantitative estimates of population size are available. Today only a small fraction of those populations return to their former numbers, in part because major rivers within the watershed, including the White and Cedar Rivers, have been diverted elsewhere. A significant proportion of the returning salmon and steelhead are of hatchery origin.

Each year, substantial numbers of juvenile salmon and steelhead are released into the WRIA 9 planning area. The largest facilities from a production perspective are the Soos Creek Hatchery operated by the Washington Department of Fish and Wildlife (WDFW) and the Keta Creek Hatchery operated by the Muckleshoot Indian Tribe. Satellite facilities associated with these hatcheries include Crisp Creek rearing ponds, Icy Creek ponds, Palmer ponds, Elliott Bay net pens, Des Moines net pens, the Seattle Aquarium, and Seatac Occupational Skills Center in Burien. Overall production in recent years approached 7 million fish, of which close to 4 million were Chinook salmon. Needless to say, this production is critical to maintaining harvest opportunity, particularly for the Native Americans exercising their treaty right to harvest salmon in their usual and accustomed areas.

Despite the apparent success of the artificial propagation program in the Green/Duwamish River, the naturally-produced Chinook[1] are part of the larger Puget Sound evolutionary significant unit (ESU) that was listed as threatened under the Endangered Species Act (ESA) in 1997. Needless to say, this listing has added significant complexity to fisheries management in the Green/Duwamish. No longer is the production of harvestable surpluses the only goal; for delisting to occur in Puget Sound, the National Marine Fisheries Service (NMFS) may require that the Green/Duwamish River supports a naturally sustaining population that has negligible risk of extinction over a 100-year time frame (McElhaney et al. 2000).

When considering conservation planning in WRIA 9, it is critical to take into account the role of hatcheries, and in particular the interactions between hatchery- and naturally-produced salmon. Although there are few topics in salmon recovery planning that elicit more passion and strongly held views, it is absolutely critical that all the factors be weighed in an objective and balanced manner.

Accordingly, the focus of this report is the interaction between hatchery- and naturally-produced salmon in the WRIA 9 planning areas. This report is focused almost exclusively on Chinook salmon because of their dominant place in the Green/Duwamish watershed; their importance in commercial, recreational, and tribal harvest; and their listed status under the ESA. In subsequent sections, we summarize the current state of knowledge regarding interactions between hatchery- and naturally-produced salmon, summarize investigations of hatchery- and naturally-produced salmon in WRIA 9, review Hatchery and Genetic Management Plans (HGMPs) and recommendations of the Hatchery Scientific Review Group (HSRG), identify critical uncertainties, and recommend research priorities.

[1] The term naturally produced Chinook refers to salmon spawned in the wild, but whose parentage and genetic origins may include some hatchery component. Since there has been widespread straying of hatchery fish onto the spawning grounds, and no mass marking of fish until recently, all Chinook produced through spawning in the river are considered “naturally produced.”

2 REVIEW OF EXISTING INFORMATION ON THE INTERACTIONS BETWEEN HATCHERY AND WILD SALMONIDS

2.1 Overview of Findings

The issues surrounding the potential beneficial and detrimental effects of hatchery-produced salmon on natural populations have been studied and reviewed by many of the region's foremost scientific panels and research groups. The primary impetus for these reviews has been the seemingly conflicting mandates of the ESA for recovering self-sustaining populations in their natural habitat, and the societal desire for harvestable surpluses of salmon; the latter often supported by artificial production. The recent *Alsea Valley Alliance v. Evans* U.S. District Court ruling (Alsea decision) in Oregon has brought this challenge into even sharper focus. Simply stated, the Alsea decision opines that the ESA does not allow the listing of a subset of an ESU while excluding genetically indistinguishable hatchery-origin fish from naturally-produced fish within an ESU. This court ruling has led NMFS to propose a revision of their listing determinations and status review policies. In anticipation of this new policy, NMFS scientists have recently completed a review of the status of West Coast salmonids ESUs (NMFS 2003, 2005).

During this same period, a number of scientific panels, boards, and committees addressed various aspects of the hatchery and wild fish interactions, including the National Research Council's Committee on Protection and Management of Pacific Northwest Anadromous Salmonids (NRC 1996); the Independent Scientific Advisory Board (ISAB) convened by the Northwest Power Planning Council and NMFS (Bisson et al. 2002); and the Recovery Science Review Panel convened by NMFS (Myers et al. 2004). Several informative research reports have been published investigating this issue, although research is not highly abundant. The findings and conclusions presented below are based on existing information gained by these investigations. All reviews cited a need for additional, focused research to better understand the potential effects of hatchery-origin salmon on wild populations.

The reviews present several consistent themes regarding the efficacy of hatchery programs in restoring long-term, self-sustaining populations. Although a goal of many hatcheries is to increase the number of natural spawners, Bisson et al. (2002) found no peer-reviewed studies that demonstrated sustained increases in natural-origin juveniles as a result of allowing hatchery-origin adults to spawn. Further, "the overall effectiveness of supplementation to maintain a population until underlying causes of decline is currently unknown" (Flagg et al. 2000).

In addition, these reviews indicate that artificial propagation may have deleterious effects on natural populations. In terms of allowing hatchery-origin fish to spawn naturally, Bisson et al. (2002) concluded that it is possible for more hatchery-reared salmon to return to spawn naturally than is biologically sound for the sustainability of wild populations. The rationale for this conclusion was based on the recognition of several potential deleterious impacts of interbreeding on the wild populations, including:

- There is convincing evidence that domestication selection can genetically alter hatchery populations in relatively few generations.
- There is convincing evidence that hatchery-reared adults returning from the ocean and spawning in the wild generally produce progeny that do not survive as well as progeny from adults of natural origin.
- There is persuasive indication that interbreeding between hatchery-reared adults and wild fish can reduce the fitness of wild populations.

An additional negative impact that can occur due to the presence of hatchery-origin fish is related to mixed-stock fisheries. Mixed-stock fisheries tend to harvest naturally-produced fish at too high a rate, resulting in under-escapement of natural-origin fish and reducing the recruitment potential of the next generation of natural-origin fish (Flagg et al. 2000).

Studies have also shown that the survival of hatchery-reared fish following their release is often considerably lower than that of wild-reared fish (Flagg et al. 2000). Several studies have indicated that the poor post-release survival of hatchery-origin fish is brought about by both the adaptive (genetic) differences between hatchery and wild populations and the environmental differences between hatchery and natural rearing environments (Flagg et al. 2000). In general, the studies indicate that the post-release survival of hatchery-produced salmon decreases as the hatchery broodstock is further removed from the local, wild population (in terms of both the number of generations the broodstock source is removed from the wild and the use of non-local broodstock). In addition, based on their review of the relative fitness of hatchery- and natural-origin salmon, Berejikian and Ford (2004) stated that hatchery programs that artificially extend the freshwater rearing phase (such as the full year rearing of "ocean-type" Chinook) cannot be assumed to have minimized the reduction in relative fitness.

A general finding of these reviews, including the recently released report of the HSRG is that hatchery success should not be based on juvenile release numbers. It should instead be based on fish survival through each life stage. Flagg et al. (2000) concluded that supplementation projects that emphasize production goals and strict adherence to size and time-of-release goals impose major selective pressures on the stock that may be very non-adaptive for fish that must spawn in the wild. The authors identified the following potential measures that could be implemented in future hatchery supplementation operations to minimize the potential for deleterious interactions between hatchery- and natural-origin fish:

- Broodstock collection throughout the seasonal run, and maintenance of differences in resulting size until release
- Reduction in rearing density to allow survival of slower growing fish (this might also require variation in feeding levels between different raceways)
- True volitional release and multi-year rearing cycles for some species of fish
- Use of surface water supplies to maintain normal growth patterns
- Use of natural-environment rearing components, predation training, and exercise
- Natural mate selection and natural incubation systems
- Use of substrate and reduced light levels in artificial incubation (if used)
- Modification of production diets and natural food items

NMFS has recently been investigating the use of more natural-like rearing environments to produce hatchery fish that are better adapted for survival after their release into the wild. The Northwest Fisheries Science Center's Natural Rearing Enhancement System (NATURES) program is investigating whether a hatchery environment with overhead cover, woody debris, natural substrate, and predator avoidance training will result in higher survival rates among hatchery-origin salmonids after their release. The working hypothesis underlying these studies is that behavioral differences between hatchery- and natural-origin salmonids may be minimized by rearing them in an environment more similar to the natural environment, and that minimizing these differences can increase post-release survival rates for hatchery-origin salmonids. However, a major uncertainty associated with this approach is whether improved survival of hatchery-origin fish will in fact contribute to or hinder recovery. As elaborated below in Section 5 (Critical Issues in WRIA 9), increasing survival of hatchery-origin fish without eliminating or even minimizing adverse genetic and ecological interactions may only exacerbate the problem.

2.2 Summaries of Literature Reviewed

The following technical publications were reviewed as background for this project. A brief summary of each is included in Appendix A.

- Bisson, P.P., et al. 2002. "Hatchery Surpluses in the Pacific Northwest." North American Journal of Fisheries 27(12): 16-27.
- Independent Scientific Advisory Board (ISAB). 2003. A Review of Salmon and Steelhead Supplementation. (Available at: http://www.nwcouncil.org/library/isab/isab2003-3.htm)
- Berejikian, B. and M. Ford. 2003. Review of Relative Fitness of Hatchery and Natural Salmon. NMFS Technical Memorandum NMFS-NWFSC-61.
- Flagg, T.A., B.A. Berejikian, J.E. Colt, W.W. Dickhoff, L.W. Harrell, D.J. Maynard, C.E. Nash, M.S. Strom, R.N. Iwamoto, and C.V.W. Mahnken. 2000. *Ecological and Behavioral Impacts of Artificial Production Strategies on the Abundance of Wild Salmon Populations*. U.S. Department of Commerce, NMFS Technical Memorandum, NMFS-NWFSC-41.
- Washington State Joint Natural Resources Cabinet. 1999. *Statewide Strategy to Recover Salmon – Extinction Is Not An Option.*
- NMFS. 2002. *Updated Action Plan for the Review of Pacific Salmon and Steelhead ESA Listings and Hatchery Policy*.

3 CURRENT HATCHERY OPERATIONS IN WRIA 9 AND INVESTIGATIONS OF HATCHERY AND WILD SALMON INTERACTIONS

3.1 Hatchery Releases in WRIA 9

Substantial numbers of juvenile salmon and steelhead are annually released into WRIA 9 from WDFW-operated Soos Creek Hatchery and Keta Creek Hatchery, which is operated by the Muckleshoot Indian Tribe. The Soos Creek Hatchery began operation in 1901 and is one of the oldest and most productive hatcheries in Puget Sound. Satellite facilities associated with these hatcheries include Crisp Creek rearing ponds, Icy Creek ponds, Palmer ponds, Elliott Bay net pens, Des Moines net pens, the Seattle Aquarium, and Seatac Occupational Skills Center in Burien. Releases from these facilities support tribal, commercial, and sport fisheries in Puget Sound and British Columbia. The hatcheries release Chinook salmon fry, fingerlings, and yearlings, coho fry and yearlings, steelhead yearlings, and chum fry (Tables 1 and 2). Chinook salmon are the dominant species released from the hatcheries. In 2003, approximately 3.7 million Chinook salmon were released into the Green River basin, including approximately 3 million hatchery fingerlings released into Soos Creek, 0.4 million fry released above Howard Hanson Dam, and 0.32 million yearlings released from Icy Creek ponds. Additionally, the hatcheries released 1.5 million coho salmon (including fish released at Elliott Bay net pens near Myrtle Edwards Park), 1.2 million chum salmon, and 263,000 steelhead. Additional coho and chum salmon were released outside the Green River basin, including about 30,000 coho fry and 50,000 chum fry into Vashon Island creeks, 160,000 coho fry and 15,000 coho yearlings into Burien-area creeks, 25,000 coho yearlings at Des Moines net pens (Puget Sound), and about 100,000 chum fry and fingerlings released in Elliott Bay from the Seattle Aquarium (HSRG 2003). In total, about 7 million hatchery-origin salmon and steelhead were released into WRIA 9 during 2003. Similar numbers have been released in past years (Ruggerone et al. 1995; Weitkamp and Ruggerone 2000; Nelson et al. 2004).

Table 1
WDFW (Soos Creek) Hatchery Releases, 2003

Species	Age	Location	Release Date	Number released			% bad clip	wt (g)
				Ad+CWT	CWT only	AD only		
Chinook	subyearling	Soos Creek	22-May	154,400	150,900	1,363,500		5.7
			23-May	4,570	48,900	316,500		6.4
			27-May	0	0	23,000		4.4
			29-May	0	0	934,000	1.33%	5.3
			Totals	158,970	199,800	2,637,000	37,186	
					Grand total:	2,995,770		
Chinook	yearling	Icy Creek	1-May	0	0	324,000	1.26%	45.4
							4,082	
Coho	yearling	Soos Creek	20-Apr	59,400	42,100	255,400	1.61%	26.7
							4,112	
Winter Steelhead	yearling	Soos Creek	1-May	0	0	37,100	0.93%	82.5
		Palmer Ponds	1-May	0	0	110,500	0.93%	82.5
		Icy Creek	1-May	0	0	7,750	0.93%	82.5
		Flaming Geyser	26-Apr	0	0	13,900	0.93%	79.6
			Totals	0	0	169,250	1,574	
Summer Steelhead	yearling	Soos Creek	1-May	0	0	31,500	1.01%	82.5
		Palmer Ponds	1-May	0	0	25,900	1.01%	82.5
		Icy Creek	1-May	0	0	2,450	1.01%	82.5
						59,850	604	

Note: Wilson, personal communication, 2003

Table 2
Salmon and Steelhead Releases by the Muckleshoot Indian Tribe, 2003

Species	Age	Date	Location	Number released: Ad+CWT	CWT only	AD only	No mark	% bad clip	Wt (g)	Comment
Chinook	subyearling	March 20-25	Above H. Hanson Dam			402,000		~5%	2.5	No CWT, no yearlings released; clip retention not quantified, but may be similar to Soos Cr (Moore, pers. comm.)
Coho	subyearling	April 14-15	Above HH				548,000	NA	1.0	
Coho	yearling	April 30-May 7	Crisp Cr				240,000	NA	29.5	
		April 30-May 7	Crisp Cr	11,000				?	29.5	96.6% CWT retention on both groups
		April 30-May 7	Crisp Cr		39,000				29.5	
Coho	yearling	~June 1	Myrtle Edwards Net Pens				352,000			Goal is 400,000 total
			Myrtle Edwards Net Pens	50,000	(included in 50K)			?		Paul Dorn, Suquamish Tribe
			Totals:	61,000	39,000		1,140,000			
						Grand total:	1,240,000			
Steelhead	yearling	April 30-May 7	Keta Cr			34,000 Ad/left ventral (pelvic)		?	82.5	Green R Native spawn in hatchery
Chum	subyearling	March 7-April 7	Keta Cr				1,200,000	NA	1.0	No marks

Note: Dennis Moore, Muckleshoot Indian Tribe, personal communication with G. Ruggerone, NRC, October 10, 2003.

Prior to 2000, juvenile salmon released from the hatcheries were not mass marked (e.g., adipose fin clip); therefore, studies in the Lower Green River and Duwamish Estuary could not distinguish hatchery- from natural-origin Chinook salmon because the size of fish overlapped considerably. The inability of researchers and managers to distinguish between hatchery- and natural-origin Chinook salmon has confounded evaluations of Chinook salmon status in key Puget Sound drainages. This was an important factor leading to the threatened species status of Puget Sound Chinook salmon (Myers et al. 1998). Beginning in 2000, the hatcheries attempted to mass mark nearly all Chinook salmon prior to release and approximately 95 to 98 percent of the fish reportedly received an adipose fin clip or a code-wire-tag (CWT). Approximately 200,000 unclipped Chinook salmon are intentionally released into the Green River with a CWT. Mass marking allowed field studies during 2001 through 2003 to distinguish most hatchery- from natural-origin juvenile Chinook salmon, thereby enabling investigations of interactions between the two stocks.

Nevertheless, there is still concern among field investigators that the estimated percentage of marked salmon is not as accurate as it could be because some fish received poor fin clips or no clip at all (Nelson et al. 2004). Inaccurate accounting of fin-clipped Chinook salmon can lead to inaccurate estimates of natural-origin Chinook abundance, migration timing, and size. Initial attempts to estimate unrecognizable fin clips at the Soos Creek Hatchery were based on grab samples of clipped fish as they traveled from the clipping station to the ponds. In 2005, subyearling Chinook salmon were randomly sampled in the ponds for unrecognizable fin clips after all fish had been mass marked. This approach provided a more accurate measure of the unrecognizable fin clip rate. The unrecognizable fin clip rate of non-CWT Chinook in 2005 was 4.1 percent (Ruggerone, Nelson, and Hall, unpublished data), a value that may have been lower than in previous years given the increased accountability for unclipped salmon. Another concern when conducting investigations of naturally-produced salmon in the Green River is that only approximately 30 percent of the 1.4 million hatchery-origin coho and none of the 1.2 million hatchery-origin chum salmon fry were marked in 2003. Incomplete marking of hatchery-origin coho and chum salmon confounds interpretation of abundance, migration timing, and size of natural-origin coho and chum salmon in the watershed. Approximately 99 percent of hatchery-origin steelhead are marked with adipose fin clips. Hatchery-origin steelhead have received an adipose fin clip for many years, thereby allowing catch and release of natural-origin steelhead by sport fishers.

3.2 Juvenile Salmon Interactions

Nelson et al. (2004) evaluated the potential effect of hatchery-origin Chinook salmon releases on the growth of natural-origin Chinook salmon sampled in the Duwamish Estuary (River Mile [RM] 0 RM 7). They reported that in 2003, hatchery-origin Chinook salmon were released during a period of high abundance of naturally-produced Chinook salmon in the Duwamish estuary (late May through early June). The authors estimated that daily growth of natural-origin Chinook salmon was relatively high during April through mid-May (0.54 millimeters [mm], or 0.86 percent per day), then growth declined 76 percent during late May through mid-June to only 0.13 mm per day (0.17 percent) (Figure 1). The decline in growth corresponded with the period of high abundances of hatchery-origin Chinook salmon in RM 0 to RM 7 habitats. Following the sharp decline in abundance of hatchery-origin Chinook salmon in mid-June, daily growth of naturally-produced Chinook salmon increased to 0.44 mm (0.52 percent per day), corresponding to a 230 percent increase in growth rate compared with the previous 3 weeks when hatchery-origin fish were abundant. Growth of hatchery-origin Chinook salmon was also relatively low during this period, indicating growth of both natural-origin and hatchery-origin Chinook salmon was influenced by the high abundance of hatchery-origin salmon.

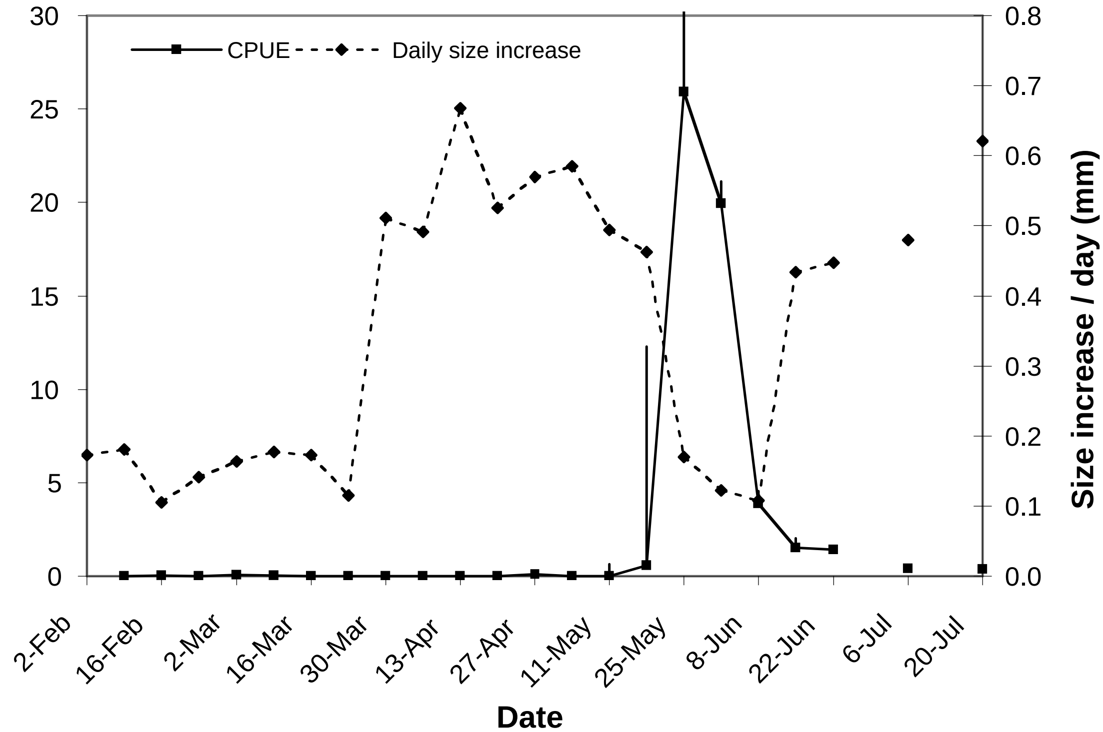

Figure 1
Change in Daily Size of Natural-origin Subyearling Chinook Salmon in Relation to the Number of Hatchery-origin Chinook Salmon Captured per Beach Seine in the Duwamish River, 2003
CPUE are geometric means + 1 SE. All fish sampled within RM 0 and RM 7, 2003
Source: Nelson et al. (2004)

In 2002, growth of naturally-produced Chinook salmon appeared to be reduced during the period of high hatchery-origin salmon abundance, but less frequent sampling during 2002 made interpretation of this finding less certain (Nelson et al. 2004). In a separate study during 2002, growth of natural-origin Chinook salmon in off-channel habitats of the Duwamish Estuary declined sharply in early and late June, suggesting that the release of hatchery-origin Chinook salmon may have reduced growth of natural-origin Chinook salmon (Goetz and Ruggerone, unpublished data). In 2003, the growth rate of natural-origin Chinook salmon in off-channel habitats in the Duwamish Estuary declined 60 percent immediately following the release of subyearling hatchery-origin Chinook salmon, then returned to typical levels (Ruggerone and Jeanes 2004).

The release of approximately 3 million hatchery-origin Chinook salmon from Soos Creek Hatchery led to exceptionally high densities of hatchery-origin salmon throughout the

Lower Green River and Duwamish Estuary during late May and June 2003 (Nelson et al. 2004). During the peak migration, beach seine catches of hatchery-origin Chinook salmon represented approximately 80 percent of the total fish catch at RM 13 and RM 6.5, 91 percent of the catch near Kellogg Island (RM 1), and approximately 80 to 90 percent of the catch in nearby nearshore marine areas. The high percentage of hatchery-origin fish occurred during a period when natural-origin Chinook salmon were initially relatively abundant in the Lower Green River and Duwamish Estuary.

To examine the possibility that high abundances of hatchery-origin Chinook salmon and other salmonids displace natural-origin Chinook salmon from key rearing habitats, Nelson et al. (2004) examined the percentage of natural-origin Chinook salmon occupying preferred habitat (RM 6.5) compared with less preferred habitats (RM 1 and RM 13) before, during, and after the period of high salmon abundance. High salmon abundance in these areas was initially due to the presence of numerous chum fry, followed by the immigration of numerous hatchery-origin Chinook salmon. Prior to May, which is the period of high fish abundance at RM 6.5, catches of natural-origin Chinook salmon at RM 6.5 represented 92 percent of the total natural-origin Chinook catch at the three index sites. During the period of high salmon abundance (May 11 through June 7), catches of natural-origin Chinook salmon at RM 6.5 declined to 65 percent of the total natural-origin Chinook catch at all three index sites. After the period of high abundance, catches of natural-origin Chinook salmon at RM 6.5 increased to 77 percent, on average. Although catches of natural-origin Chinook salmon at RM 6.5 remained somewhat high during the period of high overall abundance, the decline in the percentage of natural-origin Chinook salmon at RM 6.5 relative to other sites might have been a response to the limited habitat capacity of this preferred area, leading to dispersal of natural-origin Chinook salmon to other areas. Although these observations suggested natural-origin Chinook salmon may have been displaced from a key habitat, the authors noted that other factors may have influenced the distribution of salmon in 2003.

Off-channel habitats in the Duwamish Estuary were sampled for fish abundance and residence time on a bi-weekly basis from April 2 to July 10, 2003 (Ruggerone and Jeanes 2004). Residence time in the off-channel habitats after mark and release averaged 1 day for natural-origin and 0.5 day for hatchery-origin subyearling Chinook salmon. Residence time of natural-origin Chinook salmon declined from 1.6 days prior to the release of 3 million hatchery-origin subyearlings in late May to 0.1 day after the release, suggesting that hatchery-origin salmon may have displaced natural-origin Chinook salmon from the off-channel habitats. Growth rate of natural-origin Chinook salmon declined 60 percent immediately following the release of hatchery Chinook salmon, then returned to typical levels in early June.

Concerns have been raised by the WRIA 9 Technical Committee about possible predation by yearling hatchery-origin salmon on emerging salmon fry in the Green/Duwamish watershed. Juvenile salmon typically consume salmon fry rather than fingerlings, but field research in other watersheds has shown yearling salmon may consume other salmon up to 50 percent of their own body length (Ruggerone 1989). Most hatchery-origin yearlings are released from Icy Creek in early May, a period after most subyearling Chinook have gained considerable size and are likely at or beyond the maximum potential prey size of the yearlings released. Some larger juvenile hatchery-origin salmon outmigrants have been observed moving through Howard Hanson Dam and Tacoma Diversion Dam during fall and winter (Hickey, personal communication, October 2004), but potential predation by these fish on emerging fry in the Middle Green River has not been evaluated. Seiler et al. (2002) examined stomachs of yearling salmon and steelhead captured in the screw trap at RM 34.5 and found predation on Chinook fry to be very low. WDFW conducted additional predation studies in 2003 and 2004 and also found predation by yearling salmon to be very low (Topping, personal communication, October 2004).

Concerns have also been raised about the potential for hatchery-origin salmon to exceed the carrying capacity of the marine environment. Marine growth of salmon in the Pacific Northwest has declined over the past 25 years, leading scientists to speculate that the capacity has been exceeded (Pearcy et al. 1999). Recent studies indicate competition between salmon can lead to reduced growth and survival (Levin et al. 2001, Ruggerone et al. 2003). From 1980 to 1993, approximately 173 million hatchery-origin salmon and steelhead were released into Puget Sound watersheds each year (Ruggerone et al. 1995). Ruggerone and Goetz (2004) evaluated the growth and survival of 53 million CWT Chinook salmon released into Puget Sound and adjacent waters in an effort to evaluate potential competition with pink salmon, which are only abundant as juveniles during even-numbered years.

From 1984 to 1997, a period of relatively low production in the marine environment, juvenile Chinook salmon released during even-numbered years experienced 59 percent lower survival than those released during odd-numbered years, a trend consistent among 13 Chinook salmon stocks. Lower even-numbered-year survival of Chinook salmon was associated with reduced first-year growth and survival, and delayed maturation. Additional analyses indicated the interaction occurred within Puget Sound and the lower Strait of Georgia during the first growing season. The alternating-year mortality accounted for most of the 50 percent decline in marine survival of CWT Chinook salmon between 1972 and 1983 and 1984 and 1997.

Competition among individuals of a species is typically expected to have greater effects than competition between species. Therefore, the effect of competition between hatchery-origin Chinook on natural-origin Chinook would be expected to be even stronger than the effect of pink salmon on Chinook in Puget Sound. Each year, approximately 66 million hatchery-origin Chinook salmon are released into Puget Sound (1980 through 1993) where hatchery- and natural-origin Chinook share habitats, and must vie for similar prey resources and space. Competition of this sort would be expected to be especially high during periods of low prey availability and high conspecific abundance.

3.3 Adult Salmon Interactions

The large releases of hatchery-origin Chinook salmon produce significant numbers of hatchery-origin fish returning to the Green/Duwamish River. From 1968 to 1998, approximately 8,200 Chinook salmon were counted at the Soos Creek Hatchery per year (Weitkamp and Ruggerone 2000). Escapement to the hatchery increased to 10,100 fish from 1999 to 2002 (Packer, personal communication, October 2004; Alexandersdottir and Coshow 2003). Additionally, numerous hatchery-origin Chinook salmon strayed to natural spawning grounds. Using expansion of CWT data, WDFW estimated that approximately 55 percent, on average, of the Chinook salmon spawning naturally in the watershed had originated from the hatcheries during 1989 through 2001 (Cropp, personal communication, October 2004). At the Soos Creek Hatchery, approximately 34 percent of the recovered fish were estimated to have originated from natural spawners, including numerous hatchery-origin fish that are released upstream of the weir on Soos Creek.

Genetic data (allele frequencies) are available for Chinook sampled in the Newaukum Creek (1 year of data), a tributary to the Green River, and for Chinook collected in the Green River Hatchery on Soos Creek (Marshall, personal communication, October 2004). Chinook spawning in the mainstem of the Green River have not been sampled for genetic analysis. These data indicated Newaukum Creek and Soos Creek Hatchery Chinook salmon were genetically similar such that they could not be distinguished using genetic stock identification techniques. This result is not surprising given the stray rates suggested by CWT data and the fact that the hatchery broodstock is derived from Green River fish. The effect of interbreeding between hatchery- and natural-origin Chinook salmon on the genetic fitness of the natural stock has not been studied, but geneticists note that interbreeding between hatchery- and natural-origin stocks will alter the genetic make-up of the natural stock, even if the hatchery stock was derived from local fish (Grant 1997; ISAB 2003). The effect of interbreeding on locally-adaptive traits and fitness of the natural stock is unknown (but see comment below on timing).

In the past, hatchery personnel often selected early arriving salmon to spawn, which in turn led to earlier return timing of hatchery-origin salmon. Historical data for the Soos Creek Hatchery suggest the return timing of adult hatchery-origin Chinook has advanced, largely due to hatchery practices that tend to spawn a greater proportion of early arriving fish. The date at which 50 percent of hatchery-origin Chinook salmon returned to the Soos Creek Hatchery advanced from October 20 in 1944 to October 5 in 1965 (Weitkamp and Ruggerone 2000). The effect of the shift in spawn timing of hatchery-origin Chinook salmon on timing of natural-origin Chinook salmon has not been evaluated. Hatchery spawn timing since 1950 was assembled by Ruggerone et al. (1995), but shifts in timing have yet to be analyzed. Given the high percentage of hatchery-origin fish observed on the spawning grounds in recent years (average 55 percent), it is reasonable to suspect that timing of natural spawners has shifted earlier. Spawn timing is an important trait because it determines timing of emergence. In pristine watersheds, spawn and emergence timing have evolved to produce fry that have greater probability of finding prey and surviving. The earlier arrival of hatchery-origin adults may also lead to displacement of the later arriving natural-origin salmon spawners to suboptimal spawning habitats.

When reviewing the status of the Puget Sound Chinook salmon ESU, Myers et al. (1998) noted that watersheds that had large numbers of adult natural-origin Chinook salmon also had releases of hatchery-origin Chinook salmon in the watershed. They concluded that the large presence of hatchery-reared Chinook salmon confounded interpretation of stock status because hatchery-reared fish were not mass marked and could not be distinguished from naturally-produced salmon. The confounding effect of hatchery-produced salmon on the evaluation of stock status and the observed decline of Chinook populations in watersheds without significant hatchery production led Myers et al. to recommend a threatened listing status under the ESA.

More recently, NMFS revised estimates of the annual population growth rates of spawners in the Green River and other Puget Sound watersheds (NMFS 2003, 2005). When assuming a "worst case" scenario where reproductive success of hatchery-origin Chinook spawning in the river was equal to that of natural-origin spawner, then the mean population growth rate of the natural population was negative. Comparison of the Green/Duwamish population to other Puget Sound populations indicated that the Green/Duwamish population was declining the most rapidly. NMFS (2003) suggested that the status of the spawning population is probably between this worst case scenario and that calculated when hatchery-origin fish are removed from the analysis. In the latter case, the Green/Duwamish population was stable. It is important to note that this analysis did not consider population growth of the total Green/Duwamish population because it did not factor in fish that were harvested. Also, population growth rate does not consider the capacity of the watershed. This is important because a population might show a declining growth rate because spawner abundance was exceptionally high at the beginning of the time series.

4 REVIEW OF HATCHERY AND GENETIC MANAGEMENT PLANS FOR WRIA 9 AND HATCHERY SCIENTIFIC REVIEW GROUP RECOMMENDATIONS

HGMPs document WDFW's and the Muckleshoot Indian Tribe's planned management approach for the future operation of each hatchery program in the Green/Duwamish watershed. The following sections provide an overview of the background and goals contained in the HGMPs and the HSRG review of them.

4.1 Hatchery and Genetic Management Plans

The WDFW prepared 79 HGMPs covering all Puget Sound artificial salmonid production programs, as a requirement of Section 4(d) of the ESA, to provide significant conservation measures for Washington's hatchery programs. The Muckleshoot Indian Tribe prepared an HGMP for the Keta Creek Hatchery program. Draft versions of the HGMPs were released for public comment in July 2003. It is our understanding that WDFW will address the comments and the revised HGMPs will be provided to NMFS during the next year in an iterative, ongoing process that will lead to a Final Environmental Impact Statement.

The aim of creating the HGMPs was to devise biologically-based artificial propagation management strategies that ensure the conservation and recovery of listed ESUs of salmonids. While the HGMPs do not elaborate on these specific strategies, they describe, in a template provided by NMFS, each artificial production program for salmon and steelhead in the Puget Sound region and outline the potential effects of each program on listed species. Six HGMPs were prepared for hatchery operations in WRIA 9. These plans do not address all hatchery programs in WRIA 9. For example, HGMPs have not been prepared for the Keta Creek Hatchery chum or coho salmon program. An overview of the key components of these plans is provided in Table 3.

Table 3
Hatchery and Genetic Management Plans for WRIA 9 Hatcheries

Key Hatchery Information (Section of HGMP providing this information)	Soos/Icy Creek Fall Yearling Chinook	Soos Creek Fall Fingerling Chinook	Keta Creek Fall Chinook	Soos Creek Coho	Palmer Ponds Winter Steelhead	Palmer Ponds Summer Steelhead
General Program Overview						
Location (1.5)	Big Soos Creek, tributary to the Green River at RM 33.5. Icy Creek, tributary to the Green River at RM 48.3	RM 1 of Big Soos Creek, tributary to Green River at RM 33.5	RM 1.0 on Crisp Creek, tributary to Green River at RM 40.1	RM 1 of Big Soos Creek, tributary to Green River at RM 33.5	Unnamed stream, tributary to the Green River at RM 56.1	Unnamed stream, tributary to the Green River at RM 56.1
Type of Program[a] (1.6)	Integrated Harvest	Integrated Harvest	Integrated Harvest/Research	Integrated Harvest	Isolated harvest	Isolated harvest
Goal of Program (1.7)	Harvest augmentation	Harvest augmentation	Evaluate survival of hatchery-origin fish above Howard Hanson Dam and integrate with programs to minimize biological risks to naturally-produced fall Chinook	Harvest augmentation	Harvest augmentation	Harvest augmentation
Key Program Activities	Early Rearing	Broodstock collection, spawning, and rearing	Rearing	Broodstock collection, spawning, and rearing	Broodstock collection, spawning, hatching, and later rearing	Broodstock collection, spawning, hatching, and later rearing
Original Broodstock (6.1)	Green River fall Chinook	Green River fall Chinook	Green River fall Chinook	Green River coho (not listed)	Historical: Chambers Creek Current: Tokul Creek	Skamania stock (includes some Skykomish origin fish)
Proposed Maximum Annual Number of Adults Spawned for Broodstock[b] (6.2.2)	140	3,500	3,500 (broodstock is collected at Soos Creek Hatchery)	2,300	200 (equal male and female)	80 (equal male and female)
Number and Location of Fish Released (10.1)	300,000 smolts to Icy Creek	3.2 million fingerlings to Soos Creek	600,000 fingerlings to various Green River tributaries[b]	600,000 yearlings to Soos Creek 350,000 fry to various Green River tributaries	165,000 yearlings to Palmer Ponds 35,000 yearlings to Soos Creek 15,000 yearlings to Flaming Geyser Pond	50,000 yearlings to Palmer Ponds 30,000 yearlings to Soos Creek
Transfers in Addition to Hatchery Releases (1.11)	None are transferred	600,000 eyed-eggs to Muckleshoot Indian Tribe (Keta Creek Hatchery) 2,000 eyed-eggs to schools	None are transferred	600,000 fingerlings to Muckleshoot Indian Tribe (Keta Creek Hatchery) 550,000 unfed fry to Muckleshoot Indian Tribe (Keta Creek Hatchery) 60,000 subyearlings to co-op net pens 120,000 eyed-eggs to Des Moines Northwest Salmon and Steelhead Council net pens 25,000 fish to Seattle Aquarium 140,000 eyed-eggs and fish to other local co-op projects	100,000 pre-smolts to Muckleshoot Indian Tribe (Keta Creek Hatchery) 15,000 pre-smolts to conditioning ponds at Flaming Geyser State Park if available	None are transferred
Date HGMP Last Updated	August 21, 2002	August 21, 2002	May 2003	March 26, 2003	March 20, 2003	March 20, 2003
Breeding, Rearing, and Marking Practices						
Fertilization (Female to Male ratio) (8.3)	1:1	1:1	1:1	1:1	1:1	1:1
Selection Method (8.1)	Females chosen randomly from ripe fish with aim to spawn all ripe females each day; males chosen randomly with about 1 percent jacks used	Females chosen randomly from ripe fish with aim to spawn all ripe females each day; males chosen randomly with about 1 percent jacks Used	Females chosen randomly from ripe fish with aim to spawn all ripe females each day; males chosen randomly with about 1 percent jacks used	Females chosen randomly from ripe fish with aim to spawn all ripe females each day; males chosen randomly with about 1 percent jacks used; if female numbers exceed need, eggs taken randomly from later-spawning females, and remaining females are surplused	Spawners chosen based on ripeness	Spawners chosen based on ripeness Eyed-eggs may be transferred in from Reiter ponds to make up for escapement shortfall (ranged from 0 to 100 percent in last few years)

Table 3
Hatchery and Genetic Management Plans for WRIA 9 Hatcheries

Key Hatchery Information (Section of HGMP providing this information)	Soos/Icy Creek Fall Yearling Chinook	Soos Creek Fall Fingerling Chinook	Keta Creek Fall Chinook	Soos Creek Coho	Palmer Ponds Winter Steelhead	Palmer Ponds Summer Steelhead
Rearing Facilities (5.5)	0.25 acre earthen rearing pond	Raceways, concrete ponds, asphalt ponds	Raceways	Raceways, concrete ponds, asphalt ponds	Earthen rearing ponds, four smaller circular ponds	Concrete raceway for adult capture and round ponds for holding; no rearing
Use of "Natural" Rearing Methods (9.2.9)	None given	None given	Fish are exposed to natural bird predators in raceway rearing areas an then released into a mountain area, where they rear on average for 2 months before outmigration	None given	None given	None given
Tagging Strategy (10.7)	100 percent mass mark – CWT applied to a portion of yearlings at Icy Creek	2.8 million mass mark – Ad clip 200,000 Ad/CWT 200,000 CWT	80 percent of broodyear 1993 to 1995 tagged[c] 100 percent of broodyear 1999 and beyond – Ad clip	Broodyear 1996 was first year to be 100 percent mass marked 45,000 Ad-clip/CWT 45,000 CWT	100 percent mass-mark – Ad clip	100 percent mass-mark – Ad clip
Age/Size at Release (in fish per pound – fpp) (10.1)	Yearlings – 10 fpp	Fingerlings – 80 fpp	Fry – 150 fpp	Fry – 600 fpp Yearling – 17 fpp	Yearlings – 5 fpp	Yearlings – 5 fpp
Acclimation/Release (10.6)	From ponds into the creek	From ponds into the creek	Tank truck transportation – acclimated to stream temp during transport, approximately 45 to 90 minutes	From ponds into the creek	From ponds into the creek – acclimated into surface water previous to release	From ponds into the creek – acclimated into surface water previous to release
Disposition of Hatchery Surpluses (7.5)	Donated for food or sent upstream to spawn naturally	Donated for food or sent upstream to spawn naturally	Donated for food or sent upstream to spawn naturally	Donated for food or un-marked fish allowed upstream to spawn naturally	Distributed to Muckleshoot Tribal members	Not given
Fish Health Monitoring, Disease Treatment, and Sanitation Procedures (9.2.7)	Fish Health Specialist visits, medications, and pond-cleaning	Fish Health Specialist visits, medications, and pond-cleaning	Fish Health Specialist visits, medications, and pond-cleaning	Fish Health Specialist visits, medications, and pond-cleaning	Fish Health Specialist visits	Fish Health Specialist visits
Justification for the Program (1.8)	To provide fish for harvest while minimizing adverse genetic, demographic, or ecological effects on listed fish by: 1. Juvenile Chinook will be released as smolts to minimize emigration time to saltwater thereby minimizing potential competition with and predation on natural-origin listed fish. 2. Juvenile Chinook will be released after the usual wild Chinook emigration time to minimize potential adverse interactions. 3. All juvenile Chinook released will be acclimated at a hatchery facility capable of trapping the majority of returning adults. This practice will minimize straying and make possible the removal or regulation of hatchery fish allowed to spawn naturally. 4. Mark all reared fish. 5. Adult Chinook produced from this program will be harvested at a rate that allows adequate escapement of listed Chinook.	To provide fish for harvest while minimizing adverse genetic, demographic, or ecological effects on listed fish by: 1. Juvenile Chinook will be released as smolts to minimize emigration time to saltwater thereby minimizing potential competition with and predation on natural-origin listed fish. 2. Juvenile Chinook will be released after the usual wild Chinook emigration time to minimize potential adverse interactions. 3. All juvenile Chinook released will be acclimated at a hatchery facility capable of trapping the majority of returning adults. This practice will minimize straying and make possible the removal or regulation of hatchery fish allowed to spawn naturally. 4. Mark all reared fish. 5. Adult Chinook produced from this program will be harvested at a rate that allows adequate escapement of listed Chinook.	In 1911, the City of Tacoma constructed a diversion dam across the Green River at RM 61 to divert surface water for municipal and industrial needs. This dam blocks all upstream returning adult salmon. In 1962, the U.S. Army Corps of Engineers completed the Howard Hanson Dam at RM 64.5 and began to retain water behind this dam upstream of Tacoma's dam to regulate downstream flooding. This project will help determine if mitigation for this blockages is possible.	Coho produced while minimizing adverse genetic, demographic, or ecological effects on listed fish by: 1. Release coho as smolts with expected brief freshwater residence and time of release not to coincide with out-migration of listed fish. 2. Only appropriate stock propagated. 3. Mark all reared fish. 4. Propagation with appropriate culture methods and consistent with Co-Managers Fish Health Policy and water quality standards (e.g., National Pollutant Discharge and Elimination System [NPDES])	To provide fish for harvest while minimizing adverse genetic, demographic, or ecological effects on listed fish by: 1. Release steelhead as smolts with expected brief freshwater residence and time of release not to coincide with out-migration of listed fish. 2. Only appropriate stock will be propagated. 3. Mark all reared fish. 4. Propagation with appropriate culture methods and consistent with Co-Managers Fish Health Policy and water quality standards (e.g., NPDES).	To provide fish for harvest while minimizing adverse genetic, demographic, or ecological effects on listed fish by: 1. Release steelhead as smolts with expected brief freshwater residence and time of release not to coincide with out-migration of listed fish. 2. Only appropriate stock will be propagated. 3. Mark all reared fish. 4. Propagation with appropriate culture methods and consistent with Co-Managers Fish Health Policy and water quality standards (e.g., NPDES).

Table 3
Hatchery and Genetic Management Plans for WRIA 9 Hatcheries

Key Hatchery Information (Section of HGMP providing this information)	Soos/Icy Creek Fall Yearling Chinook	Soos Creek Fall Fingerling Chinook	Keta Creek Fall Chinook	Soos Creek Coho	Palmer Ponds Winter Steelhead	Palmer Ponds Summer Steelhead
Survival and Abundance						
Average Egg-to-Fry Survival (9.1.1)	89.8 percent	86.5 percent	N/A – Egg-to-fry rearing occurs at Soos Creek – See Soos Creek Fall Fingerling Chinook HGMP	86.5 percent	85 to 90 percent	85 percent in 2000 only (broodstock collection began in 2000)
Average Fry-to-Smolt Survival (9.2)	91.7 percent	95.4 percent	92 percent (Eyed to release)	95.4 percent	71 to 90 percent	65.1 percent – heavy bird and otter predation
Smolt-to-Adult Survival (1.12)	Actual 2.09 percent – based on 1989 to 1995	Goal 1 percent, Actual 0.41 – based on 1988 to 1996	CWT study – Attachment 2[b] Average 0.0126 – in 1993 to 1995	Actual 3.23 – based on 1988 to 1997	Goal 5 percent, Actual 1.09 percent	Goal 3 percent, Actual 1.86 percent
Number of Returning Adults (1.12)	(Based on 1987 to 1993, except 1991) [c] Harvest 3,080 Hatchery rack 221 Natural spawners 2,160	(Based on 1986 to 1993) [c] Harvest 16,474 Hatchery rack 5,210 Natural spawners 1,779	CWT study – Attachment 2[b] (Based on 1993 to 1995) Harvest (estimated) 75 In-river fisheries (estimated) 21	(Based on 1995 to 2000) 15,735	Adult production level Average 1,773 Minimum 574 Maximum 3,000	Adult production level Average 947 Minimum 189 Maximum 1,830
Progeny-to-Parent Ratios[c] (2.2.2)	Each Green River natural spawner produces 2.33 adults returning to Washington waters	Each Green River natural spawner produces 2.33 adults returning to Washington waters	N/A – no broodstock collection	Not provided	Not provided	Not provided
Annual Escapement Goal (1.12 or 2.2.2)	3,500 for hatchery 5,800 for fall Chinook in Green River drainage	3,500 for hatchery 5,800 for fall Chinook in Green River drainage	Hatchery goal: N/A 5,800 for fall Chinook in Green River drainage	Goal not given, but hatchery escapement ranged from 7,512 in 1997 to 43,989 in 2000	Hatchery goal: 200 Natural goal: less than 10 percent of annual return	Hatchery goal: 80 Natural goal: less than 5 percent of annual return
Annual Spawning Abundance Estimates for Same-species Fish in the Green River (2.2.2)	Green River fall Chinook[d] – Average 7,598 Minimum 2,476 Maximum 11,512	Green River fall Chinook[d] – Average 7,598 Minimum 2,476 Maximum 11,512	Green River fall Chinook[d] – Average 7,598 Minimum 2,476 Maximum 11,512	Not given, but see escapement above	1,581 calculated using: average production of 1,773 Hatchery: approximately 50 in 2000 Natural: approximately 8 percent of annual adult return	868 calculated using: average production of 947 Hatchery: approximately 50 in 2000 Natural: approximately 3 percent of annual adult return
Actual Proportion of Hatchery-Origin Fish on Spawning Grounds[e] (2.2.3 and 6.2.3)	22.7 percent of natural spawners in mainstem Green River from Icy Creek 18.8 percent of natural spawners in Newaukum Creek from Icy Creek	33.4 percent of natural spawners in mainstem Green River from Soos Creek 23.3 percent of natural spawners in Newaukum Creek from Soos Creek	N/A – spawning is not conducted	Not provided	Not provided	Not provided
Timing						
Release Date (10.4)	Early April – volitional release	Mid to late May – forced release	Mid to late March – forced release	Third week of April – forced release	Mid-May – volitional release	Early to mid May
Return Timing of Naturally-produced Adults of the Same Species (1.10)	Late August to late October	Late August to late October	Late August to late October	August to January	December to May	It is currently unclear whether naturally-produced summer steelhead are in the Green River
Return Timing of Hatchery Adults (1.10)	Early September to late October	Early September to late October	N/A – no adults return to this hatchery	October to December	November to February	June to December
Timing of Adult Collection and Spawning at Hatchery (1.10)	Early September to mid-October	Early September to mid-October	N/A – no adults return to this hatchery	October through November, overlaps the latter part of the Chinook run	December to mid-February	September to November
Estimated Number of Natural-Origin Fish Taken for Broodstock (2.2.3)	Estimated at less than 80 fish/year	780 to 1,380	N/A – no broodstock at this hatchery	All coho returning may be selected as broodstock	None – all broodstock are of hatchery origin	None – all broodstock are of hatchery origin and ad-clipped

Table 3
Hatchery and Genetic Management Plans for WRIA 9 Hatcheries

Key Hatchery Information (Section of HGMP providing this information)	Soos/Icy Creek Fall Yearling Chinook	Soos Creek Fall Fingerling Chinook	Keta Creek Fall Chinook	Soos Creek Coho	Palmer Ponds Winter Steelhead	Palmer Ponds Summer Steelhead
Ecological Interactions						
Listed-Fish Interactions (3.5)	Icy Creek yearling Chinook prey to an unknown extent on listed fish Competition with listed fish is unknown but considered high[f]	Low probability of preying on/competing with listed fish[f]	Competitive and predatory interactions with and by listed fish (Chinook salmon, bull trout) are unknown	Nutrient enhancement (carcasses) Predation – freshwater: no known empirical studies Predation – marine: available studies indicate this is unlikely with larger Chinook and smaller predators; can achieve this by manipulating release dates for hatchery fish. Competition: no known empirical studies, but considered minimal risk	Nutrient enhancement (carcasses) Predation – freshwater: no known empirical studies Predation – marine: available studies indicate this is unlikely with larger Chinook and smaller predators; can achieve this by manipulating release dates for hatchery fish. Competition: no known empirical studies, but considered minimal risk	Nutrient enhancement (carcasses) Predation – freshwater: no known empirical studies Predation – marine: available studies indicate this is unlikely with larger Chinook and smaller predators; can achieve this by manipulating release dates for hatchery fish. Competition: no known empirical studies, but considered minimal risk
Measures to Minimize Likelihood of Adverse Genetic or Ecological Effects to Listed Natural-Origin Fish as a Result Of Broodstock Practices (3.2)	All fish released attempted to be marked (Section 10.7)	WDFW has 2-year agreement with Muckleshoot Indian Tribe to mass mark the 1999 and 2000 brood Chinook salmon released into the Green River. Approximately 200,000 CWT fish do not have an Ad clip.	N/A – No fish are bred at this hatchery	All fish released attempted to be marked Use broodstock from throughout run timing	All fish released attempted to be marked Water quality meets NPDES permit standards	All fish released attempted to be marked Water quality meets NPDES permit standards
Measures to Minimize Likelihood of Adverse Genetic or Ecological Effects to Listed Natural-Origin Fish as a Result Of Mating Scheme (8.5)	One to one matings will be utilized to maximize the number of spawners incorporated into the gene pool. Adults will be selected randomly from the entire run. In the future, all matings will be from marked hatchery-origin adults.	One to one matings will be utilized to maximize the number of spawners incorporated into the gene pool. Adults will be selected randomly from the entire run. In the future, all matings will be from marked hatchery-origin adults.	N/A – No fish are bred at this hatchery	One to one matings will be utilized to maximize the number of spawners incorporated into the gene pool. Adults will be selected randomly from the entire run.	One to one matings will be utilized to maximize the number of spawners incorporated into the gene pool. Adults will be selected randomly from the entire run.	One to one matings will be utilized to maximize the number of spawners incorporated into the gene pool. Adults will be selected randomly from the entire run.
Measures to Minimize Likelihood of Adverse Genetic or Ecological Effects to Listed Natural-Origin Fish as a Result Of Competition or Predation (2.2.3)	Release timing is prior to second pulse of listed juvenile fish outmigration	Release timing (slightly overlaps and) follows listed fish outmigration	N/A – none listed	Release timing is prior to second pulse of listed juvenile fish outmigration	Release timing (slightly overlaps and) follows listed fish outmigration	Release as smolts; release timing overlaps listed fish outmigration
Research Conducted (12.1)	None	None	(CWT study 1993 to 1995) Coordinate with WDFW who engages in juvenile salmonid studies on the Green River	None	None	None

Notes: a Hatchery Program types described as follows: An integrated harvest program is a project in which artificially propagated fish produced primarily for harvest are intended to spawn in the wild and are fully reproductively integrated with a particular natural population. An isolated harvest program is a project in which artificially propagated fish are produced primarily for harvest and are not intended to spawn in the wild or be genetically integrated with any specific natural population.
b Text in the NGMP refers to a separate attachment to provide the information. No attachments were available.
c Based on WDFW CWT database.
d Based on WDFW Chinook run reconstruction tables.
e Based on the 12-year escapement average.
f Based on WDFW Risk Assessment.
RM = river mile
CWT = coded-wire tag
Ad clip = Adipose fin clip
fpp = fish per pound
NPDES = National Pollutant Discharge and Elimination System

4.2 Hatchery Scientific Review Group

The Puget Sound and Coastal Washington Hatchery Reform Project was created by the U.S. Congress in 2000 in order to provide an "independent scientific evaluation of hatchery programs against measurable goals, on a watershed scale, in the context of what the habitat can support and the potential impact of the programs on every stock in the watershed." The Hatchery Reform Project established the HSRG to conduct the independent scientific evaluation of hatchery reform programs in Puget Sound and coastal Washington. The objective of the HSRG is to assemble, organize, and apply the best available scientific information to provide guidance to policy makers who are implementing hatchery reform.

The HSRG has prepared a number of tools to guide the scientific evaluation of hatchery operations. The "Scientific Framework for Artificial Propagation of Salmon and Steelhead" (Appendix A of *Hatchery Reform: Principles and Recommendations of the Hatchery Scientific Review Group* [HSRG 2004]) underlies and informs all of the HSRG's tools, processes, and recommendations. The goal of the Scientific Framework is to organize the best available science pertinent to hatcheries in Puget Sound and coastal Washington. The Scientific Framework identifies four primary conditions for success of hatcheries:

1. Healthy and viable hatchery populations
2. An examination of effects of hatchery programs on wild and native populations and the environment
3. Appropriate contribution of hatcheries to conservation and harvest
4. Accountability for performance

The HSRG developed Operational Guidelines (Appendix C of HSRG 2004) to explicitly identify hatchery operational practices that are most likely to meet the Scientific Framework conditions for success. In addition, the HSRG established Monitoring and Evaluation Criteria (Appendix D of HSRG 2004) to determine the success of individual hatchery programs and to identify the types of data that hatcheries can collect to add to the scientific research database. The Operational Guidelines and the Monitoring and Evaluation Criteria provide specific information for each of the following hatchery program elements that were identified in the Scientific Framework as contributing to program success:

- Choice of broodstock
- Collection of broodstock

- Spawning
- Incubation
- Rearing
- Release and adult migration
- Accountability
- Education

Using these scientific and evaluation standards, the HSRG reviewed the HGMPs prepared for each hatchery and provided their recommendations. The HSRG overview of hatchery operations, including their recommendations and the corresponding WDFW responses, are provided in Table 4.

Table 4
Summary of HSRG Findings for Hatchery Programs in Green River

Topic	Fall Chinook	Coho	Summer/Winter Steelhead
Purpose	Harvest and Conservation	Harvest and Conservation	Harvest and Conservation
Type	Integrated	Integrated	Integrated
Operational Considerations	• Proportion of natural-origin adults among fish spawned for broodstock averaged 42 percent per year from 1990 to 1999. • CWT data show proportion of natural spawners comprised of Soos Creek Hatchery-origin adults within the mainstem Green River averaged 37.3 percent from 1989 to 1999 (with a range of 0 to 67 percent). The proportion of natural spawners comprised of Icy Creek Hatchery-origin adults averaged 18.7 percent (with a range of 0 to 100 percent) during the same 9 years. The overall proportion of natural spawners comprised of hatchery-origin adults has averaged 59.6 percent for the years 1989 to 2000 with “other” hatchery fish constituting 3.6 percent of natural spawners. These proportions should be interpreted with caution because of small sample sizes and the restricted region of the mainstem river surveyed (8 miles between mouths of Soos and Icy Creeks). In general, the proportion of natural spawners comprised of hatchery-origin adults in the Green River has exceeded 50 percent, approximately 50 percent of the time. • The proportion of natural spawners comprised of Soos and Icy Creek hatchery-origin adults in Newaukum Creek averaged 28.8 percent (with a range of 0 to 68 percent) and 17.9 percent (with a range of 0 to 42.3 percent), respectively, for 11 years between 1989 and 1999. • The annual natural escapement goal for fall Chinook salmon in the Green River drainage is 5,800 adult spawners. The annual escapement goal for the Soos Creek Hatchery is 3,500 adults. Escapement to the hatchery has exceeded 9,000 adults every year since 1995, except for 2000 when escapement was approximately 6,000. • Up to 3,500 adults are passed upstream of the adult trap for natural spawning in Soos Creek. • Adults are spawned pairwise (one-to-one) for fingerling releases. For the Icy Creek yearling program, adults are spawned in gamete pools of three males and three females. *Note: the HGMP states a fertilization ratio for yearlings at Icy Creek of one-to-one.*	• The managers plan to collect broodstock from all temporal segments of the run returning to Soos Creek, but often are not able to collect late-returning broodstock. • Fish are released from the hatchery earlier than the ideal release time because of programming constraints. • Control of predatory birds at the hatchery is difficult without adequate netting. • Pollution abatement at the hatchery site is not adequate. • Fish for the Elliott Bay net pen release site are vaccinated at Crisp Creek before being introduced into the pens. • Fish for the Elliott Bay net pen release site are not mass marked, but 10 to 12.5 percent have historically had CWT.	• This is a new program. • Fingerlings may or may not be adipose fin clipped, depending upon meeting escapement (if escapement goals are met the fingerlings are clipped, if not the pre-smolts remain unmarked and are outplanted into areas with low natural spawning).
Benefits and Risks			
Consistent with Short-term and Long-term Goals?	• Significant harvest benefits. • Program appears to be providing a demographic benefit to the overall escapement and abundance; however, the large numbers of hatchery-origin adults spawning is a significant concern, as they may be competing with natural-origin adults for spawning habitat. • A decrease in habitat quality would present a risk to meeting goals.	• Consistent with harvest goals. • The interaction (mixed parentage) of hatchery- and wild-spawning coho in the Green River is consistent with mid- and long-term goals. It is also consistent with conservation goals, in that the hatchery provides demographic support for coho spawning in the urbanized habitat of the Green River, although the risk of lost fitness through domestication is important.	• Could provide some minimal harvest benefits. • Not consistent with conservation goals as presently designed, because of the small genetic effective size of the broodstock and the potential for genetic swamping (the Ryman/Laikre effect). On the other hand, collecting more adults for broodstock could create demographic risks to the natural population.
Likelihood of Attaining Goals?	• Long-term genetic consequences of hatchery program on the natural population is unknown.	• Likely to continue to support the goals. • Habitat is unlikely to improve. • Integrated stock may be increasingly domesticated.	• Conservation goals cannot be attained. • Likelihood of attaining harvest goals is constrained by the high mortality of the broodstock, the use of low-surviving fingerling releases, and the small size of the program.
Consistent with Goals for Other Stocks?	• Predation risks on sub-yearling coho, Chinook, and chum may exist from yearling releases. • May be nutrient benefits from hatchery-origin carcasses.	• Green River chum fry, and natural-origin Chinook and coho fry are at risk of predation by coho smolts produced from the hatchery program. • Straying adults from Elliott Bay net pen site interbreed with other coho stocks and potentially reduce the population fitness (local-adaptedness) of those stocks.	• Minimal negative interactions are expected, due to the small size of the program.

Table 4
Summary of HSRG Findings for Hatchery Programs in Green River

Topic	Fall Chinook	Coho	Summer/Winter Steelhead
HSRG Recommendations	• Predation risks on sub-yearling coho, Chinook, and chum may exist from yearling releases. • May be nutrient benefits from hatchery-origin carcasses. • Manage to allow natural-origin fish to drive adaptation (goal of two-thirds natural-origin spawners). • Continue incorporating natural-origin spawners in broodstock per HSRG guidelines. • Select broodstock to represent entire run timing. • Continue to evaluate semi-natural rearing methods to increase survival and reduce domestication. • Institute volitional release. • Conduct stomach-content studies of hatchery-origin yearling Chinook from Icy Creek at Green River smolt trap to determine predation and determine necessary changes to the program (if any). • Determine spawning escapement composition and resulting recruitment. • Collect returning adults for yearling program at Icy and Newaukum Creeks. • Construct adult holding/sorting pond not in mainstem Soos Creek, including bypass facilities for adult fish passage upstream and a weir for diverting adults into holding pond.	• Release fish at later date (when fully smolted) to attain more rapid outmigration. • Incorporate natural-origin adults into hatchery broodstock to ensure sufficient gene flow (if no divergence, then at rate of 10 to 20 percent natural-origin per year). • Mark all releases, including smolts from net pens. • Evaluate straying and gene flow from different stock segments (e.g., on-site releases, upstream releases, etc.). • Do not increase the size of Elliott Bay net pen releases until the effects of straying have been evaluated. Following this, adjust release size appropriately.	• Discontinue the current conservation program, since the benefits are unlikely to exceed the genetic and demographic risks it creates. • Discontinue fingerling releases; follow HSRG steelhead release guidelines. • Evaluate the program's contribution to harvest and continue only until a harvest benefit is established and the conservation risk is addressed by selective removal of a significant proportion of returning hatchery-origin adults. • If the program continues, follow HSRG Area-Wide Recommendations for steelhead (see other steelhead program reviews).
Manager's Response	WDFW generally supports the recommendations of the HSRG, but notes that: • The target proportion of natural-origin fish in the hatchery broodstock and in natural spawning areas is a complex topic that will require additional analyses and discussion • Additional funding will be required to upgrade the facilities as recommended WDFW has taken the following actions consistent with the HSRG recommendations: • Implemented collection and evaluation of the stomach contents of smolts captured at the Green River smolt trap • Will test trap and collection facilities in 2003 for adults returning to Icy and Newaukum Creeks (subject to approval by NMFS) • Conducted a 3-year study of the magnitude and composition of natural spawning escapement in the Green River	WDFW generally supports the recommendations of the HSRG, but notes that: • The target proportion of natural-origin fish in the hatchery broodstock and in natural spawning areas is a complex topic that will require additional analyses and discussion • Delaying the release of smolts from Soos Creek Hatchery requires balancing the risk that fish held to a later date in the creek ponds will be lost in flood events; WDFW is evaluating short- and long-term solutions, including the development of incubation and early rearing facilities at Icy Creek and Palmer ponds • Additional funding will be required to evaluate the magnitude of straying	WDFW appreciates the HSRG recommendations on Wild Steelhead Management Zones, but notes: • A "white paper" on this topic could increase our understanding of HSRG concerns and recommended remedies • As a companion to the HSRG white paper, WDFW proposes to conduct a series of workshops on steelhead during 2003 to discuss recent research, performance of the hatchery programs, and management options (including integrated and segregated programs) • Implementation of any changes in the steelhead program will require consultation with the Fish and Wildlife Commission and the affected tribes; modification of the program should not occur until these tasks are completed

Notes: CWT = coded-wire tag

4.3 Evaluation of HSRG and HGMP Recommendations

The HGMPs are a long-overdue source of systematic information on salmonid hatchery programs in the Pacific Northwest. They provide consistent information on a variety of program attributes, ranging from management objectives, to source of broodstock, to life-stage-specific survivals. As a general rule, however, the majority of the information contained in HGMPs is of a descriptive rather than a quantitative nature. Moreover, as important as it is to have these documents and a source of common information on hatchery programs, there is little in the way of explanation as to why hatcheries are operated the way they are, and the ecological and genetic consequences of hatchery protocols in use. Noteworthy from a salmon conservation and ESA perspective is the failure of the HGMPs to mention the Viable Salmon Population (VSP) concept or how hatchery production may contribute to or adversely affect (depending on program purpose) the VSP parameters of natural populations spawning in the immediate vicinity of the hatcheries. Considering that the HGMP template was developed by NMFS and that the completed forms are considered to be part of the application for a Section 4(d) exclusion of hatchery programs from the taking of ESA-listed salmon ESUs, this is an inexplicable shortcoming. At a minimum, one would expect a hatchery management plan to explicitly describe how its program was either contributing to recovery or avoiding jeopardy to ESA-listed populations in the area.

In contrast to the simple template approach of the HGMPs, the HSRG report is in general a very comprehensive and thoughtful effort to systematically evaluate hatchery programs in Western Washington. The evaluation included a review of program goals, an assessment of whether the program was operated in a manner consistent with the stated goals, a risk and benefit analyses, and recommendations for improved operations. In describing their review of the Puget Sound hatcheries, the HSRG outlined an approach that took into account "the nature of the watersheds in which the programs occur and *goals for the naturally spawning populations and the individual programs set by the regional managers"* (Appendix A of HSRG 2004, emphasis added). For the purposed of the review, hatcheries were characterized by both purpose (such as conservation, harvest, education, and research) and type (such as genetically integrated or segregated).

What is unclear from the HSRG report is whether the review team critically considered whether the stated goals established by the regional managers were the "right ones." In raising this question, we are by no means suggesting that the HSRG necessarily erred by accepting the manager's stated goal, or that some of the hatchery programs were mischaracterized or were operating under the "wrong" goal. However, we are suggesting that balancing the many facets of conservation may require a higher level of review that begins with a critical look at the stated goal. Hatchery programs are typically started for a particular purpose and their goals are often legally defined by mitigation agreements. However, a goal established 50 or more years ago may be due for review. If the goal is to support and sustain harvest, then recommendations for hatchery operations would arguably be substantially different from recommendations if the purpose was conservation and rebuilding of naturally self-sustaining runs that would contribute to ESA delisting. By accepting the regional manager's goals, the HSRG limited the breadth and potential impact of their recommendations to current purpose.

In WRIA 9, the HSRG identified and reviewed 11 hatchery programs, of which only four had a stated goal that included conservation as one of their purposes: Green River fall Chinook, Green River coho, Green River chum, and Green River winter steelhead. Just as it was noteworthy that the HGMPs failed to address hatchery effects on VSP parameters of local native populations, it is perhaps even more surprising that the HSRG recommendations did not address the subject either. To the extent that hatchery programs such as those operational in the Green/Duwamish watershed were expected to contribute to conservation and recovery, it would have been extremely useful if the HSRG had addressed the question of how hatchery production was expected to support the conservation goal—and explicitly how hatchery production was expected to affect abundance, productivity, biological diversity, and spatial distribution. Despite the absence of this analysis, the HSRG made several important recommendations that have the potential to make the Green River hatcheries operate in a more efficient and effective manner.

5 CRITICAL ISSUES IN WRIA 9

Many of the hatchery reviews and scientific studies cited in Section 2 (and summarized in Appendix A) describe a litany of potential problems or adverse impacts of hatchery production on wild stocks. These range from adverse genetic and ecological interactions between hatchery- and naturally-produced fish, to indirect effects such as over-harvest of natural-origin fish in mixed-stock fisheries. Together, these adverse effects form the basis of the concern that hatcheries pose a significant risk to the survival and recovery of ESA-listed ESUs.

Many of these same studies also point out that survival of hatchery-origin fish (often referred to as "fitness" of hatchery-origin fish) is significantly less than that of their wild fish counterparts. However, they are quick to suggest that fitness can be improved by modifying hatchery practices. Perhaps the most visible of the technical efforts to improve the performance of hatcheries is NMFS' program referred to as NATURES. As noted earlier, the NATURES approach to hatchery rearing involves the use of such features as natural substrates and structure in rearing ponds, natural food items introduced from below the water surface, and predator training to provide a more natural rearing experience for hatchery-reared salmon. The rationale for such an approach is intuitively sound, and several field trials suggest that NATURES-reared salmonids do in fact survive at a higher rate than salmonids reared using traditional hatchery approaches. The increased survival is most often associated with the period immediately after release from captivity, and is ascribed to better foraging skills and predator avoidance.

Although it is superficially attractive to think of hatchery-posed risks and hatchery reform as a match set, there is potentially a flaw in this assumption that is seldom addressed. If indeed an abundance of hatchery-origin fish is the source of considerable risk to wild populations, then the goal of increasing fitness and producing more hatchery fish is counter productive to the survival of the wild population. That is not to say that hatchery reform to mitigate or avoid the ecological and genetic interaction problems wouldn't improve hatchery fish survival, but it is to say that simply improving the survival of hatchery-origin fish is perhaps moving in the wrong direction. Hence one of the more daunting critical uncertainties is whether hatcheries can develop rearing and release practices that effectively eliminate adverse interactions. For all practical purposes this means a hatchery population that does not compete with natural populations in the freshwater and estuarine environment and returns with high fidelity to their hatchery of origin.

Several additional critical issues are addressed in the following sections.

5.1 Timing of Hatchery Releases

Timing of hatchery-origin salmon releases and release location in the Green/Duwamish watershed are key factors influencing spatial and temporal overlap between hatchery- and natural-origin salmon, and are key factors to consider when evaluating potential adverse effects of hatchery releases on juvenile Chinook and other salmon. Key potential adverse effects of hatchery releases on natural-origin juvenile salmon include competition for space and prey resources and predation by hatchery-origin salmon on natural-origin salmon. Competition and predation, which can have a substantial effect on salmon abundance and productivity, are discussed in Sections 5.2 and 5.5.

Release timing of salmon and steelhead are shown for each species, life history stage and release location in Table 5. For comparative purposes, capture rates of natural-origin subyearling Chinook salmon in the Middle and Lower Green River, Duwamish Estuary, and marine nearshore habitats during 2003 are shown in Figure 2. Most subyearling Chinook salmon (approximately 3.2 million fish, mostly marked) are released from the Soos Creek Hatchery between mid-May and early June. These fish are released at a relatively large size in order to reduce rearing time in the river and estuary, and thereby reduce potential interactions with wild salmon (Fuss et al. 1993). Timing of release varies from year to year depending on growth of the fish and observations of fish behavior in the rearing facilities (Wilson, personal communication, 2003). For example, in 2002, the release of most subyearling Chinook salmon was delayed until early June because rearing water temperature was relatively cold and growth was somewhat slow. The release of subyearling Chinook salmon during mid-May to early June is after the peak migration of fry (February and March) from the Middle to Lower Green River, but it corresponds with the period of relatively high abundance of natural-origin fingerling Chinook salmon in the Lower Green River and Duwamish Estuary.

Table 5
Release Timing and Location of Major Hatchery Production Facilities in WRIA 9

Species	Age	Release Location	Release Period	Forced/Volitional	Agency
Chinook	Subyearling	Soos Cr	Mid May - Early June	Forced	WDFW
	Subyearling	Above H. Hanson Dam	Late March	Forced	MIT
	Yearling	Icy Cr	Begin early April	Volitional	WDFW
Coho	Subyearling	Above H. Hanson Dam	Late April	Forced	MIT
	Yearling	Soos Cr	3rd week April	Forced	WDFW
	Yearling	Crisp Cr	Late April-Early May	?	MIT
	Yearling	Elliott Bay	Mid June	Forced	MIT
		(HSRG indicates 300,000 fry planted at Soos Cr, but no recent records of this)			
Chum	Subyearling	Keta Cr	Early March -Early April	Forced	MIT
Winter Steelhead	Yearling	Soos Cr	Late April - Mid May		WDFW
	Yearling	Palmer	Late April - Mid May		WDFW
	Yearling	Icy Cr	Late April - Mid May		WDFW
	Yearling	Flaming Geyser	Late April - Mid May		WDFW
	Yearling (native)	Keta Cr	Late April - Mid May		MIT
	Subyearling	Green R tribs	Spring		MIT
Summer Steelhead	Yearling	Soos Cr	Late April - Mid May		WDFW
	Yearling	Palmer	Late April - Mid May		WDFW
	Yearling	Icy Cr	Late April - Mid May		WDFW
	Yearling	Flaming Geyser	Late April - Mid May		WDFW

Data source: HSRG 2003, M. Wilson (WDFW) and D. Moore (Muckleshoot Indian Tribe) personal communication with G. Ruggerone.

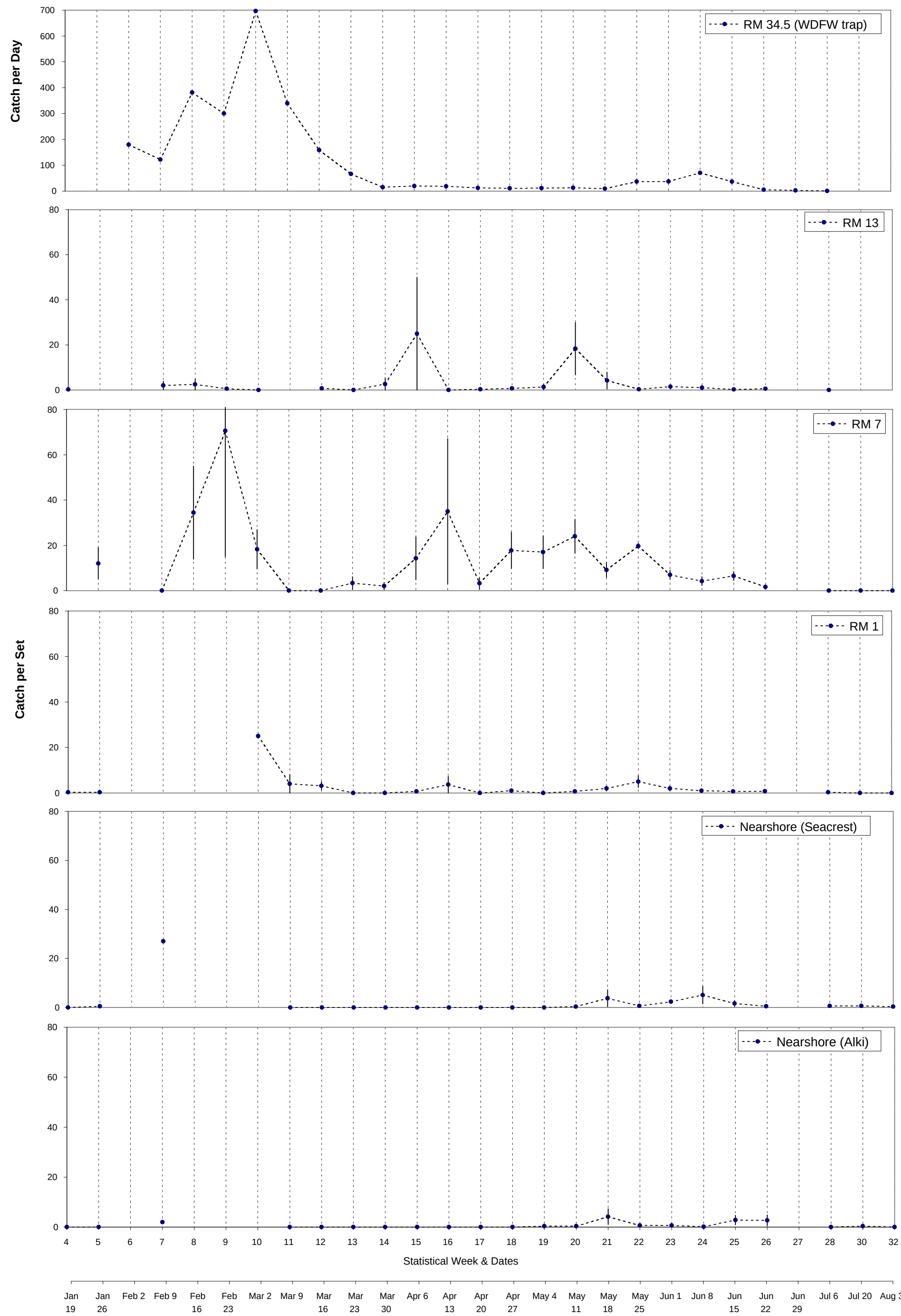

Figure 2
Time of Abundance of Natural-origin Chinook Salmon by Sampling Location in the Duwamish/Green River Watershed During 2003
Source: Nelson et al. 2004

Approximately 400,000 Chinook salmon fry (mostly marked) are also released by the Muckleshoot Indian Tribe upstream of Howard Hanson Dam. No natural salmon production currently occurs in this area, so no interaction occurs with natural salmon during the release period. Although juvenile salmon passage facilities have yet to be constructed in Howard Hanson Dam, small numbers of these Chinook salmon fry apparently escape through the dam and have been captured at the WDFW screw trap near RM 34 (Nelson et al. 2004). Additional hatchery-origin fish move through Howard Hanson Dam during late fall and winter when the dam is operated as a run-of-the-river facility, but numbers of migrating fish have not been documented (Hickey, personal communication, 2004). These fish are much larger than fry and fingerlings released into the watershed during spring. Thus, these fish may have the potential to consume emerging Chinook fry if they are present in the Middle Green River during early January through April. No information on their abundance in the Middle and Lower Green River is available, but Nelson et al. (2004) indicates catches of yearling Chinook and coho salmon were typically low at RM 13 and downstream sites.

Approximately 300,000 yearling Chinook salmon are volitionally released from Icy Creek ponds (RM 48.5) as early as early April. However, in recent years yearlings are released volitionally on May 1, then forced out of the ponds by May 15 (Antipa, personal communication, 2004). These releases occur above spawning areas of many Green River Chinook salmon, thus some yearling have the potential to consume juvenile Chinook salmon.

Approximately 2 million chum salmon fry are released from Keta Creek Hatchery during early March through early April. The Keta Creek release location is within the Middle Green River near RM 40. Numerous Chinook salmon emerge from redds within this area and downstream to approximately RM 25 (Cropp, personal communication, 2004). The timing of chum salmon release occurs within the period of peak emergence and migration of natural-origin Chinook salmon fry, which is February through March (Nelson et al. 2004). Thus, hatchery-origin chum fry will interact with natural-origin Chinook salmon.

Approximately 800,000 hatchery-origin yearling coho salmon are released into the watershed, along with 400,000 yearlings released into Elliott Bay, and another 500,000 fry released above Howard Hanson Dam. Yearling coho are released from Soos Creek and Crisp Creek Hatcheries from late April through early May. These yearling releases occur before the coho are ready to smolt because the rearing facilities are inadequate to hold the fish during high water events and many fish would be lost during a flood (HSRG 2003). Thus, yearling coho rear in the watershed and interact (see predation below) with subyearling Chinook salmon. While the duration of interaction is likely short, no data are available on residence time of yearling coho salmon. Yearling coho are also released from net pens into Elliott Bay during mid-June, a time period when Chinook salmon are relatively abundant in nearshore marine areas (Nelson et al. 2004).

Coho fry are released above Howard Hanson Dam during late April. Like Chinook salmon planted above the dam, some of these coho likely migrate into the Middle Green River during spring, fall, and winter. These fish have the potential to interact with natural-origin Chinook salmon for months. Most coho fry and yearlings released by the Muckleshoot Indian Tribe do not receive an adipose fin clip and cannot be visually distinguished from natural-origin coho salmon.

Approximately 200,000 yearling winter steelhead, 100,000 yearling summer steelhead, 33,000 native-spawned yearling steelhead, and 60,000 subyearling steelhead are released into the Green River watershed each year. Yearling steelhead are released from several Middle Green River locations, including Palmer ponds at RM 56, Icy Creek ponds, Flaming Geyser at RM 45, Soos Creek Hatchery, and Keta Creek Hatchery. Yearling steelhead are released from late April through mid-May, a time period when most fingerling migrants are still present in the Middle Green River (Nelson et al. 2004). A previous program that released winter steelhead fry upstream of Howard Hanson Dam was ended in 1998.

5.2 Juvenile Rearing Capacity in Freshwater, Estuarine, and Nearshore Habitats

All populations experience increasing mortality as abundance approaches the capacity of the habitat to support the population. Without density-dependent mortality, populations would have unlimited growth potential, an unrealistic scenario. Density-dependent mortality typically involves competition for resources and predation. The fact that populations cannot grow infinitely is shown by commonly applied Ricker or Beverton-Holt recruitment curves, which show that population growth rate decreases at higher abundances until the capacity is reached and growth rate is zero. In contrast, density-independent factors, such as high river flows that scour redds, sedimentation that kills embryos, and high temperatures or pollution that cause mortality, tend to keep populations at some level below the carrying capacity of the habitat.

If one assumes that abundance of juvenile Chinook salmon in the Green/Duwamish watershed can be described by a Ricker or Beverton-Holt recruitment curve, then it follows that the introduction of numerous hatchery-origin salmon will impact the population of natural-origin Chinook salmon. In other words, there is little question whether there is some impact of hatchery releases on natural-origin salmon. The key questions are therefore:

- To what extent are natural-origin Chinook salmon affected by hatchery-origin salmon releases?
- Are these impacts acceptable?

This section of the report will focus on the first question. The second question is one that managers and society must make based on available science and based on the answer to the first question.

The capacity of the Green/Duwamish watershed to support juvenile Chinook salmon is determined by the quantity and quality of habitat. Given the substantial loss of habitat and decline in habitat quality during the past century, the capacity of the watershed to support juvenile Chinook salmon has undoubtedly declined (see review by Kerwin and Nelson 2000). Some key factors affecting the loss of rearing habitat include:

1. Dams that block access to the upper watershed
2. Diversion of the Lake Washington and White River watersheds in the early 1900s
3. Flood control levees (and flow regulation) that limit side-channel and off-channel habitats in the Middle and Lower Green River
4. Industrialization that contributed to the loss of approximately 99 percent of estuarine habitat

Throughout the period of habitat loss, millions of hatchery-origin salmon and steelhead have been released annually into the watershed. Thus, the capacity of the Green/Duwamish River to support Chinook salmon has been influenced by both significant loss of habitat and releases of numerous hatchery-origin salmon that may compete for available resources.

The potential for adverse effects among salmon competing for resources is greater among conspecifics (intraspecific competition) than salmon of different species (interspecific competition) because niche overlap is greater among conspecifics. Ultimately, however, the effect of competition is related to abundance of the competing populations, including different species, and the abundance and quality of resource, which is in short supply.

As noted in Section 2, the HSRG (2004) and Flagg et al. (2000) reviewed potential impacts of competition between hatchery-origin and wild salmon. Relatively few studies of this important question have been conducted,[2] but these reports provide a few examples where wild salmon were displaced from preferred habitat by hatchery-origin salmon and growth of wild salmon was reduced. Although density-dependent growth has been documented in many freshwater and marine areas (where the research did not involve hatchery and wild fish interactions), the impact of reduced growth on survival and abundance has rarely been measured. However, recent publications indicate that competition can lead to significant reduction in survival and abundance of salmon (Levin et al. 2001; Ruggerone et al. 2003, Ruggerone and Goetz 2004).

There are several factors that may reduce the potential for hatchery and wild competition. First, hatchery-origin salmon may differ from wild salmon somewhat in their preferences for prey or habitat (Flagg et al. 2000). Second, in recent years, fish have been intentionally released from hatcheries at the smolt stage so that they rear less in fresh and estuarine waters and have less opportunity to compete for resources. This strategy has been employed in the Green/Duwamish watershed in the past decade (Fuss et al. 1993), except for yearling coho releases below the dams and releases of Chinook and coho fry above the dams.

There are no data to quantitatively evaluate competition in the Middle and Lower Green River where numerous fry, fingerling, and yearling Chinook, chum, coho, and steelhead are released. Releases of subyearling Chinook salmon from the Soos Creek Hatchery likely have the greatest potential for competition with natural-origin Chinook salmon in the Lower Green River (and Duwamish Estuary) because hatchery-origin Chinook are

[2] For example, the Independent Scientific Advisory Board (2001) noted that the NMFS Federal Columbia River Power System Biological Opinion (December 21, 2000) concluded that they were unable to assess the impacts of hatchery releases on wild populations because of insufficient monitoring and evaluation.

abundant, similar in size, and are released at a time when natural-origin fish are relatively abundant in the Lower Green River. In fact, new research suggests competition may adversely affect Chinook salmon in the Duwamish Estuary and in Puget Sound. The text below reviews recent findings involving the effects of competition on Green/Duwamish Chinook salmon.

Nelson et al. (2004) evaluated the potential effect of hatchery-origin Chinook salmon releases on the growth of natural-origin Chinook salmon sampled in the Duwamish Estuary (RM 0 to 7). They reported that hatchery-origin Chinook salmon were released during the period of high abundance of natural-origin Chinook salmon in the Duwamish Estuary (i.e., late May through early June). Hatchery- and natural-origin Chinook salmon were captured together in all habitats sampled. Prior to the release of subyearling hatchery-origin Chinook salmon, daily growth of natural-origin Chinook salmon was relatively high (0.54 mm, or 0.86 percent per day during April through mid-May) (Figure 1). During the release period (late May to mid-June), growth declined 76 percent to only 0.13 mm per day (0.17 percent). Following the sharp decline in abundance of hatchery-origin Chinook salmon in mid-June, daily growth of natural-origin Chinook salmon increased to 0.44 mm (0.52 percent per day), corresponding to a 230 percent increase in growth rate compared with the previous 3 weeks when hatchery-origin fish were abundant. Growth of hatchery-origin Chinook salmon was also relatively low during this period, indicating growth of both natural and hatchery natural Chinook salmon was influenced by the high abundance of hatchery-origin salmon. Diet data collected in 2003 has yet to be analyzed.

In 2002, growth of natural-origin Chinook salmon appeared to be reduced during the period of high hatchery-origin Chinook abundance, but less frequent sampling during 2002 made interpretation of this finding less certain (Nelson et al. 2004). Growth of natural-origin Chinook salmon in off-channel habitats of the Duwamish Estuary in 2002 declined sharply in early and late June, suggesting that the release of hatchery-origin Chinook salmon may have reduced growth of natural-origin Chinook salmon (Goetz and Ruggerone, unpublished data). Diet data has yet to be analyzed.

High abundances of hatchery-origin Chinook salmon and other salmonids might potentially displace natural-origin Chinook salmon from key rearing habitats. The release of approximately 3 million hatchery-origin Chinook salmon from Soos Creek Hatchery led to exceptionally high densities of hatchery-origin salmon throughout the Lower Green River and Duwamish Estuary during late May and June. During the peak migration, beach seine catches of hatchery-origin Chinook salmon represented approximately 80 percent of the total fish catch at RM 13 and RM 6.5, 91 percent of the catch near Kellogg Island (RM 1), and approximately 80 to 90 percent of the catch in nearshore marine areas. The high percentage of hatchery-origin fish occurred during a period when natural-origin Chinook salmon were initially relatively abundant in the Lower Green River and Duwamish Estuary.

To examine whether hatchery-origin Chinook salmon and chum salmon displaced natural-origin Chinook salmon from habitats in the Duwamish Estuary, Nelson et al. (2004) examined the percentage of natural-origin Chinook salmon occupying preferred habitat (RM 6.5) compared with less preferred habitats (RM 1 and RM 13) before, during, and after the period of high salmon abundance. High salmon abundance in these areas was initially due to the presence of numerous chum fry, followed by the immigration of numerous hatchery-origin Chinook salmon. Prior to May, which is the period of high fish abundance at RM 6.5, catches of natural-origin Chinook salmon at RM 6.5 represented 92 percent of the total natural-origin Chinook catch at the three index sites. During the period of high salmon abundance (May 11 through June 7), catches of natural-origin Chinook salmon at RM 6.5 declined to 65 percent of the total natural-origin Chinook catch at all three index sites. After the period of high abundance, catches of natural-origin Chinook salmon at RM 6.5 compared to the other index sites increased to 77 percent, on average. The decline in the percentage of natural-origin Chinook salmon at RM 6.5 relative to other areas during the 4 week period might have been a response to the limited habitat capacity of this small area, leading to dispersal of natural-origin Chinook salmon to other areas. Although these observations suggested natural-origin Chinook salmon may have been displaced from a key habitat, the authors noted that other factors may have influenced salmon distribution in 2003; therefore, additional sampling is needed before concluding that hatchery-origin Chinook and chum salmon displaced natural-origin Chinook salmon from key habitats.

Off-channel habitats in the Duwamish Estuary were sampled to evaluate fish abundance, residence time, and displacement of natural-origin salmon by hatchery-origin salmon during April 2 to July 10, 2003 (Ruggerone and Jeanes 2004). Residence time in the off-channel habitats after mark and release averaged 1 day for natural-origin and 0.5 day for hatchery-origin subyearling Chinook salmon. However, residence time of natural-origin Chinook salmon declined from 1.6 days prior to the release of 3 million hatchery-origin subyearlings in late May to 0.1 day after the release (most fish left their habitat and did not return during the next high tide), suggesting that hatchery-origin salmon may have displaced natural-origin Chinook salmon from the off-channel habitats. Growth rate of natural-origin Chinook salmon declined 60 percent immediately following the release of hatchery-origin Chinook salmon, then returned to typical levels in early June.

Recent research suggests that natural-origin Chinook salmon growth may be influenced by a reduction in prey consumption and displacement from habitat by hatchery-origin Chinook salmon. The recent research findings from the Duwamish Estuary suggest that natural-origin Chinook salmon in the Duwamish Estuary were unable to maintain relatively high growth rates when approximately 3 million hatchery-origin Chinook salmon were released into the watershed. A review of Chinook growth rates in estuaries (see Nelson et al. 2004) indicated Green River Chinook were intermediate among the wide range in growth rates, except when growth was exceptionally low during the hatchery release period. The period of competition was somewhat brief (approximately 3 weeks) because hatchery-origin fish appeared to migrate through the estuary somewhat rapidly. (Residence time averaged 17 days for hatchery-origin Chinook salmon captured near the Duwamish confluence with Elliott Bay in late May to June, increasing to 22 days in early July, then to 46 days in September, 2003 [Ruggerone and Volk 2004]). However, hatchery-origin Chinook salmon inhabit the Duwamish Estuary during the period of peak abundance of natural-origin fingerling Chinook salmon. The effect of reduced growth on survival and abundance of natural-origin Chinook salmon has not been quantified, but the following study involving growth and survival of CWT Chinook salmon provides evidence of significant mortality associated with reduced growth. As noted below, high growth in freshwater and estuarine habitats may help compensate for low growth and high mortality in marine waters, especially during years of poor ocean conditions, such as the late 1970s to 1990s.

HSRG (2004) and Flagg et al. (2000) provide little or no information on potential competition between hatchery-origin and wild salmonids in marine environments. However, a number of researchers have documented density-dependent growth in the ocean, leading to concern that the capacity of the ocean to support both wild and hatchery-origin salmon populations may have been exceeded (Pearcy et al. 1999). Until recently, there was little direct evidence that competition can lead to significant mortality at sea (Ruggerone et al. 2003, Ruggerone and Goetz 2004).

Consideration of potential competition between hatchery- and natural-origin Chinook salmon in nearshore areas of Puget Sound requires information on total numbers of salmon released into Puget Sound because Green River Chinook salmon rapidly disperse throughout much of Puget Sound (Nelson et al. 2004, Brennan et al. 2004). Approximately 173 million salmon and steelhead were released per year into Puget Sound watersheds (all life stages) from 1980 to 1993 (Ruggerone et al. 1995). Average annual release per species was:

- 66 million Chinook
- 38 million coho
- 66 million chum (includes egg boxes)
- 2.3 million pink
- 0.7 million steelhead

The abundance of juvenile hatchery-origin salmon and steelhead likely exceeds the abundance of naturally-produced salmon entering Puget Sound, indicating high potential for competition in the marine environment. Data collected in nearshore waters of WRIA 9 in 2003 indicated that hatchery-origin Chinook salmon represented up to 80 to 90 percent of total Chinook salmon during late May and early June, a time period when many natural-origin Chinook were entering Puget Sound (Nelson et al. 2004).

No studies are available that directly examine competition between hatchery-origin salmon and natural-origin salmon in the nearshore marine areas of Puget Sound. However, Ruggerone and Goetz (2004) evaluated the growth and survival of 53 million CWT Chinook salmon released into Puget Sound and adjacent waters in an effort to evaluate potential competition with pink salmon, which are only abundant as juveniles during even-numbered years (i.e., experimental control). From 1984 to 1997, a period of relatively low prey production in the marine environment, juvenile Chinook salmon released during even-numbered years experienced 59 percent lower survival than those released during odd-numbered years, a trend consistent among 13 Chinook salmon stocks including Green River Chinook salmon. Lower even-numbered-year survival of Chinook salmon was associated with reduced first-year growth and survival, and delayed maturation. Additional analyses indicated the interaction occurred within Puget Sound and the lower Strait of Georgia during the first growing season. The alternating-year mortality accounted for most of the 50 percent decline in marine survival of CWT Chinook salmon between 1972 and 1983 and 1984 and 1997. Although most of the pink salmon entering Puget Sound are wild, this study has implications for hatcheries because intraspecific competition can have greater effects than interspecific competition, especially if conspecifics are abundant. This study demonstrated that competition was most severe during the recent period of relatively low ocean productivity. Presumably, effects of competition in marine waters could be reduced by enhancing or maintaining high growth rates in freshwater and estuarine habitats.

5.3 Operation of Hatchery as Genetically Segregated or Integrated

Hatcheries can be classified a number of different ways, but one of the most informative is based on management of broodstock. Although Berejikian and Ford (2004) employed four categories, the HSRG (2004) divided Western Washington hatcheries into two groups: those in which broodstock was managed as genetically integrated, and those in which broodstock was managed as genetically segregated. As defined by the HSRG (2004), a hatchery program is of an integrated type "if the intent is for the natural environment to drive the adaptation of a composite population of fish that spawns both in the hatchery and the wild." In an integrated program, broodstock would be collected from natural- and hatchery-produced adults. In contrast, the goal of a segregated hatchery program is to "propagate the hatchery broodstock as a discrete population or gene pool that is reproductively segregated from naturally-spawning populations." In a segregated program, broodstock would be collected only from hatchery-origin adults and every effort would be made to minimize straying of hatchery-origin adults onto the natural spawning grounds.

Although establishing program goals and then managing broodstock one of these ways seems logical, there is a fundamental biological reality that must be taken into account—hatchery-origin fish are not the same as wild fish. Fish reared in hatcheries survive at extremely high rates (often greater than 90 percent egg-to-smolt survival) because they are protected from the natural selective forces normally encounter by juveniles in the wild. As a result, hatchery-origin fish adapt genetically to the conditions of the hatchery. This process is termed domestication. In contrast, fish spawned in the wild survive at a markedly lower rate (typically less than 5 percent egg-to-smolt survival) and are subject to an array of natural selective pressures. When compared with wild stocks, hatchery-reared salmon typically have lower adult-to-adult reproductive success when breeding in the wild (see Campton 1995 for a review). Because many of the traits associated with domestication are determined genetically, allowing domesticated salmon to interbreed with naturally-reproducing salmon will reduce the fitness of the integrated (mixed hatchery and natural) population.

This seemingly straightforward description of domestication and its effects on natural stock fitness (when hatchery and natural stocks interbreed) is also not as simple as it seems. The degree of domestication selection for a given hatchery population depends on the number of generations that the population has been in the hatchery and the strength of the domestication selection. If a hatchery has been operated using segregated broodstock management for many generations and is then shifted to integrated broodstock management, the negative effect on the productivity and viability of a naturally-spawning population would be expected to be profound (Bisson et al. 2002). However, the effects on natural populations of programs, such as those operating in the Green/Duwamish watershed, in which broodstock management has regularly incorporated adults from naturally spawning parents, as well as the release of returning hatchery-origin fish to spawn naturally, are difficult to predict. Although these integrated broodstock protocols are expected to cause less domestication than long-operating segregated programs, they do not eliminate it. The questions then become, what is the "right" proportion of returning adults from natural parents to bring into the hatchery each year? And, what proportion of returning hatchery-origin fish should be released to spawn naturally with a goal of minimizing domestication? The HSRG made the generic recommendation of 10 to 20 percent naturally-spawned fish into hatchery broodstock each year; however, this proportion is hard to evaluate unless one knows the history of those naturally-spawned fish and their degree of domestication and genetic divergence from the hatchery population. In the case of the Green/Duwamish watershed where the hatchery- and naturally-spawning fall Chinook are genetically indistinguishable, this may be a moot question.

Although there is likely to be considerable uncertainty surrounding decisions on broodstock management for many years to come, the fisheries managers making the decisions should be clear on the advantages and limitations of each management option. In the case of the Green/Duwamish watershed, where Soos Creek Hatchery has been mixing and matching natural and hatchery broodstocks for many years, and the hatchery has consistently met production goals and contributed to harvest opportunity, it is hard to argue for change. If, however, the Green/Duwamish watershed population of Chinook is expected to contribute to the recovery of Puget Sound Chinook, then hatchery broodstock represents a major uncertainty that will need to be carefully evaluated.

5.4 Straying of Hatchery Chinook Salmon to Spawning Grounds

Straying and spawning of adult hatchery-origin Chinook in the Green/Duwamish watershed is an important issue because:

1. Hatchery operations have inevitably altered the genetic make-up of the hatchery-origin fish
2. Interbreeding with natural-origin fish will therefore alter the genetic make-up of the natural population
3. Hatchery-origin salmon spawning in the wild may have lower reproductive success compared with wild fish
4. Genetically-based locally-adapted traits of a population may be altered by interbreeding
5. The presence of hatchery-origin fish on the spawning grounds confounds evaluation of productivity and abundance of wild salmon

When evaluating the percentage of hatchery-origin salmon on the spawning grounds that might be acceptable, a group of scientists gathered by NMFS concluded that there was no justification for allowing even 5 percent of the spawners to be hatchery-origin fish (Grant 1997). Grant noted that interbreeding between different populations will alter the genetic make-up of the population, but the effect of this change on the productivity and abundance of the population is very difficult to measure.

Hatchery-origin Chinook salmon in the Green/Duwamish watershed were derived from Green River Chinook salmon, suggesting that the genetic make-up of the hatchery stock was not significantly altered compared to what might have occurred if the hatcheries used non-local broodstocks. Recent estimates indicate approximately 42 percent[3] of the adult broodstock at the Soos Creek Hatchery are of natural origin (HSRG 2003). Use of natural-origin fish in the hatchery program probably helps minimize potential effects of domestication caused by hatchery operations because the natural-origin fish represent fish that were exposed to natural selective pressures, and successfully returned to spawn. However, although hatchery practices attempt to minimize domestication, there is undoubtedly some alteration in the genetic make-up because the hatchery-origin fish are not allowed to choose their mates, select appropriate spawning gravels, experience mortality associated with in-river redds, and experience competition or predation while rearing as juveniles in hatchery raceways. Allozyme data from Newaukum Creek Chinook salmon indicates that they are genetically similar to Soos Creek Hatchery salmon, probably due to the high stray rates and interbreeding as noted below. No genetic data are available for mainstem Chinook salmon, but presumably they are genetically similar to Soos Creek Hatchery Chinook salmon, given the high stray rates and use of natural-origin fish for broodstock.

Scientists and managers do not know the effects of hatchery straying on the productivity and abundance of wild Green River Chinook salmon. However, analysis of timing of return indicates the date at which 50 percent of hatchery-origin Chinook salmon returned to the Soos Creek Hatchery advanced from October 20 in 1944 to October 5 in 1965 (Weitkamp and Ruggerone 2000). Spawn timing is an important trait because it determines timing of emergence. In pristine watersheds, spawn and emergence timing have evolved to produce fry that have greater probability of finding prey and surviving; alteration of the timing between emergence and prey availability might reduce growth and survival of juvenile Chinook salmon. Alternatively, if spawn timing of natural-origin Chinook salmon has not shifted earlier, then stray hatchery-origin adults may displace some later arriving natural-origin spawners to suboptimal habitats. No observations have been made between hatchery- and natural-origin Chinook salmon on Green River spawning areas.

Recent mass-marking of Chinook salmon and analysis of CWT Chinook by WDFW provide data on hatchery-origin fish straying to the spawning grounds. HSRG (2004) reported that

[3] Tom Cropp of WDFW reported this value to be 34 percent based on different years.

59.6 percent of the Chinook salmon spawning in the mainstem Green River were hatchery-origin from 1989 to 1999. Of these, 37.3 percent were from Soos Creek Hatchery (range: 0 to 67 percent), 18.7 percent were from Icy Creek ponds (range: 0 to 100 percent), and 3.6 percent were from non-local hatcheries. In Newaukum Creek, the proportion of natural spawners comprised of hatchery-origin salmon was 46.7 percent, averaging 28.8 percent from Soos Creek Hatchery and 17.9 percent from Icy Creek ponds.

The above straying data indicates fish released from Icy Creek ponds have a relatively high stray rate. On average, Icy Creek Chinook salmon strayed four times more frequently to the mainstem and five times more frequently to Newaukum Creek compared with Soos Creek Hatchery fish. The reason for the high stray rate by Icy Creek salmon is straightforward. Until 2003, Icy Creek ponds did not have a facility to collect returning hatchery-origin fish; therefore, essentially all returning Icy Creek adults spawned in the river. In response to a HSRG (2003) recommendation, WDFW built and tested an adult collection trap in Icy Creek during 2003 in an attempt to remove hatchery-origin Chinook salmon. In 2003, all 37 Chinook salmon trapped at the facility were hatchery-origin fish (adipose fin clip, no CWT), whereas none of the 23 coho salmon were known hatchery-origin fish (i.e., no fin clip or CWT, but many juvenile coho salmon were released without a mark or tag) (Antipa, personal communication, 2004). Thus, only a small percentage of hatchery-origin salmon returning to the spawning grounds were recovered in the trap. No scales or otoliths were collected, so Icy Creek-origin fish could not be identified. WDFW plans to operate the trap again in 2004. In 2003, WDFW also searched for a location to establish a trap in Newaukum Creek, but logistical problems and lack of funding prohibited operation of a trap on Newaukum Creek in 2003 (and subsequent years).

As part of the updated status review of Chinook populations, NMFS (2003, 2005) examined annual population growth trends of Green River Chinook salmon. This analysis was based on trends of natural spawners and combined natural and hatchery spawners on the spawning grounds. The population trends analysis did not include harvests of Chinook salmon; therefore, production of the total population was not possible. Lambda (λ) was the metric used in the analysis. When only natural-origin Chinook were utilized in the analysis, the annual population growth rate (λ) was 1.023 (a 2 percent growth rate per year), indicating a relatively stable spawning population. However, when hatchery strays were included and assumed to have reproductive success equal to natural spawners, the annual population growth rate of the natural populations declined to 0.698, indicating a precipitous decline in the natural population. This estimate reflects the high percentage of hatchery spawners on the spawning grounds. This rate of decline was considerably lower than any other Chinook population in Puget Sound. NMFS noted that the actual population growth rate is likely between the two extreme-case estimates shown above.

A key factor contributing to the great numbers of hatchery-origin Chinook salmon on the spawning grounds is the inability of sport, commercial, and Indian fishermen to harvest surplus hatchery-origin Chinook salmon. From 1997 to 2003, there have been approximately 9,026 surplus hatchery-origin fish entering the Green River each year, composed of approximately 5,726 hatchery-origin fish returning to the river, and approximately 3,300 hatchery-origin fish returning to the hatchery. This value (9,026 hatchery-origin fish) is derived from independent stock composition estimates indicating the percentage of hatchery-origin fish returning to the hatchery and to river spawning areas are both approximately 60 percent (e.g., 60 percent of 9,543 river fish is 5,726; 60 percent of 5,500 Soos Creek Hatchery fish is 3,300 fish) (Cropp, personal communication, 2004). The estimated escapement to the river spawning areas is based on the official WDFW methodology as of 2003; escapement counts based on a mark-recapture study during 2000 through 2002 indicated that the official methodology under-estimated escapements to the spawning grounds. Thus, the estimated surplus of hatchery-origin Chinook salmon calculated here is likely low.

The inability of fishermen to capture surplus hatchery-origin salmon returning to the Green River stems from management decisions to ensure adequate spawning escapement of natural-origin salmon. Harvests restrictions are made in the terminal areas (Elliott Bay and Duwamish Estuary) because current commercial harvest methods (gillnets) kill all captured salmon. If live-capture gear was employed, as recommended by NMFS in other regions, then unmarked natural-origin salmon could be live-released and more marked hatchery-origin fish could be harvested. The selective fishery approach could lead to much more efficient use of hatchery-origin fish, greater harvests, reduced straying of hatchery-origin fish to the spawning grounds, and potentially greater escapements of natural-origin Chinook salmon.

5.5 Predation by Hatchery Salmon on Natural-Origin Salmon

In pristine watersheds, predation is often a major source of mortality for juvenile salmonids after emergence (Ruggerone and Rogers 1992); therefore, concern has been expressed regarding predation by hatchery-origin salmon on wild salmon (HSRG 2000, Riley et al. 2003). Predation by hatchery-origin salmonids on natural-origin salmon fry depends on the size and abundance of predators and prey, the functional and numerical responses of the predators[4], and the amount of time that predators and prey overlap in their distributions. Considering the widespread and long-term use of production hatcheries, relatively few studies have quantified predation rates by hatchery-origin salmonids (Riley et al. 2003). Some studies have reported exceptionally high predation rates; for example, millions of natural-origin Chinook salmon fry were reportedly consumed by hatchery-origin Chinook and steelhead in the Feather River, California, based on somewhat small sample sizes (Sholes and Hallock as cited in Riley et al. 2003). However, predation rates typically appear to be much lower. For example, late-release hatchery-origin steelhead smolts did not appear to consume sockeye fry in the Cedar River, whereas natural-origin steelhead readily consumed sockeye fry (Beauchamp 1995). Recent sampling by WDFW indicated migrating hatchery-origin coho and steelhead smolts consumed chum fry in Washington rivers but no quantitative estimates were made (Riley et al. 2003).

A key factor influencing potential predation by hatchery-origin salmon and natural-origin salmon is the predator and prey size ratio. Field and laboratory studies indicate piscivorous salmon can consume salmon prey up to 50 percent of their body length, but most salmon consumed are typically much smaller (Ruggerone 1989, Keeley and Grant 2001). Studies show that piscivorous salmon are limited in their ability to capture larger salmon and that large numbers of salmon are typically consumed when fry (less than 40 mm) are available.

In the Green River, approximately 3.2 million subyearling hatchery-origin salmon are released each spring, but these fish would consume very few, if any, natural-origin Chinook salmon. Subyearling hatchery-origin Chinook salmon are only slightly larger (3 mm during mid-May 2003) than natural-origin Chinook salmon when they are released in late May and

[4]Functional response is the relationship between prey consumed per predator per unit time in relation to prey abundance. Numerical response is the change in predator abundance in relation to prey abundance.

early June (Nelson et al. 2004) and they would be unable to consume natural-origin Chinook salmon.

Yearling coho (approximately 115 to 140 mm), steelhead (approximately 180 to 240 mm) and Chinook salmon (~150-180 mm) are large enough to consume natural-origin Chinook salmon. These fish are released into the Middle Green River during late April and early May when natural-origin subyearling Chinook salmon are approximately 46.0 ± 4.2 mm to 60.7 ± 9.3 mm (Nelson et al. 2004)[5]. Seiler et al. (2002) estimated predation rates of Chinook yearlings, coho smolts, steelheads smolts and parr, and sculpin collected from the RM 34 screw trap in 2000 (Table 6). Although hatchery-origin versus wild predators were not identified, most of these fish were likely hatchery-origin. On average, yearling Chinook (only eight fish sampled) consumed 0.38 salmonids, steelhead smolts consumed 0.80 salmonids, coho smolts consumed 0.52 salmonids, and trout parr consumed 0.78 salmonids per fish. Only steelhead smolts consumed Chinook salmon (0.14 Chinook per steelhead). In contrast, sculpins consumed, on average, 10.1 salmonids per sculpin, of which 9 percent were Chinook salmon (0.9 Chinook per sculpin). The high predation rates by sculpin were believed to be related to predation on juvenile salmonids within the trap live tank. Predation by smolts and yearlings was also likely biased high because they may have consumed salmon fry while in the live tank. On average, 80 percent of the salmonids consumed by the salmonids were chum fry, which were vulnerable to predation because of their small size.

[5] Mean ± standard deviation at RM 34 screw trap during 2002. Cold water led to relatively slow growth and small fork lengths in 2002.

Table 6
Fish Prey Found in Stomach Samples of Fish Captured in the RM 34 Screw Trap, 2000

Prey	Chinook Yearling	Coho Smolt	Steelhead Smolt	Trout Parr	Cutthroat	Sculpin
# Predators Sampled	8	50	44	45	6	63
Chinook	0	0	6	0	0	34
Chum	2	16	23	7	1	297
Coho	0	0	1	1	0	5
Trout	0	0	0	0	0	4
Pink	0	0	3	4	0	28
Unid. Salmon	1	10	2	23	1	262
Lamprey	0	0	0	0	0	7
Sucker fry	0	0	0	0	0	1
Dace	0	0	0	0	0	1
Salmonids/predator	0.38	0.52	0.80	0.78	0.33	10.00
Chinook/predator (adjusted for U.I. Salmonids)	0.00	0.00	0.14	0.00	0.00	0.92

Source: Seiler et al. 2002

Relatively few yearling salmon and steelhead were captured during regular sampling in the Lower Green River and Duwamish Estuary in 2002 and 2003 (Nelson et al. 2004). Low capture rates probably reflect rapid movement of these fish through these habitats. Some diet information was collected in 2003, though analyses have not been completed. Very few natural-origin Chinook salmon were consumed by yearling Chinook and coho salmon in the lower river and estuary (Nelson, personal communication, 2004).

HSRG (2004) recommended a study of predation by hatchery-origin yearling Chinook salmon at the RM 34 screw trap. Salmon and steelhead smolts were sampled in 2003 and 2004. Preliminary analyses indicate very low predation rates by yearling hatchery- and natural-origin Chinook, coho, and steelhead on juvenile salmon (Topping, personal communication, 2004). Only 10 salmonids (mostly chum fry) were observed in the stomachs of 1,636 salmon and steelhead collected in the trap during 2003 and 2004. Low predation rates in 2003 and 2004 were consistent with observations in 2000.

Although the amount of sampling of hatchery-origin yearlings and smolts in the Green River is low, available data suggests predation is likely low. Natural-origin Chinook salmon are relatively large (46.0 ± 4.2 mm to 60.7 ± 9.3 mm) when yearling salmonids are released in late April to early May. Chinook salmon at these sizes are much less vulnerable to piscivorous fishes compared with smaller fish (e.g., 30 mm chum fry). Upon release, most yearling salmon and steelhead appear to migrate rapidly through the watershed and into Puget Sound. In 2003, no yearling Chinook were observed after June 1 and no yearling coho were observed after June 30 (Nelson et al. 2004). HSRG has suggested a later release date for yearling coho because they are presently released before the complete onset of smoltification, which may lead to longer residence time in the river. Observations in other watersheds suggest yearlings rapidly move through the watershed after release (Riley et al. 2003).

Feeding behavior of hatchery-origin smolts also influences predation rates. Hatchery-origin fish are entrained on pellets and have no experience at capturing natural prey, such as natural-origin Chinook salmon that will attempt to avoid predators. It is likely that few natural-origin Chinook salmon are consumed because hatchery-origin yearlings are likely less aggressive when first released (their capture success rate is likely very low) and because they spend relatively little time in the river.

Chinook and coho fry are released upstream of Howard Hanson Dam during early spring. These fish have the potential to consume natural-origin Chinook fry if they migrate down river. However, sampling by WDFW at the dam indicated almost no downstream migration when the reservoir is storing water from approximately April through fall (Seiler, personal communication, 2004). During late fall and winter, the dam is operated for flood control and small numbers of salmon move through the dam to the Green River below. No data are presently available to evaluate predation by these fish, although some of the large salmonids captured by Nelson et al. 2004 during late winter and early spring may have originated from above Howard Hanson Dam.

Relatively little research on predation by hatchery-origin salmon on natural-origin salmon has been conducted in Puget Sound. Yearling Chinook and coho salmon can be highly piscivorous. Brennan et al. (2004) sampled juvenile salmonids along nearshore marine areas of King County and found very little predation by yearling coho and Chinook salmon (hatchery- and natural-origin) on other salmonid during April to December. Most Chinook salmon entering marine waters during peak migration in late May and June are large enough to avoid predation by yearling Chinook and coho salmon. Predation may be potentially greater during January to March when some salmon fry, including Chinook, enter Puget Sound.

5.6 Reintroduction of Anadromous Salmonids into Upper Green River Watershed

Anadromous salmonid access into the Upper Green River watershed has been completely restricted since construction of the Tacoma Diversion Dam (RM 61) and Howard Hanson Dam (RM 64.5) were completed in 1913 and 1962, respectively. Since the construction of the Tacoma Headworks Dam, the only anadromous fish in the Upper Green River watershed have been hatchery-origin salmon and steelhead juveniles that have been planted since 1982[6]. Starting in 1992, upstream passage from the Tacoma Headworks Dam to the Howard Hanson Dam reservoir for returning steelhead adults was conducted in a pilot program by the Muckleshoot Indian Tribe, WDFW, City of Tacoma, and Trout Unlimited. This program has captured between seven and 133 adult steelhead annually and provided transport above Howard Hanson Dam for natural spawning (Kerwin and Nelson 2000).

Upstream and downstream fish passage facilities are being designed and constructed to allow fish passage around the Tacoma Headworks Dam and Howard Hanson Dam. Construction on the upstream fish passage facility at the Tacoma Headworks Dam has been completed and will be operational when the downstream migration facility has been completed. The facility includes a sorting facility and a water-to-water transfer system to load fish into tanker trucks for transporting above the Howard Hanson Dam reservoir. A downstream fish passage facility will be constructed at Howard Hanson Dam and is scheduled to be ready for the Spring 2007 outmigration season.

The upstream fish passage facility provides the opportunity to control which fish are allowed access to the upper watershed. The fisheries co-managers, WDFW, and the

[6] Kerwin and Nelson (2000) reported that between 2 million and 4 million juvenile salmon and steelhead have been annually planted above Howard Hanson Dam, but Dennis Moore of the Muckleshoot Indian Tribe Keta Creek Hatchery indicated that in recent years a total of only approximately 1 million Chinook and coho juveniles have been released (Moore, personal communication, 2004). Survival rates during juvenile salmonids downstream passage past Howard Hanson Dam is estimated to be between 5 and 25 percent (Dilley and Wunderlich 1992, 1993 as cited in Kerwin and Nelson [2000]); therefore, these upper watershed hatchery fish are unlikely to significantly contribute to adult returns to the river.

Muckleshoot Indian Tribe, are continuing discussions regarding which species will be transported above Howard Hanson Dam for natural-spawning fish and the role of hatchery-origin fish in the re-establishment of anadromous salmonid populations in the Upper Green River watershed. There are several uncertainties regarding the potential effects on the viability of the wild salmonid populations that may result from the inclusion of hatchery-origin fish in the upper watershed fish community. These uncertainties fall into two main lines of questioning:

1. What effects, if any, would the use of hatchery-origin fish in the upper watershed have on wild salmonid populations that re-colonize the upper watershed?
2. What effects, if any, would hatchery-origin fish from the upper watershed have on wild salmonid populations elsewhere in WRIA 9?

In considering first question, many of the negative interactions identified in the scientific literature reviewed above (Section 2) could potentially be issues in the upper watershed, including:

1. Spawning ground displacement of wild fish.
2. Genetic intermingling that may reduce fitness.
3. Increased competition for food and space.
4. Increased predation risk is possible if predator communities increase due to greater food supply, particularly near release point for juvenile fish transported below the Tacoma Headworks Dam.
5. The increased number of hatchery-origin fish may result in more widespread occurrence of disease in WRIA 9.

There are several possible beneficial effects that could also result from allowing hatchery-origin fish in the upper watershed, including:

1. Rapidly advance the re-colonization of a naturally-spawning population in the Upper Green River watershed, possibly through a short-term hatchery program (i.e., not indefinite).
2. Increase food production for wild fish through the added input of marine nutrients provided by the carcasses of returning hatchery-origin adults to the Upper Green River watershed.

3. Opportunity to re-establish salmon races (e.g., spring Chinook) or introduce bull trout in WRIA 9 that are associated with headwater areas.

The potential effects to wild fish elsewhere in WRIA 9 (Question 2) are related to the addition of greater numbers of hatchery-origin fish in WRIA 9. Therefore, the potential effects would be lessened if the hatchery inputs were not increasing the number of releases in the river, rather than changing the release points from the Lower Green River watershed to the Upper Green River watershed. The potential negative effects to wild fish elsewhere in WRIA 9 include:

1. The number of juvenile fish in the Green River and marine nearshore exceeds the carrying capacity.
2. The additional outmigration surge of hatchery-origin fish from the Upper Green River watershed negatively impacts the rearing activities of wild or natural fish.
3. The increased availability of juvenile salmon to support predatory fish increases the predator population size and in turn the predation risks to wild or natural fish in the rest of WRIA 9.
4. The straying of hatchery-origin adults that were originally released in the Upper Green River watershed negatively affects wild or natural fish in the rest of WRIA 9.
5. The increased number of hatchery-origin fish may result in more widespread occurrence of disease in WRIA 9.

The uncertainty surrounding these potential effects does not lead to a simple answer. In fact, if hatchery-origin fish are going to be part of the Upper Green River watershed fish community, then there are numerous possible management scenarios that need to be considered to determine the potential effect on wild populations.

6 RESEARCH PRIORITIES

There are numerous questions regarding hatchery/wild fish interactions that logically flow from the many technical reports we reviewed for this project, the critical uncertainties identified in Section 5, and the WRIA 9 Research Framework (Ruggerone et al. 2004). Some are generic in the sense that they are key uncertainties associated with virtually all hatchery programs that potentially interact with natural populations, and others are quite specific to interactions in the Green/Duwamish River. All of these questions will require considerable additional research. As is always the case in research, each answer will likely lead to multiple new questions, so this initial list should be viewed as a starting point and not as an all-inclusive list. The following section briefly summarizes some of the key questions and their rationale.

6.1 Evaluation of Fitness of Hatchery Fish Spawning Naturally

Although it is well known that hatchery-origin fish have a high propensity to stray and mix with naturally-produced fish on the spawning grounds, the degree to which they mate with natural-origin fish and the fitness of their progeny is not well known. The basis for these concerns can be either the inevitable domestication effects associated with genetic adaptation to the hatchery environment, or outbreeding depression associated with the use of out-of-basin hatchery broodstocks. The latter is a reduced fitness attributed to the break up of co-adapted genes. Either of these effects is highly undesirable.

There have been several studies that have directly or indirectly focused on inbreeding and outbreeding depression associated with salmonid hatchery programs, but few have adequately addressed the question. One particularly noteworthy shortcoming is the failure of studies to follow hybrids for the multiple generations often needed to detect reduced fitness (McGinnity et al. 2003 as cited in Myers et al. 2004). In addition, few studies have been conducted on ocean-type chinook salmon; most studies concerning fitness impacts on wild stocks due to hatchery straying have been conducted on coho and steelhead reared for at least 1 year in the hatchery environment (Berejikian and Ford 2004). It is likely that interbreeding among ocean-type natural and hatchery-origin salmon is less likely to alter phenotype and genotype compared with interbreeding of races that spend 1 year in the hatchery. Berejikian and Ford (2004) suggested that adverse interbreeding effects associated with stream-type hatchery- and natural-origin salmon can be considered a worst-case scenario for ocean-type salmon, such as Chinook in the Green River.

This question was not specifically addressed in the WRIA 9 Research Framework, but its importance was identified. Controlled experiments involving mate selection and reproductive success of hatchery-origin fish have been conducted elsewhere, but data tracing progeny back to the spawning grounds are not available. The difficulty in answering this question is why NMFS assumed that reproductive success of hatchery-origin strays was equal to that of natural-origin salmon.

6.2 Evaluate Predation on Subyearlings by Yearling Hatchery Salmon

Some coho and Chinook salmon planted above Howard Hanson Dam in the spring migrate through the dam beginning in fall when the dam is operated for flood control. While it is believed these fish likely consume relatively few Chinook fry in the Middle Green River, sampling is needed to confirm this belief.

6.3 Evaluate Hatchery-Wild Interactions in the Duwamish River Transition Zone

Preliminary observations (Nelson et al. 2004; Goetz and Ruggerone, unpublished data, Ruggerone and Jeanes 2004) suggest the release of 3.2 million subyearling hatchery-origin Chinook salmon annually into the Green/Duwamish River affects the diet, growth, and residence time of natural-origin Chinook salmon in key habitats (e.g., transition zone RM 5 to RM 6.5). Further investigation and confirmation of this preliminary observation would determine whether the capacity of key habitat was insufficient to support both natural- and hatchery-origin Chinook salmon.

One aspect of this investigation could involve manipulating release timing from the hatchery. Currently, WDFW releases subyearling Chinook salmon from Soos Creek Hatchery at a time when numerous natural-origin Chinook salmon are in the Lower Green River and Duwamish Estuary. It may not be possible to delay release of these fish for another 3 weeks when most natural-origin fish have migrated from the system, but it should be considered by management. Alternatively, management might consider releasing hatchery-origin Chinook salmon into net pens in Elliott Bay to allow some imprinting, rather than releasing fish into the river. The Muckleshoot Indian Tribe has implemented this approach with coho salmon, but many coho yearlings are still released into the river. Since fish held in net pens tend to stray more than hatchery-released salmon (Ruggerone 1997), caution should be exercised in considering this option.

6.4 Determine Adequacy of Spawning Habitat in the Green/Duwamish River

The question of whether the quantity of spawning habitat in the Green/Duwamish River is sufficient to support both natural spawners and hatchery strays remains unanswered. Although spawning density data (fish per mile) for the Green/Duwamish River are available from WDFW, these data have not been evaluated in the context of available high quality spawning habitat. In other words, what percentage of the natural population is spawning in less desirable habitat and, most importantly, to what extent is this related to hatchery salmon?

6.5 Develop an Accurate Estimate of Natural Recruitment

Previous efforts to accurately assess the status of naturally spawning population of Chinook salmon in the Green/Duwamish River have been problematic due to the inability to unambiguously distinguish returning adults that are the progeny of naturally-spawning adults versus those of hatchery origin. With the implementation of mass marking of hatchery-origin fish, new, accurate data are now available to estimate numbers of natural- and hatchery-origin Chinook salmon on the spawning grounds. Additionally, new data are available to re-estimate total spawning escapement since the mark-recapture study indicated the traditional spawner survey was underestimating spawner escapement. The stray salmon and new spawner survey data should be used to estimate hatchery-origin strays throughout the dataset, which began in 1968. A recruitment curve should be developed from these new data in order to describe the productivity and capacity of the watershed. This study differs from the mean population growth rate approach utilized by NMFS, in part, because it incorporates harvests and capacity of the watershed to support salmon.

6.6 Estimate Numbers of Marked Versus Unmarked Hatchery Salmon

WDFW currently estimates numbers of marked salmon several times a day as the fish move from the marking trailer to the pond. Nelson et al. (2004) and others (Higgins, personal communication, 2004) have noted that numbers of marked salmon do not seem to match catch ratios in the Lower Green River, Duwamish Estuary, and marine nearshore areas. These researchers were aware that approximately 200,000 unmarked CWT Chinook salmon were released. A more accurate method to estimate the proportion of salmon receiving a poor adipose fin clip would be to sample the ponds after all fish are marked and are randomly mixed in the pond prior to release. Fish weight and size should also be measured. This is more of a hatchery procedural change than research per se, but the resulting data and analyses would significantly improve our ability to investigate hatchery-wild fish interactions.

6.7 Investigate Ways to Improve Attractiveness of the Hatcheries to Returning Adults

Presently, numerous hatchery-origin fish escape to the river and spawn. Improved imprinting on hatchery cues during juvenile stages might reduce straying to natural spawning areas. Basic research is needed to implement this idea.

6.8 Evaluate the Feasibility of Non-lethal Harvest Techniques

One way to increase the proportion of naturally-spawned fish returning to the spawning grounds, increase harvest of hatchery-origin fish, and reduce hatchery straying is to employ non-lethal fishing technology in the Lower Green River and Duwamish Estuary. One example of such a method would be fish traps. Although outlawed since the 1935 (Washington State Initiative 77), fish traps offer several advantages over the more traditional lethal fisheries techniques.

7 RECOMMENDATIONS AND ALTERNATIVE MANAGEMENT ACTIONS

Any recommendations regarding alternative management regimes for the Green/Duwamish River and the WRIA 9 watershed planning area are highly dependent on the long-term goals for the watershed. Our review of existing literature, HGMPs, and most importantly, the HSRG recommendations reveal that the big picture questions about the role and goals of hatcheries given the wild fish conservation efforts in the Puget Sound ESU have yet to be answered (or posed). If, for the purposes of ESA delisting and recovery, NMFS requires that the Green/Duwamish River support a naturally reproducing, self sustaining population of fall Chinook salmon population, then one set of future conditions needs to be established and one type of artificial production strategy needs to be used. Compared to the current situation in the Green/Duwamish Rivers, such a future might include greatly minimized hatchery production, and lower abundance, greater life history diversity, and more spatially distributed spawning and rearing of natural-origin fish. Alternatively, if the long-term goal for the watershed is to maximize production and maintain high harvest opportunity, then the future hatchery management regime would probably be quite similar to the one in place today. This would include continued reliance on high levels of hatchery production and acceptance of the negative interactions between hatchery- and naturally-produced fish.

The choice between these two scenarios is not a scientific decision; nor is it a choice between one or the other. The fisheries goal for a watershed is a policy that should be made with the relevant science available to the decision-maker. One of the primary purposes of this project was to assemble much of this scientific evidence that describes hatchery-wild fish interactions, and make it readily available. However, the decision-maker must weigh many other social and economic factors when making a choice, including the need to provide the in-kind and in-place fishing opportunity required by tribal treaties. Efforts to balance these needs will often lead to the evolution of hatchery programs that attempt to meet multiple objectives. One example of such a program would be one with a stated purpose of harvest and conservation. Such a program might feature maximized hatchery production in support of harvest, and integrated broodstock management in support of conservation. Depending on the specific details of how the program is managed, the reduced fitness of naturally-spawning fish can be minimized—but it will never be eliminated.

Of all the hatchery experiments that remain to be conducted, none looms larger than a watershed-scale demonstration that hatchery and natural production can be sustainably integrated. Such an experiment would involve not only a spatial scale previously untested, but a rigorous statistical design and long-term follow up. Until such an experiment is conducted, the debate will continue.

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APPENDIX A

SUMMARY OF LITERATURE REVIEWED

Hatchery Surpluses in the Pacific Northwest

Bisson et al. (2002) published in North American Journal of Fisheries 27(12): 16-27

At the request of the National Marine Fisheries Service (NMFS), the Independent Scientific Advisory Board[7] (ISAB) "reviewed scientific literature to conclude whether it was biologically sound to permit hatchery-origin adult salmon to spawn in the wild in large numbers." Based on substantial, credible evidence of potentially deleterious effects on wild salmon from hatchery-origin adults spawning with them, the ISAB concluded that it is possible for more hatchery-reared salmon to return to spawn naturally than is biologically sound for the sustainability of wild populations. The ISAB found no peer-reviewed studies that demonstrated sustained increases in natural-origin juveniles or adult abundance from providing hatchery-origin adults the opportunity to spawn in the wild. Regarding the potential deleterious impacts of interbreeding between hatchery- and wild-origin salmon, the authors found convincing evidence that:

- Domestication selection can genetically alter hatchery populations in relatively few generations.
- Hatchery-reared adults returning from the ocean and spawning in the wild generally produce progeny that do not survive as well as progeny from adults of wild origin.
- There is persuasive indication (rather than convincing evidence) that interbreeding between hatchery-reared adults and wild fish can reduce the fitness of wild populations.

The authors reached these conclusions based on consideration of literature documenting three potentially negative interactions to the genetic structure of the wild populations due to spawning with hatchery-origin adults:

- **Domestic Selection**. Hatchery-reared salmon can have an altered genetic composition compared to wild populations in relatively few generations. This divergence would result from the different selective pressures for survival and growth in the hatchery compared to those encountered by wild fish. This domestication is determined to be unavoidable, but the deleterious impacts of hatchery rearing on survival in the wild can

[7] The ISAB was established by the Northwest Power Planning Council and NMFS to provide independent scientific advice and recommendations on issues related to regional fish and wildlife recovery programs under the Northwest Power Act and the Endangered Species Act. The ISAB is designed to foster a scientific approach to fish and wildlife recovery and ensure the use of sound scientific methods in the planning and implementation of research and recovery strategies related to these programs.

be minimized, such as through the Northwest Fisheries Science Center's Natural Rearing Enhancement System (NATURES)[8] rearing program.

- **Outbreeding Depression**. A decrease in fitness caused by the mating of too distantly-related parents, which results in a loss of local adaptation, is possible. This could occur as a result of two processes. First, there can be a reduction in the frequency of favorable alleles through a high number of hatchery-selected alleles swamping the wild-origin local allele adaptations. The authors offer the example that if there is a 10 percent difference in the fitness of the hatchery and wild alleles, then immigration rates for hatchery salmon of more than 10 percent will overwhelm natural selection. Second, different ancestral lineages (e.g., stocks, evolutionary significant units [ESUs]) that exhibit similar life history patterns are likely to do so using different combinations of genes. The disruption of these combinations through interbreeding can change the genetic composition of the offspring and reduce the fitness of the resulting population.
- **Reduced Effective Population Size (Inbreeding Depression)**. The use of a limited number of parents to produce a large percentage of the population's progeny can result in the reduction of fitness of progeny from too closely-related parents. This can result because the progeny are more often homozygous for deleterious recessive alleles than the progeny of more distantly-related parents. In this way, deleterious recessive genes that are natural, but infrequent due to the natural selection against them, are carried forward into the next generation. The result is that the deleterious recessive genes become more widespread and can reduce population fitness.

A Review of Salmon and Steelhead Supplementation

Independent Scientific Advisory Board (2003 available at http://www.nwcouncil.org/library/isab/isab2003-3.htm)

This report of the ISAB is a follow up to the hatchery surplus report cited above. It was completed in response to NMFS and Northwest Power Planning Council requests for the ISAB to consider the risks and benefits of hatchery supplementation to natural populations of salmon and steelhead, and whether natural and artificial production could be integrated to increase capacity and productivity of the combined population for the foreseeable future.

[8] NATURES is a NMFS research project focusing on developing salmon culture practices to enable hatcheries to produce wild-like salmonids with increased post-release survival.

Based on a thorough review of the literature, demographic modeling, and review of ongoing supplementation programs in the Columbia River Basin, the ISAB concluded the following:

- Supplementation can be expected to increase the number of salmonids spawning naturally in a target population, which in turn will provide a greater harvest opportunity than would be expected in the unsupplemented population.
- The increased abundance and productivity of the supplemented population will not likely persist once supplementation ceases.
- Supplementation reduces the fitness of the natural spawning component in an integrated population, and this reduction in fitness will persist in the natural spawning population for several generations after the supplementation ceases.
- Data required to rigorously analyze the performance of supplementation are not being collected. This failure makes it impossible to accurately judge the benefits to abundance, or the risks to natural spawning fitness.
- Although it is attractive as a framework for assessing the decisions about whether to proceed with a supplementation program, the necessary data population performance is seldom available to make a reasoned decision.

The ISAB followed up these conclusions with recommendations to proceed with great caution in the use of supplementation, establish clear performance standards and carefully monitor results, and establish explicit decision criteria for whether continue or halt supplementation.

A Review of Relative Fitness of Hatchery and Natural Salmon – Preliminary Review Draft

Berejikian and Ford, National Marine Fisheries Service, Northwest Fisheries Science Center. Preliminary Review Draft December 19, 2003

This white paper summarizes current information on the relative fitness of hatchery- and natural-origin Pacific salmon and steelhead and evaluates whether there are any general patterns relating the origin and history of hatchery stocks to their relative fitness. The goal was to provide narrower ranges of relative fitness values for hatchery fish in order to improve estimates of population growth rates (Lambda). The authors state that the results of their review "should not be used to make inferences about the long-term genetic or ecological effects of naturally spawning hatchery fish" because the findings may have little long-term effects on the natural population due to either environmental factors or because the fitness is so low that genetic introgression into the natural population does not occur.

A total of 18 studies on relative fitness of hatchery fish were reviewed. These studies were classified into four broad broodstock management scenarios:

1. **Non-local, Domesticated Hatchery Stocks**. This type of stock is characterized by at least two full generations of hatchery propagation and release of smolts into areas not inhabited by its founding population.
2. **Local, Natural-origin Hatchery Stocks**. The broodstock for this type of hatchery consists entirely or primarily of natural-origin fish in each generation, and the stock is released in the area in which the broodstock were collected.
3. **Local, Multi-generation Hatchery Stocks**. This type of stock is characterized as having been artificially propagated for at least two full generations and having smolts released within the same river system inhabited by the founding natural population. These stocks can contain varying mixtures of hatchery- and natural-origin fish into the hatchery broodstock each generation, and some may have received some transfers of genetic material from an out-of-basin stock. The WRIA 9 hatcheries fall into this category.
4. **Captive and Farmed Stocks**. These types of stocks are reared in captivity through the entire lifecycle. This broad category may include both local and non-local stocks. Captive stocks are typically founded annually from natural adults (intended to be released for natural spawning) and try to maintain genetic integrity and similarity to the founder population. Farmed stocks are intended to provide a marketable food product, intentionally domesticated, and are not intentionally released to the natural environment.

All of the studies identified for Scenarios 1 and 4 found evidence of highly reduced relative fitness for non-local, domesticated hatchery stocks, captive broodstocks, and farmed populations. The authors concluded that it is reasonable to assume that steelhead and coho stocks in these categories will have low (less than 35 percent) lifetime relative fitness in the wild compared to native, natural populations. That is, the survival rate of hatchery fish in these categories will be approximately one-third that of the native, natural populations. Based on the only study found addressing Scenario 2, the authors conclude that first generation, local hatchery steelhead stocks can have relatively high (greater than 90 percent) lifetime relative fitness in the wild compared to native, natural populations.

Results reported in the seven studies identified that investigated Scenario 3 hatchery practices were highly variable. In some cases the studies showed substantial reductions compared to natural fish, while in other cases there was either no reduction or even higher fitness than natural fish. Based on the three steelhead studies included in this group, the authors conclude that hatchery steelhead will have low relative lifetime fitness, similar to that reported for fish in Scenario 1. The authors found that for the other species studied, including Chinook salmon, there was generally greater relative fitness achieved than was found in the steelhead. However, the authors concluded that there was not enough information to characterize the relative fitness over the full life cycle and a broad range of relative fitness values may apply.

All of the studies reviewed studied salmon with life histories that involve more than one full year in freshwater. In the absence of data on species or life history forms that have a minimal freshwater life history phase, the authors suggest that the results found in the existing studies can be considered worst-case scenarios. However, for hatchery programs that artificially extend the freshwater rearing of hatchery fish (such as the full year rearing of ocean-type Chinook), the authors state that these hatchery fish "cannot be assumed to have minimally reduced relative fitness."

Ecological and Behavioral Impacts of Artificial Production Strategies on the Abundance of Wild Salmon Populations – A Review of Practices in the Pacific Northwest

Flagg, T.A. and nine authors (2000) National Marine Fisheries Service, Northwest Fisheries Science Center, NOAA Technical Memorandum NMFS-NWFSC-41

This report documents the major theoretical and observed ecological and behavioral impacts of salmonid hatchery production strategies on the abundance and trends of wild salmonid populations. A comparison of hatchery and wild salmon biology concludes that the artificial-culture environment conditions salmonids to respond to food, habitat, conspecifics, and predators differently than fish reared in natural environments. Present culture techniques also alter selection regimes, which may result in genetic divergence between hatchery and wild populations.

The impacts of hatchery-reared fish on wild fish are discussed in five sections addressing: 1) the effects on wild population abundance through a supplementation, 2) production strategy, 3) competition and predation, 4) fish health, and 5) migratory behavior. For supplementation projects[9], authors conclude the following.

- Supplementation can maintain populations until underlying causes of decline are corrected.
- The genetic impacts of supplementation can be minimized with appropriate broodstock collection, fertilization, and rearing protocols.
- Monitoring and evaluation of most older supplementation projects is inadequate. At least five major projects with appropriate monitoring and evaluation plans are underway in the Pacific Northwest. All are still in the supplementation period. The response of these populations in the post-supplementation period is unknown at this time.
- The fitness of artificially propagated fish used for supplementation can be improved with more appropriate rearing and release protocols. The use of conventional rearing protocols significantly reduces success.
- The use of out-of-basin stocks or highly domesticated hatchery stocks is highly undesirable.
- Because of the high variability of adult escapement estimates, 10 to 15 years of data (or more) is needed to determine if the population has increased or decreased. Alternative monitoring parameters are needed for estimating the impacts of supplementation.

Supplementation projects that emphasize production goals and strict adherence to size and time-of-release goals impose major selective pressures on the stock that may be very non-adaptive for fish that must spawn in the wild. The authors identify the following potential aspects for future hatchery supplementation operation to minimize the potential for deleterious interactions between hatchery- and natural-origin fish.

- Collect broodstock throughout the seasonal run and maintain resulting differences in size until release.
- Reduce rearing density to allow survival of slower growing fish. This might also require variation in feeding levels between different raceways.
- Utilize true volitional release and multi-year rearing cycles for some species of fish.
- Use surface water supplies to maintain normal growth patterns.

[9] Cuenco (1993) defines supplementation as “the stocking of fish into the natural habitat to increase the abundance of naturally-reproducing fish populations.”

- Use natural environment rearing components (NATURES), predation training, and exercise.
- Employ natural mate selection and natural incubation systems.
- Use natural substrates and reduced light levels in artificial incubation (if used).
- Modify production diets and utilize natural food items.

Intra-specific (same species) competition among salmonids occurs more often and with greater severity than inter-specific (different species) competition. For naturally- and hatchery-reared Chinook salmon and steelhead reared in freshwater, competition is most likely to occur when they share the same microhabitats and food items. There are several studies cited showing that the less hatchery fish share the habitat and dietary requirements of wild fish, the less likely the two forms are to compete. Thus the release of spring Chinook salmon fry into habitat with resident wild Chinook salmon has great potential for producing competition between the two rearing types. In contrast, the release of well imprinted and rapidly outmigrating spring Chinook salmon smolts from hatcheries that are geographically separate from wild fish rearing and spawning areas may generate very little competition between hatchery- and wild-reared salmon. Inter-specific competition between steelhead and Chinook salmon is believed to be minimized by the different age classes occupying different spring-summer microhabitats. The progressive movement of juveniles into high velocity water, coupled with different species-specific emergence times, minimizes inter-specific competition between the two species.

The following hatchery practices were identified to minimize the potential for competition between hatchery- and naturally-produced salmon:

- Release hatchery salmon as true smolts, which rapidly migrate downstream to the estuary and marine environment.
- Properly imprint hatchery fish to promote their return to their natal hatchery.
- Minimize spatial and temporal overlap of hatchery and wild salmon to minimize competition for rearing sites.
- Locate hatcheries away from natural spawning areas.

Predation on wild Chinook salmon by hatchery steelhead and Chinook has been well documented. In the Columbia and Snake Rivers, the range of impact on the prey populations may range from 0 percent to greater than 22 percent. In considering the dynamics of other predator populations, such as northern pike minnow, the potential for positive and negative impacts were recognized. A positive effect of the presence of hatchery fish is "predation buffering" in which the presence of hatchery fish reduces the likelihood of a wild fish being eaten. Alternatively, a negative effect could be the long-term increase in the predator population due to the presence of high numbers of hatchery fish. The authors suggest that potential effect of hatchery rearing and release strategies on the vulnerability of hatchery salmon to predation can be reduced by implementing improved rearing and release strategies. For rearing, semi-natural rearing techniques that improve cryptic coloration, anti-predator conditioning, and disease control can significantly reduce the vulnerability of hatchery fish to predation. Release strategies that may reduce vulnerability include releasing fish at night. Due to sparse information and the influence of multiple other factors, it is uncertain whether a single "pulse" release or "volitional" releases will most affect predation rates on hatchery salmon.

The authors found little evidence to suggest that disease transmission from hatchery fish to wild fish is routine. It was suggested for the Columbia River that hatchery supplementation projects be conducted in a manner consistent with the Salmon Disease Control Policy developed by the fisheries co-managers in 1992.

Potential migratory behavioral interaction between hatchery and wild fish includes a downstream schooling influence in which wild fish are swept downstream by large numbers of downstream migrant hatchery fish. There are no quantitative studies of the impacts of such behavior on Pacific salmon species

In examining competition, it was concluded that when using good hatchery rearing and release protocols designed to minimize the potential for competition by promoting the spatial and temporal separation of hatchery- and natural-origin salmon, no negative effects on natural fish are expected during the freshwater lifestages.

In summary, the authors found that there is not adequate information available to properly assess the potential effects of hatchery operations on wild stocks. Policies and procedures to integrate hatcheries with conservation and sustainability need to be developed.

Statewide Strategy to Recover Salmon – Extinction Is Not an Option

Washington State Joint Natural Resources Cabinet, September 21, 1999.

This document provides a brief summary of the historic use of hatcheries in Washington and establishes hatcheries as one of the human factors affecting salmon. The authors write that new management regimes that favor conservation and "employ adaptive management in the context of entire watersheds will ensure [that] hatcheries become part of the solution to salmon recovery."

Updated Action Plan for the Review of Pacific Salmon and Steelhead ESA Listings and Hatchery Policy

NMFS, February 11, 2002.

In response to the *Alsea Valley Alliance v. Evans* decision (Alsea decision), NMFS is reevaluating how it treats hatchery fish in Endangered Species Act (ESA) listing determinations. The Alsea decision ruled as illegal the NMFS policy of including a hatchery population in an ESU but then excluding it from protection under the ESA. Following the Alsea decision, NMFS received six petitions to delist 15 ESUs of Pacific salmon and steelhead. This document summarizes a Federal Register notice published on February 11, 2002 in which NMFS issued its determinations of whether to accept the petitions and reaffirmed its commitment to review its policy on the treatment of hatchery salmon populations in ESA status reviews and listing determinations. NMFS had originally planned to revise its hatchery policy by September 2002, and clearly articulate how hatchery fish will be considered in the evaluation of the risk of extinction of ESUs and in making subsequent listing determinations. However, subsequent schedule updates provided at the NMFS Northwest Regional Office website (http://www.nwr.noaa.gov/HatcheryListingPolicy/_AlseaResponse.html) explain that draft versions of the proposed policy and status reviews will be completed by March 2004 with final versions completed by March 2005. At the time of this report, a revised policy has not yet been released.

In a second promised clarification of policy, NMFS is also planning to issue guidelines for using hatchery populations to accelerate recovery, and strategies for operating hatcheries that, over the long term, would assure that artificial propagation of salmon stocks will not undermine recovery efforts under the ESA.

Note: On July 17, 2002, NMFS asked states and tribes to comment on a draft hatchery listing policy. This "draft predecisional ESA document" is available online but is not developed enough to distribute, release, or cite. Since the document is available online, information from the draft as well as from an accompanying Question and Answer document is included in this summary. The NMFS documents refer to the "considerably lower" hatchery smolt survival rates and mentions ongoing work to improve hatchery salmon survival rates after their release by using hatchery environments designed to simulate natural conditions (e.g., with overhead cover, woody debris, natural substrate, and predator avoidance training). In regards to whether artificial propagation can "contribute to naturally spawning self-sustaining salmonid populations over the long term," NMFS concludes that there is no substantial scientific information to demonstrate that Pacific salmon can be successfully sustained over the long term solely through artificial propagation.

The draft policy outlines the NMFS approach to delineating ESUs and making listing determinations; however, the approach also offers insight into those hatchery practices that NMFS considers beneficial or non-detrimental to the natural populations. In making listing determinations, NMFS proposes that the ESA requires that listing determinations are "based on whether an ESU is likely to be self-sustaining in their natural ecosystems." As part of the status review for identifying ESUs and their risks of extinction, NMFS proposes to include a determination of which hatchery populations are part of the ESU. NMFS "will consider a hatchery population as part of an ESU only if it is representative of the ecological and genetic diversity of the ESU, and if it has not diverged appreciably from the parent population." The following factors were identified as possible indicators of the hatchery population's divergence from the natural population:

- Size and age at return
- Spawning time
- Length of time the hatchery population has been isolated and the degree of domestication selection
- Degree to which natural broodstock has been regularly incorporated into the hatchery population
- History of incorporating non-ESU fish or eggs into the hatchery population
- Attention given to genetic considerations in selecting and mating broodstock
- Use of genetic engineering or cytological manipulation

In those ESUs where hatchery populations are present at the time of a listing determination, NMFS will consider whether an artificial propagation program within an ESU should be taken into account as being protective of the natural population based on the following factors:

- The extent to which the hatchery population(s) is representative of the range in behavior for the life history type(s) of concern in the ESU. For example, the range in run timing for a hatchery spring-run or fall-run population should be representative of the natural population, and not be indicative of substantial directional selection due to insufficient broodstock sampling or mating procedures.
- The artificial propagation program must: 1) act to preserve an ESU's genetic resources, or 2) demonstrate that it is benefiting and contributing to the abundance, productivity, distribution, and diversity of naturally-spawning fish in the ESU over the long term.
- Whether the hatchery is operated in a manner consistent with the best management practices (as specified in the NMFS guidance, in effect at the time of the listing decision). Such a hatchery will minimize risks to the naturally-spawning populations, as well to populations in any ESUs listed under the ESA.
- Whether there must be information demonstrating a high likelihood that the protective benefits of such efforts will be realized.
- Whether there are adequate monitoring, evaluation, and corrective procedures in place to assure that any adverse effects will be effectively detected, diagnosed, and remedied. Part of an effective monitoring and evaluation program is the inclusion of methods for discriminating between hatchery and natural fish in evaluating status and trends.

Subsequent schedule updates provided at the NMFS Northwest Regional Office website (http://www.nwr.noaa.gov/HatcheryListingPolicy/AlseaResponse.html) explain that draft versions of the proposed policy and status reviews will be in March 2004 with final versions ready by March 2005.