Appendix F

Ecological Interactions White Paper

Cumulative Impact of Hatchery Origin Fish on Natural Origin Fish in the Columbia River Estuary

The Importance of the Columbia River (CR) Estuary

There is a strong consensus that estuaries are important in terms of providing rearing habitat for growth, potential refuge from predation and a physiological transition before emigrating to the higher salinity in the marine environment (Quinn 2005, Thorpe 1994). Unfortunately, the Columbia River (CR) estuary has suffered a major loss of shallow water rearing habitat in the past century. This loss of habitat has been documented by Bottom et al. 2005 in their excellent treatment of the role of the CR estuary in the Decline and Recovery of Pacific Salmon in which they point out that the loss of wetland habitat since 1870 has been a major factor in the capacity of the estuary to support juvenile salmon. It is estimated that 77% of tidal marshes and 62% of swamps which existed before 1870 have been lost. The diking and filling of marshes and swamps have reduced the surface area by 20% (Bottom et al. 2005). These changes in the CR estuary in terms of habitat loss are likely to have the biggest impact on the capacity to support juvenile salmon: however, the impact of habitat loss in the CR estuary in terms of salmonid carrying capacity is unknown (Bottom et al 2005). More specifically, it has been established that subyearling Chinook and chum are species that use the CR estuary more than other species. Chinook are found in the estuary in every month of the year but were most abundant from May to September whereas chum fry are found in the estuary from March to June (Bottom et al. 1983, Dawley et al. 1986, McCabe et al. 1986). These two species, subyearling Chinook and chum salmon, show a preference for shallow water marsh and swamp habitat.

In Rich's pioneering work of Chinook life history patterns in the CR estuary, he determined from Chinook scales that 5 forms of Chinook life history types were common prior to 1920 (Rich 1920). These life history strategies are characterized by fall Chinook that are subyearlings and which emigrate to the estuary and to the ocean in their first year of life. Bottom et al 2005 has concluded that the Chinook life history diversity described by Rich 1920 has been simplified by habitat loss and has concentrated the remaining salmon into more limited and fragmented regions. The spring Chinook, steelhead and coho life history forms are characterized as stream type and emigrate to the estuary after one year in freshwater. These larger smolts were primarily found to be migrating in the thalweg of the CR in the deepwater channels, side channels and to a lesser extent in shallow water areas as contrasted with the subyearling ocean type habitat distribution behavior (Dawley 1986 et al., Schreck et al. 1995-1997, Schreck and Stahl 1998).

This use of the shallow water habitat in the estuary by fall Chinook is described by field studies in other Northwest estuaries and can be extrapolated to the CR. However, lack of research in the CR estuary in the tidal channel, sloughs, and marshes habitats presently limit the understanding of rearing requirements of CR fall Chinook salmon (Bottom et al. 2005). It is important to understand that the CR estuary has suffered anthropogenic impacts to the present day that are inhibiting the possibility that the historical life history patterns are able to evolve and thrive.

Given the impact of habitat loss in the estuary, the cumulative impact of hatchery origin fish (HOF) on natural origin fish (NOF) in the estuary is a significant scientific research uncertainty. The HSRG 2009, Bottom et al. 2005, Fresh et al. 2005, Naish 2008 and Kostow 2009 support this point.

The effect of (HOF) on listed (NOF) is a significant and important issue to the CR Basin. The effects of ecological interactions (competition, predation and disease transfer) of HOF on listed NOF represents a tradeoff of risks weighed against the economic benefits of harvesting hatchery fish. Research studies on ecological interactions have been conducted in freshwater but there is a paucity of information in the mainstem, estuary, and near shore marine environment in terms of the cumulative impact of large numbers of hatchery releases. This is relevant at the present time because of the concerns over the risks of using hatcheries to address the decline of listed stocks of salmon and steelhead in the Columbia River (Mitchell Act DEIS 2010).

Recently, the Columbia River Hatchery Reform System-Wide Report by the Hatchery Scientific Review Group 2009, the Review of Hatchery Science by the Recovery Implementation Science Team (RIST) 2009 and the Recommendations for Broad Scale Monitoring to Evaluate the Effects of Hatchery Supplementation on the Fitness of Natural Salmon by the Ad Hoc Supplementation Monitoring and Evaluation Workgroup 2008 have reviewed the genetic risks of hatcheries but did not address the risks from ecological interactions. This is because of large data gaps in research in the mainstem, estuary and the near-shore marine environments as contrasted to the number of studies in the freshwater environment.

It is an important perspective to understand that salmon and steelhead in a natural setting have evolved to avoid competing between species as this is a waste of energy resources. Natural selection pressures on these salmon populations have promoted a fascinating array of micro habitat partitioning and temporal differences to avoid competition for limiting resources of food and space (Quinn 2007, Naish et al. 2008). In other words, unique life history strategies have evolved to maximize food and spatial resources in order to maximize marine survival. Previous research in the Columbia River estuary by (Rich 1910) as reported in Bottom et al. 2005 has documented the rich variability found for Chinook salmon juveniles in terms of utilization of the estuary habitat. Seasonal seine hauls and trawl surveys have documented partitioning of the estuary habitat by salmon and steelhead both spatially and temporally. The use of the estuary varies by species, age and season. For example, chum salmon juveniles have evolved to utilize the estuary shallow water habitats of the estuary as they leave the freshwater streams. Chum salmon emigrate from the freshwater streams soon after emergence from the gravel and are essentially fry when they enter the estuary. As such they are potentially vulnerable to predation so they have evolved an earlier timing into the estuary during February through April. In the pristine state spatial and temporal overlap of species would be minimized in the estuary as mechanisms to avoid competition for food and space would have evolved. The contemporary landscape for the CR estuary is a sharp contrast to the pristine situation in terms of habitat simplicity and ecological impact (Bottom et al. 2005).

While information on the distribution of hatchery and natural origin smolts in the estuary is limited it can be summarized as large stream type yearling spring Chinook and steelhead and coho smolts are found in the main, deep water channels of the estuary while underyearling ocean type Chinook and chum are found in the shallow tidewater margins (Dawley et al. 1986, Bottom et al. 2005, McCabe 1986).

Competition

The general principle of competition is that it is the demand by two or more individuals of the same or different species for a resource that is actually or potentially limiting Larkin (1956).

Fresh (1997) points out that competition is a natural process in shaping the abundance of salmon and steelhead throughout their evolutionary history. Fresh (1997) goes on to state that these anadromous salmonids have evolved characteristics that minimize loss of fitness due to the effects of competition otherwise they would have been extinct. In the case of the CR estuary where wild salmon and hatchery salmon co-exist for a time, they may compete directly for limited resources of food and space through agonistic interactions as in interference competition, or by exploitative competition through depletion of food (Berejekian et al 2009).

The cumulative impact of multiple HOF on NOF is an uncertainty at the present time because ecological interactions are least studied in estuaries as compared to freshwater environments, and most studies have evaluated only the impact on single hatchery programs or single watersheds in freshwater (Pearsons 2008). Pearsons (2008) makes the point that exploitative competition may be important in estuary environments that experience large numbers of hatchery fish at different times. Supporting his point, Fresh (1997) states that competition generally is most likely to occur between hatchery and wild salmonids in the estuarine environments where food resources are limited and fish become concentrated on their way to the ocean. With respect to the CR estuary, Fresh (1997) states that to his knowledge estimates of the amount of food available does not exist even though studies cite dietary overlap as evidence of interspecific competition and because of that are not conclusive if food is not limiting. Moreover, because so little is known about salmonid behavior and ecology in the CR estuary between HOF and NOF salmon it is difficult to conclude that actual competition for limited resources is occurring (Flagg et al. 2000).

Based upon the knowledge gained from studies in freshwater it is documented that intraspecific competition is greater in magnitude than interspecific competition due to greater niche overlap within species than between. (Fraser 1969, Allee 1974, Bisson et al.1988, Lonzarich 1994, Flagg et al 2000, Hasegawa and Maekawa 2008). Fresh 1997 points out that interspecific competition is one mechanism used to partition scarce resources like habitat and food in streams (Hartman 1965, Glova 1986, Fausch and White 1986, Hearn 1987). Further, competition among sympatric (co-occuring) salmonid species is minimized by species specific differences in habitat preference (Hearn 1987, Bisson et al 1988, Dolloff and Reeves 1990.

An interesting study by Leven and Williams 2002 has found a negative effect of Snake River hatchery steelhead releases on wild Snake River Chinook salmon. In their paper the authors speculate that stress is a possible mechanism based upon the hatchery steelhead size dominance over wild Chinook when confined to barges which transport these two species below Bonneville dam. The stress was described in laboratory studies reported by Maule et al. 1996 and could make these Snake River wild spring-summer Chinook vulnerable to predation after release from the barges (Leven and Williams 2002). This is a possible working hypothesis that could be tested by further research and as Berejekian et al. 2009 suggest that updating this study with data collected since the original publication could improve the precision of the relationship and offer new insights.

As a conclusion to their recent review Berejekian et al. 2009 states that ecological interactions are regulated by habitat partitioning among species and species-specific estuary resident times. This is especially germane to the present discussion of the cumulative impact of hatchery origin salmon on natural origin salmon in the CR estuary.
Research which is summarized here has shown that stream type salmon, steelhead yearlings, yearling spring Chinook and yearling coho salmon smolts being larger and having greater swimming speed migrate as smolts in the deeper water main channel habitats and they past thorough the CR estuary more quickly than ocean type salmon, subyearling fall Chinook and chum salmon, which spend time rearing and tend to occupy shallow water habitats like peripheral bays, marshes and swamps.

Predation
Salmon and steelhead reside in estuaries and nearshore environments before moving in to off shore marine habitats (Healey 1980, Simenstad et al. 1982, McCabe et al 1986, Pearcy 1992). Among salmonid species estuarine residency can vary from days to months within different estuaries and between years based upon environmental conditions of temperature, stream flow, prey availability, and the physical characteristics of estuaries (HSRG 2004, Simenstad et al 1982). As contrasted with studies in freshwater there is little evidence that wild salmonids are preyed on by other salmonids in estuarine or nearshore environments (HSRG 2004). Intrageneric predation in the CR estuary was rare according to McCabe 1986. Generally, cutthroat trout and steelhead smolts were thought to be primary fish predators in estuaries (Emmett 1997, Simenstad et al. 1992, Fresh NOAA Fisheries NW Fisheries Science Center 2009, personal communication). Coho salmon smolts in the CR estuary were found with stomach contents almost entirely comprised of invertebrates and no salmonids as prey (Durkin 1982). Fresh (1997) indicates that much of the information on predation of hatchery fish on wild salmonids is circumstantial, for example, from analysis of fishery management databases. Fresh (1997) uses the example of the dramatic decline of Puget Sound chum salmon runs associated with coho salmon hatchery program initiation (Johnson 1973). In his analysis, Johnson concluded that hatchery coho were the cause of the sharp decline in wild chum salmon populations but it is possible that other factors such as degraded spawning habitat were responsible (Johnson 1973). Berejekian et al. (2009) pointed out literature that supports the predation saturation theory that predation may decrease in the prey population if the numbers of hatchery produced fish exceeds the capacity of predator population to consume additional prey (Peterman and Gatto 1978, Ruggerone and Rodgers 1984, Fresh and Schroder (1987).
On the other hand, increases in predator populations based upon long term hatchery production in the CR have resulted in an increase in Northern pike minnow populations and of avian predators such as Caspian terns (Kim et al 1986, Beamsderfer and Reiman 1991). The implication of these findings is that wild fish are potentially at risk in the CR estuary due to non salmonid and avian predators as well which are attracted to abundant hatchery fish.
The HSRG (2004) has concluded that within the estuarine environment that intrageneric predation of wild juvenile salmonids is not common but they acknowledge that this may reflect difficulties in sampling but also the limited number of studies compared to the freshwater environment. Moreover, they suggest that the relative risk of predation by hatchery fish may be low compared to more significant predation by marine fish.

Additionally, they state that they are unaware of research studies that have been designed to look for predation by hatchery reared salmonids in estuarine or nearshore habitats (HSRG 2004). Very recent research being conducted by NOAA Fisheries NW Fisheries Science Center in the CR estuary with regard to food habitats of HOF yearling Chinook and steelhead juveniles indicates that these species have either empty stomachs or if full have non-salmonid fish, insects or amphipods but not juvenile salmonids (Laurie Weitkamp, NOAA Fisheries NW Fisheries Science Center. 2009, personal communication).

Disease Transfer

A recent review by Naish et al 2008 concludes that there is little known about the risk of disease transfer from hatchery fish to wild fish. The concern is that hatchery fish could potentially amplify and transmit endemic disease pathogens to susceptible wild fish. At this time, this is a gap in knowledge and is an uncertain risk with regard to the CR estuary specifically. Other informative publications include an extensive review in Flagg et al 2000, Kostow 2009 and RIST 2009.

Analysis of the numbers of salmon smolts reaching the CR estuary

Based upon the previous discussion of research implications of the cumulative effect of HOF and NOF in the CR estuary it is illustrative to look at the relative proportion of HOF to NOF by ESU and species for all smolts entering the CR estuary (Table 1). This data has been summarized from the 2007 smolt emigration year and is an estimate of the number of smolts entering the CR estuary after river mortality has been taken into account. The data for HOF are actual release numbers from the 2007 release year. In contrast, the NOF numbers are estimates of the natural production of smolts derived from the AHA model which is habitat based and calculates the smolt production from population productivity and habitat capacity. As such, the numbers of NOF are derived from the model so the estimates may not accurately reflect the actual numbers of smolts emigrating from freshwater streams and entering the estuary in any given year.

Table 1 - Number of NOF and HOF Smolts Entering the Columbia River Estuary in 2007

ESU	Smolt Type	
	Natural	Hatchery
Columbia River Chum	4,957,380	299,923
Deschutes River Summer/Fall-run Chinook	588,375	- 0
Lower Columbia River Chinook	3,980,763	51,094,476
Lower Columbia River Coho	566,517	16,472,024
Lower Columbia River Steelhead	189,064	2,920,754
Middle Columbia River Spring-run Chinook	198,466	3,391,020
Middle Columbia River Steelhead	282,457	466,625
Snake River Basin Steelhead	371,216	4,510,839
Snake River Fall-run Chinook	95,179	1,566,741
Snake River Sockeye	2,163	51,581
Snake River Spring/Summer-run Chinook	395,252	4,241,739
Southwest Washington Steelhead	32,733	321,635

Upper Columbia Coho	195,541	2,967,394
Upper Columbia River Spring-run Chinook	120,309	1,690,940
Upper Columbia River Steelhead	111,382	405,533
Upper Columbia River Summer/Fall-run Chinook	4,953,016	11,459,932
Upper Willamette River Chinook	274,650	5,574,448
Upper Willamette River Steelhead	177,737	594,356
Wenatchee River Sockeye	328,990	86,801

Table 2 displays the number, percentage and species composition of HOF and NOF smolts that reach the CR estuary. The information in Table 2 estimates that 86% of the smolts reaching the estuary are of HOF versus 14% NOF. This data clearly shows that HOF are the majority of salmon smolts reaching the CR estuary under all alternatives.

Table 2 - Species Composition of HOF and NOF Smolts Reaching the Columbia River Estuary in 2007

	Species Composition	
	%	**Totals**
HOF TOTALS	86	108,116,762
NOF TOTALS	14	17,821,190
TOTALS		125,937,952
HOF		
Fall Chinook	52	56,263,555
Spring Chinook	20	21,582,092
Coho	18	19,439,418
Steelhead	9	9,219,742
Chum	1	299,923
NOF		
Fall Chinook	47	8,317,018
Spring Chinook	13	2,288,989
Coho	4	762,058
Steelhead	7	1,164,589
Chum	28	4,957,380

The data from Table 2 suggest that 52% of the HOF are Fall Chinook at roughly 56 million smolts as contrasted to the NOF model estimate which are 47% Fall Chinook at just over 8 million smolts. The estimated proportion of NOF, which are chum salmon fry is 28% or 4.9 million. Chum salmon smolt production in the CR estuary is estimated to be larger for NOF than HOF. The fact that fall Chinook HOF and chum NOF are so abundant represents a significant challenge as they reach the CR estuary because based upon the previous discussion of research findings the habitat these species are dependent on is the most impacted.

Table 3 - Intraspecific and Interspecific Interactions of HOF and NOF Smolts Reaching the Columbia River Estuary in 2007

Interaction Type	Density Metric
Hatchery Fall Chinook X Natural Fall Chinook	6.8
Hatchery Spring Chinook X Natural Fall Chinook	2.6
Hatchery Fall Chinook X Natural Chum	11.3
Hatchery Spring Chinook X Natural Chum	4.4
Hatchery Coho X Natural Fall Chinook	2.3
Hatchery Coho X Natural Chum	3.9
Hatchery Steelhead X Natural Fall Chinook	1.1
Hatchery Steelhead X Natural Chum	1.9
Hatchery Steelhead X Natural Steelhead	7.9
Hatchery Coho X Natural Coho	25.5
Hatchery Steelhead X Natural Spring Chinook	4.0
Hatchery Spring Chinook X Natural Spring Chinook	9.4

Table 3 displays the density ratio or metric for intraspecific and interspecific ecological interactions by species. This metric measures the number of HOF smolts to model estimates of the number of NOF smolts that reach the estuary. Calculating the density metric is a measure of quantifying the potential risk of competition and/or predation that might occur in the estuary. The nature of this impact (competition, predation and to a lesser extent disease transfer) is dependent on the species evaluated. For example, the ecological interaction literature discussed earlier suggests that intraspecific interactions are expected to produce higher risk of negative impacts from the point of view of competition for food or space in the estuary. Data from Table 3 indicates that 4 of the 5 highest densities are from intraspecific interactions of HOF on NOF from coho which is the highest (25.5) to Fall Chinook as the lowest (6.8). The exception to this is the interspecific interaction of HOF Spring Chinook on NOF chum which is high (11.3) and could be an indicator of the risk of predation since HOF spring chinook will be over 50% larger than NOF chum salmon in the estuary. If we interpret Table 3 from the point of view of competition risk we would focus on the intraspecific interactions of HOF on NOF. To reiterate, the highest densities were found for HOF coho on NOF coho. The literature from freshwater streams suggests HOF coho have significant advantages in competitive interactions over NOF coho such that NOF can be displaced from territories in streams. These impacts could translate to the CR estuary and underscore a cause for concern (Berejekian et al 1999, Flagg et al 1995, Nielson 1994, Nickelson 2003, Rhodes and Quinn 1999). The second highest densities for intraspecific interactions were for HOF Spring Chinook on NOF Spring Chinook (9.4). There is an indication in the literature of a negative relationship between Snake River HOF spring Chinook and NOF spring Chinook during poor climate years compared to average years suggesting when food is perhaps limited that competition is greater (Leven et al 2001). This research does not propose a causal mechanism but it does represent an elevated risk in terms of intraspecific interaction. In a similar manner, HOF steelhead on NOF steelhead (7.9) shows the third highest densities of all the species interactions. Kostow and Zhou 2006 and Kostow 2009 indicate the negative ecological impact of Clackamas, Oregon HOF steelhead on NOF steelhead as contrasted with Levin and Williams 2002 work which showed no relationship between Snake River HOF steelhead and NOF steelhead independent of climate conditions. The specific habitat and temporal overlap of these HOF and NOF is unknown and represents a data gap. Spring Chinook, coho and steelhead are all stream type fish and as the literature discussed earlier suggests they tend to migrate through the estuary more quickly than ocean type species and if the hatchery fish are true smolts, they should show a tendency to migrate out of the estuary. Very current data on food habitats of steelhead and yearling spring Chinook show no evidence of salmonid prey being eaten (Laurie Weitkamp, NOAA Fisheries, Northwest Fisheries Science Center. 2009, personal communication). On the other hand, densities of HOF fall Chinook on NOF fall Chinook are high (6.8) and can suggest an impact in terms of competition for food and space. This species exhibits an ocean type evolutionary strategy and research has shown that it has the longest estuarine residency of any species in the CR. As such, there is the real potential for the risk of ecological interaction in terms of competition; however, little data is available to confirm or deny. The other source of concern is the serious loss of shallow water habitat in the CR estuary and the fact that rearing habitat will be in short supply. The highest of the interspecific interactions is for HOF fall Chinook on NOF chum(11.3) which has the potential for competition and/or predation. Both of these species use the estuary extensively and potentially have similar shallow water habitat requirements. As such the higher density value represents a higher risk from the impact of ecological interactions. This data together with the spatial and temporal overlap of salmon smolts in the CR estuary is a method to evaluate risk and can be an approach to explore risk reducing strategies. A practical application of this approach would involve focusing on the highest densities and developing a hatchery release guideline to lower smolt numbers and spread out release times over the season in an effort to lower densities relative to NOF of the same species. Present hatchery release timing guidelines are a mixture of past experiments on size and time of release which were aimed at optimizing marine survival, physiological readiness to osmoregulate and avoidance of predation risk on NOF smolts but a strategy of sequencing the releases based upon near-shore prey abundance should be considered as optimizing early marine survival while ameliorating impacts of high densities of HOF to NOF in the estuary.

Conclusions

1. The significant habitat loss of shallow water habitat in the CR estuary has narrowed the fully functioning life history options of the historical subyearling fall Chinook phenotypes as well as chum salmon fry which depend on the estuary for rearing.
2. There is a pressing need for habitat restoration initiatives in the CR estuary. This is particularly critical since the most abundant HOF smolts being produced and the most abundant NOF smolts are subyearling fall Chinook.
3. Hatcheries are producing large numbers of yearling smolts with stream type life history strategies that tend to migrate quickly and occupy the deep water channels in the estuary.
4. HOF fall Chinook subyearlings probably rear in the estuary and could overlap

spatially and temporally with NOF fall Chinook and NOF chum and as such represent a higher risk for ecological interactions.

5. The risk of HOF coho as predators on chum fry could be higher if HOF coho are released from hatcheries too early so that they overlap temporally.
6. Intraspecific competition between HOF fall Chinook and NOF Fall Chinook can be a potential risk from the point of view of competition for food. This competition could compromise growth in NOF Fall Chinook such that it would take longer to reach a critical size threshold above which mortality from predation will be reduced.
7. Less available shallow water estuarine habitat will impact NOF ocean type species such as fall Chinook and chum and could increase density and therefore competition with HOF fall Chinook.
8. Conduct field research on the temporal and spatial habitat needs and food preferences of HOF and NOF species in the CR estuary.
9. Investigate the level of predation of HOF and NOF yearling stream type species such as, steelhead, spring Chinook, coho and cutthroat through studies of food habitats and habitat distribution.

Recommendations

1. Work with agencies and tribes to incorporate a system wide approach as is suggested by HSRG 2009 in their recommendation 11 generally, and more specifically, seek to minimize any negative ecological interactions associated with the cumulative impact of HOF on NOF in the CR estuary. HSRG recommends limiting the hatchery production to the minimum needed to meet the system wide harvest and conservation goals of the various managers taking into account the carrying capacity of the mainstem, estuary and ocean.
2. Implement HSRG 2009 recommendation 13 working with agencies and tribes to maximize survival of HOF consistent with conservation goals. Methods discussed essentially involve releasing quality smolts that are actively smolting so they will more rapidly emigrate from the CR estuary.
3. Evaluate innovative methods to spread out HOF releases so as to reduce densities of HOF to NOF in the CR estuary and time the releases so HOF potential predators enter the CR estuary after chum fry reach a critical minimum size.
4. Identify research priorities to address data gaps in knowledge for temporal and spatial habitats requirement of HOF and NOF in the CR estuary.
5. Implement the principle outlined in HSRG 2009 that states monitor, evaluate and adaptively manage hatchery program to become more effective in meeting goals for conservation and harvest. The application of this principle should be applied to critical research in the CR estuary that will define how to avoid the risk of negative cumulative impacts of HOF on NOF.
6. Conduct studies to evaluate the fate of released HOF and NOF smolts after release from smolt transportation barges below Bonneville Dam.
7. Conduct modeling exercises working with agencies and tribes to evaluate methods of spreading out the releases from hatcheries so as to reduce the high densities of HOF fall Chinook as they reach the CR estuary. This approach will allow the exploration of concepts to reduce the temporal overlap and thereby lower the risk of ecological interactions of HOF fall Chinook on NOF fall Chinook and chum salmon.

8. Conduct a series of one day expert panel workshops to identify critical research gaps in knowledge of freshwater, main stem, estuary and near shore marine habitats on ecological interactions that would provide additional guidance on development of recommendations for development of research designs.
9. Recommend modeling approaches where feasible to further quantify risk in freshwater, estuary and near-shore marine habitats both in terms of single hatchery impacts on single natural listed stocks, as well as, cumulative effects of hatchery stocks on natural listed stocks.

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