5. Limiting Factors and Threats

NMFS generally describes the reasons for a species' decline in terms of limiting factors and threats. NMFS defines limiting factors as the biological and physical conditions that limit a species' viability and defines threats as those human activities or natural processes that cause the limiting factors. We define threats as human activities or natural events that cause or contribute to limiting factors. Threats may exist in the present or be likely to occur in the future. While the term "threats" carries a negative connotation, it does not necessarily mean that activities identified as threats are inherently undesirable. They are typically legitimate and necessary human activities that may at times have unintended negative consequences on fish populations. These activities have the potential to also be managed in a manner that minimizes or eliminates the negative impacts. As described in Chapter 2, there have been many significant improvements in management activities that affect limiting factors and survival of Snake River fall Chinook since they were listed.

Snake River fall Chinook threats and limiting factors operate across all stages of the life cycle. While each of these factors independently affects the status of the ESU, they also have synergistic and cumulative effects throughout the ESU's life cycle. Achieving viability depends on the concerted effort of all factors working together, not cancelling each other out, and adjusting over time as the ESU's conditions change. Thus, designing effective recovery strategies and actions requires understanding limiting factors and threats collectively and also understanding the feasibility of managing activities to reduce negative impacts. Effective recovery also requires agility to adjust actions and priorities as new information on threats, both individually and synergistically, emerges.

Many human activities contributed to Snake River fall Chinook salmon's threatened status. NMFS status reviews (NMFS 1991, 1999, 2005; Busby 1999, Good et al. 2005) that led to the original listing decision and subsequent affirmations of threatened status cite loss of primary spawning and rearing areas upstream of the Hells Canyon Complex, effects of the FCRPS downstream of Hells Canyon through the estuary, increase in nonlocal hatchery contribution to adult escapement over Lower Granite Dam, and relatively high aggregate harvest impacts by ocean and in-river fisheries as the factors causing the steady and severe decline in abundance of Snake River fall Chinook (Good et al. 2005). The most recent status reviews (ICTRT 2010 and NMFS 2011) added concerns about the effects on natural population productivity and diversity from increasing proportions of hatchery-origin fish on the spawning grounds. [1]

[1] In NMFS five-year review of the Snake River fall Chinook salmon's status (NMFS 2010), we concluded that the species was at moderate risk of extinction. Combined abundance and productivity parameters received a moderate risk rating, however NMFS noted considerable uncertainty in both the abundance and productivity estimates due to the inability to discriminate between hatchery and naturally produced fish. The spatial structure parameter received a low risk rating due to the occupancy of at least four of the five major spawning areas. We rated the diversity parameter at moderate risk driven by changes in major life history patterns, shifts in phenotypic traits and high levels of genetic homogeneity in samples from natural-origin returns. In addition, NMFS noted the substantial selective pressure imposed by current hydropower operations and cumulative harvest impacts also contributing to the moderate risk rating.

NMFS typically organizes discussions of threats and limiting factors according to the four Hs, habitat, hydropower, harvest and hatcheries, which represent the types of threats. However, because Snake River fall Chinook spawn primarily in the mainstem river, in this case it is best to consider mainstem habitat and hydropower factors together. The following section is organized accordingly beginning with river reach overviews of hydropower and habitat limiting factors and threats followed by tributary habitat, harvest, hatcheries, predation, competition, toxics, and climate change.

5.1 Mainstem Snake and Columbia River Habitat Including Hydropower

The loss of habitat now inundated by reservoirs is extensive: Snake River fall Chinook salmon once spawned in the mainstem of the Snake River from its confluence with the Columbia River upstream to Shoshone Falls (RM 615). The spawning grounds between Huntington (RM 328) and Auger Falls (RM 607) were historically the most important for this species. Hydropower projects on the mainstem Snake River have inundated, or blocked access to, most of this area in the past century. Only limited spawning activity occurred downstream of RM 273, about one mile below the present location of Oxbow Dam (Waples et al. 1991).

The specific effects of hydro operations and other threats on mainstem Snake and Columbia River habitat are discussed according to river reach, beginning with the historical spawning and rearing habitat upstream of Hells Canyon Dam, through the lower mainstem Snake River to Lower Granite Dam, followed by the mainstem migration corridor through FCRPS reservoirs and dams on the Lower Snake and Columbia Rivers and finally through the estuary and plume.

5.1.1 Historical Mainstem Snake River Habitat Upstream of Hells Canyon Complex

Although reintroduction of a fall Chinook population above the Hells Canyon Complex would improve the probability of persistence of the ESU, the mainstem habitat upstream of the Hells Canyon Complex is presently too degraded to support anadromous fish. Water quality factors include altered thermal regime, excessive nutrients, and anoxic or hypoxic conditions. Other factors affecting the quality of this habitat include altered flows, inundated habitat, and interruption of geomorphological processes (entrapment of sediment). Substantial information on water quality upstream of the HCC is available in the Idaho Power Company's application to FERC for relicensing (IPC 2003).

Total Maximum Daily Loads (TMDLs) to improve water quality in the upstream mainstem are under negotiation, but these assume a time frame of 70 to 100 years to reduce pollutants. In its Comments and Preliminary Recommended Terms and Conditions for the Hells Canyon

Hydroelectric Project (NMFS 2006)[2], NMFS recommended additional funding to accelerate habitat restoration in the upstream mainstem. NMFS has not, however, used its fishway authority under section 18 of the Federal Power Act to require fish passage at any of Idaho Power Company's dams, first, because of the poor water quality in the Snake River upstream of the HCC, which would, at present, prevent the successful reintroduction of naturally producing fall Chinook, and second, because insufficient information is available to identify an alternative fish passage method for juveniles that has a high likelihood of success. NMFS recommended that future studies to inform decisions regarding fish passage be required as part of the new license conditions (NMFS 2006).

The following subsections review limiting factors and threats in the historically accessible mainstem upstream of the Hells Canyon complex in more detail.

5.1.1.1 Blocked Access/Inundated Areas

As described in Chapter 2 of this plan, the Hells Canyon Complex of dams and reservoirs blocks access to the historically most productive spawning areas of the Snake River, a total of 367mainstem river miles. The Hells Canyon Complex alone inundates 95 miles of historical fall Chinook habitat.

The impact of lost upstream habitat cannot be overstated. Historically accessible spawning areas were more productive than the current downstream areas, first, because of geomorphology; they contained more of the wide alluvial floodplains with unconsolidated sediment, bars and islands that are favorable to spawning (Dauble et al. 2003) than do the current areas of altered habitat. These areas may also have been more productive because of inflowing springs, such as Thousand Springs, near Hagerman, Idaho, which moderated seasonal water temperature changes. Compared to downstream reaches of the Snake River, winter temperatures in the reaches downstream of the Thousand Springs area are substantially warmer during the winter and cooler during summer, conditions that likely provided substantial survival benefits to pre-spawning adults, incubating eggs, fry, and rearing juveniles. This area is now altered by several hydroelectric projects (see Table 2-1 and Figure 2-2).

The remaining habitat below Hells Canyon Dam is less productive than either the historical Thousand Springs reach or the Marsing reach, both in terms of redd capacity and juvenile rearing capacity (Dauble et al. 2003). In addition, because fry likely emerged several weeks earlier in the upstream areas, their entire life history, including downstream migration, would have progressed earlier than observed in contemporary spawning areas, particularly compared to the lower Hells Canyon reach (NMFS 2006).

This effect is corroborated by the work of Krcma and Raleigh (1970) and Mains and Smith (1964) (cited in NMFS 2006). Krcma and Raleigh's (1970) data indicate that about 98 percent of

[2] FERC must consult with NMFS regarding the effects of the proposed license action on essential fish habitat (EFH), as required by the Magnuson-Stevens Fishery Conservation Act (MSA), and on listed species under the Endangered Species Act (ESA).

the Snake River fall Chinook juveniles reached parr size and started emigrating by the end of May (1962 and 1963). In comparison, today, only about 50 percent of the fish rearing in the lower Hells Canyon reach have reached parr size and started to emigrate by the end of May (Connor et al. 2002). Mains and Smith (1964) observed that downstream migration of subyearling fall Chinook salmon was largely completed at RM 82 by mid-June, compared to mid- to late July since 2002, a difference of 2 to 4 weeks. Fall Chinook salmon smolts migrating from historically accessible spawning areas would thus experience lower temperatures, higher turbidity (which reduces predation), and higher flows and thus, higher survival levels compared to subyearlings emigrating from contemporary spawning areas (Connor et al. 1998; Connor et al. 2003b; Smith et al. 2003) (cited in NMFS 2006).

5.1.1.2 Degraded Water Quality

Degraded water quality starts far upstream of the Hells Canyon reach, and even far upstream of Shoshone Falls, the upstream historical limit for anadromous fish. Development of the Snake River plain for irrigated and dryland agriculture, livestock grazing, confined animal-feeding operations (Buhidar et al. 1999), mining, timber harvest, and urban and residential settlements has been underway for two centuries. At the beginning of the 20th century, the Bureau of Reclamation began a series of public works projects to provide irrigation to Idaho farmlands on the Snake River plain. Five major dams were constructed as far upstream as Jackson Lake in Wyoming: Swan Falls Dam, 1901, Milner Dam, 1905, Minidoka Dam, 1906, Jackson Lake Dam, 1916, American Falls Dam 1927. Another phase of dam construction began in the 1950s.

Agricultural runoff into the Snake and its tributaries returns some of the irrigation water, which now carries additional pollutants from activities on land. For example, Milner Dam, upstream of Shoshone Falls, diverts most or all of the Snake River for agricultural irrigation. “A percentage of this diverted water then makes its way back to the Snake River through agricultural runoff or as spring flows that are supplemented by injection wells designed for that purpose” (Chandler et al. 2001). Habitat in this area is now “severely degraded, with high nutrient inputs and significantly reduced flows compared with predevelopment times” (Chandler et al. 2001.)In short, a host of anthropogenic factors have resulted in extremely large nutrient loads in the mainstem Snake River that result in nuisance algal growth and anoxic conditions (and toxic hydrogen sulfide) in the spawning gravels. These conditions would not support incubating fall Chinook salmon through emergence (Groves and Chandler 2005).

Currently, this segment of the Snake River, with associated tributaries, tops the Environmental Protection Agency’s (EPA) Section 303(d) list of impaired water for all Snake River segments (36 are listed). It is third in the state of all listed waters, following the Clearwater and St. Joe river basins. The major pollutants listed include total suspended solids, phosphorus, sediment, and nutrients (Chandler et al. 2001).

Although the Marsing Reach, from downstream of Swan Falls Dam to the town of Marsing, Idaho (RM 425), is still-free-flowing, it is in a segment of the river [from C.J. Strike to the Boise River] that has also been classified as water quality limited and is on the 303(d) list for sediment, nutrients, pH, bacteria, DO levels, and flow alterations (Chandler et al. 2001).

High concentrations of organic matter, along with chlorophyll *a* and nutrients, contributed by upstream tributaries into the Snake River and accumulated in sediment in low-flow years (Myers et al. 2003), create eutrophic conditions in Brownlee Reservoir. Snake River chlorophyll *a* concentrations measured at the headwaters of Brownlee Reservoir can be five times higher than concentrations measured 120 miles upstream at Swan Falls Dam (Worth 1994). The nutrient loads, primarily phosphorous and nitrogen compounds, fuel the explosive growth of algae (both attached and free-floating) in the Snake River. The nutrients and algae settle out in the transition zone of Brownlee Reservoir where they are biologically processed (oxidized). The biological processing of these large quantities of algae results in increasingly hypoxic (low oxygen) conditions within the lower strata of Brownlee Reservoir (NMFS 2006, Myers et al. 2003). Hypoxic waters are eventually drawn into the turbines at Brownlee Dam in the late summer and fall and exported downstream through the other two projects. Dissolved oxygen levels in Oxbow and Hells Canyon reservoirs usually are approximately the same as in Brownlee (Myers et al. 2003). The effects of these conditions downstream of Hells Canyon Dam are discussed in Section 5.1.2.1.

High flows or, more rarely, lack of electrical demand, causes water to be released over the spillway bays at the three Hells Canyon Complex dams. Spilled water entrains atmospheric gases into the water column, resulting in supersaturated levels of total dissolved gases (TDG). The effect of elevated TDG levels downstream of Hells Canyon Dam are discussed in Section 5.1.2.1.

5.1.1.3 Altered Flows

Flows are significantly altered by agricultural irrigation. However, historically, low summer flows were probably not an issue in historical habitat because (as cited earlier), the juveniles had already migrated out of the system by mid-June. Flows are also altered by hydroelectric power plants operations on which can dramatically alter river flows as a result of load-following. Outflows could fluctuate dramatically on a daily basis. If anadromous fish were present, excessive load-following operations could potentially dewater redds and strand or entrap juveniles in shallow water areas.

5.1.1.4 Summary of threats and limiting factors in historical habitat above Hells Canyon Complex (if fish were there)

Threat: Hydropower projects.
Related limiting factors: Fish passage, blocked and inundated habitat, total dissolved gas levels below Brownlee.
Threat: Reservoirs.
Related limiting factors: reduced velocities.

Threat: Load-following.
Related limiting factors: Potential stranding and entrapment of juveniles.

Threat(s): Land uses that alter river habitat: irrigated and dryland agriculture, livestock grazing, confined animal-feeding operations, mining, timber harvest, and urban and residential settlements
Related limiting factors: excessive nutrients, sedimentation, toxic pollutants, low dissolved oxygen in water and spawning gravels, altered flows and elevated total dissolved gas levels (?) is this at Brownlee? Not a result of land use?

5.1.2 Mainstem Snake River Habitat from below Hells Canyon Dam to Mouth of Salmon River (Hells Canyon Reach)

The Upper Mainstem Snake River reach (RM 247 to 188) includes the Snake River from below Hells Canyon Dam to immediately upstream of the Salmon River inflow. Here the river is rapid flowing and narrow, characterized by high, steep canyon walls and stretches of white water. The flow and volume of this reach is dominated by the outflow of the Hells Canyon Complex (HCC) reservoirs, especially Brownlee reservoir. Long-term fluctuations in flow have altered riparian vegetation and daily fluctuations can result in stranding fry in the shallows. Although this reach was historically not a high production area, it is now one of the two main spawning areas for Snake River fall Chinook. Numerous threats associated with operation of the Hells Canyon complex contribute to many factors that limit Snake River fall Chinook viability in this reach.

5.1.2.1 Water Quality

Water quality changes for fall Chinook below Hells Canyon Dam include altered thermal regime, low dissolved oxygen, high total dissolved gas, and changes in sediment processes and turbidity.

Altered Thermal Regime
Because of its large size, Brownlee Reservoir alters the thermal regime of the Snake River downstream of Hells Canyon Dam by delaying warming in the spring and cooling in the fall (Graves 1999; NMFS 2003, Groves and Chandler 2003). In addition, because of the US Army Corps of Engineers flood control requirements (drafts of up to 101 feet in extreme runoff years), this effect is greatest in low flow years when drafts for flood control are not required, and least in high flow years when large drafts for flood control are required.

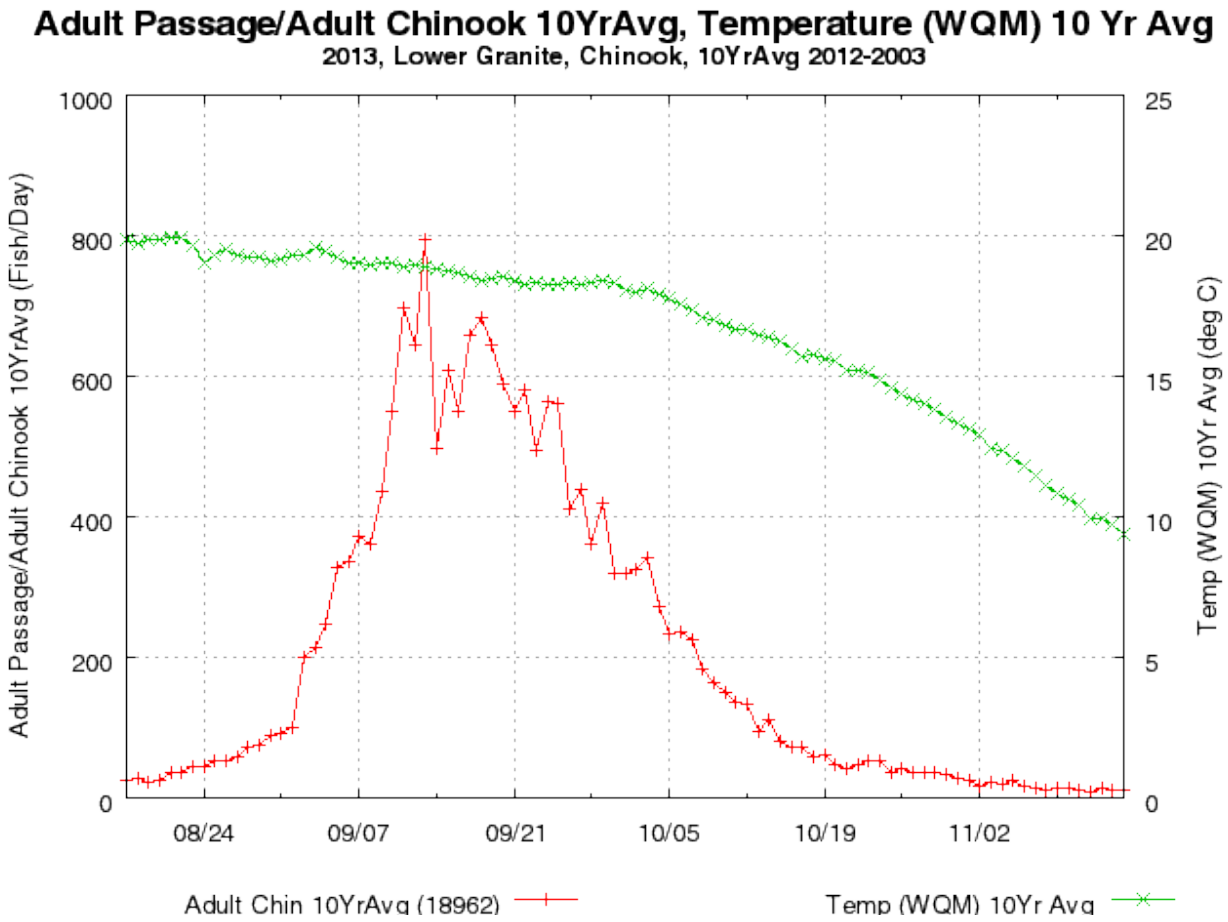
<u>Effects on adults</u>: About 90 percent of adult fall Chinook salmon pass Lower Granite Dam and enter the free-flowing Hells Canyon reach between late August/early September and late October. This, taken together with delayed fall cooling downstream of Hells Canyon Dam), means that the great majority of adult fall Chinook salmon migrating, holding, and spawning downstream of Hells Canyon Dam are currently exposed to warmer temperatures for longer periods of time than occurred historically either in the presently available mainstem Snake River habitat or the habitat formerly accessible upstream. Based on the literature concerning maximum temperature for salmon in general, and the water quality standards set in relation to that information, it would be expected that, compared to fall conditions without the Hells Canyon Complex or with Brownlee Dam operated at minimum pool year round, the following effects

would occur: increased pre-spawning mortality (lethal effects) and decreased spawning viability or egg viability (non-lethal effects) (ODEQ 1995a; McCullough 1999; WDOE 2000a, EPA 2001). Further, because fall Chinook spawning has been found typically not to occur until temperatures fall below 16°C (Groves and Chandler 1999), it is likely that some spawning has been delayed, at least in the lowest flow years when the effect on temperature is greatest.[3] 2011e).

Snake River water temperatures naturally decrease through the fall period. Water temperatures upstream of the Salmon River confluence typically range from 20 to -23C in early September down to 15 to 20 C in late September. In the mainstem lower Columbia River, median passage times and the rate at which fall Chinook wander into cool-water tributaries increases substantially when temperatures exceed 21C (Gonia, et. al., 2006). Increased pre-spawning mortality and decreased viability of gametes has been observed for Chinook salmon at temperatures greater than 20 C (EPA, 2001; Mann and Perey, 2005). however, there is presently no evidence that indicates significant pre-spawning mortalities or egg-to-fry losses of fall Chinook salmon are occurring in the Hells Canyon reach of the Snake River.

[3] Consider this discussion from Chandler and Groves 2003: "Adult fall chinook below Hells Canyon Dam currently experience comparable exposure to high temperatures during the early migration period (pre-September 15) as did adult fall chinook before construction of Hells Canyon Dam; however, construction of the HCC resulted in extended exposure to water temperatures above 14.5 °C for approximately two to three weeks longer than in reaches above the HCC (Table 1). Most of the reaches, including the pre-HCC Oxbow Reach, were approximately 10 °C by the end of October, whereas the present-day Hells Canyon Reach averages about 13.5 °C.

There has been no empirical demonstration of the effect of this prolonged exposure of adult chinook salmon to elevated temperature for free-ranging fish. The temperatures of the extended exposure are declining from between 16 to 18 °C to 14.5 °C. These lower temperatures are within the suitability range for migrating adults (Groves and Chandler 2001b, Poole et al. 2001) and for optimal swimming speed (Poole et al. 2001), but they are slightly above the range suitable for gamete viability during holding (> 13−16 °C, Poole et al. 2001). Experiments cited as reference for potential effects of elevated temperatures on gamete viability used adults held in holding ponds, with subsequent incubation temperatures held relatively high throughout the entire period (McCullough 1999). How these findings equate to free-ranging fish is unknown and may be site specific and stock specific. In a free-flowing river, there are thermal refugia associated with hyporheic upwelling, deep pools, and tributary inflows. In addition, temperatures are typically cooler throughout most of the incubation period in a natural setting than in these experiments. " (Chandler & Groves 2003)

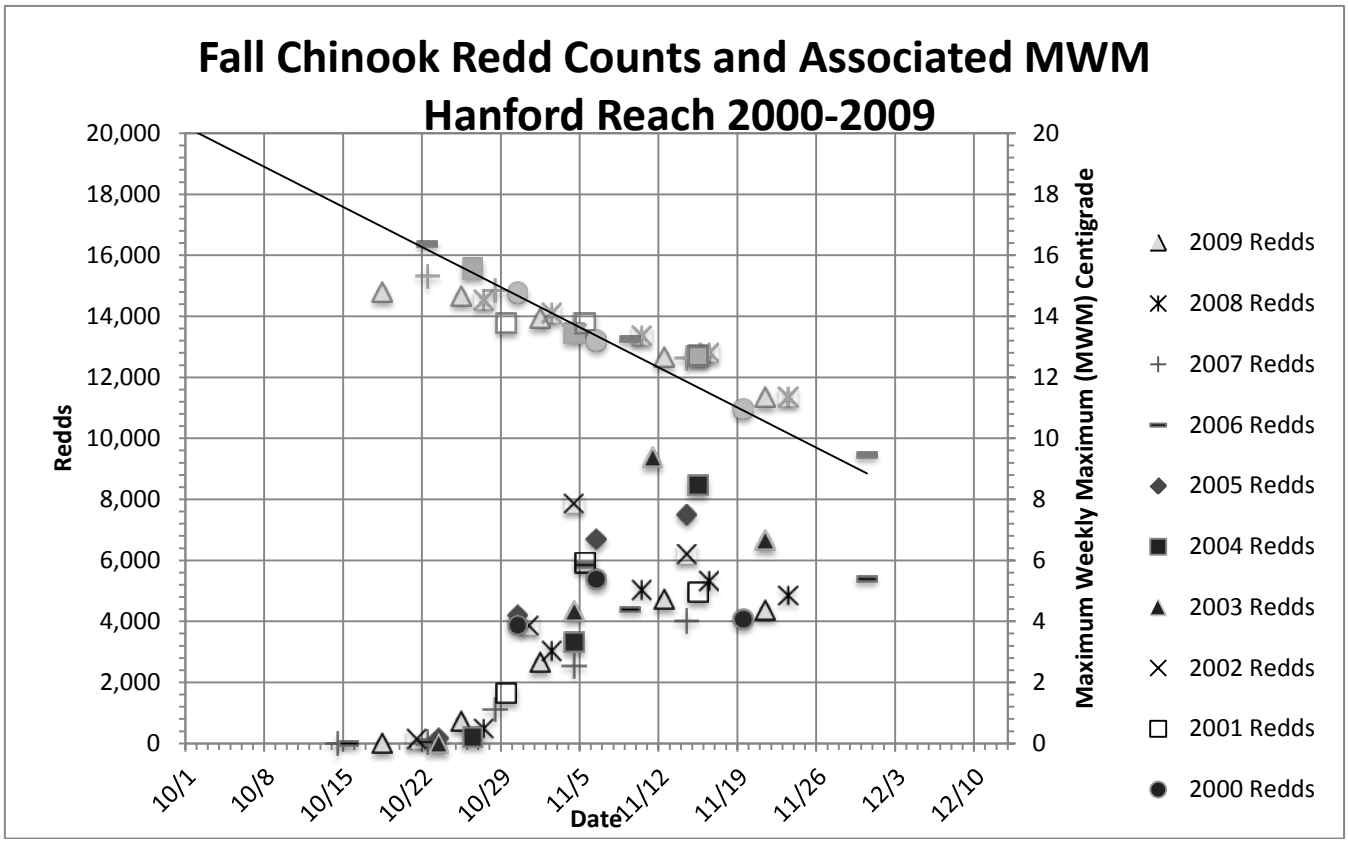


Recent (2003-2012) average migration timing of fall Chinook salmon and average daily temperatures at Lower Granite Dam is presented in Figure XX. The timing and distribution of adults upstream of Lower Granite Dam is not well known. Fall Chinook are known to thermoregulate by delaying migration and using localized cool water areas (Goniea et al. 2006, Clabough et al. 2007). It is possible that some adult fall Chinook salmon – especially those migrating past Lower Granite Dam in late August and early September when temperatures are highest – may be holding downstream of the Clearwater River confluence (which is typically cooled below historical temperatures by releases of cold water at Dworshak Dam). They might also hold up downstream of the confluence with the Salmon River which cools more rapidly than the Snake River (primarily because of Brownlee Reservoir) in the fall. If so, these behaviors would further serve to minimize potential effects relating to the delayed cooling of Snake River water temperatures resulting from the Hells Canyon Complex.

The current temperature standard in the Snake River for spawning salmon species is 13 C (Oregon and Idaho have a 13C 7DADM (7-day average daily mean) criterion starting on October 23rd).

Based on weekly spawning surveys conducted from 2000 through 2009, the majority of Snake River fall Chinook in the Hells Canyon reach spawn from around October 22 through November 20 at water temperatures ranging from about 16° C to 12° C.[4] More than half of total spawning has taken place at water temperatures in excess of 13° C (Figure 5-).,More recent studies using Snake River fall Chinook suggest that spawning at initial temperatures between 14.5 C and 16.0 C with a declining temperature regime does not result in significant decreases in egg survival.(NMFS 2011e, Geist et al. 2010 and Geist et al. 2011). It is known that Chinook that enter freshwater in the summer and fall tolerate and spawn in warmer water than do fish that enter freshwater in the spring (comparing Chambers 1956 [spring Chinook] to Seymour 1956 [fall Chinook] in Raleigh et al. 1986.

By comparison, fall Chinook from the Upper Columbia River summer/fall Chinook ESU that spawn in the Hanford reach of the Columbia River also spawn in water temperatures in excess of 13° C (Figure 5-2), and this is a robust population that is not listed under the ESA. Although Snake River fall Chinook and Upper Columbia River summer/fall Chinook are separate ESUs, they are very similar genetically and display similar habitat needs (NMFS August 25, 2011). Such habitat needs and tolerances vary between ESUs and populations.



[4] EPA (2001) noted that "for fall-spawning fish, spawning may be initiated in the field at temperatures of 57.2-60.8°F (14-16°C)." Experiments done at constant incubation temperatures, however, show that survival of eggs under these conditions is low. Consequently, spawning temperatures >57.2°F (14°C) are considered to provide marginal to poor egg survival for these early-spawning fish.

Figure 5-1. Middle Columbia fall Chinook ESU redd counts at Hanford Reach in relation to maximum water temperatures

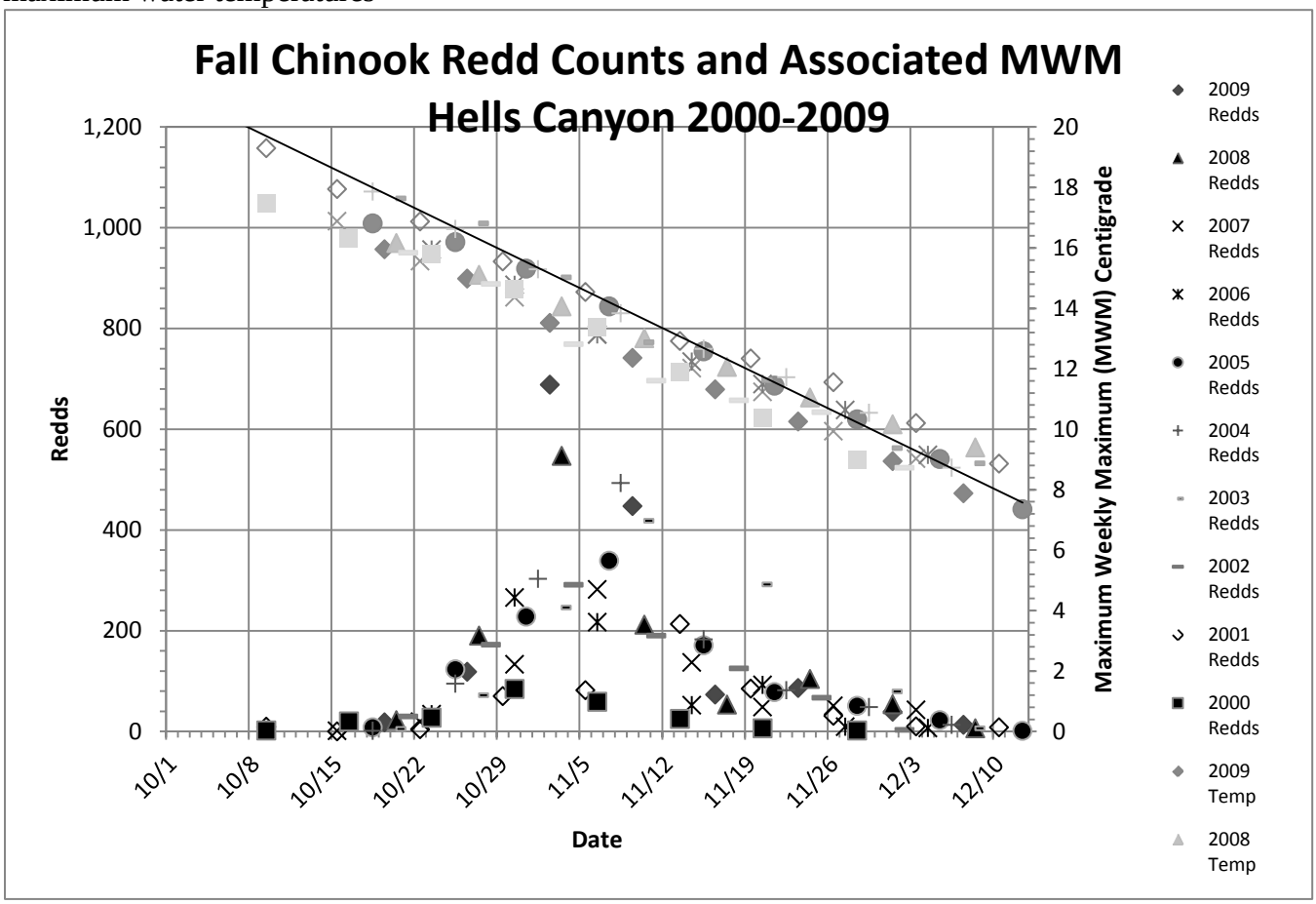


Figure 5-2. Snake River fall Chinook ESU redd counts in Hells Canyon in relation to maximum water temperatures

Effects on eggs and fry: Delayed cooling in the fall or delayed warming in the spring may either accelerate or delay the emergence of juvenile fall Chinook in the Hells Canyon reaches, depending upon when spawning occurs. Higher juvenile survival rates are correlated with lower temperatures, higher flows, and higher turbidity levels (Connor et al. 1998; Connor et al. 2003b; Smith et al. 2003). For subyearling migrants, maximum juvenile survivals occur nearest the peak of the spring freshet and decline throughout the summer as flows and turbidity levels decline and temperatures increase. Therefore, HCC effects that delay emergence, and ultimately the migration timing, of juvenile fall Chinook salmon increase the mortality rates of these fish as they migrate downstream through the Corps' lower Snake River projects (NMFS 2006).

Effects on nearshore environment: Nearshore areas of the Snake River are important foraging environments for fall Chinook salmon smolts as they migrate (Waples et al. 1991). For example, juveniles are known to rear in nearshore areas of Lower Granite Reservoir until temperatures exceed 18°C (Connor et al. 2002), when they are likely to move closer to the thalweg. Connor et

al. (1999) noted that the number of juveniles captured in nearshore areas along both the free-flowing Snake River and Lower Granite Reservoir decreases markedly with increasing temperatures (approximately 17°C) and decreasing flows. This behavior greatly increases the rate at which smolts migrate by placing them in the thalweg (the fastest, deepest water available) of the free flowing river (Connor et al. 1999). In a free-flowing river, this behavior would improve smolt survival by reducing the likelihood of smolts encountering predators associated with shorelines and reducing the amount of time smolts are exposed to predators. This behavior would also improve survival in the upstream, more riverine reaches, of the lower Snake River impoundments. However, in the lowermost, lacustrine, reaches, where greatly increased cross-sectional area of the river results in tremendously reduced water velocities, this behavior probably provides less benefit because predators can more easily maintain their position at any point in the reservoir (Tiffan et al.2009).

Dissolved Oxygen (DO)

As described in Section 5.1.1.2, hypoxic waters from Brownlee, Oxbow, and Hells Canyon reservoirs are drawn into the turbines in the late summer and fall and exported downstream. Dissolved oxygen levels released from Hells Canyon Dam often do not meet State water quality criteria for coldwater biota (8 mg/L water column DO as an absolute minimum) between August and October or for salmonid spawning (11 mg/L water column DO as an absolute minimum) between October and December (NMFS 2006). This water is reoxygenated by rapids downstream of Hells Canyon Dam; however, the effect likely lasts for 10 or more miles, depending upon starting dissolved oxygen levels in water releases, temperature, and mixing rates at rapids in downstream areas (Graves 2000).

Exposure to dissolved oxygen levels between 3 and 6 mg/L on pre-spawning adults is not well understood, but can include negative impacts such as avoidance, delayed migration, reduced swimming speeds, reduced fecundity, reduced spawning condition, and death (ODEQ 1995b; WDOE 2000b). The effects of constant exposure to low dissolved oxygen levels on early life history stages of salmonids are relatively well known. Below 8 mg/L the size of fish at emergence and the survival of fish can be negatively impacted. Below 5 or 6 mg/L, the survival of embryos is often low (ODEQ 1995b; WDOE 2000b). Low dissolved oxygen levels could therefore result in the death of exposed fall Chinook salmon eggs, or reduced fitness of exposed fry upon emergence (in redds created within the affected area below the dam). Aerial surveys indicate relatively little spawning within 10 miles downstream of Hells Canyon Dam (e.g. Garcia et al. 2004 found 17 to 18 percent of total redds in this area);

Total Dissolved Gas

IPC manages the Hells Canyon Complex to prevent spill to the extent possible. However, flows routinely exceed powerhouse capacities during the spring months (March through June) and sometimes exceed these flow levels during the winter as well (IPC 2003). When powerhouse capacities are exceeded, over-generational (uncontrolled) spill occurs. Spilling water at hydroelectric plants often causes atmospheric gases to be entrained in the water column, causing the water to become supersaturated with these gases, primarily with dissolved nitrogen.

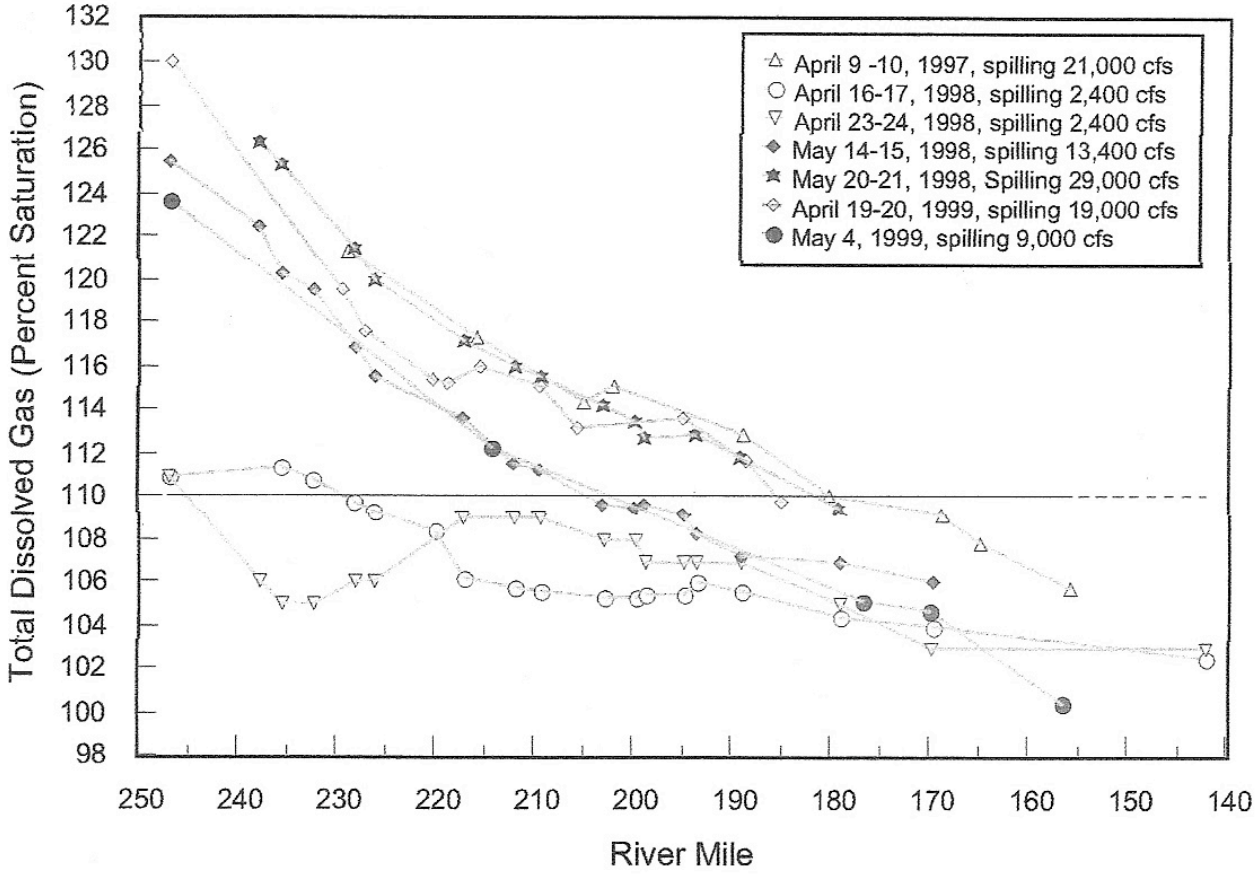


Figure 5-3. Downstream dissipation of total dissolved gas within Hells Canyon relative to the 100% saturation standard. Source: IPC 2003 (Myers and Parkinson 2003), Appendix E.2.2-4. [NEED PERMISSION to use this figure]

Figure 5-3 depicts the dissipation of the supersaturated gases downstream of the Project. TDG levels increase rapidly as spill volumes increase to 20 kcfs (1,000 cubic feet per second), from 110 to 130 % percent. Between 20 and 40 kcfs, TDG levels increase more slowly, from about 130 to 135 percent (Figure 5-3). TDG levels exceeding 120 percent do not reach 110 percent saturation (i.e. equilibrate to Idaho or Oregon's TDG standard) for 40 to 70 miles below the Project.

The tolerance of anadromous salmon and steelhead to TDG supersaturation varies greatly by life stage. Weitkamp (1977) summarized TDG research on various life stages of species of fish. For salmonids, eggs appear quite resistant to the effect of high TDG levels, while sac-fry are particularly sensitive. The susceptibility of juvenile fish to TDG supersaturation appears to increase with increasing size. Prior to emergence from the gravel, eggs and fry benefit from hydrostatic compensation. That is, each one meter of depth compensates for approximately 10 percent of TDG saturation (Weitkamp 1977).

Based on the distribution of over-generational flows at the Project (IPC 2003), fall Chinook salmon eggs, alevins (or sac-fry), fry, and rearing juveniles are most likely to be affected by elevated TDG levels below the Project. Because of hydrostatic compensation, only those eggs and sac-fry in the shallowest redds (those within about 3.5 meters of the waters surface) face any real exposure to TDG supersaturated waters. Those in the shallowest areas (less than 1 meter in depth), most proximally situated to Hells Canyon Dam, would experience the highest TDG levels (between 125 and 135 percent at the highest spill levels) and would most likely be impacted by gas bubble disease (Weitkamp 1997; Ryan et al. 2000; McGrath et. al. 2005).

Sediment and Turbidity

The Hells Canyon Complex prevents the downstream movement of sediments, thus cutting off a substantial source of these materials in the existing fall Chinook spawning habitat downstream of the Hells Canyon dam.

NMFS is concerned that spawning areas below the Hells Canyon dam, especially those closest to the dam within the upper Hells Canyon reach, may be diminishing (both in extent due to erosion, and quality due to armoring) over time. The turbidity of outflows is also reduced because small sediment particles settle out in the three reservoirs (IPC 2003; IDEQ and ODEQ 2004).

Smith et al. (2002) observed substantially (up to 60 percent) reduced survival of juvenile fall Chinook salmon released at Pittsburg Landing (in the upper Hells Canyon Reach) compared to those released at Billy Creek (in the lower Hells Canyon Reach) in 2000 and 2001. The authors attributed the reduced survival to lower flows and turbidity levels than were observed in previous years in which this study was conducted. Clearer water (lower turbidity) likely increases the vulnerability of juvenile salmonids to sight-feeding predators by increasing predator reactive distance and predator encounter rates (NMFS 2000).

5.1.2.2 Altered Flows

Daily and hourly flow fluctuations due to load following are likely to result in entrapment or stranding of juveniles or dewatering of redds. However, since 1991, IPC has followed a program to provide stable flow from Hells Canyon Dam during fall Chinook spawning season and “a minimum discharge throughout the incubation period until fry emergence is considered complete” (Groves and Chandler 2001). Brink et al. (2007) describe IPC’s management plan for preventing juvenile entrapment.

Seasonally, HCC flood control and refill operations contribute to substantially reduced flows in the mainstem migration corridor, Columbia River estuary, and plume during the spring outmigration (USBR 2004; NMFS 2004; NMFS 2005). Reduced spring flows in the lower Snake River and Columbia River are correlated with increased juvenile travel times; adversely affect the estuary; and diminish the size of the Columbia River plume in the Pacific Ocean, all of which are areas of special importance to rearing and migrating juvenile Chinook (as well as coho, chum, sockeye salmon, and steelhead) (NMFS 2004; NMFS 2005).

5.1.2.3 Summary of Below Hells Canyon Reach Threats and Limiting Factors

Threat: Upstream reservoirs and Hells Canyon Dam.
Related limiting factors: (1) Reduced outflow water quality -- altered thermal regime, low dissolved oxygen levels in late summer and fall, elevated TDG levels in winter and spring. As a result, lower survival for fall Chinook; delayed emergence and higher mortality for rearing juveniles; gas bubble disease. (2) Altered flows (on a seasonal, daily, and hourly basis), resulting in altered migration patterns, juvenile fish stranding and entrapment. (3) Interruption of geomorphological processes (entrapment of sediment), resulting in reduced turbidity, higher predation, potential reduction in spawning gravels.

5.1.3 Lower Mainstem Snake River Habitat - from Mouth of Salmon River to Lower Granite Dam Reservoir

The Lower Mainstem Snake River reach (RM 188 to 147) includes the Snake River from the mouth of the Salmon River to the beginning of the Lower Granite Dam reservoir near Lewiston, Idaho. The Salmon and Grande Ronde rivers contribute flow to this reach along with some smaller tributaries including the Imnaha River and Asotin Creek. The channel widens near RM 180, with gently sloping shorelines and a lower gradient than in the Hells Canyon Reach. Downstream of the Salmon and Grande Ronde rivers, there are long, deep pools and runs and low-gradient rapids (Groves and Chandler 2003). Here spawning gravels and rearing areas are more often contiguous.

Altered Flows: As in the Upper Mainstem reach, long-term fluctuations in flow have altered riparian vegetation. Daily fluctuations can result in stranding fry in the shallows. However, the effects of the Hells Canyon Complex in this reach are substantially attenuated due to the influence of the Salmon and Grande Ronde rivers. These tributaries have water quality and flow issues of their own (see Section 5.2), with varying effects on water quality in the mainstem.

Altered Temperature Regime: High water temperatures may be a limiting factor in this reach, although some studies indicate that Snake River fall Chinook are more tolerant of higher temperatures than other Chinook (NMFS 2011e, Geist et al. 2010 and Geist et al. 2011). IDEQ has begun a TMDL for temperature for the Lower Mainstem reach (Don Zaroban, IDEQ, personal communication, June 2011). A preliminary comparison of USGS temperature gage data from 1999 to 2005 found peak summer water temperatures in the Salmon River and the mainstem Snake quite similar, reaching 75°F (24°C) in both (Don Zaroban, IDEQ, personal communication, June 2011). Comprehensive reviews of temperature effects on life stages of Chinook salmon (ODEQ 1995a, McCollough 1999, WDOE 2000a, and EPA 2003) indicate that growth rates decline rapidly even when food is not limited when temperatures exceed 16°C; disease resistance declines as temperatures approach 16°C; and stress and even mortalities may occur when temperatures exceed 18°C. However, recent studies of survival and growth rates of Snake River fall Chinook under various temperature regimes (Geist et al. 2010 and Geist et al. 2011) show that Snake River fall Chinook are much more tolerant of higher temperatures than the Chinook cited generally in the literature.

5.1.3.1 Summary of Lower Mainstem Threats and Limiting Factors

Threat: Upstream dam operations
Related limiting factors: Altered thermal regime, altered flows

Threat: Land uses adjacent to Snake River and tributaries
Related limiting factors: Degraded water quality, altered thermal regime, lowered disease resistance, higher stress and mortality

5.1.4 Mainstem Migration Corridor- FCRPS Reservoirs and Dams on Lower Snake and Columbia Rivers

The mainstem migration corridor runs from the estuary and plume through the four federal dams on the Columbia River- Bonneville, The Dalles, John Day, and McNary dams, and the contiguous reservoirs formed on the Lower Snake River by Ice Harbor, Lower Monumental, Little Goose, and Lower Granite dams. In addition to blocking access to, or inundating historical production areas, other hydro system modifications to the remaining mainstem habitat are significant, affecting both juvenile and adult migration.

5.1.4.1 Adults - Migrating

NMFS has estimated the average survival for adult Snake River fall Chinook salmon migrating upstream between Bonneville Dam and Lower Granite Dam at 81 percent for those that migrated in river as juveniles and approximately 75 percent for those that were transported as juveniles, equating to a per project adult survival (7 dams) of 97 percent and 96 percent, respectively (NMFS 2008f, based on Adult Survival Estimate Appendix of NOAA's Supplemental Comprehensive Analysis [NMFS 2008b]). Recent data (2008, 2009, and 2010) are higher, showing closer to 90 percent survival for both categories (NMFS 2012).

However, salmon may have difficulty finding ladder entrances, and fish also may fall back over the dam, either voluntarily (e.g., adults that "overshoot" their natal stream and migrate downstream through a dam on their own volition), or involuntarily (entrained in spillway flow after exiting a fish ladder). Some adults that fall back or migrate downstream pass through project turbines and juvenile bypass systems (NMFS 2008f). Telemetry studies have shown that fish that fall back through the spillways are less likely to reach spawning grounds than those that do not.

Snake River adult upstream migrants are affected by thermal blocks that are longer in duration and larger in size than would have existed historically in the Columbia River and Lower Snake River mainstems. The relatively late entry of these fish subjects them to relatively high temperatures and low flows. This combination favors fish that enter later when temperatures are somewhat lower (ICTRT 2010). However, aside from a few project related delays, there has not

been a significant thermal blockage in the Snake River since the use of Dworshak dam to cool temperatures began in 2003.

5.1.4.2 Juveniles – Rearing and Migrating

- Increased reservoir volumes create slower water velocities and slow juvenile migration rates (ICTRT 2010) (Tiffan et al. 2009).

- Passage through the FCRPS dams and reservoirs results in mortality from various sources. Snake River juvenile migrants pass eight federal mainstem dams on their way to the ocean, via three routes: through turbines, by way of the spillway, or through the juvenile bypass system. Juvenile salmonid survival typically is highest through spillways, followed by bypass systems, then turbines (Muir et al. 2001). Survival of Snake River fall Chinook juveniles has been studied primarily with hatchery fish, because of the methodological complications of the fall Chinook dual life history. NMFS used the survival of hatchery released subyearling Chinook from Lower Granite to McNary dam – expanded to the Lower Granite to Bonneville Dam reach - as surrogates in the 2008 FCRPS BiOp for assessing mainstem survival rates. This analysis estimated current average survival rates of surrogate hatchery fish to range between 18.7% and 53.4% (NMFS 2008a). NMFS conservatively assumed that structural and operational changes at the mainstem dams would have no additional benefits for subyearling Chinook (i.e., that future Prospective survival rates would be no different than Current survival rates).

- Studies show that juvenile salmon experience approximately an 11 percent mortality rate per mainstem dam when they pass by way of turbines (Whitney et al. 1997).

- A high proportion of juvenile Snake River fall Chinook salmon are collected and transported by barge around the Lower Snake River and mainstem Columbia River dams to below Bonneville Dam, although transport rates have decreased since 2005 when increased spill levels were enacted at the Snake River collector projects. Transportation could be selective against the smaller-sized migrants (ICTRT 2010). However, data are not yet available for the effects of transportation on Snake River fall Chinook.

  While it is known that many Snake River fall Chinook juveniles are transported from Lower Granite, Little Goose, and Lower Monumental dams to downstream of Bonneville Dam where they are released, because of their varied life history strategies and current hatchery marking protocols, it is not possible to accurately estimate what proportion of the juvenile population is transported, or estimate how many of these are hatchery-origin and how many are natural fish (Draft Supplemental Hydro Module, May 2011). MORE RECENT DATA are NEEDED

- Before the construction of the Hells Canyon complex and Snake River mainstem dams, juveniles had typically completed their migration from the Snake River basin by the end of June. Hydropower operation strategies have led to a greater expression of alternative life histories. In particular, the intentional summer releases of cold water from Dworshak

Reservoir to cool the lower Snake River reservoirs has allowed juvenile fall Chinook to successfully rear there before outmigrating as yearlings. This life-history strategy appears to be successful, as the proportion of fish that out-migrate as yearlings and return to spawn as adults has increased substantially compared to historical levels. While this may represent a favorable adaptation and indicate that there is substantial phenotypic plasticity in the SR fall Chinook ESU, it is not desirable to lose the historically dominant subyearling life history (Connor et al. 2005; Heggs et al. 2013).

- Ecosystem alterations attributable to hydropower dams and modification of estuarine habitat have increased predation on Snake River fall Chinook juveniles. This is discussed in more detail in Section 5.5, Predation.

5.1.4.3 Summary of Mainstem Migration Corridor FCRPS Threats and Limiting Factors

Threat: FCRPS reservoirs and multiple dams, turbines, transportation

Related Limiting Factors: (1) For adult fish, difficulty finding fish ladders, fallback. (2) For juvenile fish, slowed migration, increased mortality, increased predation (see Section 5.5)

5.1.5 Estuary and Plume

In the lower Columbia River and estuary, diking and reduced peak spring flows have eliminated much of the shallow water and low velocity habitat needed by juvenile salmonids for feeding, growth, refuge from predators, and the transition to salt water. Dikes are constructed for purposes of agriculture and other development in riparian areas; spring flows are managed in the FCRPS and Upper Snake hydrosystems for irrigation or reservoir storage. (NMFS 2008f and NMFS 2011a)

Changes in the volume and timing of Columbia River flow caused by upstream water management have altered both the size and structure of the plume during the spring and summer months (Northwest Power and Conservation Council 2000). Reductions in spring freshets and associated sediment transport processes have permanently changed the food web in the estuary and plume (Casillas 1999 cited in NMFS 2011a).

Historically, Snake River fall Chinook exhibited an ocean-type life history, spending less time rearing in freshwater than spring/summer Chinook, and, potentially, more time in the estuary. However, close to half of Snake River fall Chinook juveniles now overwinter in the reservoirs and migrate downstream as yearlings (Heggs et al. 2013). Recent acoustic tag data indicate that both yearling and subyearling Chinook (including a sample of 1,392 yearling Snake River Chinook but not differentiating fall Chinook) move quickly from below Bonneville Dam to the mouth of the Columbia River. Median travel time for yearling Chinook from Knapp Point, just below the confluence of the Willamette River, to the mouth of the Columbia was 2.36 days and for subyearling Chinook the same distance, a median of 2.38 days (McMichael et al. 2011.)

Mortality of juveniles after passing Bonneville Dam that would not occur in a natural, unobstructed river system is called latent mortality (Williams et al. 2005). Latent mortality could result from injuries, stress, disease, or depletion of energy reserves caused by passage through the hydropower system. However, the range of estimates of latent mortality is extremely wide (0.01 – 64 percent) (ISAB 2007), suggesting that it has not yet been accurately quantified (NMFS 2012).

Summary of Estuary and Plume Threats and Limiting Factors

Threat: Dikes and other agricultural uses of the estuary
Related limiting factors: Lack of access to estuary habitat; altered food web

Threat: FCRPS flow management: reduced spring flows and other flow alterations
Related limiting factors: Unknown. Research is needed.

5.2 Tributary Habitat

The lower mainstems of the Clearwater, Grande Ronde and Tucannon River systems likely supported production historically, but at much lower levels than the mainstem reaches. The Imnaha and Salmon River mainstems had substantially less habitat capable of supporting fall Chinook salmon spawning and rearing (ICTRT 2007.)

5.2.1 Lower Clearwater River

The Lower Clearwater River is defined as the mainstem Clearwater River from the mouth of the North Fork Clearwater River to the confluence with the Snake River at Lewiston. Dworshak Dam, without fish passage, is located about 2 miles up the North Fork from its confluence with the mainstem Clearwater. Snake River fall Chinook reach the Clearwater subbasin from September through December and spawn mainly in the mainstem below the confluence with the North Fork (Arnsberg and Connor 1992; Garcia et al. 1999, cited in Ecovista 2003). However, spawning adults have been observed throughout the mainstem Clearwater River, and in the lower portions of the mainstem South Fork Clearwater River.

Limiting factors for salmonids spawning and rearing in the Lower Clearwater River include temperature, sediment, and flow issues (variability and base flow) (Ecovista et al. 2003). The IDEQ listed 432 miles of streams within the Lower Clearwater and its tributaries as water quality limited, mainly for thermal modification, sediment, habitat alteration, and flow (Ecovista et al. 2003).

The Clearwater River contributes approximately one third the flow of the Snake River and ten percent of the flow of the Columbia River system annually (USFS 1969 cited in Maughn 1972). The Clearwater drains approximately 9,645 square miles, originating in the Bitterroot Mountains

and flowing through mainly federal lands on the eastern half and private and tribal lands on the western half of the subbasin, including the Nez Perce Reservation. From the town of Ahsahka, where the North Fork of the Clearwater enters, the Lower Clearwater flows through semi-arid canyons and prairie (Ecovista et al. 2003). Land uses in the area include livestock grazing, timber harvest, agriculture, roads, rural residences, mining, and recreation, with the addition of industry in or near the city of Lewiston. Impoundments, irrigation projects, and small water diversions have a significant impact, with 56 dams of varying size counted in the Lower Clearwater subbasin (Ecovista et al 2003).

The Lower Clearwater is highly influenced by operations at Dworshak Dam, located 1.9 miles up the North Fork Clearwater, which alters natural temperature and flow regimes (Ecovista et al. 2003). Dworshak is operated to meet both local and regional flood control requirements during the winter and spring each year. Refilling the project reduces spring flows in the lower Clearwater, Snake, and Columbia rivers. Starting in 1992, releases at Dworshak dam have been made to improve migration conditions (temperature and flow) in the Lower Snake River. Recent operations to cool temperatures and augment flows include releases of up to 14,000 cfs between late June and mid-September.

Assessing the effects of the release of cold water from Dworshak in the summer is complex. Summer water temperatures in the lower Snake can otherwise rise to harmful levels in some years, delaying or even killing the both adult (steelhead, sockeye, and summer and fall Chinook) and juvenile migrants (fall Chinook); in that respect, the cold water from Dworshak is a benefit. On the other hand, cold water in the Lower Clearwater can slow the growth of juvenile salmonids incubating and rearing in this area, disrupt the cues that prompt outmigration (Connor et al. 2001, ICTRT 2010), and also provide thermal refuges in the Lower Snake River reservoirs where juveniles can oversummer. Consequently, summer flow augmentation appears to contribute substantially to juvenile fall Chinook from the Clearwater holding over an extra year in freshwater. While this new adaptation represents “the expression of an alternative life history strategy [which] may ultimately serve to reduce the overall extinction risk at both the population and ESU levels” (ICTRT 2010), there is some concern that if the yearling migrant life history strategy became predominant, it would represent a loss of the historical life history pattern and could increase the risk to the ESU. At this time, it appears that the subyearling life-history strategy continues to be conserved in the Snake River rearing areas and the relative contributions of each life history strategy to the ESU is fairly stable.

Summary of Clearwater River Threats and Limiting Factors

Threats: Land uses that affect river habitat, including livestock grazing, timber harvest, agriculture, roads, rural residences, mining, and recreation
Related limiting factors: High water temperatures, increased sediment, excessive nutrients, channel alterations, pollutants

Threat: Urban development and industry
Related limiting factors: toxic pollutants

Threat: Impoundments, irrigation projects, and small water diversions

Related limiting factors: Reduced habitat quantity, degraded water quality, entrapment and stranding

Threat: Dworshak Dam
Related limiting factors: Blocked access, altered flows, altered thermal regime, encouragement of new life history pattern

5.2.2 Lower Grande Ronde River

Limiting factors for salmonid spawning and rearing in the lower Grande Ronde River include lack of habitat quantity and diversity (primary pools, large wood, glides, and spawning gravels), excess fine sediment, degraded riparian conditions, low summer flows, and poor water quality (high summer water temperatures, low concentrations of dissolved oxygen, nutrients). The Oregon Department of Environmental Quality (ODEQ) identified many stream segments within the Grande Ronde subbasin as water quality limited because of algae, bacteria, dissolved oxygen, flow modification, habitat modification, nutrients, pH, sedimentation and temperature (ODEQ 2000, NPCC 2004).

The Grande Ronde subbasin encompasses an area of about 4,000 square miles in northeastern Oregon and southeastern Washington. The Grande Ronde River headwaters are in the Blue Mountains and the Wallowa Mountains of Oregon. The river flows generally northeast 212 miles to join the Snake River at river mile (RM) 169, about 20 miles upstream of Asotin, Washington and 493 miles from the mouth of the Columbia River. Most of the Lower Grande Ronde watershed is in Washington. Along the streams and on the valley floors, most of the land is privately owned. Land uses surrounding the Grande Ronde River are primarily agriculture (water diversions), livestock grazing, roads, timber harvest, and recreation (NMFS 2010, NPCC 2004).

Human activities that have contributed to altered stream conditions include logging, fire suppression, grazing, cultivation and other agricultural development, draining of wetlands, ditching and diking of streams, water withdrawal and the introduction of non-native plant and animal species.

Summary of Grande Ronde River Threats and Limiting Factors

Threats: Logging, fire suppression, grazing, cultivation and other agricultural development, draining of wetlands, ditching and diking of streams, water withdrawal and the introduction of non-native plant and animal species
Related limiting factors: lack of habitat quantity and diversity (primary pools, large wood, glides, and spawning gravels), excess fine sediment, degraded riparian conditions, low summer flows, and poor water quality (high summer water temperatures, low concentrations of dissolved oxygen, nutrients).

5.2.3 Imnaha River

Little empirical research exists on limiting factors for fall Chinook production in the Imnaha River. Adult fall Chinook enter the Imnaha at a time of year when water temperatures are dropping and base flows are increasing (October through the end of November). It is not known whether fine sediment in the mainstem could be limiting substrate availability. Outmigration of subyearlings is also coincident with a period of favorable flow and reduced stream temperatures (end of May through the first half of July) (Ecovista 2004).

Fall Chinook are present only in the mainstem below the town of Imnaha (Ecovista 2004). The Imnaha River joins the Snake River at river mile (RM) 191.7, approximately 48 river miles upstream of Lewiston, Idaho, and 3.4 miles upstream of the Salmon River confluence. The subbasin drains approximately 850 square miles of land in northeastern Oregon (Ecovista 2004). The headwaters of the Imnaha River drain the eastern escarpment of the Wallowa Mountains. The subbasin is sparsely populated and contains only the small town of Imnaha (population 25) within its boundaries. The subbasin is 71 percent publicly owned.

The ODEQ is developing a TMDL for the Imnaha. The ODEQ has listed the entire Imnaha River mainstem and some stream reaches in key tributaries as limited in water quality (the §303[d] list), all for temperature, based on 50º F (10º C) for year round bull trout spawning, rearing, and adult presence. However, some fisheries biologists and hydrologists contend that the current temperature regime is within the natural potential, given the low-elevation grassland ecosystem, the size of the drainage basin, and limited amounts of riparian modification (USFS 1998d, USFS 2000, cited in Ecovista 2004).

Summary of Imnaha River Threats and Limiting Factors

Threats: Uncertain
Related limiting factors: Not studied

5.2.4 Tucannon River

WDFW classified sediment load and habitat quantity as “primary” limiting factors for fall Chinook in the Tucannon subbasin and habitat diversity and channel stability as secondary (WDFW 2004). Sediment impacts on egg incubation and fry colonization are moderate to high in most reaches (WDFW 2004). Losses of key habitat quantity are considered small to moderate for most life stages; however, losses for fry and juveniles less than one year old are high in some stream reaches (WDFW 2004).

Some Snake River fall Chinook spawn in the lower Tucannon River, but these are entirely Lyons Ferry Hatchery fish. Loss of occupancy of naturally produced spawners in the Tucannon MaSA increased the distance between the Snake River Fall Chinook ESU and downstream ESUs in the Columbia Basin (ICTRT 2007).

Milks et al. (2003) documented fall Chinook use of the lower Tucannon River, observing that RM 0.0 to 0.1 is used primarily for migration, RM 0.1 to 0.4 primarily for rearing and migration, and RM 0.4 to 17.3 primarily for spawning and rearing.

The Tucannon River subbasin encompasses 503 square miles in southeastern Washington. The Tucannon River originates in the Blue Mountains and enters the Snake River at River Mile 62.2 near the mouth of the Palouse River. Melting snow from the Blue Mountains provides much of the annual runoff to the streams and rivers in the subbasin; the water level in many streams diminishes greatly during the summer months. Vegetation in the subbasin is characterized by grasslands and agricultural lands at lower elevations and evergreen forests at higher elevations. Major land uses in the subbasin are related to agriculture; cropland, forest, rangeland, pasture, and hay production account for more than 90 percent of the land within the watershed. Approximately 75 percent of the Tucannon subbasin is in private ownership; most of this land is in the lower portion of the watershed (Columbia Conservation District 2004).

Summary of Tucannon River Threats and Limiting Factors:

Threat: Agriculture
Related limiting factors: sediment load and habitat quantity, habitat diversity and channel stability

5.3 Hatcheries

Hatchery programs can affect all four VSP parameters, and in so doing can benefit or be a limiting factor for salmonid populations. Hatchery programs can benefit salmonid viability by supplementing natural spawning of depressed natural populations and thereby increasing abundance and spatial distribution, and by serving as a source population for re-populating unoccupied habitat. They thus can be used to reduce extinction risk during rebuilding, and possibly increase the abundance of natural-origin fish. On the other hand, hatcheries can pose risks to salmon population viability, including (1) genetic changes that alter diversity patterns and reduce fitness of wild fish; and (2) ecological effects such as increased competition for food and space, predation, and disease. There may also be cases in which a hatchery program provides neither benefit nor risk. In addition, the presence of large numbers of hatchery fish can add uncertainty to our understanding of the status of the wild population. This is especially true when marking rates are low, but large numbers of hatchery fish on the spawning grounds adds uncertainty even if they are 100% marked. Hatcheries themselves can also impose physical environmental changes in a variety of ways, such as increasing or decreasing stream flow, and creation of migration barriers. In the sections below we systematically consider the effects of the Snake River fall Chinook salmon hatchery programs on the four VSP parameters. In general, the hatchery programs have increased abundance and spatial structure, but the size of the programs relative to the level of natural production and consequent high proportion of hatchery-origin fish on the spawning grounds raises concerns about productivity and diversity. For a more comprehensive treatment of these and all other hatchery program issues, see the recent biological opinion on the Snake River fall Chinook salmon hatchery programs (NMFS 2012).

5.3.1 Abundance

In 1990 the estimated number of natural-origin Snake River fall Chinook passing Lower Granite Dam reached a historical low of 78 fish. In recent years the composite (natural-origin + hatchery-origin) returns over Lower Granite Dam has often exceeded 10,000 fish, and in 2010 exceeded 40,000. The proportion of natural-origin fish in the run has on average been only 22% of the composite run, but numbers in the thousands, a dramatic improvement over the abundance levels in the 1990s. The increased abundance is partly a reflection of the increased size of the hatchery programs, which were constrained in the 1990s by concerns about straying to about 20% of their current levels. There are several possible contributing causes to the increased abundance, including reduced harvest rates, improved in-river rearing and migration conditions, the development of life history adaptations to current conditions, and improved ocean conditions benefiting the relatively northern migration pattern (Cooney and Ford 2007). Undoubtedly there are more natural-origin fish present now than before the hatchery programs began, but it is not possible to state how much of this is due to a real growth in natural productivity rather than a consequence of more natural-origin fish being produced simply because the hatchery programs have artificially put more fish on the spawning grounds. As pointed out in the Biological Opinion (NMFS 2012), now that the hatchery programs have reached their “mature” sizes, the relative contribution of the hatchery programs to abundance and other factors should be easier to determine.

5.3.2 Spatial Structure

The increased abundance of spawners has been accompanied by an expanded spatial distribution of spawners. It is not clear to what extent this represents the population radiating into new highly productive areas—which would be a positive indicator in terms of recovery—and to what extent it is a reflection of fish being forced into new areas as a result of competition for spawning sites because of the high abundance or because of the particular location of hatchery release sites. Another possibility is an indirect effect caused by the ability of spawners to condition spawning gravel (Montgomery et al. 1996). In this case, even though the large number of fish may be forcing fish into non-optimal spawning areas, their spawning activity there may be increasing the value of these areas. Again, the concurrent increase in hatchery production and improvement in other factors affecting the population makes it impossible to clearly assess the benefit of the hatchery programs to spatial structure.

5.3.3 Productivity

Hatchery programs can influence productivity genetically and ecologically. Conceptually they can increase productivity in very small populations by decreasing genetic drift (the random loss of genetic diversity) but otherwise they pose risk due to outbreeding depression and hatchery-induced selection. Ecologically they can potentially benefit productivity to some extent by conditioning spawning gravel and adding marine-derived nutrients to the ecosystem, but can

depress productivity through competition and predation. The larger the hatchery program relative to natural production, the greater the risk, both genetic and ecological.

5.3.1.1 Genetic effects

Genetic drift is the random loss of genetic diversity. The smaller the population, the greater the loss due to drift. In considering genetic drift, the critical population size metric is effective population size, which is census size adjusted for variation in the reproductive contribution of individuals (e.g., uneven sex ratio, differential mating success, etc.). Typically the effective size of a population is much smaller than the census size. Hatchery programs can increase effective size by increasing the number of spawners and decreasing the variation in reproductive success, but they can also depress effective size by magnifying the reproductive success of a small number of spawners (Ryman and Laikre 1991). Although it appears that the hatchery programs predominate in determining the effective size of the Snake River fall Chinook salmon population and the effective size is considerably lower than the census size, the effective size is large enough for genetic drift to not be considered a serious concern in this population (NMFS 2012).

Outbreeding depression is caused by gene flow from other populations. Natural gene flow from straying is common, and considered an important aspect of salmon biology (Quinn 2005). Hatchery programs, however, can cause straying to at unnaturally high levels due to program size, a greater tendency of hatchery-origin fish to stray, or the deliberate inclusion of non-native fish into hatchery broodstocks or releases. If the new genetic material is from populations better adapted to other areas, the gene flow may cause the recipient population to become less well adapted, reducing productivity. In theory, outbreeding effects can persist for several generations (Edmands and Timmerman 2002). In the 1990s, straying of fish from other hatchery programs into the Snake River fall Chinook salmon population became a major concern. Efforts to control it became a serious constraint on hatchery program size for several years. The straying problem is now under control due to adjustments in those programs and careful control of the level of non-program fish in the Snake River fall Chinook salmon hatchery programs. Although the level of straying into the Snake River fall Chinook salmon population raises a concern about outbreeding depression, there is no evidence for the population actually having sustained a fitness reduction from outbreeding depression, and no way to evaluate it at this point.

Hatchery-induced selection, also called domestication, is caused by the hatchery and natural spawning and rearing environments differing in ways that cause fish with particular genotypes to be more successful in the hatchery environment than the natural environment. The concern is that if returning hatchery fish interbreed with naturally produced fish, the population as a whole will become less adapted to the natural environment, and thus less productive. The magnitude of fitness reduction resulting from hatchery-induced selection depends on: (1) the extent to which the hatchery and natural environments differ in ways that cause genetic change (i.e.; differences in selective regime) that are different from those in the natural environment; (2) the extent of gene flow between hatchery-origin and natural-origin fish, both in the hatchery and on the spawning grounds; and (3) the length of time this has been going on. In assessing genetic risk or genetic impact, all three factors must be considered. For example, a program with strongly selective fish culture, such as spawning only the earliest part of the run or culling all juveniles

that don't smolt by a certain date, may have a relatively small genetic impact if hatchery-wild interbreeding rates are low. In contrast, a program with weaker selective fish culture, such as trying to minimize differences between the hatchery and wild environments, may have a relatively high genetic impact if hatchery-wild interbreeding rates are high. Although there is a substantial and growing body of empirical literature documenting hatchery-induced selection, demonstrating that fitness consequences can be large, the data and theory do not allow for precision in estimating the magnitude of fitness effects in any particular situation, or offer any guidance on the reversibility of the effects. An additional consideration in the case of Snake River fall Chinook salmon is that no information of this sort is available for this population and almost all the data available is based on fish that are released as yearling smolts (spring Chinook, coho, and steelhead). Snake River fall Chinook salmon production, both natural and hatchery, is a mix of yearling and non-yearling smolts. The effects of hatchery-induced selection may be less in fish with sub-yearling life histories.

With regard to the first factor above, for the most part, the Snake River fall Chinook hatchery programs are typical hatchery programs in that they collect broodstock at a trap or as volunteers to the hatcheries, release smolts, and follow standard hatchery practices in doing so. There are some aspects of fish culture in the programs that may affect life history. Although this may have productivity consequences, in conforming with the VSP-factor organization of this section, these details will be dealt with under Diversity. The dominant concern regarding hatchery-induced selection in the Snake River fall Chinook salmon hatchery programs is the presumed extent of gene flow, based on the high proportion of natural spawners that are of hatchery origin. In theory, the effect of large numbers of hatchery-origin fish spawning in the wild can be alleviated somewhat by inclusion of natural-origin fish in the hatchery broodstock. In recent years the proportion of natural-origin fish in the broodstock has been under 10%, and the proportion of hatchery-origin fish on the spawning grounds has been over 70% (WDFW et al. 2011). A useful metric that considers the two rates of gene flow (hatchery to natural and vice versa) is proportionate natural influence (PNI) (Mobrand et al. 2005; Paquet et al. 2011). Based on the proportions above, the Snake River fall Chinook population currently has a PNI of 0.06. Theoretically, natural selective forces dominate only at PNI levels above 0.5; the Hatchery Scientific Review Group (2009) recommends a PNI target of at least 0.67 for a primary population that is intended to reach viable status.

5.3.1.2 Ecological effects

As mentioned above, solely by virtue of their ability to increase the abundance of spawners, hatchery programs can theoretically increase productivity through delivery of marine-derived nutrients and through conditioning of spawning gravel. Assuming the Snake River fall Chinook salmon spawning population is much larger at present than it would be without hatchery programs, these two effects could be considerable. On the other hand, the river is considerably more eutrophic than it was historically, possibly decreasing the importance of marine-derived nutrients. Estimation of the magnitude of the net benefits would require detailed knowledge of the retention of the added nutrients in the freshwater ecosystem and the incremental improvement in spawning ground condition, and the relative importance of these effects compared to the potentially negative impacts of the hatchery fish. The presence of large

numbers of hatchery fish to the system may also be depressing productivity at the adult stage by increasing competition for spawning sites. Buhle et al. (2009) and Chilcote et al. (2011; 2013) found in other salmon populations that natural productivity is depressed as the proportion of hatchery-origin spawners increases. Competition for space and food can also potentially depress the survival of rearing and outmigrating juveniles. Although the potential for competition seems high because of the large numbers of hatchery fish released, the impact cannot be estimated without a detailed study of habitat usage and food web dynamics. Another potential ecological concern at the juvenile life stage is predation. The extent of direct predation by hatchery-origin juveniles on natural-origin juveniles is likely to be insignificant because of the size differential and the fact that the hatchery fish for the most part are actively migrating. Indirect predation, predation by other species attracted by the large releases of hatchery juveniles, could be significant, but indirect predation effects have not been quantified.

5.3.4 Diversity

5.3.4.1 Subpopulation structure

A major diversity concern about the current hatchery programs for Snake River fall Chinook is that they may be preventing development or maintenance of subpopulation structure by collecting broodstock primarily at Lower Granite Dam and the two hatcheries, and releasing their progeny without regard for where the parents originated or were released. Operation of the hatchery programs for Snake River fall Chinook salmon thus presumes that only a single panmictic (well-mixed) population is being managed[5]. However, the size and diversity of the geographical areas used by Snake River fall Chinook for spawning and rearing (e.g., Lower Granite Dam and Hells Canyon Dam are 129 river miles apart, spawning occurs in a range of habitat conditions), coupled with some limited information on homing fidelity (Garcia et al. 2004), supports the potential that a naturally reproducing population would have significant subpopulation structure. This subpopulation structure could factor significantly in the viability of the population. Also, a recent genetic study by Marshall and Small (2010) shows some evidence for an existing substructure.

5.3.4.2 Life history patterns

Typically the goal of mating protocols at salmon hatcheries is to mate fish randomly. Currently spawning protocols at both Snake River fall Chinook salmon hatcheries depart from this. Older, larger fish are being used preferentially both as a means of compensating for previous protocols resulting in overrepresentation of younger age classes, and as a means of trying to mimic natural spawning structures based on the work of Schroder et al. (2008) and Hankin et al. (2009). These protocols may be an improvement over a strategy of random mating, as fish definitely do not mate randomly in the wild, but it is too early to say what the diversity consequences will be. Another strategy with uncertain diversity consequences is the release of 15% of the hatchery

[5] An NPT effort to develop a program component for the South Fork Clearwater is an exception.

production as yearlings, rather than subyearlings, the dominant juvenile life history. This practice was adopted to achieve higher survivals of hatchery fish; survival rates to adulthood of yearling releases are routinely twice as high as those of subyearlings. Although the dominant life history pattern for these fish is subyearling outmigration, a portion of outmigrants, especially those emigrating from the Clearwater River, overwinter in reservoirs of the hydropower system and enter the ocean as yearlings (Connor et al. 2002; Connor et al. 2005). This may represent a response to relatively low stream temperatures accentuated by cool water releases from Dworshak Dam. To the extent this response is selected for in an evolutionary sense (Williams et al. 2008), the high survival success of the yearling releases may change the life history more and at a faster rate than would naturally occur. Research is underway to understand the genetic basis of outmigration age in this population.

5.3.5 Critical Uncertainties Related to Hatcheries

As discussed above, there is considerable concern and uncertainty about the effect of the Snake River fall Chinook salmon hatchery programs on the population. In general, the critical uncertainties here are not very different from those that exist for many hatchery programs culturing listed species, because the Snake River fall Chinook salmon hatchery programs are not unusual in design or operation. Most supplementation programs involve a high proportion of hatchery production relative to natural production, and thus involve the same uncertainties about the effects of hatchery-induced selection and ecological interactions. The major factor increasing uncertainty over the norm in the case of Snake River fall Chinook salmon is that the population is very difficult to study because of geographic extent, habitat, and logistics. These special and general uncertainties are more important in the case of Snake River fall Chinook salmon than in many other populations because the current population is the only extant population in the ESU, and therefore must reach a level of viability or high viability for the ESU to be recovered.

Below we list major uncertainties regarding the effects of the hatchery programs on Snake River fall Chinook salmon. We enumerate these again in Chapter X, which summarizes Key Information Needs.

1. Number of fish on the spawning grounds. Underlying much of the genetic and ecological concern about the effect of the hatchery programs is the perception that the hatchery production is quite large compared to the natural production, but the absolute number and hatchery/natural composition of spawners is uncertain. The population spawns primarily in the Clearwater and Snake Rivers and their tributaries upstream of Lower Granite Dam, but also spawns in dam tailraces and some areas downstream of the Lower Snake dams. Redd counts are imprecise because in the larger rivers the water may be so deep that not all the redds are visible. The vast majority of spawning occurs above Lower Granite Dam, making dam counts the best estimate of the number of spawners, but an unknown amount of fallback occurs at the dam. Updated escapement estimates incorporating an estimate of fallback based on reviewing past studies are being generated and fallback studies are being initiated under the current permits to reduce this uncertainty.

2. The hatchery-natural composition on the spawning grounds. Currently about 22% of the fish released by the hatcheries are unmarked, so hatchery-natural proportions must be estimated based in part on coded wire tag expansions. Recent past estimates have also been based in part on a scale-pattern analysis that has been shown to be unreliable. In addition, there may be biases due to sampling rates at the dam. A reanalysis of data from previous years is underway to provide improved estimates of hatchery-natural composition of fish passing Lower Granite Dam. Additionally, a new parentage-based tagging approach has been implemented. Under this method, all adults spawned at the hatchery will be genotyped. Returning unmarked adults can then be traced back to hatchery parents. Fish that cannot be matched to hatchery parents are assumed to be of natural-origin.

3. Reproductive success in the wild of hatchery-origin spawners relative to natural-origin spawners, and consequent fitness loss caused by hatchery-natural interbreeding. Research available to date demonstrates that hatchery-origin fish are usually less successful reproducing on the spawning grounds than natural-origin fish. Therefore hatchery-natural composition in the broodstock and on the spawning grounds must be adjusted for relative reproductive success in order to be translated to gene flow. This population poses two serious challenges in this regard. First, as previously mentioned, there are reasons to expect that fish with subyearling smolt life histories, such as Snake River fall Chinook, might experience less fitness loss due to the hatchery environment than fish with yearling smolt life histories, but there is very little information on relative reproductive success of hatchery fish with subyearling life histories. Second, because of logistical difficulties, an *in situ* study of relative reproductive success like those done on other populations may not be likely in this population, and no promising alternative approach has been proposed.

4. Natural productivity of the population overall and major population segments. The population occupies well over 100 stream miles of large river habitat. As previously mentioned, the total number of spawners is not precisely known, and the situation is worse for specific areas because many redds are not visible, and carcass recoveries are difficult in most of the spawning areas. Juvenile sampling is also very difficult. Understanding area-specific productivity is important in the evaluation of potential for subpopulation structure.

5. Correlation between hatchery-origin spawner abundance and productivity.

6. Density dependent juvenile survival mechanisms relationship to productivity. Investigate the nature of potential mechanisms (e.g., interactions in the initial natal rearing areas or during the downstream migration phase.)

7. Existing subpopulation structure and potential for subpopulation structure development. Determine if major spawning area genetic substructure is consistent with or trending towards levels associated with a naturally functioning population. Subpopulation structure requires geographically separated regions of sustainable production and adequate restriction of gene flow (i.e., homing fidelity of adults) between them. At this point there is no understanding of whether production centers of this sort exist nor what kinds of modifications to the hatchery programs might keep gene flow sufficiently low to allow the structure to be maintained.

8. Correlation between size of hatchery releases and juvenile survival.

9. Diversity consequences of non-random mating strategies.

9. Diversity consequences of the proportion of yearling fish released.

5.3.6 Summary of Hatchery Threats and Limiting Factors

Threat: High proportion of hatchery fish as juveniles
Related limiting factors: Potential for competition with wild fish in rearing areas for food and other resources

Threat: High proportion of hatchery fish as adults
Related limiting factors: Genetic change, loss of fitness; disease transmission; competition for resources, including spawning areas; higher mortality from incidental harvest

Threat: Hatchery operations, including methods of broodstock collection and selection for traits not beneficial in natural environment

5.4 Harvest

This section summarizes fishery-related mortality to Snake River fall Chinook. The Fishery Module (Appendix B) overviews the details of various fisheries, management processes, analyses, and other fisheries-related information in more detail.

Snake River fall Chinook are harvested incidentally during fisheries that target harvestable hatchery and non-listed natural-origin fish. Harvest effects on natural Snake River fall Chinook including include mortality of fish that are caught and released, encounter fishing gear but are not landed, or are harvested incidentally to the target species or stock. Indirect effects also might include genetic, growth, or reproductive changes when fishing rates are high and selective by size, age, or run timing.

Due to their patterns of ocean distribution and the timing of their spawning run up the Columbia River, Snake River fall Chinook are subject to incidental harvest in a wide range of both ocean and in-river fisheries. Coastal fisheries in California, Oregon, Washington, British Columbia, and southeast Alaska have reported recoveries of tagged fish from the Snake River. The timing of the return and upriver spawning migration of Snake River fall Chinook overlaps with the Hanford Reach upriver bright Chinook salmon returns, as well as several large hatchery runs returning to lower river release areas or to the major hatcheries adjacent to the lower mainstem Columbia River. In locations where the fish are harvested, it is infeasible to distinguish listed natural Snake River fall Chinook from the large numbers of natural unlisted fish that are targeted for harvest.

5.4.1 Exploitation Rates

No direct estimates of ocean harvest impacts on natural-origin Snake River fall Chinook salmon are available. However, ocean exploitation rates based on coded wire tag (CWT) results for sub-yearling releases of Lyons Ferry Hatchery fish are used as surrogates in fisheries management modeling. Total harvest mortalities for the combined ocean and inriver fisheries can be expressed in terms of exploitation rates, which provide a common currency for comparing ocean and inriver fishery impacts. Fisheries in the Columbia River are generally managed subject to harvest rate limits. Harvest rates are expressed as the proportion of the run returning to the river that is killed in river fisheries.

The Pacific Salmon Commission's Chinook Technical Committee (CTC) provides estimates of total exploitation rates for Snake River fall Chinook based on an analysis of tagged sub-yearling Chinook released from Lyons Ferry Hatchery for catch years 1988 to 1994 and 2003 to 2010 (Table 5.1). There were too few tag recoveries during the intervening years to conduct the necessary analysis. The total exploitation rate for Snake River fall Chinook averaged 62% and 31% from 1988 to 1994 and 2003 to 2010, respectively.

Year	Exploitation Rate (%)
1988	73.3
1989	76.2
1990	68.8
1991	43.6
1992	56.9
1993	49.5
1994	42.8
…	…
2003	33.9
2004	25.5
2005	35.9
2006	33.5
2007	15.2
2008	28.8
2009	22.6
2010	49.6

Table 5.1. Total exploitation rates for Snake River fall Chinook (CTC 2012.)

Chinook Technical Committee (CTC). 2012. 2012 Exploitation Rate Analysis and Model Calibration. Report TCCHinook (12)-4.

In recent years, about 10% of the incidental take has occurred in the southeast Alaska fishery, about 22% in the Canadian fishery (primarily off the west coast of Vancouver Island), about 26% in the coastal fishery (primarily off Washington, and to a lesser degree off Oregon and Northern California), with the remaining 42% occurring in the non-Treaty and treaty Indian fisheries in the

Columbia River (CTC 2102). In-river gillnet and sport fisheries are "shaped" in time and space to maximize the catch of harvestable hatchery and natural (Hanford Reach) stocks while minimizing impacts on the intermingled Snake River fall Chinook.

Reductions in ocean fishery impacts on Snake River fall Chinook resulted from management measures designed to protect weakened or declining stocks specific to each set of fisheries. Fishery reductions have occurred through a series of agreements negotiated through the Pacific Salmon Treaty which was first ratified in 1985. The Chinook Annex of the Pacific Salmon Treaty was renegotiated most recently, resulting in a new 10-year agreement covering the period from 2009 through 2018. Among other things the Agreement results in harvest reductions of 15% in Southeast Alaskan fisheries and 30% in fisheries off the west coast of Vancouver Island.

As indicated above, fisheries in the Columbia River are managed subject to harvest rate limits. Harvest rates are expressed in terms of the proportion of the run returning to the river that is killed in the river fishery and therefore cannot be compared directly with the exploitation rate estimates shown in Table 5.1.

Table 5-2. Observed harvest rate in the Columbia River on SR fall Chinook compared to the maximum allowable harvest rate limit under the 2008-2017 U.S. v Oregon Management Agreement.

Year	Observed HR (%)*	Allowed HR (%)	Difference
1996	26.4	31.3	4.9
1997	32.2	31.3	-0.9
1998	26.6	31.3	4.7
1999	30.3	31.3	1.0
2000	28.8	31.3	2.5
2001	21.1	31.3	10.2
2002	28.1	31.3	3.2
2003	21.7	31.3	9.6
2004	20.4	31.3	10.9
2005	26.0	31.3	5.3
2006	26.9	31.3	4.4
2007	22.7%	31.3	8.6
2008	27.4%	31.3	3.9
2009	37.9%	45.0	7.2
2010	25.9%	45.0	9.1
2011	32.7%	45.0	12.3

Year	Observed HR (%)*	Allowed HR (%)	Difference
2012	34.1%	45.0	10.9
1996-2000 Avg.	28.9%	31.3	2.4
2000-2007 Avg.	24.5%	31.3	6.8
2008-2012 Avg.	31.6%	45.0	13.4

* TAC 2013 (or I can write a memo to the file including the data in the table since TAC documents are not public)

Fisheries in the Columbia River were managed for many years subject to an ESA-related harvest rate limit of 31.3%. The harvest manage structure was changed with adoption of the most recent U.S. v. Oregon Agreement. Under the 2008-2017 U.S. *v.* Oregon Management Agreement, the harvest of SR fall Chinook in the Columbia River may vary from year-to-year based on the abundance-based harvest rate schedule in Table 5-3. Allowable harvest on any given year depends on the abundance of unlisted upriver fall Chinook and natural-origin Snake River fall Chinook. The allowable harvest rate ranges from 21.5% to 45.0%.

The harvest rate schedule in Table 5-3 modifies the past practice of managing fisheries subject to a fixed harvest rate, providing a management structure that is responsive to the status of the species. Under the new schedule, harvest may vary up or down depending on the overall abundance of unlisted upriver fall Chinook and listed natural-origin Snake River fall Chinook. The harvest rate schedule is generally calibrated to provide higher harvest rates when abundance is high enough to accommodate the increased harvest and still meet the TRT recovery abundance threshold of 3,000 natural-origin fish to Lower Granite Dam. Conversely, when numbers are low, harvest rates are reduced to provide greater protection. As shown in Table 5.2 the actual harvest rates have been consistently well below the harvest rate limit.

Table 5-3. Abundance-based harvest rate schedule for SR fall Chinook salmon under the 2008-2017 U.S. v Oregon Management Agreement. (TAC 2008; copied from Harvest Module)

State/Tribal Proposed SR Fall Chinook Harvest Rate Schedule					
Expected URB River Mouth Run Size	**Expected River Mouth SR Wild Run Size [1]**	**Treaty Total Harvest Rate**	**Non-Treaty Harvest Rate**	**Total Harvest Rate**	**Expected Escapement of Snake R. Wild Past Fisheries**
< 60,000	Or < 1,000	20%	1.50%	21.50%	784
>60,000	And > 1,000	23%	4%	27.00%	730
>120,000	And > 2,000	23%	8.25%	31.25%	1,375
> 200,000	And > 5,000	25%	8.25%	33.25%	3,338
	And > 6,000	27%	11%	38.00%	3,720
	And > 8,000	30%	15%	45.00%	4,400

State/Tribal Proposed SR Fall Chinook Harvest Rate Schedule					
Expected URB River Mouth Run Size	**Expected River Mouth SR Wild Run Size [1]**	**Treaty Total Harvest Rate**	**Non-Treaty Harvest Rate**	**Total Harvest Rate**	**Expected Escapement of Snake R. Wild Past Fisheries**

1. If the SR natural fall Chinook forecast is less than level corresponding to an aggregate URB run size, the allowable mortality rate will be based on the SR natural fall Chinook run size.

Notes:
Treaty Fisheries include: Zone 6 Ceremonial, subsistence, and commercial fisheries from August 1-December 31.
Non-Treaty Fisheries include: Commercial and recreational fisheries in Zones 1-5 and mainstem recreational fisheries from Bonneville Dam upstream to the confluence of the Snake River and commercial and recreation SAFE (Selective Areas Fisheries Evaluation) fisheries from August 1-December 31.
The Treaty Tribes and the States of Oregon and Washington may agree to a fishery for the Treaty Tribes below Bonneville Dam not to exceed the harvest rates provided for in this Agreement.
Fishery impacts in Hanford sport fisheries count in calculations of the percent of harvestable surplus achieved.
When expected river-mouth run sizes of naturally produced SR Fall Chinook equal or exceed 6,000, the states reserve the option to allocate some proportion of the non-treaty harvest rate to supplement fall Chinook directed fisheries in the Snake River.

5.4.2 Indirect Effects

Harvest has the potential to affect migration timing, maturation timing and size-at-age. Based on the current timing and distribution of the fisheries with CWT recoveries, ocean harvest of Snake River fall Chinook salmon is assumed to impact both maturing and immature fish (Chinook Technical Committee 2007). As a result, the cumulative impact of ocean harvest is higher on components of the run maturing at older ages. Snake River fall Chinook salmon are also harvested by in-river fisheries directed at more abundant fall Chinook salmon runs. Age-specific exploitation rates of in-river fisheries also increase with age-at-return. Annual in-river exploitation rates are reported in two categories: jacks (primarily age-2s, some smaller age-3s) and adults (dominated by age-4 and age-5 returns).

> These potential effects are not a limiting factor at this time, and they would result not just from harvest alone, but from collective effects of hydropower, hatchery and harvest influence. Time series of size, growth and age should be monitored.

5.4.3 Summary of Harvest Threats and Limiting Factors

Threat: Fisheries
Related limiting factors: Mortality.
Potential limiting factors to keep an eye on: Indirect selection for age, size, or run timing

5.5 Predation

This section summarizes the impacts on Snake River fall Chinook from predation in the mainstem Columbia and Snake Rivers and in the tributaries in which some fall Chinook spawning occurs.

Ecosystem alterations attributable to hydropower dams and modification of estuarine habitat have increased predation on Snake River Chinook and steelhead populations. Some of the predator species' abundance levels have increased dramatically, particularly in localized areas, with associated changes in predation. (LCREP 2006).

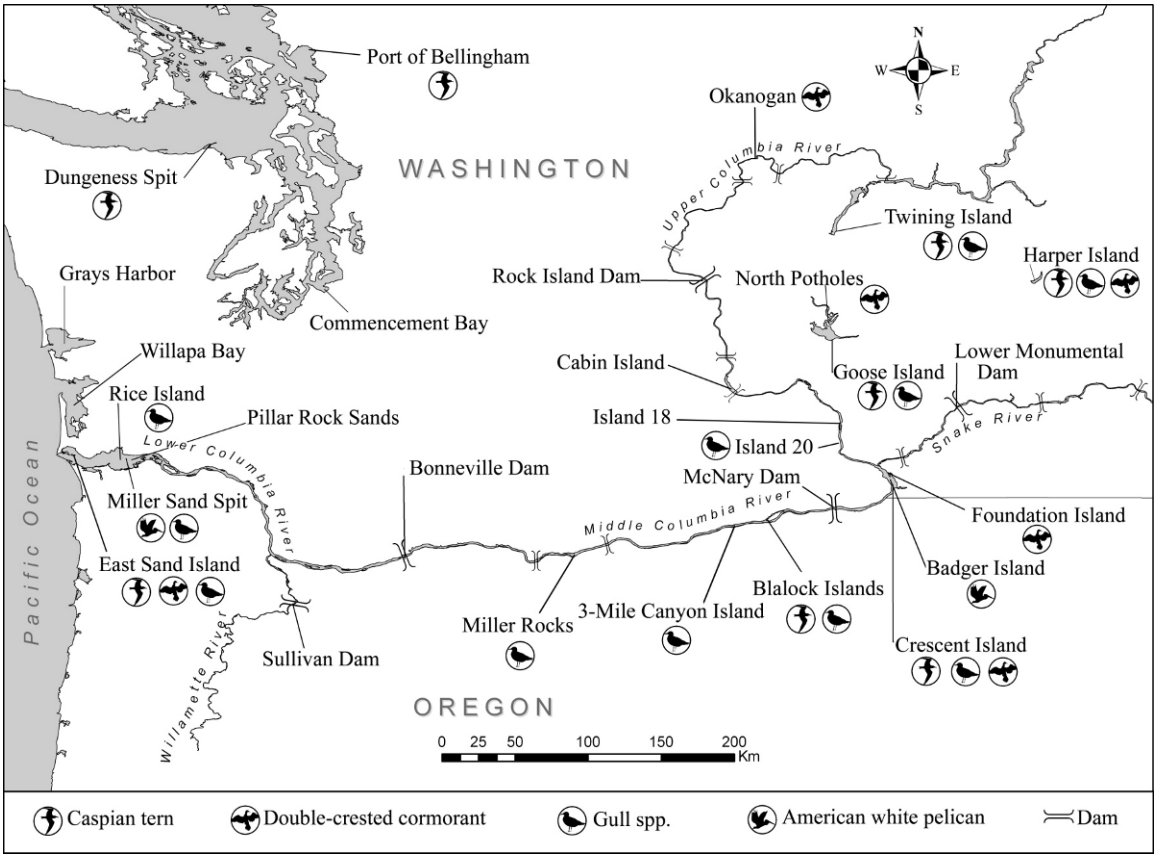
Table 5-3. Predators to Snake River Chinook salmon and steelhead in the Columbia River.

PREDATOR	SPECIES	COLUMBIA RIVER LOCATION
Avian	Caspian Terns	Estuary and Crescent Island and Potholes Reservoir
Avian	Double-Crested Cormorants	Estuary and Foundation Island
Piscivores	Northern pikeminnow, Walleye, Smallmouth Bass, and Channel Catfish	Total length; highest in dam impoundments and below Hells Canyon Dam Complex
Pinnipeds	Pacific harbor seals, Stellar sea lions, and California sea lions.	Below and in the forebay of Bonneville Dam

Avian Predation

In the estuary, the number and/or predation effectiveness of Caspian terns, double-crested cormorants, and a variety of gull species has increased because of habitat modification (LCREP 2006; Fresh et al. 2005) and an influx of avian predators to the Columbia River Basin from other locations. Avian predators were estimated to have consumed 10 to 30 percent of the total estuarine salmonid smolt production of 1997 (LCREP 2004). Although Caspian tern predation has decreased because of management efforts to reduce the available island habitat, double-crested cormorant predation has increased (Roby and Collis 2011). The 2010 season summary of Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and

Mid-Columbia River (Collis and Roby 2011) estimates that terns nesting on East Sand Island near the mouth of the Columbia River consumed 5.3 million juvenile salmonids in 2010, and double-crested cormorants also nesting on East Sand Island consumed 19.2 million juvenile salmonids. Age zero Chinook, which would include Snake River fall Chinook made up a major portion of the cormorant colony salmon consumption. The fact that subyearlings, in general, are in shallow water and spend more time in the estuary than stream-type (age one plus) juveniles makes them more vulnerable to cormorants. However, tag studies are showing that interior Columbia subyearlings, which tend to be larger than lower river subyearlings, typically spend less than a week in the river from Bonneville dam to the Columbia River mouth. Snake River fall Chinook yearlings, which are spring migrants, spend approximately three to four days in the estuary (citations). Thus, Snake River fall Chinook probably are less exposed to estuary predation than other subyearlings from the Willamette and Lower Columbia. Tern, cormorant, and gulls from colonies on islands in the Columbia River and the Lower Snake also prey on juvenile salmonids, but predation in the estuary is an order of magnitude greater (Ibid.). It is also significant that estuarine predation affects juveniles that have survived the migration corridor and may be more likely to return as adults.



Map 1. Study area in the Columbia River basin and coastal Washington showing the locations of active and former breeding colonies of piscivorous colonial waterbirds mentioned in this report (Roby & Collis 2011).

Table 5-3. Predators to Snake River Chinook salmon and steelhead in the Columbia River.

PREDATOR	SPECIES	COLUMBIA RIVER LOCATION
Avian	Caspian Terns	Estuary and Crescent Island and Potholes Reservoir
Avian	Double-Crested Cormorants	Estuary and Foundation Island
Piscivores	Northern pikeminnow, Walleye, Smallmouth Bass, and Channel Catfish	Total length; highest in dam impoundments and below Hells Canyon Dam Complex
Pinnipeds	Pacific harbor seals, Stellar sea lions, and California sea lions.	Below and in the forebay of Bonneville Dam

Pinnipeds

Marine mammals (pinnipeds) prey on winter and spring migrating adult salmon and steelhead in the lower Columbia River and as they attempt to pass over Bonneville Dam (USACE 2007); Snake River fall Chinook for the most part are not migrating when marine mammals are most abundant and are likely much less affected than either spring or summer Chinook.

Non-native fish predation

Predation by non-salmonid fish is a significant concern (Table 5-3.) Within the Columbia River basin, juvenile Pacific salmon could encounter no fewer than eight documented non-native predator and competitor fish species en route to the estuary (Sanderson et al. 2009). Northern pikeminnows and non-native predatory species (e.g., smallmouth bass, walleye, channel catfish, etc.) congregate near dams or at hatchery release sites to feed on migrating smolts. The largest portion salmon of lost to fish predators is in the reservoirs. However, many of the studies that measured predation on juvenile salmonids have not determined the predator and prey population sizes needed to estimate an overall predation impact. On an individual population basis, the effects of predation by non-native fish species may be similar to that associated with passage through the hydro system (Sanderson et al. 2009.)

Similarly, predation by nonnative fishes on outmigrating smolts is roughly equivalent to the productivity declines attributed to habitat loss and degradation (Beechie et al. 1994). Although it is difficult to make direct comparisons between adult and juvenile mortality with respect to population impacts, predation rates on juvenile outmigrants are also similar in magnitude to harvest-related mortality rates on adults (3 percent to 84 percent; McClure et al. 2003).

Beamesderfer and Nigro (1989) estimated that walleye annually consumed an average of 400,000 salmonids (250,000 to 2,000,000), or up to 2 percent of the salmonid run from 1983-1986. Rieman et al 1988 found that of the total salmon consumed, northern pikeminnow consumed 78% of the salmon predated in the John Day Pool. Walleye only accounted for 13%. Abundance of walleye in the lower Columbia River appears highly variable, but losses of juveniles and smolts to walleye was estimated at up to 2 million fish per year, which compares to 4 million for pikeminnow (Tinus and Beamesderfer 1994).

Sculpins, suckers, and cyprinids (including northern pikeminnow) made up the majority of smallmouth bass diets in the John Day Reservoir; however, bass still ate a large number of salmonids, primarily young-of-the-year Chinook salmon that co-inhabit littoral areas in July and August (Poe et al. 1991). Downstream of Bonneville Dam, bass diets consisted of sculpins (46 percent), cyprinids (19 percent), suckers (16 percent), and salmonids (12 percent).

In the Yakima River, smallmouth bass appeared to have a preference for fall Chinook, which made up to 47 percent of their diet in May; they consumed up to 35 percent of the outmigrants (Fritts and Pearsons 2004). In the Columbia River near Richland, WA, salmonids made up nearly 60 percent of smallmouth diets (Tabor et al. 1993).

In the Snake River, Shively et al. (1991) and Nelle and Bennett (1999) found lower consumptive rates of juvenile salmonids in the areas they studied compared to the Columbia River studies mentioned above. However, even though consumption rates are relatively low, the large number of individual predators can result in substantial losses of migrating juveniles.

Fishing regulations in Oregon and Washington could potentially be used to control non-native fish predator populations. Fishing regulations currently limit the catch of smallmouth bass and walleye in the Columbia and Snake Rivers (Table 5-4). The State of Washington recently proposed regulatory changes to increase bag limits of non-native fish that are preying on juvenile salmonids.

Table 5-4. Fishing regulations for the Columbia Basin for smallmouth bass and walleye (from State fishing regulations).

Species	Oregon (Columbia River)	Washington	
		Columbia River	Snake River
Smallmouth bass	5 fish per day, no more than 3 of which can be > 15 inches.	From mouth to McNary Dam: 5 fish per day, no more than 3 of which can be > 15 inches. Upstream of McNary Dam: 10 fish per day, only 1 fish can be > 14 inches.	10 fish per day, only 1 fish can be > 14 inches.
Walleye	No minimum size or limit.	From mouth to Priest Rapids Dam:	No minimum size, 10 fish per day of which 5

Species	Oregon (Columbia River)	Washington	
		Columbia River	Snake River
		No minimum size, 10 fish per day of which 5 can be > 18 inches, and one can be > 24 inches. Upstream of Priest Rapids Dam: 5 fish per day, minimum size of 16 inches, and only 1 fish can be > 22 inches.	can be > 18 inches, and one can be > 24 inches.

Summary of Threats and Limiting Factors (Predation is a limiting factor)

Threat: Dam operation, reservoirs, alterations to estuary
Related limiting factors: Increased predation by birds and non-native fish

5.6 Competition

Competition for resources can occur between natural-origin and hatchery fish, or between salmonids and other species.

5.6.1 Mainstem Snake and Columbia Rivers

Competition for food resources or rearing habitat among salmonids, and between salmonids and other fish, may occur during downstream migration in the mainstem Snake and Columbia Rivers and in the estuary, depending on numbers of fish, available rearing habitat, and residence time (LCFRB 2004).

Competition may occur on the spawning grounds between hatchery-origin and natural-origin spawners. NMFS has noted that "the apparent leveling off of natural returns [of Snake River fall Chinook] in spite of the increases in total brood year spawners may indicate that density dependent habitat effects are influencing production or that high hatchery proportions may be influencing natural production rates (Ford et al. 2010)." However, more study is needed. This is a critical uncertainty for Snake River fall Chinook.

Competition can also occur between salmonids and non-native species. The effects of introduction of non-native species in the estuary, including include 21 new invertebrates, plant species such as Eurasian water milfoil, and non-native fish such as shad, are poorly understood. The American shad in particular, because of the sheer tonnage of their biomass, may play a particularly important role in the degradation of the estuary ecosystem. Palmisano et al. (1993a,

1993b) concluded that increased numbers of shad likely compete with juvenile salmon and steelhead, resulting in reduced abundance and production of salmon and steelhead. A study to assess whether or not juvenile shad enhance growth rates of non-native predators (allowing them to prey on salmonids at earlier ages) is underway (BPA funded study began this year). Most recently, invasive Siberian shrimp appear to be increasing in abundance in the Snake and Columbia River reservoirs. This species is thought to favor similar prey items as fall Chinook rearing in the Snake River reservoirs and is therefore, likely a direct competitor.

Competition may be a significant factor limiting viability of fall Chinook, but additional research is needed to understand this critical uncertainty.

5.6.2 Snake River Tributary Streams

The extent of competition with other species in Snake River system tributary streams is generally unknown. Hatchery-produced B-run steelhead are released into the Clearwater River and may compete with Snake River fall Chinook (Ecovista 2003.) These are important critical uncertainties to address in the RM&E plan.

5.6.3 Summary of Threats and Limiting Factors (Competition is a limiting factor)

Threat: High proportion of hatchery fish on spawning grounds
Related limiting factor: Competition for spawning areas, decreased production

Threat: Increased abundance of non-native species
Related limiting factor: Competition for space in spawning and rearing areas; competition for food; increased predation

5.7 Toxics

Throughout its migration corridor and in some rearing and spawning rearing areas, Snake River fall Chinook are exposed to chemical contaminants from agricultural, industrial, and urban land uses that may disrupt behavior and growth, reduce disease resistance, and potentially cause increased mortality. Recent NMFS Biological Opinions (NMFS 2008, 2009, 2010, 2011) have concluded that, if applied improperly, several current use pesticides could jeopardize the continuing existence of Snake River fall Chinook or damage critical habitat. The EPA State of the River Report for Toxics (EPA 2009) identified several additional classes of contaminants (e.g., mercury, polycylic aromatic hydrocarbons, PCBs, PBDEs, DDTs) that may have adverse effects on Snake River fall Chinook salmon, as they are found at levels of concern in many locations throughout the Snake River basin and along the Snake River fall Chinook migration corridor. In fact, recent studies have documented accumulation of persistent organic pollutants, including DDTs, PCBs, and PBDEs in outmigrating juvenile Snake River fall Chinook collected

in the Lower Columbia River and Estuary (Sloan et al. 2010; Johnson et al. 2013). However, comparable data on contaminant exposure and uptake in Snake River fall Chinook are lacking for many critical habitats, including reaches of the Lower Snake and Mid-Columbia rivers containing population centers (e.g. Hanford and the tri-cities of Kennewick, Pasco, and Richland) that are sources of contaminants associated with urban and industrial activity.

Our understanding of the effects on aquatic life impacts of many contaminants, alone or in combination with other chemicals (potential for synergistic effects) is incomplete. For example, in addition to the contaminant groups mentioned above, Snake River fall Chinook may also be exposed to "contaminants of emerging concern" such as pharmaceuticals and personal care products, that are unregulated and whose effects on fish are uncertain. Even for those contaminant classes whose effects are better characterized, our understanding of their interactions with other stressors, food-web mediated effects, and effects in complex mixtures is limited, and this lack of knowledge may lead us to underestimate the risks associated with currently permitted concentrations of these toxicants. Some key information needs for toxics include:

Water quality impairments are common within the Snake River fall Chinook ESU habitat. Figure 5-7 shows 303(d) listed streams and NPDES permit sites in the region. Appendix C provides a detailed account of contaminants found within the Snake River fall Chinook migration corridor. The following is a summary of that information.

Throughout its migration corridor and in some rearing and spawning rearing areas, agricultural land uses may affect Snake River fall Chinook. Irrigation began on lands adjacent to the Snake River around 1880. Irrigated agriculture developed in a band several miles wide on either side of the river, and agriculture is a predominant land use to this day. Agricultural runoff returns to the river and also recharges the aquifer. It also carries various contaminants from pesticides, fertilizers, and/or animal wastes.

The river also carries effluent from Boise,Idaho Falls, Twin Falls, and Lewiston, Idaho, as well as Clarkston, Washington and the tri-cities of Kennewick, Pasco, and Richland, before its confluence with the Columbia River. These population centers are sources of contaminants associated with urban and industrial activity. The Columbia River, which this species uses as a migration corridor, similarly passes through agricultural lands, receives urban and industrial runoff in both mainstem and tributaries, and borders the Hanford Nuclear Reservation for approximately 50 river miles.

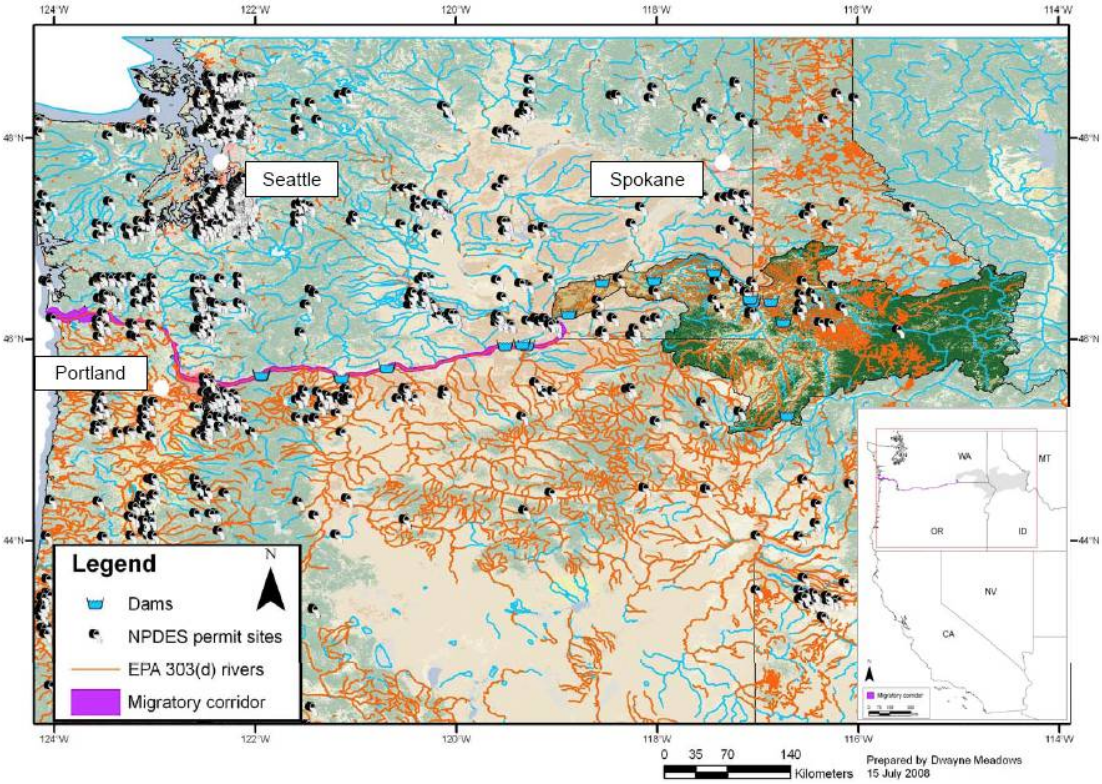


Figure 5-7. NPDES permit sites and 303(d) listed streams in Snake River fall Chinook migratory corridor and spawning range. (Source: NMFS 2008 pesticide BiOP).

Because Snake River fall Chinook exhibit an ocean-type life history, and as subyearlings may make extensive use of shallow, vegetated estuary habitats (Fresh et al. 2005), they are also at risk for exposure to contaminants present in the Lower Columbia River and estuary, including toxicant inputs from large urban centers such as Portland, OR and Vancouver, WA.

Two recent reports, the Independent Scientific Advisory Board (ISAB) report entitled Columbia River Basin Food Webs: Developing a Broader Scientific Foundation for Fish and Wildlife Restoration (ISAB 2011), and the Environmental Protection Agency's Columbia River Basin State of the River Report for Toxics (EPA 2009) have drawn attention to the threat of toxic contaminants to salmon recovery in the Columbia Basin. The State of the River Report for Toxics (EPA 2009) highlighted dichlorodiphenyltrichloroethane (DDTs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and mercury as examples of contaminants of concern for the Columbia and Snake Rivers, based on the fact that these chemicals are found throughout the Columbia and Snake Basins, are persistent in the environment, contaminate food sources, increase in concentration in fish and birds, and pose risk to both humans and wildlife (EPA 2009).

Appendix C provides a more extensive overview of toxics information pertinent to the Snake River. In summary, mercury contamination is a potential risk within the Snake River Basin (IDEQ/ODEQ 2004, EPA 2009, Essig 2010, IOSC 2011). Additional contaminants that have received attention from NMFS because of their potential effects on listed salmonids include current use pesticides, polycyclic aromatic hydrocarbons (PAHs) and copper (NMFS 2008, 2009,

2010, 2011; LCREP 2007; Yanagida et al. 2011; Arkoosh et al. 2001; Johnson et al. 2007, 2001; Hecht et al. 2007). These contaminants may have adverse effects on Snake River salmon, and they are found at levels of concern in many locations throughout the Snake River basin.

In addition to these contaminant groups, there are many other contaminants of concern with potential effects on salmon that were identified in the State of the River Report for Toxics. These included metals such as arsenic and lead; radionuclides; combustion byproducts such as dioxin; and "contaminants of emerging concern" such as pharmaceuticals and personal care products. Additional information including geographically targeted studies on these contaminants is needed to evaluate their potential risk to threatened and endangered salmon.

Summary of Toxics Threats and Limiting Factors

Threats: Agricultural runoff, legacy mining contaminants, urban and industrial runoff, effluent, and wastes
Related limiting factors: contaminants such as DDTs, PCBs, PBDEs, metals, mercury, radionuclides, dioxin, etc., causing mortality, disease, reduced fitness

5.8 Climate Change

Likely changes in temperature, precipitation, wind patterns, and sea level height have implications for survival Snake River fall Chinook, in both their freshwater and marine habitats. Relevant recent descriptions of expected changes in Pacific Northwest climate include Elsner et al. (2009), Mantua et al. (2009), Mote and Salathe (2009), Salathe et al. (2009), Mote et al. (2010), and Chang and Jones (2010). Reviews of the effects of climate change on salmon and steelhead in the Columbia River Basin include ISAB (2007), NMFS (2010), and Hixon et al. (2010). The NMFS Northwest Fisheries Science Center will also be producing annual updates describing new information regarding effects of climate change relevant to salmon and steelhead as part of the FCRPS Adaptive Management Implementation Plan. The following is a short summary derived from the above sources of potential climate change effects that may be pertinent to Snake River fall Chinook.
Climate records show that the Pacific Northwest has warmed about 1.0 C since 1900, or about 50% more than the global average warming over the same period. The warming rate for the Pacific Northwest over the next century is projected to be in the range of 0.1-0.6 °C per decade. While total precipitation changes are predicted to be minor (+1-2%), increasing air temperature will alter the snow pack, stream flow timing and volume, and water temperature in the Columbia Basin (Figure 5-8).

Mainstem River and Tributary Habitat
Climate experts predict physical changes to rivers and streams in the Columbia Basin that include:

- Snow pack will diminish, and stream flow volume and timing will be altered. More winter flooding is expected in transitional and rainfall-dominated basins, and historically transient watersheds will experience lower late summer flows.

- A trend towards loss of snowmelt-dominant and transitional basins is predicted.
- Water temperatures will continue to rise, with <1 °C increase expected by the 2020s but 2-8 °C predicted by the 2080s. By the 2080s, the number of subbasins that exceed 21.5 °C is anticipated to double and thermal barriers >21 °C are expected to increase in duration from 1-5 weeks in the 1980s to 10-12 weeks in the 2080s.

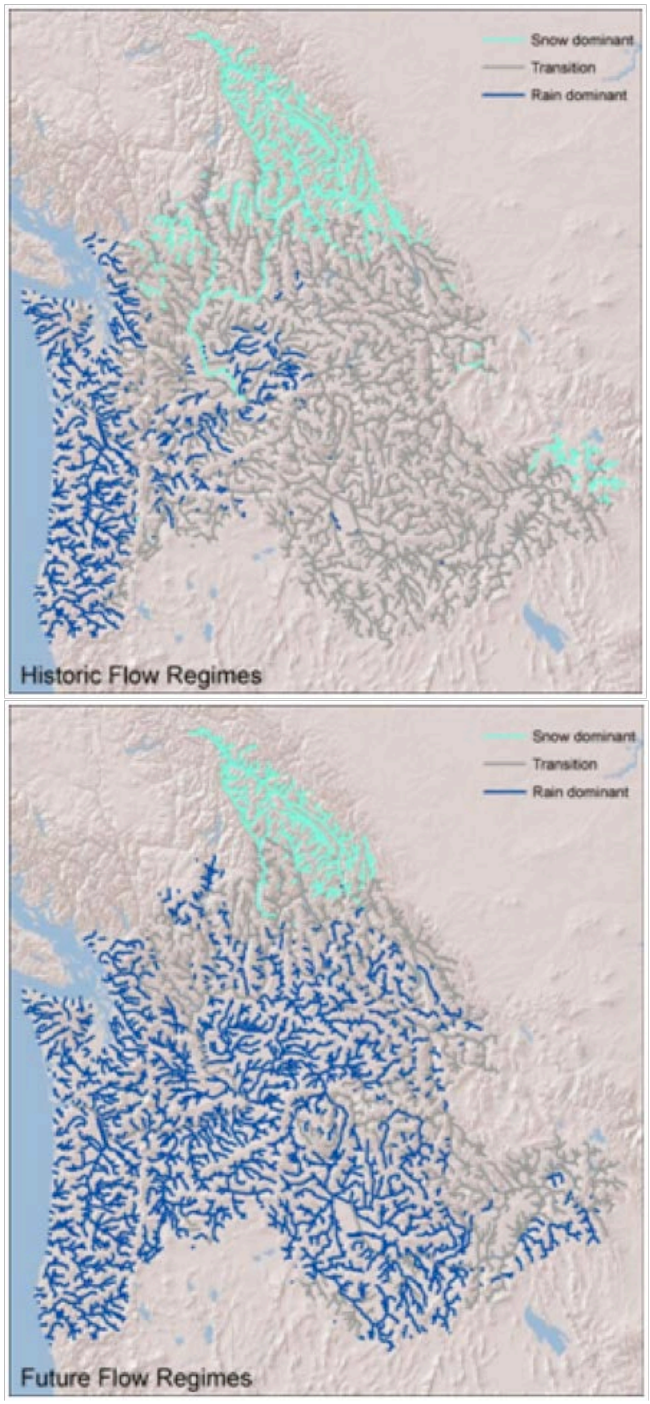


Figure 5-8. Preliminary maps of predicted hydrologic regime for (A) the period 1970-1999 and (B) the period 2070-2099 using emission scenario A1B and global climate model CGCM3.1(T47), based on classification of

annual hydrographs as in (Beechie et al. 2006). Data from University of Washington Climate Impacts Group (http://www.hydro.washington.edu/2860/).

These changes in air temperatures, river temperatures, and river flows are expected to cause changes in salmon and steelhead distribution, behavior, growth, and survival, in general. While the magnitude and timing of these changes and specific effects on Snake River fall Chinook are poorly understood at present they could include the following:

- Warmer water temperatures during incubation may result in earlier fry emergence, which could be either beneficial or detrimental, depending upon location and prey availability.
  - Warmer temperatures will increase metabolism, which may either increase or decrease juvenile growth rates and survival, depending upon availability of food.
  - Overwinter survival may be reduced if increased flooding in tributary streams reduces suitable habitat.
  - Timing of smolt migration may be altered such that there is a mismatch with ocean conditions and predators.
  - Higher temperatures may favor food competitors of juvenile fall Chinook, such as American shad, and reduced flow in late spring and summer may lead to delayed migration of juvenile fall Chinook and higher mortality passing dams.
  - Higher temperatures during adult migration may lead to increased mortality or reduced spawning success due to lethal temperatures, delay, increased fallback at dams, or increased susceptibility to disease and pathogens.

The degree to which phenotypic or genetic adaptations may partially offset these effects (e.g. if the population responds by
is being studied but is currently poorly understood.

Estuary Habitat

While Snake River fall Chinook appear to use the estuary less than other Chinook salmon ESUs with subyearling life histories, effects to the estuary could include:

- Warmer waters in shallow estuary rearing habitat.
- Increased sediment deposition and wave damage may reduce the quality of rearing habitat because of higher winter freshwater flows and higher sea level elevation.
- Lower freshwater flows in late spring and summer may lead to upstream extension of the salt wedge, possibly influencing the distribution of salmonid prey and predators.
- Increased temperature of freshwater inflows may extend the range of warm-adapted non-indigenous species that are normally found only in freshwater.

Marine Environment

Effects of climate change in marine environments include increased ocean temperature, increased stratification of the water column, changes in the intensity and timing of coastal upwelling, and ocean acidification. Hypotheses differ regarding whether coastal upwelling will decrease or intensify, but even if it intensifies, the increased stratification of the water column may reduce the ability of upwelling to bring nutrient-rich water to the surface.

There are also indications in climate models that future conditions in the North Pacific region will trend toward conditions that are typical of the warm phases of the Pacific Decadal Oscillation, but the models in general do not reliably reproduce the oscillation patterns. Hypoxic conditions observed along the continental shelf in recent years appear to be related to shifts in upwelling and wind patterns that may be related to climate change.

Climate-related changes in the marine environment are expected to alter primary and secondary productivity, the structure of marine communities, and, in turn, the growth, productivity, survival, and migrations of salmonids, although the degree of impact on listed salmonids currently is poorly understood. A mismatch between earlier smolt migrations (because of earlier peak spring freshwater flows and decreased incubation period) and altered upwelling may reduce marine survival rates. Ocean warming also may change migration patterns, increasing distances to feeding areas.

In addition, rising atmospheric carbon dioxide concentrations drive changes in seawater chemistry, increasing the acidification of seawater and thus reducing the availability of carbonate for shell-forming invertebrates, including some that are prey items for juvenile salmonids. This process of acidification is under way, has been well documented along the Pacific coast of the United States, and is predicted to accelerate with increasing greenhouse gas emissions.

Ocean acidification has the potential to reduce survival of many marine organisms, including salmon. However, because there is currently a paucity of research directly related to the effects of ocean acidification on salmon and their prey, potential effects are uncertain. Laboratory studies on salmonid prey taxa have generally indicated negative effects of increased acidification, but how this translates to the population dynamics of salmonid prey and the survival of salmon and steelhead is uncertain. Modeling studies that explore the ecological impacts of ocean acidification and other impacts of climate change concluded that salmon landings in the Pacific Northwest and Alaska are likely to be reduced.

Summary of Likely Impacts to Snake River fall Chinook.
It is possible that Snake River fall Chinook may be among those salmonids either least affected, or most likely to adapt to climate change effects on the mainstem and tributary habitat because 1) adults are able to avoid peak summer temperatures and still spawn, 2) juveniles will likely grow faster if winter/spring conditions are warmer and migrate earlier - avoiding elevated summer temperatures; and 3) use of tributary habitat seems to be limited by winter temperature minimums; and 4) they appear to rely less on estuary habitat than other Chinook salmon ESUs with subyearling life history patterns. However, they could be quite susceptible to changes in the Estuary and Ocean environments.

Summary of Climate Change Threats and Limiting Factors

Threat: Climate change: warmer air and water temperatures and increased acidification in the Pacific Northwest and ocean.