Key life history strategies and relationship to habitat

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Role of local adaptation
Local adaptation is thought to occur in salmonid populations. Such traits as; age and size of maturity, developmental rate, temperature tolerance, disease resistance, and morphology have all been postulated to be related to local adaptation.

Taylor (1997) suggested three criteria are needed to demonstrate local adaptation:

- A trait must have an additive genetic basis.
- Variability in expression of the trait must be associated with variability in survival, reproductive success, or some other component of fitness.
- The mechanisms by which natural selection acts on the trait to increase the trait must be identified.

Taylor (1997) suggests that local adaptation has never been *directly* demonstrated, but there have been numerous studies that show circumstantial evidence that it does exist. Such traits as swimming performance, temperature tolerance, and direction of migration (e.g., sockeye fry) all have been shown to be correlated with environmental variables.

It appears that salmonids have adapted life history strategies that allows them to "hedge their bets" against major catastrophic natural events, such as volcano eruptions and glaciation. There are many factors that must be considered in determining whether such things as genetic diversity play a significant role in a species' extinction risk. For example, Levin and Schiewe (2001) point out that the elephant seal has low biological (genetic) diversity but is not endanger of becoming extinct because of it. They pose the important challenge that fisheries biologists need to determine if salmon are like elephant seals.

However, such factors as the inability of many attempts to relocate salmonids to new habitat are evidence that salmonids have evolved specializations suited to particular environments (Levin and Schiewe 2001). While the possibility remains that some highly variable traits may not reflect genetic adaptations (i.e., that increase fitness), managers should ensure that populations are given a reasonable chance to express as much local adaptation as possible.

Evidence exists that demonstrate that apparent local adaptation may occur relatively rapidly. Hendry et al. (2000) demonstrated that sockeye in Lake Washington became reproductively isolated (as evidenced by swimming direction of fry and other life history characteristics) in as little as 13 generations. Quinn and Unwin (1993) showed that considerable phenotypic differences were found in chinook salmon in New Zealand. The suite of changes occurred in less than 20 generations. All of these fish had diverged from one donor stock, suggesting that environmental and genetic factors could lead to relatively rapid changes between independent populations.

In the Wenatchee Basin, there is ample evidence of relatively quick local adaptation. Populations of sockeye, chinook, and steelhead were thought to be in extremely low abundance by the 1930s (Fish and Hanavan 1948; Bryant and Parkhurst 1950; Mullan et al. 1992). The Grand Coulee Fish Maintenance Project, which was a mitigation project to compensate for construction of Grand Coulee Dam (see appendix _ for more detail), captured all salmonids ascending Rock Island Dam between 1939 and 1943.

Spring (and some later running fish in some years) chinook salmon and steelhead were released only in Nason Creek (and prevented from moving out of it by weirs) and released from the new fish hatchery on Icicle Creek. Most summer/fall chinook were released into a fenced section immediately downstream of Lake Wenatchee. Sockeye were released upstream of a rack at the outlet of Lake Wenatchee and released from Icicle Creek.

Since the GCFMP, the largest percentage of spring chinook spawn in the Chiwawa River followed by Nason Creek, the upper Wenatchee River, and the White/Little Wenatchee rivers. There is some evidence that spring chinook in the White River may be distinct (based on genetic markers) from other spring chinook in the Wenatchee Basin. It is important to note that the salmon used in the GCFMP were an admixture of fish destined for *all* tributaries upstream of Rock Island Dam, and therefore the fish that were released or spawned in the Wenatchee River were not “adapted” to the local conditions (although there may have been a very small percentage (based on Tumwater Dam counts) of fish that originated from the basin). In summary, the circumstantial information suggests that substantial changes in spawning distribution, and perhaps adaptation have taken place in as little as two to five generations (redd counts began in the late 1950s).

Summer/fall chinook released as part of the GCFMP were an admixture of fish ascending Rock Island Dam, and “forced” to spawn in historic habitat of the upper Wenatchee and released into Icicle Creek. Since the GCFMP, these fish have increased their spawning distribution throughout the mainstem Wenatchee River again, in as little as two to five generations).

The admixture of steelhead spawned in Nason Creek and released in Icicle Creek has spread throughout the Wenatchee River. However, since non-migratory forms that were not impacted by the GCFMP may have resided in spawning tributaries, it is more difficult to draw inferences about the potential amount of local adaptation that has occurred since the GCFMP.

Most sockeye salmon captured at Rock Island Dam during the GCFMP were from fish destined upstream of the Grand Coulee Dam site (Chapman et al. 1995 CPb). Since the GCFMP, these fish have established spawning populations in The Little Wenatchee and White Rivers. Genetic studies have shown these fish to be distinct from those that have been established in the Okanogan River. This adaptation to Lake Wenatchee was first indicated by returning fish in the 1940s and 1950s, and genetic samples were first done in the 1980s. The available information suggests divergence of this population within 2-10 generations.

While the GCFMP attempted to reestablish coho salmon from the very low numbers of fish that they were able to trap, these attempts were unsuccessful, as were other attempts through released of exogenous stocks.

While habitat disturbances have impacted westslope cutthroat and bull trout, it is not likely that local adaptation has changed significantly from historic, although some populations within the basin may have had to adapt to changes in migration conditions and perhaps other impacts, but this is difficult to determine because of the lack of historical information.

Below, we discuss key life stages of focal species and their relationship to the habitats they use during these stages.

Spring chinook

Time of entry and spawning

Adult spring chinook begin entering the Wenatchee River basin in May. Spawning begins in very late July through September, peaking in mid- to late August (Chapman et al. 1995 CPa). The onset of spawning in a stream reach is temperature driven (usually when temperatures drop below 16 °C). Temperature may be influenced by riparian conditions. Nason Creek has probably been most affected by loss of riparian and geofluvial process that could affect temperature.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Wenatchee or natal tributaries. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Healy (1991) reports the range of depths of spawning as between 41 to > 700 cm (~1-23 ft) and velocities of between 10 to 150 cm/s (.33-5 ft/s) for chinook salmon (this includes ocean-type chinook too). Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Healy (1991) reports that incubation and emergence success was related to oxygen levels and percolation through the gravel. When percolation was 0.03 cm/s (0.001 ft/s), survival to hatching was 97%. However, emergence reduced to 13% when percolation was 0.06 cm/s (0.002 ft/s). When oxygen fell below 13 ppm, mortality of eggs increased from 3.9% at 13 ppm to about 38% at 5 ppm.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include ocean-type chinook too).

In the Wenatchee Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. However, Nason Creek because of its location near a railroad and major highway has long term restoration needs that could most likely increase incubation success, although empirical information is needed to determine if this is a need first.

Fry

Spring chinook fry utilize near-shore areas, primarily eddies, within and behind large woody debris, undercut tree roots, or other cover (Hillman et al. 1989a; Healy 1991). Conservation and restoration of riparian areas of natal streams within the Wenatchee Basin would increase the type of habitat that fry utilize.

Parr

Downstream movement of parr from natal streams is well documented. French and Wahle (1959) found that juvenile chinook migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Since 1992, sampling by WDFW has found spring chinook emigrating from the Chiwawa River as pre-smolts from late summer through the fall. In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; A. Murdoch, WDFW, personal communication).

Movement of juvenile chinook from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Bjornn (1971) related subyearling chinook movement in an Idaho stream indirectly to declining temperature in the stream as fish try to find suitable overwintering habitat. Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery- produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of subyearlings from the mainstem Wenatchee River. This may or may not be true of the higher order streams that feed the upper reaches of the Wenatchee River, which produce most of the spring chinook in that basin. Hillman et al. (1989 CPa) related subyearling chinook movement from an Idaho stream to declining temperatures, but acknowledged that it may consist of fish seeking higher-quality winter habitat, as suggested by Bjornn (1971).

Hillman and Chapman (1989) found that Tumwater Canyon is where most fish rear over the winter before their smolt migration begins in the spring. During the daytime, juvenile chinook used instream and overhead cover extensively, although as they got larger (and stream flows reduced), they sought areas that were deeper and higher velocity (Hillman et al. 1989 CPa). Substrate preference also changed as the juvenile chinook got larger and hydraulic conditions changed from predominantly sand, large boulder, and bedrock to sand, sand-gravel, and cobble. As temperatures dropped below 10 °C, salmon were observed primarily near boulder rip-rap, or concealed themselves in the substrate.

During nighttime hours during the warmer months, chinook moved inshore and rested all night in shallow, quiet water (Hillman et al. 1989 CPb). In the colder months, chinook sought deeper water with larger substrate.

Conservation of high functioning habitat in natal tributaries and Tumwater Canyon, restoration of riparian and geofluvial processes in or near known and potential parr rearing areas will have the highest likelihood of increasing parr survival.

Smolt

Wenatchee River spring chinook smolts begin migrating in March from natal areas. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Summer/fall chinook

Time of entry and spawning

Adult summer/fall chinook begin entering the Wenatchee River basin in June. Spawning begins in very late September through mid November, peaking in mid- to late October. The onset of spawning in a stream reach is temperature driven (usually when temperatures drop below 16 °C). Temperatures in the mainstem Wenatchee are influenced by climate, Lake Wenatchee, and tributary flows.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Wenatchee. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase or maintain the occurrence of deeper pools.

Redd characteristics

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150 cm/s (.33-5 ft/s) for chinook salmon (this includes spring-type chinook too). Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

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Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include spring-type chinook too).

In the Wenatchee Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. Because of naturally occurring conditions and major events like fire, Peshastin, Mission, and Icicle creeks have had heavy sediment load events in the last 10-15 years. Most of the spawning area for Wenatchee summer/fall chinook occurs upstream of these tributaries.

Fry

Fry emerge mostly in April and May. Most subyearling summer/fall chinook leave the Wenatchee River within a few weeks after emergence. Beak (1980) found that weekly catches of chinook salmon fry declined sharply from over 700 in early June to about 25 in early July, then to zero by early August. This decline comports well with the observations of Hillman and Chapman (1989). Hillman and Chapman (1989) also demonstrated that the rate of emigration of subyearling chinook was highest in June, then declined through the summer.

Summer/fall chinook fry utilize near-shore areas, primarily eddies, within and behind large woody debris, undercut tree roots, or other cover (Hillman et al. 1989a; Healy 1991). They noted that in the spring this type of habitat was scarce in the Wenatchee River, but where it did occur, it was fully occupied. Conservation and restoration of riparian areas and increases in off-channel habitat in the lower Wenatchee Basin may increase the type of habitat that summer/fall chinook fry utilize, although they may still emigrate through the system without utilizing these habitats.

Sockeye

Time of entry and spawning

Adult sockeye begin entering the Wenatchee River basin in late June. Spawning takes place in September. The onset of spawning in a stream reach is temperature driven. Temperature may be influenced by riparian conditions. Conserving riparian areas in the White and Little Wenatchee rivers will help ensure that remaining important spawning habitat stays intact.

Prespawning

Adults may hold in the deeper pools and under cover of the mainstem Wenatchee until arriving in Lake Wenatchee, where they hold prior to spawning. The availability of and number of deep pools and cover may be important to offset potential prespawning mortality, but most holding occurs in the lake. Preservation of the lake environment that ensures stratification (they appear to hold below the thermocline) is important at this stage.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Depth of water does not seem to be critical for sockeye spawning (Burgner 1991; Chapman et al. 1995 CPb). Sockeye appear to choose lower water velocity water to spawn compared to other salmonids (Wydoski and Whitney 2003). Allen and Meekin (1980) found velocities over spawning areas ranging from 0.56 to 3.34 fps, and average 1.52 fps. Conservation of remaining naturally geofluvial processes in the White and Little Wenatchee rivers, and restoration of areas that may have been affected by previous land use activities will ensure quality spawning habitat remains.

Incubation and emergence

Egg incubation usually lasts between 50-140 days, which is primarily dependent on temperature (in Chapman et al. 1995 CPb). Emergence of sockeye occurs in the Wenatchee Basin in March through April (Allen and Meekin 1973, 1980).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Chapman et al. (1995 CPb) compiled information for sockeye throughout their range for various life stage survivals. Incubation survival generally ranged from 25-60%, although some measurements were at both extremes (0%; 100%). Allen and Meekin reported that incubation for Wenatchee sockeye was 0-100%. Egg to fry survival ranged below 10% to slightly less than 50% for sockeye throughout their range.

In the Wenatchee Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. Conservation of existing conditions (e.g., riparian, old growth forest, etc.) within the upper watersheds of the Little Wenatchee and White rivers will help ensure that floods will have less of an impact.

Fry

After fry emerge primarily at night, they begin their movement towards Lake Wenatchee (Chapman et al. 1995 CPb). During daylight hours, fry hide under stones and within debris, and begin moving again at dawn. Because of the relatively short distance that fry would have to migrate to Lake Wenatchee, it is reasonable to assume that they can reach the lake within one night under most conditions. Fry appear to arrive in Lake Wenatchee between March and May.

After fry enter a lake, they may either move immediately offshore, or remain in limnetic areas to rear until zooplankton production increases offshore (Burgner 1991; Chapman et al. 1995 CPb). In Lake Wenatchee, Chapman et al. (1995 CPb) reported that Allen and Meekin (1980) did not find fry in near-shore areas during their surveys in the 1970s, but felt that it was reasonable to assume that this behavior did occur because of the conditions fry encounter when they enter the lake.

Since fry enter Lake Wenatchee at its western shore, where there is currently minimal development, conserving this area as potential sockeye rearing habitat may help overall sockeye production. Other near-shore habitat has been and is currently affected by land use activities. However, most of the other shoreline habitats do not have large limnetic areas because of a sharp drop off to deeper waters, so restoration of these areas may not increase production to a great degree, although there may still be certain areas (primarily along the north shore) that would benefit from restoration factors.

Parr

Sockeye juveniles have complex diel vertical migration patterns to balance risk of being preyed upon to finding food. Chapman et al. (1995 CPb) cite Brett (1980) who concluded that the vertical migration doesn't begin until the nursery lake stratifies. In general, juveniles seek cold, dark water (below the thermocline) in the day, rise towards the surface at dusk, feed, and then hold below the surface waiting for dawn when they feed again before migrating down again (Burgner 1991; Chapman et al. 1995 CPb). Chapman et al. (1995 CPb) noted that Lake Wenatchee does not typically develop a strong thermocline and temperatures and dissolved oxygen conditions allow sockeye to use all depths throughout all photic regions within the lake.

Lake Wenatchee is an oligotrophic lake; cold, well-oxygenated, but infertile. Historically, many septic systems may have leaked into the lake. The overall effect may have been increases in zooplankton, which may have had a positive affect on sockeye production. Recently, the formation of a waste water system may have reduced the production of sockeye, although this is speculative in nature.

Bull trout have evolved with sockeye. Historically, bull trout numbers were reduced from fishing pressure. Since they were listed as threatened in 1998, fishing pressure has been either reduced or eliminated. Increases of bull trout have been observed on the spawning grounds, and has probably had an effect on the production of sockeye in the lake.

Maintaining the high quality functionality of Lake Wenatchee, while minimizing the impacts of current land use practices are the factors that may either maintain or increase sockeye productivity. Adding nutrients to Lake Wenatchee in a balanced manner would undoubtedly increase the production of sockeye.

Smolt

Wenatchee River sockeye smolts begin migrating from Lake Wenatchee in April. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Steelhead

Time of entry and spawning

Adult steelhead enter the Wenatchee River basin from August through the following April. Spawning begins in very late March through May, peaking in mid- to late April (Murdoch and Viola 2003). The onset of spawning in a stream reach is temperature driven. Other factors may influence steelhead spawning compared to salmon species because of the time of year spawning occurs.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Wenatchee or natal tributaries. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Wydoski and Whitney (2003) report that spawning is usually found at a mean depth of 0.7 to 1.34 ft and water velocities of 1.8 to 2.3 fps. Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Incubation success is dependent on factors such as water flow through the redds and temperature (Pauley et al. 1986). Eggs usually hatch in 4 to 7 weeks and fry emerge 2 to 3 weeks after that (Shapovalov and Taft 1954).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Wenatchee Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. However, Nason Creek because of its location near a railroad and major highway has long term restoration needs that could most likely increase incubation success, although empirical information is needed to determine if this is a need first.

Fry

In the Wenatchee River, Hillman and Chapman (1989) found most juvenile steelhead rearing in Tumwater Canyon. During daylight, age-0 steelhead used slower, shallower water than chinook, stationed individually over small boulder and cobble substrate (Hillman et al. 1989 CPa). As they grew, they picked deeper and faster habitat over cobble and boulders. As with chinook juveniles, in winter, they concealed themselves in interstitial spaces among boulders near the stream bank, but did not cluster together. No interaction was observed between chinook and steelhead at anytime (Hillman et al. CPa, CPb).

During nighttime hours, steelhead moved downstream and closer to shore. At dawn, steelhead moved upstream. Most steelhead chose sand and boulder substrates, and during winter, chose deeper, larger substrate (Hillman et al. 1989 CPb).

Hillman and Miller (2002) remarked that in ten years of surveying the Chiwawa River, age-0 steelhead most often used riffle and multiple channel habitats, but were also found associated with debris in poll and glide habitat.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Wenatchee Basin would increase the type of habitat that fry utilize.

Parr

Downstream movement of parr from natal streams occurs within the Wenatchee Basin (Murdoch et al. 2001). French and Wahle (1959) found that juvenile steelhead migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Since 1992, sampling by WDFW has found steelhead emigrating from the Chiwawa River as pre-smolts beginning in spring, but primarily in the fall. In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; A. Murdoch, WDFW, personal communication).

Movement of juvenile steelhead from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery- produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of chinook and steelhead juveniles from the mainstem Wenatchee River.

Hillman and Chapman (1989) found that most steelhead remained in Tumwater Canyon area to rear through all seasons. The amount of habitat diversity and complexity in this reach compared to other reaches was believed to be responsible for this behavior.

Conservation of high functioning habitat in natal tributaries and Tumwater Canyon, restoration of riparian and geofluvial processes in or near known and potential parr rearing areas will have the highest likelihood of increasing parr survival.

Smolt

Wenatchee River steelhead smolts begin migrating in March from natal areas. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Bull trout

Spawning

Bull trout spawn in the Wenatchee River basin from August through September. The onset of spawning in a stream reach is temperature driven, apparently at the onset of dropping temperatures.

Prespawning

When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Fraley and Shepard (1989) characterized selected areas as having low compaction and low gradient, and potentially near upwelling influences and proximity to cover. In general, mean velocities over redds range from 0.13-2.0 fps, with water depth ranging from 0.71-2.0 ft. Brown (1992) noted that these metrics comported well with those found within the Wenatchee Basin.

Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Optimum incubation for bull trout is lower than other salmonids (2-4 °C; in Brown 1992). Because of the lower temperatures, bull trout development within the redd is usually longer than other salmonids. Emergence may take another three weeks after hatching.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Wenatchee Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. However, Nason Creek because of its location near a railroad and major highway has long term restoration needs that could most likely increase incubation success, although empirical information is needed to determine if this is a need first.

Because bull trout development within the redd takes a long period of time, they may be more vulnerable to increases in sediments or degradation other water quality (Fraley and Shepard 1989).

Fry

Fry (< 100 mm) are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris. Age-0 bull trout are consistently found near the substrate, usually over gravel-cobble areas.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Wenatchee Basin would increase the type of habitat that fry utilize.

Parr

Hillman and Miller (2002) state that most juvenile bull trout are consistently found in multiple channels, pool, and riffles, and a few in glides. Juveniles were found in association with the stream bottom over rubble and small boulder substrate or near woody debris.

Downstream movement of juveniles (> 100 mm) from natal streams occurs within the Wenatchee Basin (Murdoch et al. 2001). Since 1992, sampling by WDFW has found bull trout emigrating from the Chiwawa River, having two modes; one in spring, and the other in the fall.

Movement of juvenile bull trout from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Murdoch et al. (2001) also speculated that movement in the fall may also be correlated to the size and age at which bull trout become piscivorous. Most of the juveniles emigrating from the Chiwawa River are most likely migrating to Lake Wenatchee (Kelly-Ringold and DeLavergne 2003).

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that is limiting bull trout production in the Wenatchee Basin is competition with brook trout. Brook trout are found in most areas that bull trout are found (Hillman and Miller 2002).

Westslope cutthroat trout

Spawning

Westslope cutthroat trout (WSCT) spawn between March and July, when water temperatures begin to warm. Spawning and rearing streams tend to be cold and nutrient poor.

Prespawning

When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Adult cutthroat trout need deep, slow moving pools that do not fill with anchor ice in order to survive the winter. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. USFWS (1999) state that WSCT redds are usually found in water that is about 0.7 ft deep with mean velocities of 1.0 to 1.3 fps.

Incubation and emergence

Eggs incubate for several weeks and emergence occurs several days after hatching (USFWS 1999).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and

Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Wenatchee Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. However, Nason Creek because of its location near a railroad and major highway has long term restoration needs that could most likely increase incubation success, although empirical information is needed to determine if this is a need first.

Fry

After emergence, fry are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Wenatchee Basin would increase the type of habitat that fry utilize.

Parr

Juvenile cutthroat trout overwinter in the interstitial spaces of large stream substrate. Hillman and Miller (2002) state that most juvenile WSCT are consistently found in multiple channels and pools.

Downstream movement of juveniles from natal streams occurs within the Wenatchee Basin (Murdoch et al. 2001). Since 1992, sampling by WDFW has found WSCT emigrating from the Chiwawa River.

Movement of juvenile WSCT within streams is most likely related to changing habitat requirements as the fish grows, or winter refuge.

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that is limiting WSCT production in the Wenatchee Basin is competition with brook trout. Brook trout are found in many areas that WSCT are found (Hillman and Miller 2002).

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Entiat Subbasin

Role of local adaptation
Local adaptation is thought to occur in salmonid populations. Such traits as; age and size of maturity, developmental rate, temperature tolerance, disease resistance, and morphology have all been postulated to be related to local adaptation.

Taylor (1997) suggested three criteria are needed to demonstrate local adaptation:

- A trait must have an additive genetic basis.
- Variability in expression of the trait must be associated with variability in survival, reproductive success, or some other component of fitness.
- The mechanisms by which natural selection acts on the trait to increase the trait must be identified.

Taylor (1997) suggests that local adaptation has never been *directly* demonstrated, but there have been numerous studies that show circumstantial evidence that it does exist. Such traits as swimming performance, temperature tolerance, and direction of migration (e.g., sockeye fry) all have been shown to be correlated with environmental variables.

It appears that salmonids have adapted life history strategies that allows them to "hedge their bets" against major catastrophic natural events, such as volcano eruptions and glaciation. There are many factors that must be considered in determining whether such things as genetic diversity play a significant role in a species' extinction risk. For example, Levin and Schiewe (2001) point out that the elephant seal has low biological (genetic) diversity but is not endanger of becoming extinct because of it. They pose the important challenge that fisheries biologists need to determine if salmon are like elephant seals.

However, such factors as the inability of many attempts to relocate salmonids to new habitat are evidence that salmonids have evolved specializations suited to particular environments (Levin and Schiewe 2001). While the possibility remains that some highly variable traits may not reflect genetic adaptations (i.e., that increase fitness), managers should ensure that populations are given a reasonable chance to express as much local adaptation as possible.

Evidence exists that demonstrate that apparent local adaptation may occur relatively rapidly. Hendry et al. (2000) demonstrated that sockeye in Lake Washington became reproductively isolated (as evidenced by swimming direction of fry and other life history characteristics) in as little as 13 generations. Quinn and Unwin (1993) showed that considerable phenotypic differences were found in chinook salmon in New Zealand. The suite of changes occurred in less than 20 generations. All of these fish had diverged from one donor stock, suggesting that environmental and genetic factors could lead to relatively rapid changes between independent populations.

In the Entiat Basin, there is evidence of relatively quick local adaptation. Populations of chinook and steelhead were thought to be in extremely low abundance by the 1930s (Fish and Hanavan 1948; Bryant and Parkhurst 1950; Mullan et al. 1992). The Grand Coulee Fish Maintenance Project, which was a mitigation project to compensate for construction of Grand Coulee Dam (see appendix _ for more detail), captured all salmonids ascending Rock Island Dam between 1939 and 1943.

Steelhead (1939 only) and summer/fall chinook (1939, 1940) were released in the Entiat River (and prevented from moving out of it by weirs) and released from the new fish hatchery.

Since the GCFMP, spring chinook spawn in the mainstem Entiat and Mad rivers. It is important to note that the salmon used in the GCFMP were an admixture of fish destined for *all* tributaries upstream of Rock Island Dam, and therefore the fish that were released or spawned in the Entiat River were not "adapted" to the local conditions (although there may have been a very small percentage of fish that originated from the basin). In summary, the circumstantial information suggests that changes in spawning distribution, and perhaps adaptation have taken place in as little as two to five generations (redd counts began in the late 1950s).

Summer/fall chinook were not thought to have inhabited the Entiat River prior to released of fish through the GCFMP (see Chapman et al. 1994 or appendix _) Since the GCFMP, a small population has been established, in as little as two to five generations.

The admixture of steelhead spawned in Entiat River or released from the hatchery has increased their spawning distribution. However, since non-migratory forms that were not impacted by the GCFMP may have resided in spawning tributaries, it is more difficult to draw inferences about the potential amount of local adaptation that has occurred since the GCFMP.

Sockeye salmon did not inhabit the Entiat River historically. However, as part of the GCFMP, fish were released from the Hatchery. A very small population is still seen occasionally. It is not known if these fish are naturally reproducing or "strays" from other populations.

While the GCFMP attempted to reestablish coho salmon from the very low numbers of fish that they were able to trap, these attempts were unsuccessful, as were other attempts through released of exogenous stocks.

While habitat disturbances have impacted westslope cutthroat and bull trout, it is not likely that local adaptation has changed significantly from historic, although some populations within the basin may have had to adapt to changes in migration conditions and perhaps other impacts, but this is difficult to determine because of the lack of historical information.

Below, we discuss key life stages of focal species and their relationship to the habitats they use during these stages.

Spring chinook

Time of entry and spawning

Adult spring chinook begin entering the Entiat River basin in May. Spawning begins in very late July through September, peaking in mid- to late August (Chapman et al. 1995 CPa). The onset of spawning in a stream reach is temperature driven (usually when temperatures drop below 16 °C). Temperature may be influenced by riparian conditions. Land use within the Entiat and Mad rivers has affected riparian areas, conservation of remaining areas of riparian and restoration of riparian areas will increase production for many life stages.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Entiat or Mad rivers. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Healy (1991) reports the range of depths of spawning as between 41 to > 700 cm (~1-23 ft) and velocities of between 10 to 150 cm/s (.33-5 ft/s) for chinook salmon (this includes ocean-type chinook too). Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Healy (1991) reports that incubation and emergence success was related to oxygen levels and percolation through the gravel. When percolation was 0.03 cm/s (0.001 ft/s), survival to hatching was 97%. However, emergence reduced to 13% when percolation was 0.06 cm/s (0.002 ft/s). When oxygen fell below 13 ppm, mortality of eggs increased from 3.9% at 13 ppm to about 38% at 5 ppm.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include ocean-type chinook too).

In the Entiat Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry

Spring chinook fry utilize near-shore areas, primarily eddies, within and behind large woody debris, undercut tree roots, or other cover (Hillman et al. 1989a; Healy 1991). Conservation and restoration of riparian areas of natal streams within the Entiat Basin would increase the type of habitat that fry utilize.

Parr

Downstream movement of parr from natal streams is well documented. French and Wahle (1959) found that juvenile chinook migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Since 1992, sampling by WDFW has found spring chinook emigrating from the Chiwawa River as pre-smolts from late summer through the fall. In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; A. Murdoch, WDFW, personal communication). A similar movement of parr probably occurs in the Entiat River.

Movement of juvenile chinook from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Bjornn (1971) related subyearling chinook movement in an Idaho stream indirectly to declining temperature in the stream as fish try to find suitable overwintering habitat. Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery- produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of subyearlings from the mainstem Wenatchee River. This may or may not be true of the areas of the Entiat River which produce most of the spring chinook in that basin. Hillman et al. (1989) related subyearling chinook movement from an Idaho stream to declining temperatures, but acknowledged that it may consist of fish seeking higher-quality winter habitat, as suggested by Bjornn (1971).

Mullan et al. (1992) found most of the chinook rearing in Entiat rivermiles 3-6. In the Wenatchee River during the daytime, juvenile chinook used instream and overhead cover extensively, although as they got larger (and stream flows reduced), they sought areas that were deeper and higher velocity (Hillman et al. 1989 CPa). Substrate preference also changed as the juvenile chinook got larger and hydraulic conditions changed from predominantly sand, large boulder, and bedrock to sand, sand-gravel, and cobble. As temperatures dropped below 10 °C, salmon were observed primarily near boulder rip-rap, or concealed themselves in the substrate.

During nighttime hours during the warmer months, chinook moved inshore and rested all night in shallow, quiet water (Hillman et al. 1989 CPb). In the colder months, chinook sought deeper water with larger substrate. Entiat River spring chinook most likely use similar habitats as those in the Wenatchee River.

Conservation of high functioning habitat in the Entiat and Mad rivers, restoration of riparian and geofluvial processes in or near known and potential parr rearing areas will have the highest likelihood of increasing parr survival.

Smolt

Entiat River spring chinook smolts begin migrating in March from natal areas. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Summer/fall chinook

Time of entry and spawning

Adult summer/fall chinook begin entering the Entiat River basin in June. Spawning begins in very late September through mid November, peaking in mid- to late October. The onset of spawning in a stream reach is temperature driven (usually when temperatures drop below 16 °C). Temperatures in the mainstem Entiat are influenced by climate and tributary flows.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Entiat. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase or maintain the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Healy (1991) reports the range of depths of spawning as between 41 to > 700 cm (~1-23 ft) and velocities of between 10 to 150 cm/s (.33-5 ft/s) for chinook salmon (this includes spring-type chinook too). Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Healy (1991) reports that incubation and emergence success was related to oxygen levels and percolation through the gravel. When percolation was 0.03 cm/s (0.001 ft/s), survival to hatching was 97%. However, emergence reduced to 13% when percolation was 0.06 cm/s (0.002 ft/s). When oxygen fell below 13 ppm, mortality of eggs increased from 3.9% at 13 ppm to about 38% at 5 ppm.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include spring-type chinook too).

In the Entiat Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. Because of naturally occurring conditions and major events like fire, tributary creeks have had heavy sediment load events in the last 10-15 years.

Fry

Fry emerge mostly in April and May. Most subyearling summer/fall chinook leave the probably leave the Entiat River within a few weeks after emergence, as has been observed within the Wenatchee River. In the Wenatchee River, Hillman and Chapman (1989) demonstrated that the rate of emigration of subyearling chinook was highest in June, then declined through the summer.

Summer/fall chinook fry utilize near-shore areas, primarily eddies, within and behind large woody debris, undercut tree roots, or other cover (Hillman et al. 1989a; Healy 1991). They noted that in the spring this type of habitat was scarce in the Wenatchee River, but where it did occur, it was fully occupied. Conservation and restoration of riparian areas and increases in off-channel habitat in the lower Entiat Basin may increase the type of habitat that summer/fall chinook fry utilize, although they may still emigrate through the system without utilizing these habitats.

Steelhead

Time of entry and spawning

Adult steelhead enter the Entiat River basin from August through the following April. Spawning begins in very late March through April, potentially going into May, peaking in mid- to late April in the Mad River (Archibald 2003). The onset of spawning in a stream reach is temperature driven. Other factors may influence steelhead spawning compared to salmon species because of the time of year spawning occurs.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Entiat River or natal tributaries. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Wydoski and Whitney (2003) report that spawning is usually found at a mean depth of 0.7 to 1.34 ft and water velocities of 1.8 to 2.3 fps. Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Incubation success is dependent on factors such as water flow through the redds and temperature (Pauley et al. 1996). Eggs usually hatch in 4 to 7 weeks and fry emerge 2 to 3 weeks after that (Shapovalov and Taft 1954).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Entiat Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry

In the Wenatchee River, Hillman and Chapman (1989) found most juvenile steelhead rearing in Tumwater Canyon. During daylight, age-0 steelhead used slower, shallower water than chinook, stationed individually over small boulder and cobble substrate (Hillman et al. 1989 CPa). As they grew, they picked deeper and faster habitat over cobble and boulders. As with chinook juveniles, in winter, they concealed themselves in interstitial spaces among boulders near the stream bank, but did not cluster together. No interaction was observed between chinook and steelhead at anytime (Hillman et al. CPa, CPb).

During nighttime hours, steelhead moved downstream and closer to shore. At dawn, steelhead moved upstream. Most steelhead chose sand and boulder substrates, and during winter, chose deeper, larger substrate (Hillman et al. 1989 CPb).

Hillman and Miller (2002) remarked that in ten years of surveying the Chiwawa River, age-0 steelhead most often used riffle and multiple channel habitats, but were also found associated with debris in poll and glide habitat.

It is reasonable to assume that Entiat Basin steelhead utilize similar habitats as those in the Wenatchee Basin.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Entiat Basin would increase the type of habitat that fry utilize.

Parr

Downstream movement of parr from natal streams occurs within the Wenatchee Basin (Murdoch et al. 2001). French and Wahle (1959) found that juvenile steelhead migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Since 1992, sampling by WDFW has found steelhead emigrating from the Chiwawa River as pre-smolts beginning in spring, but primarily in the fall. In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; A. Murdoch, WDFW, personal communication). Similar timing of movement probably occurs in the Entiat Basin.

Movement of juvenile steelhead from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery- produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of chinook and steelhead juveniles from the mainstem Wenatchee River. It is reasonable to assume that similar behavior is seen in Entiat River steelhead.

Mullan et al. (1992) found that most steelhead reared in the lower portions of the Entiat and Mad rivers. The amount of habitat diversity and complexity in these reaches compared to other reaches was believed to be responsible for this behavior.

Conservation of high functioning habitat in natal tributaries and the Mad and Entiat rivers, restoration of riparian and geofluvial processes in or near known and potential parr rearing areas will have the highest likelihood of increasing parr survival.

Smolt

Entiat River steelhead smolts begin migrating in March from natal areas. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Bull trout

Spawning

Bull trout spawn in the Entiat River basin from August through September. The onset of spawning in a stream reach is temperature driven, apparently at the onset of dropping temperatures.

Prespawning

When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Fraley and Shepard characterized selected areas as having low compaction and low gradient, and potentially near upwelling influences and proximity to cover. In general, mean velocities over redds range from 0.13-2.0 fps, with water depth ranging from 0.71-2.0 ft. Brown (1992) noted that these metrics comported well with those found within the Entiat Basin. Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Optimum incubation for bull trout is lower than other salmonids (2-4 °C; in Brown 1992). Because of the lower temperatures, bull trout development within the redd is usually longer than other salmonids. Emergence may take another three weeks after hatching.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Entiat Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Because bull trout development within the redd takes a long period of time, they may be more vulnerable to increases in sediments or degradation other water quality (Fraley and Shepard 1989).

Fry

Fry (< 100 mm) are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris. Age-0 bull trout are consistently found near the substrate, usually over gravel-cobble areas.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Entiat Basin would increase the type of habitat that fry utilize.

Parr

Hillman and Miller (2002) state that most juvenile bull trout are consistently found in multiple channels, pool, and riffles, and a few in glides. Juveniles were found in association with the stream bottom over rubble and small boulder substrate or near woody debris.

Downstream movement of juveniles (> 100 mm) from natal streams probably occurs within the Entiat Basin. Since 1992, sampling by WDFW has found bull trout emigrating from the Chiwawa River, having two modes; one in spring, and the other in the fall.

Movement of juvenile bull trout from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Murdoch et al. (2001) also speculated that movement in the fall may also be correlated to the size and age at which bull trout become piscivorous.

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that may have impacts on bull trout production in the Entiat Basin is competition with brook trout. Brook trout are found in the upper Entiat, but may not be distributed throughout the basin (P. Archibald, USFS).

Westslope cutthroat trout

Spawning

Westslope cutthroat trout (WSCT) spawn between March and July, when water temperatures begin to warm. Spawning and rearing streams tend to be cold and nutrient poor.

Prespawning

When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Adult cutthroat trout need deep, slow moving pools that do not fill with anchor ice in order to survive the winter. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. USFWS (1992) state that WSCT redds are usually found in water that is about 0.7 ft deep with mean velocities of 1.0 to 1.3 fps.

Incubation and emergence

Eggs incubate for several weeks and emergence occurs several days after hatching (USFWS 1999).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Entiat Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry

After emergence, fry are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Entiat Basin would increase the type of habitat that fry utilize.

Parr

Juvenile cutthroat trout overwinter in the interstitial spaces of large stream substrate. Hillman and Miller (2002) state that most juvenile WSCT are consistently found in multiple channels and pools.

Downstream movement of juveniles from natal streams probably occurs within the Entiat Basin.

Movement of juvenile WSCT within streams is most likely related to changing habitat requirements as the fish grows, or winter refuge.

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that may have impacts on bull trout production in the Entiat Basin is competition with brook trout. Brook trout are found in the upper Entiat, but may not be distributed throughout the basin (P. Archibald, USFS).

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Lake Chelan Subbasin

Role of local adaptation

Local adaptation is thought to occur in salmonid populations. Such traits as; age and size of maturity, developmental rate, temperature tolerance, disease resistance, and morphology have all been postulated to be related to local adaptation.

Taylor (1997) suggested three criteria are needed to demonstrate local adaptation:

- A trait must have an additive genetic basis.
- Variability in expression of the trait must be associated with variability in survival, reproductive success, or some other component of fitness.
- The mechanisms by which natural selection acts on the trait to increase the trait must be identified.

Taylor (1997) suggests that local adaptation has never been *directly* demonstrated, but there have been numerous studies that show circumstantial evidence that it does exist. Such traits as swimming performance, temperature tolerance, and direction of migration (e.g., sockeye fry) all have been shown to be correlated with environmental variables.

It appears that salmonids have adapted life history strategies that allows them to "hedge their bets" against major catastrophic natural events, such as volcano eruptions and glaciation. There are many factors that must be considered in determining whether such things as genetic diversity play a significant role in a species' extinction risk. For example, Levin and Schiewe (2001) point out that the elephant seal has low biological (genetic) diversity but is not endanger of becoming extinct because of it. They pose the important challenge that fisheries biologists need to determine if salmon are like elephant seals.

However, such factors as the inability of many attempts to relocate salmonids to new habitat are evidence that salmonids have evolved specializations suited to particular environments (Levin and Schiewe 2001). While the possibility remains that some highly variable traits may not reflect genetic adaptations (i.e., that increase fitness), managers should ensure that populations are given a reasonable chance to express as much local adaptation as possible.

Evidence exists that demonstrate that apparent local adaptation may occur relatively rapidly. Hendry et al. (2000) demonstrated that sockeye in Lake Washington became reproductively isolated (as evidenced by swimming direction of fry and other life history characteristics) in as little as 13 generations. Quinn and Unwin (1993) showed that considerable phenotypic differences were found in chinook salmon in New Zealand. The suite of changes occurred in less than 20 generations. All of these fish had diverged from one donor stock, suggesting that environmental and genetic factors could lead to relatively rapid changes between independent populations.

In the Chelan Basin, historical populations of westslope cutthroat trout and bull trout have been impacted by introduction of non native rainbow, lake, and brook trout and kokanee salmon and potentially other factors. The extent that these factors have pressured native stocks into adaptive responses is unknown. Bull trout have not been observed within the basin since the late 1950s (see below).

While habitat disturbances and introduction of exogenous species have impacted westslope cutthroat, it is unknown to what extent local adaptation has changed from historic. Cutthroat have to compete for limited spawning habitat within the basin and altered lake levels to access this habitat (other than the Stehekin River) in addition to other impacts created by the exogenous fish interactions.

Below, we discuss key life stages of focal species and their relationship to the habitats they use during these stages.

Bull trout

Native bull trout are thought to be extirpated in Lake Chelan. None have been observed in Lake Chelan, its tributaries or in sport catch counts since the late 1950s (Brown 1984). Some remnant populations may still reside in tributaries of Lake Chelan, but verified captures of bull trout have not occurred from the lake in five decades (Brown 1984).

Westslope cutthroat trout

Spawning
Historic WSCT populations are believed to have spawned in appropriate tributaries in May through June. Currently, it appears that they spawn from mid June to mid August, primarily in July.

Operation of Lake Chelan Dam appears to have delayed spawning timing of cutthroat. Chelan PUD and the fisheries management group have agreed to modify operations in the new license that is being sought by the PUD to increase access earlier in the year for WSCT spawning.

Spawning habitat within the secondary tributaries of Lake Chelan is thought to be limiting, and competition with species such as suckers, may decrease productivity of WSCT within the Chelan Basin.

Prespawning
When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Adult cutthroat trout need deep, slow moving pools that do not fill with anchor ice in order to survive the winter. Many populations within the Chelan Basin overwinter in the lake (adfluvial), and therefore

some of the factors above may not be relevant. However, for those fluvial populations, intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. USFWS (1999) state that WSCT redds are usually found in water that is about 0.7 ft deep with mean velocities of 1.0 to 1.3 fps.

Incubation and emergence

Eggs incubate for several weeks and emergence occurs several days after hatching (USFWS 1999).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

Fry

After emergence, fry are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Entiat Basin would increase the type of habitat that fry utilize.

Parr

Juvenile cutthroat trout overwinter in the interstitial spaces of large stream substrate. Hillman and Miller (2002) state that most juvenile WSCT are consistently found in multiple channels and pools.

Downstream movement of juveniles from natal streams occurs within the Chelan Basin, especially for adfluvial populations.

Movement of juvenile WSCT within streams is most likely related to changing habitat requirements as the fish grows, or winter refuge.

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that is limiting WSCT production in the Chelan Basin is competition with brook trout. Brook trout are found in many areas that WSCT are found (in Kaputa et al. 2002).

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Methow River Subbasin

Role of local adaptation
Local adaptation is thought to occur in salmonid populations. Such traits as; age and size of maturity, developmental rate, temperature tolerance, disease resistance, and morphology have all been postulated to be related to local adaptation.

Taylor (1997) suggested three criteria are needed to demonstrate local adaptation:

- A trait must have an additive genetic basis.
- Variability in expression of the trait must be associated with variability in survival, reproductive success, or some other component of fitness.
- The mechanisms by which natural selection acts on the trait to increase the trait must be identified.

Taylor (1997) suggests that local adaptation has never been *directly* demonstrated, but there have been numerous studies that show circumstantial evidence that it does exist. Such traits as swimming performance, temperature tolerance, and direction of migration (e.g., sockeye fry) all have been shown to be correlated with environmental variables.

It appears that salmonids have adapted life history strategies that allows them to "hedge their bets" against major catastrophic natural events, such as volcano eruptions and glaciation. There are many factors that must be considered in determining whether such things as genetic diversity play a significant role in a species' extinction risk. For example, Levin and Schiewe (2001) point out that the elephant seal has low biological (genetic) diversity but is not endanger of becoming extinct because of it. They pose the important challenge that fisheries biologists need to determine if salmon are like elephant seals.

However, such factors as the inability of many attempts to relocate salmonids to new habitat are evidence that salmonids have evolved specializations suited to particular environments (Levin and Schiewe 2001). While the possibility remains that some highly variable traits may not reflect genetic adaptations (i.e., that increase fitness), managers should ensure that populations are given a reasonable chance to express as much local adaptation as possible.

Evidence exists that demonstrate that apparent local adaptation may occur relatively rapidly. Hendry et al. (2000) demonstrated that sockeye in Lake Washington became reproductively isolated (as evidenced by swimming direction of fry and other life history characteristics) in as little as 13 generations. Quinn and Unwin (1993) showed that considerable phenotypic differences were found in chinook salmon in New Zealand. The suite of changes occurred in less than 20 generations. All of these fish had diverged from one donor stock, suggesting that environmental and genetic factors could lead to relatively rapid changes between independent populations.

In the Methow Basin, there is ample evidence of relatively quick local adaptation. Populations of sockeye, chinook, and steelhead were thought to be in extremely low abundance by the 1930s (Fish and Hanavan 1948; Bryant and Parkhurst 1950; Mullan et al. 1992). The Grand Coulee Fish Maintenance Project, which was a mitigation project to compensate for construction of Grand Coulee Dam (see appendix _ for more detail), captured all salmonids ascending Rock Island Dam between 1939 and 1943.

As part of the GCFMP, spring and summer/fall chinook salmon and steelhead were not forced to spawn in a fenced section of river, like the Wenatchee and Entiat, but were released in the Methow River from the Winthrop Hatchery beginning in the early 1940s.

Since the GCFMP, the largest percentage of spring chinook spawns in the Chewuch and Twisp, and upper Methow rivers. It is important to note that the salmon used in the GCFMP were an admixture of fish destined for *all* tributaries upstream of Rock Island Dam, and therefore the fish that were released in the Methow River were not "adapted" to the local conditions (although there may have been a very small percentage of fish that originated from the basin). In summary, the circumstantial information suggests that substantial changes in spawning distribution, and perhaps adaptation have taken place in as little as two to five generations (redd counts began in the late 1950s).

Summer/fall chinook may never have inhabited the Methow River (Craig and Suomela 1941; Mullan et al. 1992). Summer/fall chinook released as part of the GCFMP was an admixture of fish ascending Rock Island Dam, and released into main river. Since the GCFMP, these fish have increased their spawning distribution throughout the mainstem Methow River, in as little as two to five generations.

The admixture of steelhead released in the Methow has spread throughout the basin. However, since non-migratory forms that were not impacted by the GCFMP may have resided in spawning tributaries, it is more difficult to draw inferences about the potential amount of local adaptation that has occurred since the GCFMP.

Sockeye salmon did not inhabit the Methow River historically. However, as part of the GCFMP, fish were released from Winthrop Hatchery. A very small population is still seen occasionally. It is not known if these fish are naturally reproducing or "strays" from other populations.

While the GCFMP attempted to reestablish coho salmon from the very low numbers of fish that they were able to trap, these attempts were unsuccessful, as were other attempts through released of exogenous stocks.

While habitat disturbances have impacted westslope cutthroat and bull trout, it is not likely that local adaptation has changed significantly from historic, although some populations within the basin may have had to adapt to changes in migration conditions and perhaps other impacts, but this is difficult to determine because of the lack of historical information.

Below, we discuss key life stages of focal species and their relationship to the habitats they use during these stages.

Spring chinook

Time of entry and spawning

Adult spring chinook begin entering the Methow River basin in May. Spawning begins in very late July through September, peaking in mid- to late August (Chapman et al. 1995 CPa). The onset of spawning in a stream reach is temperature driven (usually when temperatures drop below 16 °C). Temperature may be influenced by riparian conditions. Land use within the Methow Basin has affected riparian areas, conservation of remaining areas and restoration of disturbed riparian areas will increase production for many life stages.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Methow River or natal tributaries (Chewuch, Twisp). The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Healy (1991) reports the range of depths of spawning as between 41 to > 700 cm (~1-23 ft) and velocities of between 10 to 150 cm/s (.33-5 ft/s) for chinook salmon (this includes ocean-type chinook too). Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Healy (1991) reports that incubation and emergence success was related to oxygen levels and percolation through the gravel. When percolation was 0.03 cm/s (0.001 ft/s), survival to hatching was 97%. However, emergence reduced to 13% when percolation was 0.06 cm/s (0.002 ft/s). When oxygen fell below 13 ppm, mortality of eggs increased from 3.9% at 13 ppm to about 38% at 5 ppm.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include ocean-type chinook too).

In the Methow Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry

Spring chinook fry utilize near-shore areas, primarily eddies, within and behind large woody debris, undercut tree roots, or other cover (Hillman et al. 1989a; Healy 1991). Conservation and restoration of riparian areas of natal streams within the Methow Basin would increase the type of habitat that fry utilize.

Parr

Downstream movement of parr from natal streams is well documented. French and Wahle (1959) found that juvenile chinook migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Since 1992, sampling by WDFW has found spring chinook emigrating from the Chiwawa River as pre-smolts from late summer through the fall. In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; A. Murdoch, WDFW, personal communication). A similar movement of parr probably occurs in the Methow River.

Movement of juvenile chinook from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Bjornn (1971) related subyearling chinook movement in an Idaho stream indirectly to declining temperature in the stream as fish try to find suitable overwintering habitat. During the daytime, juvenile chinook use instream and overhead cover extensively, although as they got larger (and stream flows reduced), they sought areas that were deeper and higher velocity (Hillman et al. 1989 CPa). Griffith and Hillman (1986) observed that juvenile chinook in the Methow also used deep pools and selected stations close to woody debris and boulder rip-rap. However, Giffith and Hillman note that chinook appeared to be more dispersed in the Methow than in the Wenatchee. Substrate preference also changed as the juvenile chinook got larger and hydraulic conditions changed from predominantly sand, large boulder, and bedrock to sand, sand-gravel, and cobble. As temperatures dropped below 10 C, salmon were observed primarily near boulder rip-rap, or concealed themselves in the substrate.

During nighttime hours during the warmer months, chinook moved inshore and rested all night in shallow, quiet water (Hillman et al. 1989 CPb). In the colder months, chinook sought deeper water with larger substrate. Methow River spring chinook most likely use similar habitats as those in the Wenatchee River.

Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery- produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of subyearlings from the mainstem Wenatchee River. This may or may not be true of the areas of the Methow River which produce most of the spring chinook in that basin.

Conservation of high functioning habitat in the upper Methow, Chewuch, and Twisp rivers, restoration of riparian and geofluvial processes in or near known and potential parr rearing areas (especially the lower reaches of the Twisp and Chewuch rivers) will have the highest likelihood of increasing parr survival.

Smolt

Methow River spring chinook smolts begin migrating in March from natal areas. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Summer/fall chinook

Time of entry and spawning

Adult summer/fall chinook begin entering the Methow River basin in June. Spawning begins in very late September through mid November, peaking in mid- to late October. The onset of spawning in a stream reach is temperature driven (usually when temperatures drop below 16 °C). Temperatures in the mainstem Methow are influenced by climate and tributary flows.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Methow. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase or maintain the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Healy (1991) reports the range of depths of spawning as between 41 to > 700 cm (~1-23 ft) and velocities of between 10 to 150 cm/s (.33-5 ft/s) for chinook salmon (this includes spring-type chinook too). Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Healy (1991) reports that incubation and emergence success was related to oxygen levels and percolation through the gravel. When percolation was 0.03 cm/s (0.001 ft/s), survival to hatching was 97%. However, emergence reduced to 13% when percolation was 0.06 cm/s (0.002 ft/s). When oxygen fell below 13 ppm, mortality of eggs increased from 3.9% at 13 ppm to about 38% at 5 ppm.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and

Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include spring-type chinook too).

In the Methow Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry

Fry emerge mostly in April and May. Most subyearling summer/fall chinook leave the probably leave the Methow River within a few weeks after emergence, as has been observed within the Wenatchee River. In the Wenatchee River, Hillman and Chapman (1989) demonstrated that the rate of emigration of subyearling chinook was highest in June, and then declined through the summer.

Summer/fall chinook fry utilize near-shore areas, primarily eddies, within and behind large woody debris, undercut tree roots, or other cover (Hillman et al. 1989a; Healy 1991). Chapman et al (1994 CPa) noted that in the spring this type of habitat was scarce in the Wenatchee and Methow rivers, but where it did occur, it was fully occupied. Conservation and restoration of riparian areas and increases in off-channel habitat in the lower Methow Basin may increase the type of habitat that summer/fall chinook fry utilize, although they may still emigrate through the system without utilizing these habitats.

Steelhead

Time of entry and spawning

Adult steelhead enter the Methow River basin from August through the following April. Spawning begins in very late March through April, potentially going into May, peaking in mid- to late April (Jateff and Snow 2002). The onset of spawning in a stream reach is temperature driven. Other factors may influence steelhead spawning compared to salmon species because of the time of year spawning occurs.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Methow River or natal tributaries. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Wydoski and Whitney (2003) report that spawning is usually found at a mean depth of 0.7 to 1.34 ft and water velocities of 1.8 to 2.3 fps. Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Incubation success is dependent on factors such as water flow through the redds and temperature (Pauley et al. 1996). Eggs usually hatch in 4 to 7 weeks and fry emerge 2 to 3 weeks after that (Shapovalov and Taft 1954).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Methow Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry

In the Wenatchee River, Hillman and Chapman (1989) found most juvenile steelhead rearing in Tumwater Canyon. During daylight, age-0 steelhead used slower, shallower water than chinook, stationed individually over small boulder and cobble substrate (Hillman et al. 1989 CPa). As they grew, they picked deeper and faster habitat over cobble and boulders. As with chinook juveniles, in winter, they concealed themselves in interstitial spaces among boulders near the stream bank, but did not cluster together. No interaction was observed between chinook and steelhead at anytime (Hillman et al. CPa, CPb).

During nighttime hours, steelhead moved downstream and closer to shore. At dawn, steelhead moved upstream. Most steelhead chose sand and boulder substrates, and during winter, chose deeper, larger substrate (Hillman et al. 1989 CPb).

Hillman and Miller (2002) remarked that in ten years of surveying the Chiwawa River, age-0 steelhead most often used riffle and multiple channel habitats, but were also found associated with debris in poll and glide habitat.

It is reasonable to assume that Methow Basin steelhead utilize similar habitats as those in the Wenatchee Basin.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Methow Basin would increase the type of habitat that fry utilize.

Parr

Downstream movement of parr from natal streams occurs within the Wenatchee Basin (Murdoch et al. 2001). French and Wahle (1959) found that juvenile steelhead migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Since 1992, sampling by WDFW has found steelhead emigrating from the Chiwawa River as pre-smolts beginning in spring, but primarily in the fall. In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; A. Murdoch, WDFW, personal communication). Similar timing of movement probably occurs in the Methow Basin.

Movement of juvenile steelhead from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery- produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of chinook and steelhead juveniles from the mainstem Wenatchee River. It is reasonable to assume that similar behavior is seen in Methow River steelhead.

Mullan et al. (1992) found that most steelhead reared about river miles 5-15 in the Methow River, 4-27 in the Twisp River, and around rivermile 8 in the Chewuch River. The amount of habitat diversity and complexity in these reaches compared to other reaches may be responsible for this behavior.

Conservation of high functioning habitat in Methow, Twisp and Chewuch rivers (and other smaller tributaries), restoration of riparian and geofluvial processes in or near known and potential parr rearing areas will have the highest likelihood of increasing parr survival.

Smolt

Methow River steelhead smolts begin migrating in March from natal areas. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Bull trout

Spawning

Bull trout spawn in the Methow River basin from August through September. The onset of spawning in a stream reach is temperature driven, apparently at the onset of dropping temperatures.

Prespawning

When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Fraley and Shepard (1989) characterized selected areas as having low compaction and low gradient, and potentially near upwelling influences and proximity to cover. In general, mean velocities over redds range from 0.13-2.0 fps, with water depth ranging from 0.71-2.0 ft. Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Optimum incubation for bull trout is lower than other salmonids (2-4 °C; in Brown 1992). Because of the lower temperatures, bull trout development within the redd is usually longer than other salmonids. Emergence may take another three weeks after hatching.

Because bull trout development within the redd takes a long period of time, they may be more vulnerable to increases in sediments or degradation other water quality (Fraley and Shepard 1989).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Methow Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry

Fry (< 100 mm) are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris. Age-0 bull trout are consistently found near the substrate, usually over gravel-cobble areas.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Methow Basin would increase the type of habitat that fry utilize.

Parr

Hillman and Miller (2002) state that most juvenile bull trout are consistently found in multiple channels, pool, and riffles, and a few in glides. Juveniles were found in association with the stream bottom over rubble and small boulder substrate or near woody debris.

Downstream movement of juveniles (> 100 mm) from natal streams probably occurs within the Methow Basin. Since 1992, sampling by WDFW has found bull trout emigrating from the Chiwawa River, having two modes; one in spring, and the other in the fall.

Movement of juvenile bull trout from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Murdoch et al. (2001) also speculated that movement in the fall may also be correlated to the size and age at which bull trout become piscivorous.

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that is limiting bull trout production in the Methow Basin is competition with brook trout. Brook trout are found in most areas that bull trout are found (Mullan et al. 1992).

Westslope cutthroat trout

Spawning

Westslope cutthroat trout (WSCT) spawn between March and July, when water temperatures begin to warm. Spawning and rearing streams tend to be cold and nutrient poor.

Prespawning

When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Adult cutthroat trout need deep, slow moving pools that do not fill with anchor ice in order to survive the winter. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. USFWS (1999) state that WSCT redds are usually found in water that is about 0.7 ft deep with mean velocities of 1.0 to 1.3 fps.

Incubation and emergence
Eggs incubate for several weeks and emergence occurs several days after hatching (USFWS 1999).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

In the Methow Basin, fall flooding has a high frequency of occurrence. This may negatively affect incubation and emergence success, especially in years of extreme flows (e.g., 1990 and 1995). Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry
After emergence, fry are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Methow Basin would increase the type of habitat that fry utilize.

Parr
Juvenile cutthroat trout overwinter in the interstitial spaces of large stream substrate. Hillman and Miller (2002) state that most juvenile WSCT are consistently found in multiple channels and pools.

Downstream movement of juveniles from natal streams probably occurs within the Methow Basin.

Movement of juvenile WSCT within streams is most likely related to changing habitat requirements as the fish grows, or winter refuge.

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that is limiting WSCT production in the Methow Basin is competition with brook trout. Brook trout are found in many areas that WSCT are found (Mullan et al. 1992).

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Okanogan River Subbasin

Role of local adaptation
Local adaptation is thought to occur in salmonid populations. Such traits as; age and size of maturity, developmental rate, temperature tolerance, disease resistance, and morphology have all been postulated to be related to local adaptation.

Taylor (1997) suggested three criteria are needed to demonstrate local adaptation:

- A trait must have an additive genetic basis.
- Variability in expression of the trait must be associated with variability in survival, reproductive success, or some other component of fitness.
- The mechanisms by which natural selection acts on the trait to increase the trait must be identified.

Taylor (1997) suggests that local adaptation has never been *directly* demonstrated, but there have been numerous studies that show circumstantial evidence that it does exist. Such traits as swimming performance, temperature tolerance, and direction of migration (e.g., sockeye fry) all have been shown to be correlated with environmental variables.

It appears that salmonids have adapted life history strategies that allows them to “hedge their bets” against major catastrophic natural events, such as volcano eruptions and glaciation. There are many factors that must be considered in determining whether such things as genetic diversity play a significant role in a species’ extinction risk. For example, Levin and Schiewe (2001) point out that the elephant seal has low biological (genetic) diversity but is not endanger of becoming extinct because of it. They pose the important challenge that fisheries biologists need to determine if salmon are like elephant seals.

However, such factors as the inability of many attempts to relocate salmonids to new habitat are evidence that salmonids have evolved specializations suited to particular environments (Levin and Schiewe 2001). While the possibility remains that some highly variable traits may not reflect genetic adaptations (i.e., that increase fitness), managers should ensure that populations are given a reasonable chance to express as much local adaptation as possible.

Evidence exists that demonstrate that apparent local adaptation may occur relatively rapidly. Hendry et al. (2000) demonstrated that sockeye in Lake Washington became reproductively isolated (as evidenced by swimming direction of fry and other life history characteristics) in as little as 13 generations. Quinn and Unwin (1993) showed that considerable phenotypic differences were found in chinook salmon in New Zealand. The suite of changes occurred in less than 20 generations. All of these fish had diverged from one donor stock, suggesting that environmental and genetic factors could lead to relatively rapid changes between independent populations.

In the Okanogan Basin, there is ample evidence of relatively quick local adaptation. Populations of sockeye, chinook, and steelhead were thought to be in extremely low abundance by the 1930s (Fish and Hanavan 1948; Bryant and Parkhurst 1950; Mullan et al. 1992). The Grand Coulee Fish Maintenance Project, which was a mitigation project to compensate for construction of Grand Coulee Dam (see appendix _ for more detail), captured all salmonids ascending Rock Island Dam between 1939 and 1943.

Sockeye were released upstream of a rack at the outlet of Lake Osoyoos and juveniles released in the lake. No releases of spring, summer/fall chinook or steelhead occurred in the Okanogan Basin during the GCFMP.

It is important to note that the salmon used in the GCFMP were an admixture of fish destined for *all* tributaries upstream of Rock Island Dam, and therefore were not "adapted" to the local conditions (although there may have been a very small percentage (based on Zosel Dam counts) of fish that originated from the basin). In summary, the circumstantial information suggests that substantial changes in establishment of populations, and perhaps adaptation have taken place in as little as two to five generations (redd counts began in the late 1950s).

Summer/fall chinook were not released into the Okanogan River during the GCFMP, but have established significant spawning populations in the Okanogan and Similkameen rivers. This occurred within as little as two to five generations.

Steelhead were not released in the Okanogan Basin during the GCFMP, but have established spawning populations, primarily in the Similkameen and other smaller tributaries to the Okanogan River. However, since non-migratory forms that were not impacted by the GCFMP may have resided in spawning tributaries, it is more difficult to draw inferences about the potential amount of local adaptation that has occurred since the GCFMP. The occurrence of this population is undetermined too, and may have been established after hatchery releases began in the 1960s.

Most sockeye salmon captured at Rock Island Dam during the GCFMP were from fish destined upstream of the Grand Coulee Dam site (Chapman et al. 1995 CPb). Since the GCFMP, these fish have established spawning populations Okanogan River upstream of Lake Osoyoos. Genetic studies have shown these fish to be distinct from those that have been established in the Wenatchee River. This adaptation to Lake Osoyoos was first indicated by returning fish in the 1940s and 1950s, and genetic samples were first done in the 1980s. The available information suggests divergence of this population within 2-10 generations.

While habitat disturbances have impacted westslope cutthroat and bull trout, it is not likely that local adaptation has changed significantly from historic, although some populations within the basin may have had to adapt to changes in migration conditions and perhaps other impacts, but this is difficult to determine because of the lack of historical information. Bull trout are not currently known to exist in the Okanogan Basin.

Below, we discuss key life stages of focal species and their relationship to the habitats they use during these stages.

Spring chinook

There are no naturally spawning populations of spring chinook in the Okanogan Basin at this time. However, there are cooperative efforts underway to reintroduce them.

Summer/fall chinook

Time of entry and spawning

Adult summer/fall chinook begin entering the Okanogan River basin in July, temperature permitting. Spawning begins in very late September through mid November, peaking in mid- to late October. The onset of spawning in a stream reach is temperature driven (usually when temperatures drop below 16 °C). Temperatures in the mainstem Okanogan are influenced by climate, the lakes in British Columbia, and tributary flows, and other factors.

Prespawning

Adults hold in the deeper pools and under cover of the mainstem Okanogan. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Another factor affecting prespawning survival is temperature related. Temperature in the summer months in the Okanogan Basin can get higher than optimum for salmonid survival. Elevated temperatures are considered to be a result of both natural conditions, such as the north-south orientation and the low gradient, and human-influenced conditions, including lack of riparian vegetation, elevated sediment delivery, dam operations, and irrigation withdrawals. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase or maintain the occurrence of deeper pools. Increased riparian will aid in reducing temperatures as well as modifying other land use practices.

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Healy (1991) reports the range of depths of spawning as between 41 to > 700 cm (~1-23 ft) and velocities of between 10 to 150 cm/s (.33-5 ft/s) for chinook salmon (this includes spring-type chinook too). Preservation or restoration of naturally occurring geofluvial function insures that the proper spawning habitat is available.

Incubation and emergence

Healy (1991) reports that incubation and emergence success was related to oxygen levels and percolation through the gravel. When percolation was 0.03 cm/s (0.001 ft/s), survival to hatching was 97%. However, emergence reduced to 13% when percolation was 0.06 cm/s (0.002 ft/s). When oxygen fell below 13 ppm, mortality of eggs increased from 3.9% at 13 ppm to about 38% at 5 ppm.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include spring-type chinook too).

In the Okanogan Basin, other factors have led to increases in sedimentation. This may negatively affect incubation and emergence success. Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. Because of naturally occurring conditions and anthropogenic effects, sedimentation in the Okanogan Basin is an important limiting factor for summer/fall chinook.

Fry

Fry emerge mostly in April and May. Most subyearling summer/fall chinook probably leave the Okanogan River within a few weeks after emergence. Beak (1980) found that weekly catches of chinook salmon fry declined sharply from over 700 in early June to about 25 in early July, then to zero by early August. This decline comports well with the observations of Hillman and Chapman (1989). Hillman and Chapman (1989) also demonstrated that the rate of emigration of subyearling chinook was highest in June, then declined through the summer.

Summer/fall chinook fry utilize near-shore areas, primarily eddies, within and behind large woody debris, undercut tree roots, or other cover (Hillman et al. 1989a; Healy 1991). They noted that in the spring this type of habitat was scarce in the Wenatchee River, but where it did occur, it was fully occupied. Chapman et al. (1994 CPa) believed that this type of habitat was probably not limited within the Okanogan Basin. If this is true, then fry (or at least a larger percentage of fry) may rear longer in the Okanogan Basin than the Wenatchee or Methow. However, because of higher temperatures in the mainstem Okanogan, they most probably migrate downstream to the mainstem by the end of June (Chapman et al. 1994 CPa).

Conservation and restoration of riparian areas in the lower Okanogan Basin may increase the type of habitat that summer/fall chinook fry utilize, although they may still emigrate through the system without utilizing these habitats because of other factors, such as temperature.

Sockeye

Time of entry and spawning

Adult sockeye begin entering the Okanogan River basin in July, but is temperature dependent. Chapman et al (1995 CPb) found a strong relationship between passage at Zosel Dam (at the mouth of Lake Osoyoos) and temperature. In some years, there was a bimodal distribution of passage, as temperatures rose and subsequently dropped. In some years, entry into Lake Osoyoos can be delayed into late August or September. Spawning takes place in October. The onset of spawning in a stream reach is temperature driven. As previously mentioned, temperature in the Okanogan is influenced by natural conditions and some land use practices. Conserving and restoring riparian areas and natural geofluvial processes in the Okanogan Basin, in addition to modified land use practices, will help ensure that important spawning habitat is conserved, or created.

Prespawning
Adults may hold in the deeper pools and under cover of the mainstem Okanogan until arriving in Lake Osoyoos, where they hold prior to spawning. Prespawning mortality for the Okanogan sockeye has been estimated to range between 20-40% (Chapman et al. 1995 CPb). While the availability of and number of deep pools and cover may be important to offset potential prespawning mortality in the Okanogan River, temperature is most likely the key factor in prespawning survival in the Okanogan, as previously mentioned. Modifications mentioned above should help at this life stage also.

Redd characteristics
Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Depth of water does not seem to be critical for sockeye spawning (Burgner 1991; Chapman et al. 1995 CPb). Sockeye appear to choose lower water velocity water to spawn compared to other salmonids (Wydoski and Whitney 2003). Allen and Meekin (1980) found velocities over spawning areas ranging from 0.56 to 3.34 fps, and average 1.52 fps. Conservation of remaining naturally geofluvial processes in the White and Little Wenatchee rivers, and restoration of areas that may have been affected by previous land use activities will ensure quality spawning habitat remains.

Incubation and emergence
Egg incubation usually lasts between 50-140 days, which is primarily dependent on temperature (in Chapman et al. 1995 CPb). Emergence of sockeye occurs in the Okanogan Basin in late March through April (Allen and Meekin 1973, 1980).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Chapman et al. (1995 CPb) compiled information for sockeye throughout their range for various life stage survivals. Incubation survival generally ranged from 25-60%, although some measurements were at both extremes (0%; 100%). Allen and Meekin reported that incubation for Okanogan sockeye was 2-94%. Egg to fry survival ranged below 10% to slightly less than 50% for sockeye throughout their range.

A myriad of land use practices have affected sockeye incubation survival, especially past water management practices. Currently, Douglas PUD has sponsored the development of a water management model that has increased the survival of sockeye eggs in recent years (R. Klinge, personal communication).

Fry

After fry emerge primarily at night, they begin their movement towards Lake Osoyoos (Chapman et al. 1995 CPb). During daylight hours, fry hide under stones and within debris, and begin moving again at dawn. Because of the relatively short distance that fry would have to migrate to Lake Osoyoos, it is reasonable to assume that they can reach the lake within one night under most conditions. Fry arrive in Lake Osoyoos between March and May.

After fry enter a lake, they may either move immediately offshore, or remain in limnetic areas to rear until zooplankton production increases offshore (Burgner 1991; Chapman et al. 1995b). In Lake Osoyoos, fry are known to stay near-shore until June (Chapman et al. CPb). Reduction or mitigation of near-shore development may help sockeye fry entering the lake near its northern shore.

Parr

Sockeye juveniles have complex diel vertical migration patterns to balance risk of being preyed upon to finding food. Chapman et al. (1995 CPb) cites Brett (1980) who concluded that the vertical migration doesn't begin until the nursery lake stratifies. In general, juveniles seek cold, dark water (below the thermocline) in the day, rise towards the surface at dusk, feed, and then hold below the surface waiting for dawn when they feed again before migrating down again (Burgner 1991; Chapman et al. 1995 CPb). Lake Osoyoos typically develops a strong thermocline, where temperatures in the epilimnion are high and oxygen low in the hypolimnion, and therefore sockeye may be restricted to the metalimnion, although probably make physiological trade-offs to graze zooplankton. Allen and Meekin (1980) observed that sockeye juveniles were found only in the north basin of Lake Osoyoos, and were found deeper as the season progressed. The south basin appears to be inhospitable to sockeye production because of temperature and oxygen limitations, and blue green algae production (in Chapman et al. 1995 CPb).

Lake Osoyoos is a very eutrophic lake; shallow, warm, and enriched by agricultural influences. Artificial enrichment of the lake affects the water quality in the late summer. Modification of land use practices may increase the negative effects on water quality and potentially increase rearing habitat within the lake.

Exotic predators like bass are also firmly established with Lake Osoyoos and the lower Okanogan River. Removal or reduction of predator species would also improve survival of sockeye parr and smolts.

Smolt

Okanogan River sockeye smolts begin migrating from Lake Osoyoos in May. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Steelhead

Time of entry and spawning
Adult steelhead enter the Okanogan River basin from August through the following April. Spawning begins in very late March through May, peaking in mid- to late April. The onset of spawning in a stream reach is temperature driven. Other factors may influence steelhead spawning compared to salmon species because of the time of year spawning occurs.

Prespawning
Adults hold in the deeper pools and under cover of the mainstem Okanogan or natal tributaries. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools. Steelhead may not be affected by high Okanogan temperatures because of their life history.

Redd characteristics
Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Wydoski and Whitney (2003) report that spawning is usually found at a mean depth of 0.7 to 1.34 ft and water velocities of 1.8 to 2.3 fps. Preservation or restoration of naturally occurring geofluvial function and water quality and quantity would help insure that the proper spawning habitat is available.

Incubation and emergence
Incubation success is dependent on factors such as water flow through the redds and temperature (Pauley et al. 1986). Eggs usually hatch in 4 to 7 weeks and fry emerge 2 to 3 weeks after that (Shapovalov and Taft 1954).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

Water quality and quantity issues are acute in the Okanogan Basin. Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds. Modification of land use practices may improve incubation survival.

Fry
In the Wenatchee River, Hillman and Chapman (1989) found most juvenile steelhead rearing in Tumwater Canyon. During daylight, age-0 steelhead used slower, shallower water than chinook, stationed individually over small boulder and cobble substrate

(Hillman et al. 1989 CPa). As they grew, they picked deeper and faster habitat over cobble and boulders. As with chinook juveniles, in winter, they concealed themselves in interstitial spaces among boulders near the stream bank, but did not cluster together. No interaction was observed between chinook and steelhead at anytime (Hillman et al. CPa, CPb).

During nighttime hours, steelhead moved downstream and closer to shore. At dawn, steelhead moved upstream. Most steelhead chose sand and boulder substrates, and during winter, chose deeper, larger substrate (Hillman et al. 1989 CPb).

Hillman and Miller (2002) remarked that in ten years of surveying the Chiwawa River, age-0 steelhead most often used riffle and multiple channel habitats, but were also found associated with debris in poll and glide habitat.

Because of various factors mentioned above, the amount of the type of habitat fry utilize is limited within the Okanogan Basin. Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Okanogan Basin would increase the type of habitat that fry utilize.

Parr

Downstream movement of parr from natal streams most likely occurs within the Okanogan Basin. French and Wahle (1959) found that juvenile steelhead migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Since 1992, sampling by WDFW has found steelhead emigrating from the Chiwawa River as pre-smolts beginning in spring, but primarily in the fall. In general, movement from the Chiwawa River included some yearlings leaving as early as March, extending through May, followed by subyearlings leaving through the summer and fall (until trapping ceases because of inclement weather; A. Murdoch, WDFW, personal communication).

Movement of juvenile steelhead from the higher-order streams in the fall appears to be a response to the harsh conditions encountered in the upper tributaries. Hillman and Chapman (1989) suggested that biotic factors, such as intraspecific interaction for available habitat with naturally- and hatchery- produced chinook, nocturnal sculpin predation, and interspecific interactions may accelerate movement of chinook and steelhead juveniles from the mainstem Wenatchee River. Whether these interactions occur in the Okanogan River is unclear at this time.

Restoration of high functioning habitat in natal tributaries, and restoration of riparian and geofluvial processes in or near known and potential parr rearing areas will have the highest likelihood of increasing parr survival.

Smolt

Okanogan River steelhead smolts begin migrating in March from natal areas. Investigation of suspected or potential impediments to migration or injury or mortality should be identified and investigated. If areas are shown to unnaturally impede migration or injure or kill fish, then they should be fixed.

Bull trout

Bull trout are not known to presently exist in the Okanogan Basin, including Canadian waters. Historically, Salmon Creek and Loup Loup Creek were known habitat (Fisher et al. 2002).

Westslope cutthroat trout

Spawning
Westslope cutthroat trout (WSCT) spawn between March and July, when water temperatures begin to warm. Spawning and rearing streams tend to be cold and nutrient poor.

Prespawning
When adults are migrating upstream to spawning areas, they associate with cover; debris, deep pools, and undercut banks. The availability of and number of deep pools and cover is important to offset potential prespawning mortality. Adult cutthroat trout need deep, slow moving pools that do not fill with anchor ice in order to survive the winter. Intact riparian habitat will increase the likelihood of instream cover, and normative channel geofluvial processes will increase the occurrence of deeper pools.

Redd characteristics
Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. USFWS (1999) state that WSCT redds are usually found in water that is about 0.7 ft deep with mean velocities of 1.0 to 1.3 fps.

Incubation and emergence
Eggs incubate for several weeks and emergence occurs several days after hatching (USFWS 1999).

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases.

Road building activities in the upper watersheds may also increase siltation, as well as grazing and mining activities. All three factors were once more prevalent than they are now in the basin, and conditions have improved in most watersheds.

Fry
After emergence, fry are usually found in shallow, slow backwater side channels or eddies, in association with fine woody debris.

Conservation and restoration of natural geofluvial processes and riparian areas of natal streams within the Okanogan Basin would increase the type of habitat that fry utilize.

Parr

Juvenile cutthroat trout overwinter in the interstitial spaces of large stream substrate. Hillman and Miller (2002) state that most juvenile WSCT are consistently found in multiple channels and pools.

Downstream movement of juveniles from natal streams occurs within the Wenatchee Basin (Murdoch et al. 2001). Since 1992, sampling by WDFW has found WSCT emigrating from the Chiwawa River.

Movement of juvenile WSCT within streams is most likely related to changing habitat requirements as the fish grows, or winter refuge.

Conservation of high functioning habitat in natal tributaries, restoration of riparian and geofluvial processes in or near known and potential juvenile rearing areas will have the highest likelihood of increasing parr survival.

Another factor that is limiting WSCT production in the Okanogan Basin is competition with brook and rainbow trout. Brook trout are found in many areas that WSCT are found (Fisher et al. 2002).

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Upper Middle Mainstem

The Upper Middle Mainstem (UMM) Columbia River is used by spring chinook, sockeye, and steelhead primarily as a migration corridor. As such, discussion on those species will not occur in this section. Some rearing may take place within the reservoirs of the UMM for the three species mentioned above, but little is known of the ecology (habitat segregation) within the UMM.

Summer/fall chinook are known to spawn and rear in the UMM. Bull trout appear to use the UMM mostly as a migration corridor, but some rearing undoubtedly occurs. Pacific lamprey also use the UMM as a migration corridor, but rearing is also known to occur here too. Sturgeon spend their entire lives within the UMM.

Role of local adaptation
Local adaptation is thought to occur in salmonid populations. Such traits as; age and size of maturity, developmental rate, temperature tolerance, disease resistance, and morphology have all been postulated to be related to local adaptation.

Taylor (1997) suggested three criteria are needed to demonstrate local adaptation:

- A trait must have an additive genetic basis.
- Variability in expression of the trait must be associated with variability in survival, reproductive success, or some other component of fitness.
- The mechanisms by which natural selection acts on the trait to increase the trait must be identified.

Taylor (1997) suggests that local adaptation has never been *directly* demonstrated, but there have been numerous studies that show circumstantial evidence that it does exist. Such traits as swimming performance, temperature tolerance, and direction of migration (e.g., sockeye fry) all have been shown to be correlated with environmental variables.

It appears that salmonids have adapted life history strategies that allows them to “hedge their bets” against major catastrophic natural events, such as volcano eruptions and glaciation. There are many factors that must be considered in determining whether such things as genetic diversity play a significant role in a species’ extinction risk. For example, Levin and Schiewe (2001) point out that the elephant seal has low biological (genetic) diversity but is not endanger of becoming extinct because of it. They pose the important challenge that fisheries biologists need to determine if salmon are like elephant seals.

However, such factors as the inability of many attempts to relocate salmonids to new habitat are evidence that salmonids have evolved specializations suited to particular environments (Levin and Schiewe 2001). While the possibility remains that some highly variable traits may not reflect genetic adaptations (i.e., that increase fitness), managers should ensure that populations are given a reasonable chance to express as much local adaptation as possible.

Evidence exists that demonstrate that apparent local adaptation may occur relatively rapidly. Hendry et al. (2000) demonstrated that sockeye in Lake Washington became reproductively isolated (as evidenced by swimming direction of fry and other life history characteristics) in as little as 13 generations. Quinn and Unwin (1993) showed that considerable phenotypic differences were found in chinook salmon in New Zealand. The suite of changes occurred in less than 20 generations. All of these fish had diverged from one donor stock, suggesting that environmental and genetic factors could lead to relatively rapid changes between independent populations.

In the UMM, there is evidence of relatively quick local adaptation. Populations of sockeye, chinook, and steelhead were thought to be in extremely low abundance by the 1930s (Fish and Hanavan 1948; Bryant and Parkhurst 1950; Mullan et al. 1992). The Grand Coulee Fish Maintenance Project, which was a mitigation project to compensate for construction of Grand Coulee Dam (see appendix _ for more detail), captured all salmonids ascending Rock Island Dam between 1939 and 1943.

Some summer/fall chinook adults (apparently jacks primarily; Fish and Hanavan 1948) were released into the mainstem Columbia upstream of Rock Island Dam in 1942 and 1943 during the GCFMP. Apparently the numbers of fish were small.

Since the GCFMP, summer/fall chinook have reestablished spawning populations downstream of Wells Dam and in the lower portion of the Chelan River. In summary, the circumstantial information suggests that substantial changes in spawning distribution, and perhaps adaptation have taken place in as little as two to five generations (redd counts began in the late 1950s).

Lamprey were not mentioned in Fish and Hanavan (1948) and therefore it is difficult to determine if any changes in habitat caused by mainstem dams have caused adaptation in any way. Mainstem have impacts that are described below, but may not have caused a loss in distribution (except Grand Coulee and Chief Joseph). However, current dams, like Tumwater in the Wenatchee and past dams that existed in the Entiat and Methow rivers definitely had an impact on lamprey since they prevented passage (it is unclear if Tumwater prevents passage, but few or none have been observed upstream of it in recent years). Since lamprey are known to exist in those basins, it is clear that they were able to redistribute and establish spawning populations after access was reestablished. However, since the distribution of spawning populations is not known at this time (Appendix _), and the time frame is not clear either on how long it took to reestablish these populations, inferences cannot be made on how quickly lamprey are able to adapt to differing conditions.

Sturgeon are known to have been impacted by dams in the UMM. Primary changes that have taken place concern connectivity and potential impacts on spawning. Recent information has established that very low numbers of sturgeon exist in the UMM, but information pertaining to their ability to adapt to the changes in their habitat is unknown at this time.

Below, we discuss key life stages of focal species and their relationship to the habitats they use during these stages.

Summer/fall chinook

Time of entry and spawning

Adult summer/fall chinook begin entering the UMM in June. Spawning begins in very late September through November, peaking in late October.

Prespawning

Adults hold in the deeper waters of the UMM until spawning commences. Prespawning mortality is most likely not as high in the UMM as tributaries because there are more refugia for adults (e.g., deeper water, cooler upwelling spots).

Redd characteristics

Important habitat needs for redd building include the availability of clean gravel at the appropriate size, and proper water depth and velocity. Healy (1991) reports the range of depths of spawning as between 41 to > 700 cm (~1-23 ft) and velocities of between 10 to 150 cm/s (.33-5 ft/s) for chinook salmon (this includes spring-type chinook too). Currently, spawning of chinook occurs in the tailraces of Chelan and Wells dams on gravel bars.

Incubation and emergence

Healy (1991) reports that incubation and emergence success was related to oxygen levels and percolation through the gravel. When percolation was 0.03 cm/s (0.001 ft/s), survival to hatching was 97%. However, emergence reduced to 13% when percolation was 0.06 cm/s (0.002 ft/s). When oxygen fell below 13 ppm, mortality of eggs increased from 3.9% at 13 ppm to about 38% at 5 ppm.

Stream conditions (e.g., frequency of flooding, extreme low temperatures) may affect egg survival too. Floods can scour eggs from the gravel by increasing sediment deposition that reduces oxygen and percolation through the redd. Healy (1991) cites Shaw and Maga (1943) as showing that siltation may be more lethal earlier in the incubation period than in later phases. Overall, Healy (1991) reports that spawning to emergence ranged from 40-100% (these estimates include spring-type chinook too).

In the UMM, incubation success is primarily related to operations of dams.

Fry

Fry may emerge over a longer time period in the UMM than in tributaries (Chapman et al. 1994). This is probably caused by the variety of temperatures found in the various spawning areas. Fry that have emerged from spawning areas within the UMM most likely behave as fry do from the Hanford Reach (downstream of Priest Rapids Dam). Most fry leave the Hanford Reach before the end of July, and may rear in the McNary

Dam reservoir before passing (Chapman et al. 1994). From juvenile passage studies conducted at dams within the UMM, post emergent fry (< 50 mm) are seen at Rocky Reach and Rock Island dams in April and May, respectively. Larger, active migrants (> 75 mm) appear at Priest Rapids Dam from June through August.

Rondorf and Grey (1987) found that fry used the shallow, littoral areas in May, favoring water less than 2 m deep. Chapman et al. (1994) report that Hillman (unpublished) observed subyearling chinook at night within the Rock Island reservoir in backwater areas along the river margin. The fish rested on sand/silt substrate in water velocities less than 1 cm/s and depth of less than 1 m.

It is doubtful that habitat is limiting fry production within the UMM. However, hydropower operations may make fry more susceptible to stranding if not coordinated. Currently, reservoir levels are collaboratively regulated through coordination between federal operators upstream of the UMM and PUD operators, so stranding in this section of the Columbia River is basically not an issue, although it has occurred in the past.

Pacific lamprey

Adult lamprey use the UMM as a migration corridor and for overwintering, and are not known to spawn within it. Spawning occurs within tributaries, but larvae may be washed into the UMM, where rearing is known to occur.

Ammocoetes (larvae) have been captured in silty depositional areas in the Rocky Reach tailrace (Goldar Associates 2003 CPa). It is likely that other areas with appropriate habitat are being utilized by lamprey larvae prior to migration as macrothalmia.

Impacts to lamprey in the UMM may be limited to passage at hydroprojects as adults and on their seaward migration. However, the impacts have not been measured, but current relicensing plans include management plans for lamprey.

White sturgeon

Spawning

White sturgeon occur throughout the UMM. Spawning occurs from late May to mid August (Goldar and Assoc. 2003 CPb). Spawning appears to occur in the immediate tailrace area of the hydro projects. Temperature and discharge are thought to initiate spawning, although discharge was not significantly correlated to spawning events in the Wanapum and Rock Island tailraces (Goldar and Assoc. 2003 CPc).

Substrates where eggs have been collected in the UMM were composed of sand to small cobble. Mean water velocities were 1.1 to 1.8 m/s (Goldar and Assoc. 2003 CPb).

Currently, there is not enough information to determine if habitat or abiotic factors may be limiting spawning in the UMM. Spawning may not be limited; however, there does not appear to be large numbers of spawning adults. Adults also do not appear to use the fish ladders at UMM hydroprojects, so their movements are limited between projects, although downstream movement is known to occur (Goldar and Assoc. 2003 CPb).

Juvenile rearing

While there have been no studies to date within the UMM, juvenile sturgeon are known to inhabit depths of 5 to > 14 m, with water velocities < 0.25 m/s. Substrate usually consists of sand, sand/silt, or small gravel (in Goldar and Assoc. 2003 CPc).

Currently, there has been no inventory of juvenile rearing areas within the UMM, but juvenile habitat is most likely not limiting.

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