Population Structure, Status and Life Histories of Upper Columbia Steelhead, Spring and Summer/fall Chinook, Sockeye, Coho Salmon, Bull Trout, Westslope Cutthroat Trout, Non-migratory Rainbow Trout, Pacific Lamprey, and Sturgeon

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Introduction

This report defines the population structure, current and historic status, and life histories of “focal” fish species that inhabit the Columbia Cascade Province (CCP). Focal fish species are species of interest within the CCP that would benefit from restoration and conservation actions through the Subbasin Planning process.

1. Definition of species/populations

Species can be defined as a group of interbreeding populations that are reproductively isolated from other such groups. These populations exhibit various traits, such as the ability to produce viable, fertile offspring, have similar morphological characteristics, and genetic exchange is generally isolated from other populations. The term population can be defined various ways, but in the evolutionary context, Ridley (1996) defines it as, a group of organisms, usually a group of sexual organisms that interbreed and share a gene pool.

The ESA (1973, amended in 1978) defined “species” to include, “any subspecies of fish or wildlife or plants and any **distinct population segment** of any species of vertebrate fish or wildlife, which interbreeds when mature.” Waples (1991), further defined the term *distinct population segment*, a vertebrate population will be considered distinct (and hence a “species”) for the purposes of conservation under the Act if the population represents an evolutionary significant unit (ESU) of the biological species.

1.1 Levels of population structure

1.1.1 General

Various terms are used in salmonid biology to define levels of population structure or ecological types. Brannon et al. (2002) state that population structure is defined by the life history strategies that have evolved to maximize fitness under varying environmental conditions within geographic ranges.

Ricker (1972) defined the term *stock* to describe the fish spawning in a particular lake or stream at a particular season, and did not interbreed with any other group to a *substantial degree*. Exactly what the term, *substantial degree* means in Ricker’s definition can have a varying effect on how stocks are considered *independent* of one another (McElhaney et al. 2000). McElhaney et al. (2000) state that if less than 10% of the population are “strays” then there is some theoretical basis to label the population as *independent* (see below).

Other distinctions of populations into runs, races, or demes, have been used synonymously with the term stock (Brannon et al. 2002). Brannon et al. (2002) further discusses the term race in defining their racial model that determines the life history characteristics of chinook and steelhead. They define race as, *a genetically distinct group within the species that is carried across and identifiable throughout the geographic range of the species.* There is also recognition among biologists that sub-populations exist within the larger population structure.

In the Columbia River, chinook have been identified as "spring", "summer", or "fall" run fish based on their entry into the river from the ocean (Burner 1951; French and Wahle 1965). This division into three segments is arbitrary (Mullan 1987). Thompson (1951) showed that the historical (before Caucasian interference) chinook run entering the Columbia River was a bell-shaped curve from February to November, peaking between June 10-20, and tapering off to tails before and after this time. Early harvest of the most productive segment of the run (those entering in the early summer period) left the spring and fall components as artifacts of overfishing (Beiningen 1976).

Steelhead in the Columbia River are usually designated as either "summer-or winter" types (Busby et al. 1987), which is based, again, on their entry into freshwater to spawn. Brannon et al. (2002) concluded that population structure of chinook salmon and steelhead trout within the Columbia Basin is "a reflection of diversity in life history forms expressed by ongoing adaptive evolution in diverse environments," which is primarily dictated by temperature.

1.1.2 ESU

Another approach to separating salmonid populations is the ESU concept. Waples (1991) defined ESUs as the determining population structure for delineating whether "species" should be listed under the ESA. An ESU is a population (or group of populations) that, 1) is reproductively isolated from other conspecific population units, and 2) represents an important component in the evolutionary legacy of the species. ESUs may contain multiple populations that are connected by some degree of migration, and hence may have broad geographic areas, transcending political borders. Determining exactly what the evolutionary significance of a population is may be difficult.

1.1.3 Distinct Population Segment

As amended in 1978, the ESA allows listing of *distinct population segments* (DPS) of vertebrates as well as named species and subspecies. However, the ESA did not provide specific guidance on what constituted a DPS, and thus created some ambiguity (Platts et al. 1993). Because of this ambiguity, NMFS (now NOAA Fisheries) and the USFWS created a policy in 1996 to recognize and define DPSs in relation to ESA listings (61 FR 4722). Because NMFS had established a policy in 1991 that defined species under the ESA (56 FR 58612) for Pacific salmonids, it maintained its delineation for the ESA that a population segment would be a DPS if it was an ESU (see above).

Three elements were considered by NMFS and USFWS in the decision regarding the status of a possible DPS as endangered or threatened under the Act (61 FR 4722). These are applied similarly for addition to the lists of endangered and threatened wildlife and plants, reclassification, and removal from the ESA lists:

- Discreteness of the population segment in relation to the remainder of the species to which it belongs;
- The significance of the population segment to the species to which it belongs; and
- The population segment's conservation status in relation to the Act's standards for listing (i.e., is the population segment, when treated as if it were a species, endangered or threatened?).

1.1.4 Independent populations

Ford et al. (2001), as part of their exercise to determine interim recovery levels for Upper Columbia[1] spring chinook and steelhead ESUs, defined *independent populations*, as:

Aggregations of one or more local breeding units (demes) that are closely linked by exchange of individuals among themselves, but are isolated from other independent populations to such an extent that exchanges of individuals among the independent populations do not appreciably affect the population dynamics or extinction risk of the independent populations over a 100-year time frame.

Ford et al. (2001) used the following metrics to define independent populations:

- spatial and temporal spawning distribution,
- correlations in abundance,
- genetics,
- physical patterns of environment utilized,
- phenotypic similarities,
- life history patterns,
- mark/recapture data,
- homing fidelity.

1.1.5 Genetic Diversity Units and Major Ancestral Lineages

As part of the state of Washington's effort to identify larger groups of populations (or stocks), Busack and Marshall (1995) defined two potential groupings as genetic diversity units (GDU) and major ancestral lineages (MAL).

A GDU is a group of genetically similar stocks that is genetically distinct from other such groups. The stocks [in a GDU] typically exhibit similar life histories and occupy ecologically, geographically, and geologically similar habitats. A GDU may consist of one stock.

A MAL is a group of one or more genetic diversity units whose shared genetic characteristics suggest a distant common ancestry, and substantial reproductive isolation from other MALs. Some of these groups are likely to the result of colonization and diversification preceding the last period of glaciation.

1.1.6 Metapopulations

Another view is that populations can be grouped into metapopulations. Metapopulations can be defined as an assemblage of closely related populations within a geographic identity (Williams et al. 2000). Reiman and Dunham (2000) describe three conditions that they felt

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[1] NOAA Fisheries (previously NMFS) defines the Upper Columbia as the section of river upstream of the confluence of the Yakima River. Common local usage is that the mid-Columbia spans the area from the confluence of the Yakima River to Grand Coulee Dam, and the Upper Columbia is upstream of that dam to it's origin. For consistency sake, the NOAA Fisheries definition will be followed.

defined metapopulations:

- habitat consists of discrete patches or collections of habitats capable of supporting local breeding populations;
- the dynamics of occupied patches are not perfectly synchronous;
- dispersal among the component populations influences the dynamics and/or the persistence of the metapopulation or at least some of the local populations.

Brannon et al. (2002) further broke down metapopulations of chinook and steelhead in the Columbia River into first- second-, or third-order categories, which related to how spatially separated the populations were. First-order metapopulations refers to “genetically similar populations spatially segregated around given temporal profile within distinct geographic areas.” Second- and third-order metapopulations are distinguished by their degree of relatedness, determined by percent nucleotide divergence (Brannon et al. 2002).

Reiman and Dunham (2000) pointed out that a metapopulation view of salmonids implied that, the spatial geometry (size, number, distribution) of suitable habitats matters to the dynamics and long-term persistence of these species’ populations. This point has an obvious application when determining what restoration or conservation measures are prioritized.

CRITFC (1995) further defined metapopulations in the Columbia River;

Healthy salmon populations have complex population structures characterized by the return of multiple age classes and by limited mixing between neighboring populations. This variety in life history patterns allows them to persist through periodic disasters and unfavorable environmental conditions and to colonize newly available areas.

The complex structure of salmon populations most likely functions as a metapopulation. . . . The ability of naturally reproducing populations to persist and flourish in a fluctuating environment depends on demographic factors, genetic factors and interactions between local populations. . . . While a mufti-attribute approach to describing stock structure is a difficult task, it has the advantage of avoiding the shortcomings of any single approach and more accurately describes the important traits which have allowed these fish to persist for thousands of years.

1.1.7 Other terms

In the USFWS draft recovery plan (USFWS 2002), other terms were used to describe population differentiation of bull trout throughout the range they looked at. The information below is taken directly from that report (edited).

Local populations

Relatively small amounts of genetic diversity within a tributary but high levels of genetic divergence between tributaries (Leary et al. 1993; Taylor et al. 1999; Spruell et al. 2000) generally characterize groups of bull trout that spawn in various tributaries. This suggests that many bull trout have a high fidelity to specific streams (Kanda and Allendorf 2001) and can be characterized as local populations. The results of many studies support the hypothesis that many streams support local populations that are isolated reproductively (Kanda et al. 1997; Kanda 1998; Spruell et al. 1999; Kanda and Allendorf 2001; Neraas and Spruell 2001). As noted by Spruell et al. (1999), these widespread patterns of genetic variation most likely reflect historical population structures, past evolutionary events, and the general life history of bull trout.

Core Areas

The recovery plan [USFWS 2002] considers local populations of bull trout to be partially isolated, but have some degree of gene flow among them. Such groups meet the definition of (Meffe and Carrol 1994) and function as (Dunham and Rieman 1999) a metapopulation. The intent of the recovery plan is to have core areas reflect the metapopulation structure of bull trout. Within a bull trout metapopulation, local populations are expected to function as one demographic unit (Hanski and Gilpin 1997). All local populations within a bull trout metapopulation would be at a common risk of extinction and have a relatively high degree of genetic relatedness (Kanda and Allendorf 2001). In theory, bull trout metapopulations can be composed of two or more local populations. However, Rieman and Allendorf (2001) have suggested that between 5 and 10 local populations are necessary for a bull trout metapopulation to function effectively.

The USFWS (2002) also discuss another definition as recovery units, but this does not delineate population structure so much as management structure for recovery plans (see further explanation below).

Conclusion

For purposes of subbasin planning, we choose to use the term* independent populations *to describe a local breeding group of fish that may be part of a larger metapopulation.

2. Historic and current population structure for fish species from the Columbia Cascade Province

2.1 Upper Columbia Spring Chinook

2.1.1 Historic distribution

Mullan (1987) felt that because of the geology of the region upstream of the current Grand Coulee Dam site, that that spring chinook were not very abundant, with the possible exceptions of the San Poil and Spokane River basins. Fulton (1968) described the historic distribution of spring chinook in the Upper Columbia. He relied heavily on the fieldwork of French and Wahle (1965) for his information on distribution. He combines descriptions of spring chinook distributions in the Wenatchee River basin as: Most *of main river; portions of Chiwawa, Little Wenatchee, and White rivers; and Nason, Icicle, and Peshastin creeks.* Fulton (1968) includes most of the mainstem Entiat as habitat for spring and summer chinook, noting that steep gradients of tributaries prevent salmon use. Fulton (1968) shows chinook use of the Methow River basin as *Main stream* (Methow) *and large tributaries....Lower portion of main stream* (Twisp River) .... *Main stream* (Chewuch River) *to 52 km. above the mouth.* Fulton mentioned that the Chewuch River had the largest spring chinook run of any single stream above Rocky Reach Dam. Current information (see below), supports the observation by Fulton, although the mainstem Methow now appears to support more spawning, possibly because of the current hatchery programs.

Fulton (1968) reports no use of the Okanogan River or it's tributaries by spring chinook. However, Craig and Suomela (1941) contain affidavits that indicate use of Salmon Creek by chinook salmon. Based on the time at which these fish were observed, they were spring chinook. In 1936, spring chinook were observed in the Okanogan River upstream from Lake Osoyoos by Canadian biologists (Gartrell 1936).[2] That observation for May estimated 100-300 adults present "on the spawning grounds." We know of no other recent years when use of the Okanogan River by spring chinook was noted.

It has been suggested that spring chinook (and steelhead) formerly used the Similkameen River upstream from falls that lay at the present site of Enloe Dam. Chapman et al. (1995 CPa) found no evidence that such use occurred. The underlying source for Fulton's (1968) inclusion of the Similkameen River upstream from the site of Enloe Dam as anadromous salmon habitat was WDF (1938). Perusal of that source does not support the Fulton observation. WDF (1938) describes existence of potential spawning habitat in the area upstream from Enloe Dam, but provides no documentation of historical use of the area by salmon or steelhead (*O. mykiss*). Cox and Russell (1942) state:

> *From testimony of a Mr. McGrath at Nighthawk, who had been in that country over 40 years, we learned that before any power dam was built* (Enloe Dam), *the 15' to 20' natural falls already mentioned prevented salmon ascending any farther. He had often fished the river at Nighthawk but had never heard of a salmon being seen or caught above the natural falls. He stated that the Indians came in to fish at these falls each summer.....Therefore, we conclude that this power dam did not interfere with any salmon runs....*

Accounts of the traditional story of coyote suggest that salmon never passed upstream of the falls, and the Native people of the Similkameen valley never sought to have fish passage there, further confirming that anadromous fish never passed the falls (Vedan 2002).

2.1.2 Current distribution

Spring chinook currently spawn and rear in the upper main Wenatchee River upstream from the mouth of the Chiwawa River, overlapping with summer chinook in that area (Peven 1994). The primary spawning grounds of spring chinook in the Wenatchee River, in order of importance, are: Chiwawa River, Nason Creek, Little Wenatchee, and White River (Icicle River is not included because it is believed that most of the spawning population from this stream consist of adult returns to the Leavenworth NFH (Peven 1994)).

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[2] Gartrell (1936) contains the only reference that we found to spawning by spring-run salmon in the main Okanogan River. We regard this information cautiously.

Hamstreet and Carie (2003) describe the current spawning distribution for spring chinook as between river miles 16 and 28 in the Entiat River and 1.5 to 5 in the Mad River, its major tributary. The primary spawning grounds in the Methow River currently are, in order of importance: the mainstem Methow, Twisp, Chewuch, and Lost rivers (Scribner et al. 1993).

WDW et al.(1989) states: *Natural spring chinook production in the Okanogan and Similkameen subbasins is currently not feasible due to extensive habitat alterations in the accessible reaches.* Failure of inclined-plane traps to capture spring chinook smolts during trapping of sockeye smolts in the lower Okanogan River (McGee and Truscott 1982; McGee et al. 1983) empirically supports that judgment. Bryant and Parkhurst (1950) and Fulton (1970) claim spring chinook used Omak Creek, although the affidavits in Craig and Suomela (1941) do not mention such use. Weitkamp and Neuner (1981) captured a handful of chinook juveniles in a floating trap in the Okanogan River in 1981 that were large enough to be spring chinook. The trap was downstream from the confluence of Salmon Creek, and could have resulted from spring chinook that spawned in Salmon Creek. None were captured in 1982-1983 (McGee and Truscott 1982; McGee et al. 1983).

Meyers et al. (1998) defined the Upper Columbia River spring-run ESU as stream-type chinook that spawn in the Wenatchee, Entiat, and Methow rivers. They explain that the biological review team (BRT) felt that in spite of the tremendous amount of hatchery influence on these fish, they still represented an important genetic resource, partially because it was presumed it still contained the last remnants of the gene pools for populations from the headwaters of the Columbia River.

Ford et al. (2001) concluded that there were currently three independent populations of spring chinook within the Upper Columbia spring chinook ESU; Wenatchee, Entiat, and Methow basins. This comports with recent spawning ground surveys in the Wenatchee, Entiat, and Methow River basins (see below).

Brannon et al. (2002) separated the Methow spring chinook first-order metapopulation from the Wenatchee and Entiat populations, which were linked together.

Within these populations there are other sub-populations that Ford et al. (2001) suggested should be considered when reviewing management actions within these geographic areas to maintain potential adaptive advantages of these sub-populations.

The Interior Columbia Basin Technical Recovery Team (ICBTRT), in its draft report (ICBTRT 2003) agree with the initial designation of independent populations by Ford et al. (2001).

In conclusion, for the purposes of sub-basin planning, we assume that there are three independent populations (Wenatchee, Entiat, and Methow) within the larger metapopulation that spawns naturally upstream from Rock Island Dam. Within these independent populations, there are also sub-populations that should be considered during management processes.

2.2 Summer Steelhead

2.2.1 Historic distribution

Steelhead historically used all major (and some minor) tributaries within the Upper Columbia Basin for spawning and rearing (Chapman et al. 1994 CPa). Fulton (1970) described steelhead using the Wenatchee River and eight of its tributaries: lower Mission, Peshastin, Icicle, Chiwaukum, Nason creeks, and the Chiwawa, Little Wenatchee, and White rivers. Fulton noted the mainstem Entiat and Mad Rivers as producing steelhead. In the Methow, Fulton (1970) lists the mainstem, Twisp, and Chewuch Rivers, and lower Beaver Creek. WDF/WDW (1993) also listed Gold, Wolf, and Early Winters creeks, and the Lost River as historic steelhead habitat. In the Okanogan Basin, Fulton (1970) named Omak and Salmon creeks as producing steelhead, and the upper Similkameen, but that is questioned based on uncertainty of fish being able to ascend Enloe Falls prior to the dam at that site (Chapman et al. 1994 CPa). Mullan et al. (1992CPa) stated that steelhead never used the Okanogan in great numbers, and that Salmon Creek (blocked by a dam in 1916) and Similkameen (see discussion above concerning fish upstream of the falls) were the most probable steelhead producing streams in the basin.

Howell et al. (1985) also listed minor tributaries of the Columbia River such as Squilchuck, Stemilt, Colockum, Tarpiscan, Brushy, Tekison, and Quilomene creeks as potentially producing steelhead, but never in great numbers.

Mullan et al (1992 CPa) noted that the Spokane River, upstream from the current Grand Coulee dam site, was a major producer of steelhead but noted:

"*The inescapable conclusion is that headwater lacustrine environments produced negligible numbers of steelhead. This conclusion, combined with the inaccessibility or infertility of nearly all tributary systems above the Sanpoil River, helps explain why steelhead were confined to a relatively few tributary habitats*."

2.2.2 Current distribution

Busby et al. (1996) determined that the ESU for Upper Columbia summer steelhead comprised the populations that currently spawn in the Wenatchee, Entiat, Methow, and possibly Okanogan rivers. The BRT felt that because of past hatchery practices (see below) there have been substantial homogenization of the gene pool. However, there is probably remnant genetic material from ancestral populations that could have been "stored" in resident populations (Mullan et al. 1992 CPa). Ford et al. (2001) agreed with the delineation described by Busby et al. (1996), but described each subbasin, with the possible exception of the Okanogan, as an *independent population*.

Brannon et al. (2002) combined all of the first-order metapopulations of summer steelhead upstream of the Yakima River into one metapopulation.

The ICBTRT recently listed the Okanogan Basin steelhead as an independent population: "*The current status of steelhead endemic to the Okanogan is unknown. Currently, low numbers of natural steelhead return to this system, but may be offspring from hatchery* *returns. However, the Okanogan appears to have supported an independent population of steelhead historically. Although habitat conditions for rearing are highly degraded in the system, the Okanogan and its tributaries in the U.S. and Canada appear to have contained sufficient habitat to have supported an independent population of steelhead. In addition, the Okanogan is found in a substantially different habitat than other populations in this ESU, further supporting delineation of this population*" (ICBTRT 2003).

Beginning in 2001, WDFW has been conducting spawning ground surveys for steelhead in the Wenatchee and Methow rivers (Murdoch et al. 2001; Jateff and Snow 2002). These efforts are in conjunction with hatchery evaluations that are currently taking place within the Upper Columbia Basin for Chelan and Douglas Counties Public Utility District (PUD) funded mitigation efforts. Current spawning distribution in the Wenatchee Basin, in order of importance appears to be: the Wenatchee River between the Chiwawa River and Lake Wenatchee, Nason, Chiwawa, and Icicle creeks. Other tributaries were not surveyed, such as the Little Wenatchee and White rivers, or Chiwaukum, Peshastin, or Mission creeks, but are most likely used by steelhead for possible spawning and rearing.

In the Methow River, Jateff and Snow (2002) found, in order of importance appears to be: Twisp River, Winthrop National Fish Hatchery creek, mainstem Methow River, Chewuch River, and Beaver Creek. Other creeks that were surveyed and had fewer than 15 redds were, Methow Hatchery creek, Lost River, Buttermilk, Boulder, Eight-Mile, and Lake creeks. War and Wolf creeks were surveyed but showed no redds.

In conclusion, for the purposes of sub-basin planning, we assume that there are four independent populations (Wenatchee, Entiat, Methow, and Okanogan) of steelhead within the larger metapopulation that spawns naturally upstream from Rock Island Dam.

2.3 Upper Columbia Summer/fall chinook

2.3.1 Historic distribution

Summer/fall chinook formerly spawned in suitable depths, velocities, and substrates from the current site of Priest Rapids Dam to the uppermost accessible sites in the Columbia River, near Golden, B.C. The suitable sites were not evenly distributed along the river length (Chapman 1943, Edson 1958), just as they are irregularly distributed now in the Hanford Reach (Swan et al. 1988). No permanent summer/fall habitat extirpation has occurred in the tributaries of the mid-Columbia River upstream from the Hanford Reach and downstream from Chief Joseph Dam except in the Okanogan River. Summer/fall chinook once used the Okanogan River upstream from Lake Osoyoos for spawning and rearing (WDF 1938; Vedan 2002). They cannot currently reach those upstream areas because of McIntyre Dam downstream from Lake Vaseaux.

In the Columbia River in Washington State, summer/fall chinook salmon spawned in the Columbia, Wenatchee, Okanogan, and Similkameen rivers (Craig and Suomela 1941). Apparently they also spawned in the Chelan River because Chapman (1941) observed them spawning downstream from the powerhouse on the Chelan River as early as 1937. In the Columbia River, Chapman (1943) found chinook spawning near Kettle Falls, upstream from Grand Coulee Dam site. Fish and Hanavan (1948) reported chinook redds in the Columbia

River upstream from the confluence of the Chelan River to Grand Coulee Dam. Meekin (1967) documented chinook salmon redds in the Columbia River between Brewster and Washburn Island.

Apparently, summer/fall chinook did not spawn in the Entiat River (Craig and Suomela 1941; Mullan 1987). Also, Craig and Suomela (1941) found no evidence that summer/fall chinook salmon spawned in the Methow River; although, they indicate that it was possible that a few spawned in the lower Methow River. Meekin (1967) also believes that no summer/fall chinook spawned in the Methow River.

Fulton (1968) indicates that chinook of the spring- and summer-run races used the Similkameen River before Enloe Dam was constructed just upstream from what he called *passable falls*. The underlying source is WDF (1938). As noted elsewhere in this report, that source does not document use of the river upstream from Enloe Dam.

Most loss of summer/fall chinook spawning and rearing occurred in the areas upstream from the impassable Grand Coulee Dam. Additional loss occurred when Chief Joseph, Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids dams were constructed. The degree to which the resulting reservoirs offset loss of productive rearing remains unmeasured.

Tumwater Dam (RM 32.7) and Dryden Dam (RM 17.6) on the Wenatchee River were partial obstacles to upstream passage of adults before 1957. Between 1957 and 1986, some observers considered fish passage facilities inadequate, and new facilities were constructed in the late 1980s. Mullan et al. (1992 CPa) were skeptical that the dams were serious obstacles before the fishways were improved.

2.3.2 Current Distribution

Some observers, pointing to migration timing patterns of early- and late-arriving components of the summer/fall chinook of the mid-Columbia, would distinguish summer-run from fall-run. Chapman et al. (1994 CPa) did not concur with that reasoning. Late-run chinook destined to spawn in tributaries of the upper Columbia and in limited areas of the main Columbia upstream from Rock Island Dam arrive earlier than fish destined to spawn in Wanapum pool and the Hanford Reach, and the frequency distribution of arrivals of early fish appears to have a slight discontinuity as it blends into fall arrivals. Discontinuous spawning in space should be sufficient explanation for the latter. Most late-arriving fish probably spawn in the main Columbia River, while most earlier arrivals spawn in tributaries, although some radio tagged fish classed as "fall chinook" appeared in the Okanogan River when last seen in 1993 (Stuehrenberg et al. 1995). Temperatures of the main Columbia River differ enough from tributaries to lead to later spawning in the former (Brannon et al. 2002). An additional timing discontinuity at McNary Dam results from the spatial discontinuity between spawning areas of the upper Columbia region from Wanapum Dam downstream and those in the main Wenatchee River and upstream from Rocky Reach Dam.

Utter (1993), Chapman et al. (1994 CPa), Waknitz et al (1995), and Meyers et al. (1998) all concur that the current metapopulation, or ESU, for summer/fall chinook (ocean-type chinook) extends roughly from the confluence of the Snake River to Chief Joseph Dam tailrace, including populations in the Yakima, Wenatchee, Entiat, Methow, and Okanogan basins.

Brannon et al. (2002) designated the mainstem spawners downstream of Rock Island Dam (which includes the Hanford Reach) as part of a metapopulation belonging to the mid-Columbia and Snake River populations, which includes the Klickitat, Deschutes, John Day, lower portions of the Grande Ronde and Clearwater rivers. Upstream of Rock Island Dam, they characterize the lower Wenatchee, Okanogan, Similkameen (and presumably), mainstem Columbia River spawners as one metapopulation.

Brannon et al.'s (2002) divergence in their designation of population structure can be explained from within their report:

Our present understanding of population structure contrasts with the view that "racial" types, defined as subspecies, account for the life history forms observed today. From ecological, life history, and genetic analyses of chinook populations, we conclude that population structure in the Columbia Basin, as well as elsewhere, is a reflection of diversity in life history forms expressed by ongoing adaptive evolution in diverse environments. The genetics of the population units are the result of both multiple colonization events and dispersal into habitats through temporal adaptation. We have presented evidence of temperature as a dominant factor in the environment that defines what life history options are available to chinook salmon . . . The point is that while chinook are separated into several life history forms over a temporal framework, each has the potential of establishing other life history options when given such opportunities, as demonstrated in the Great Lakes and New Zealand (Quinn et al. 2000; Unwin et al. 2002), and gene exchange should be expected to occur whenever population units overlap temporally regardless of their origin.

Summer/fall chinook salmon typically spawn in the Wenatchee River between RM 1.0 and Lake Wenatchee (RM 54). Within that area the distribution of redds of summer/fall chinook has changed. Peven (1992 CPa) notes that, since the early 1960s, numbers of redds have decreased downstream from Dryden Dam (RM 17.5), while they have increased upstream from Tumwater Dam (RM 32.7). On a smaller scale, Peven (1992 CPa) reports that, since at least 1975, densities of redds (i.e., redds/mile) were highest near Leavenworth (RM 23.9-26.4) and in Tumwater Canyon (RM 26.4-35.6).

In the Methow River, summer/fall chinook salmon spawn between RM 2.0 and the Winthrop hatchery diversion dam (RM 51.6). Chinook redds are scattered throughout that area, with a redd found within almost every river mile (Hillman and Miller 1993). The overall distribution of redds of summer/fall chinook in the Methow River has changed little since 1987, when ground surveys began (Miller 2003). During that period, redds were most abundant between Carlton and Twisp (RM 27.2-39.6), and least abundant between Winthrop and the hatchery diversion dam (RM 49.8-51.6) (Hillman and Miller 1993).

In the Okanogan Basin, summer/fall chinook salmon spawn in both the Okanogan and Similkameen rivers. In the Okanogan River, chinook usually spawn between RM 14.5 (just downstream of Malott) and Zosel Dam (RM 77.4). In the Similkameen River, chinook spawn between its mouth and Enloe Dam (RM 8.9). In both rivers, redds are highly clumped, and those distributions have not changed since 1987 when ground surveys were first conducted (Hillman and Miller 1993; Miller 2003). During that period, densities of redds in the Okanogan River were highest between Okanogan and Omak (RM 26.1-30.8), McLoughlin Falls and Tonasket (RM 48.9-56.8), and the Similkameen River confluence and Zosel Dam (RM 74.1-77.4); they were lowest between Tonasket and the Similkameen River confluence (RM 56.8-74.1) (Hillman and Miller 1993). In the Similkameen River during the same period, densities of redds were highest between the mouth and the county road bridge (RM 0-5). Unlike in other mid-Columbia streams, Hillman and Miller (1993) found that summer/fall chinook in the Okanogan Basin constructed most of their redds near islands, i.e., in braided segments.

A small number of summer/fall chinook salmon spawn in the Chelan and Entiat rivers (Peven 1992 CPb). Spawning in the Chelan River is limited to the short segment below the Chelan powerhouse. In 1990 and 1991, Giorgi (1992) found chinook redds in the Chelan River between the boat ramp and about 150 feet downstream from the railroad bridge. Spawning of summer/fall chinook salmon in the Entiat River is a result of the Entiat National Fish Hatchery, which released chinook into the river between 1941 and 1976 (Mullan 1987). While late-run chinook may never have spawned naturally in the Entiat River, there does appear to be a self-sustaining population present currently. This population is small in relation to the Wenatchee or Similkameen River basins.

Numerous redds are also counted immediately downstream of Wells Dam. Since the 1960s, fish have been observed spawning in this area too (S. Hays, personal communication).

In conclusion, for the purposes of sub-basin planning, we assume that there is one large metapopulation of summer/fall chinook between the confluence of the Snake River and Chief Joseph Dam, but specific tributaries, in addition to limited areas of mainstem Columbia spawning, contain independent populations that need to be considered in management actions.

2.4 Sockeye salmon

2.4.1 Historic Distribution

Historically, Upper Arrow, Lower Arrow, Whatshan, and Slocan Lakes in the Upper Columbia River drainage in British Columbia were utilized by sockeye salmon as nursery lake habitat (Mullan 1986). In addition, Fulton (1970) stated that sockeye salmon probably ascended to Kinbasket, Windermere, and Columbia Lakes in the Canadian portion of the Columbia River, and Mullan (1986) suggested that the presence of kokanee indicated the past use of these lakes by sockeye salmon too. WDF (1938) and Chapman (1943) reported observations of sockeye salmon at Kettle Falls on the Columbia River and at Upper and Lower Arrow Lakes on the Upper Columbia River in British Columbia prior to Grand Coulee Dam construction.

Within the Columbia River Basin in Washington state upstream of the Snake River, historical populations of sockeye salmon existed in the Yakima, Wenatchee, and Okanogan Rivers (Mullan 1986). Sockeye salmon once utilized Lakes Okanogan and Skaha in the Okanogan

River Basin for juvenile rearing (Bryant and Parkhurst 1950; Fulton 1970; Mullan 1986; Vedan 2002). Sockeye salmon access to Lakes Okanogan and Skaha in British Columbia was blocked by dams in 1915 and 1921, respectively. Access to Lake Osoyoos remained open, but the population was severely depleted in the early 1900s (see below). No anadromous fish are known to have inhabited the Chelan Basin, and the fact that there were no indigenous kokanee in the Lake suggests that sockeye were never present (B. Behnke, personal communication; Chelan PUD 2000).

Fulton (1970) listed Palmer Lake on the Similkameen River, a tributary of the Okanogan River, as originally supporting native sockeye salmon, while Craig and Suomela (1941) suggested that salmon could not have ascended Enloe Falls, based on affidavits of local long-term residents (see previous discussion).

The current Enloe Dam blocks access to all but the lower six miles of the Similkameen River. Sockeye salmon have been observed on numerous occasions since 1936 in the Similkameen River below the dam, during the Okanogan River sockeye salmon migration (Chapman 1941; Bryant and Parkhurst 1950; Chapman et al. 1995 CPa).

2.4.2 Current Distribution

Currently, Lake Wenatchee, in the Wenatchee Basin, and Lake Osoyoos, in the Okanogan Basin are the two main sockeye salmon producing lakes in the entire Columbia River Basin. Gustufson et al. (1997) listed these two populations as separate ESUs. Mullan (1986), WDF/WDW (1993), Chapman et al. (1995 CPb), and Shaklee et al. (1996) listed these as independent populations also.

The principal spawning areas for Wenatchee Basin sockeye are approximately in the lower 4 miles of the Little Wenatchee River and the lower 5 miles in the White River (Peven 1992 CPb). Some fish spawn in the Napequa River (a tributary of the White River) too.

In the Okanogan Basin, spawning occurs in the mainstem Okanogan River between the head of Lake Osoyoos (RM 90) to the outlet of Vaseux Lake (RM 106) (Peven 1992 CPb).

In conclusion, for the purposes of sub-basin planning, we assume there are two independent populations of sockeye salmon; one in the Wenatchee Basin and one in the Okanogan Basin.

2.5 Coho salmon

Coho salmon are considered extirpated in the Upper Columbia River (Fish and Hanavan 1948, Mullan 1984). Mullan (1984) estimated that upstream of the Yakima River, the Methow River and Spokane River historically produced the most coho, with lesser runs into the Wenatchee and Entiat. There are conflicting reports of whether the Okanogan Basin historically produced coho (Craig and Suomela 1941; Vedan 2002).

There were two attempts in the twentieth century to rebuild coho populations. Between the early 1940s and the mid-1970s, the USFWS raised and released coho as part of their mitigation responsibilities for the construction of Grand Coulee Dam (Mullan 1984). Chelan PUD also had a coho hatchery program until the early 1990s. While some natural production may have occurred from these releases, the programs overall were not successful, primarily due to the reliance on lower river stocks that were maladapted to the upper Columbia (Mullan 1984, see below).

Recently, the Yakama Indian Nation has begun a more concerted effort to reintroduce coho into the Upper Columbia (Scribner et al. 2002). Preliminary results so far are promising. Current efforts to rebuild coho are primarily in the Wenatchee and Methow basins, where the YIN program is concentrated.

In conclusion, coho have been extirpated from the CCP. However, managers need to consider and track the effort by the YIN to reintroduce coho, and management actions taken accordingly.

2.6 Pacific lamprey

2.6.1 Historic distribution

Historical distribution of Pacific lamprey in the Columbia and Snake Rivers was coincident wherever salmon occurred (Simpson and Wallace 1978). It is likely that Pacific lamprey occurred historically throughout the Wenatchee, Entiat, Methow, and Okanogan basins. If we assume that Pacific lamprey and salmon used the same streams, one could conclude that Pacific lamprey occurred in the Wenatchee River, Chiwawa River, Nason Creek, Little Wenatchee River, White River, Icicle Creek, Peshastin Creek, and Mission Creek in the Wenatchee River basin.[3] In 1937, WDF (1938) collected several juvenile lamprey that were bypassed from irrigation ditches in Icicle and Peshastin creeks, and the lower mainstem Wenatchee River. Pacific lamprey would have also used the Entiat and Mad rivers in the Entiat Basin and the Methow, Twisp, Chewuch , and Lost rivers, and Wolf and Early Winters creeks in the Methow Basin. In the Okanogan Basin, lamprey may have used the Okanogan River, Similkameen River, Salmon Creek, and Omak Creek.

Because Grand Coulee Dam was built without fish passage facilities, the Fish and Wildlife Service developed the Grand Coulee Fish Maintenance Project (GCFMP) (Fish and Hanavan 1948; see below). Fish and Hanavan (1948) do not mention the capture of lamprey. Apparently these fish were allowed to pass Rock Island Dam.

2.6.2 Current Distribution

The current distribution of Pacific lamprey in the Columbia River and tributaries extends to Chief Joseph Dam and to Hells Canyon Dam in the Snake River (Close et al. 1995). Both dams lack fishways and limit the distribution of anadromous fish. Within the CCP, the distribution of lamprey is not well known. We know that they still exist in the Wenatchee, Entiat, and Methow systems, but the distributions within those systems are mostly unknown. BioAnalysts (2000) used anecdotal information to describe the extent of Pacific lamprey distribution in the CCP. They cautioned that the following description may be confounded by the presence of river lamprey. In most cases, observers they cited reported the occurrence

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[3] Currently, lamprey have not been observed upstream of Tumwater Canyon. This may suggest that hydraulic conditions within Tumwater Canyon are a migration barrier for lamprey and they may never have existed in the mainstem or tributaries upstream of the canyon.

of lamprey but did not identify the species. Thus, the descriptions below may apply to both species.

In the Wenatchee River basin, lamprey appear to occur primarily downstream from Tumwater Dam. Jackson et al. (1997) indicated that they have observed no Pacific lamprey ascending Tumwater Dam during the last decade. Because they monitored fish movement at Tumwater Dam between May through September, it is possible that they missed lamprey that migrate upstream to spawning areas during the spring (prior to May). Washington Department of Fish and Wildlife (WDFW) captured no lamprey in the lower Chiwawa River during the 1992-1999 trapping period or near the mouth of Lake Wenatchee (in BioAnalysts 2000). Hillman and Chapman (1989) surveyed the entire Wenatchee River during 1986 and 1987 and found no lamprey upstream from Tumwater Dam. The lack of lamprey in the upper Wenatchee is consistent with the work of Mullan et al. (1992 CPa), who found no lamprey in the mainstem or tributaries of the upper Wenatchee River basin.

Pacific lamprey have been observed in the lower Wenatchee River. Hillman (unpublished data) found many ammocoetes in the Wenatchee River near the town of Leavenworth and adult lamprey in the lower Wenatchee River (near RM 1.0). Kelly (USFWS, personal communication, in BioAnalysts 2000) found an adult Pacific lamprey in the Wenatchee River near the golf course in Leavenworth). Lamprey are also seen in the smolt monitoring trap in the lower Wenatchee River every year near the town of Monitor (A. Murdoch WDFW, personal communication). Apparently lamprey spawn in the irrigation canal just upstream from Monitor. These observations indicate that lamprey currently exist in the lower Wenatchee River (RM 0 to <27) and perhaps in the lower portions of Icicle, Peshastin, and Mission creeks.

Lamprey currently use the Entiat River basin. Kelly (USFWS, personal communication, in BioAnalysts 2000) found juvenile lamprey near RM 16 on the Entiat River. Although the USFWS has observed no adult lamprey near the hatchery, they occasionally find ammocoetes in settling ponds during spring high-flows (W. Edwards, USFWS, personal communication in BioAnalysts 2000). These observations suggest that Pacific lamprey exist at least in the lower 16 miles of the Entiat River.

Pacific lamprey are currently observed in the Methow River system. McGee et al. (1983) captured Pacific lamprey ammocoetes near RM 5 on the Methow River. They commented that the occurrence of ammocoetes in the catch increased with rapid rises in water level. In 1995, Hubble and Harper (1999) collected lamprey near the mouth of the Chewuch River during the period April through July. They captured no lamprey during the period August through November. Although unconfirmed, it is likely that lamprey also exist in the Twisp River.

It appears that lamprey do not presently use the Okanogan system. Sampling by McGee et al. (1983) found no lamprey there. Hillman (unpublished data) electrofished portions of the Okanogan and Similkameen rivers and collected no adult lamprey or ammocoetes. Although no lamprey have been observed in the Okanogan system recently, suitable spawning and rearing habitat appear to be available.

In conclusion, there ***may*** *be independent populations within the tributaries of the upper Columbia region, but additional information is needed to determine Pacific lamprey distribution and population delineation in the CCP before management actions are considered.*

2.7 Bull trout

2.7.1 Historic

Cavender (1978) first described bull trout as a separate species from Dolly Varden (*Salvelinus malma*). Confusion existed between the two species because of the many external similarities of appearance and morphology. However several genetic studies have confirmed that there is a distinction between the two (Phillips et al. 1989; Crane et al. 1994).

The genetic relationship among various groups of bull trout within the species can be complex (Rieman and Allendorf 2001). Bull trout and Dolly Varden each appear to be more closely related genetically to other species of *Salvelinus* than they are to each other (Phillips et al. 1989; Pleyte et al. 1992).

The two char species are widely distributed in Washington State, with the exception of the Columbia Plateau extending to the Idaho border (east of the Columbia, south of the Spokane and north of the Snake rivers), and a large part of the south western part of the state (Goetz, 1989; Mongillo 1993; Brown 1992). Most of the char east of the Cascade Mountains are believed to be bull trout, and most west of the mountains, Dolly Varden (Brown 1992).

While historic distribution is difficult to determine (Rieman et al. 1997), bull trout are believed to have been historically present in the CCP in the, Methow, Lake Chelan, Entiat, Wenatchee, and possibly Okanogan river basins (Brown 1992; Mongillo 1993). Fish were most likely present within the mainstem Columbia River in this region, including the area between Chief Joseph and Grand Coulee dams; they still currently use the mainstem upstream from Grand Coulee (Mongillo 1993).

In the state of Washington, reductions of bull trout have primarily occurred in the eastern part of the state, with the most notable being the extinction of bull trout in the lower portions of the Yakima and possibly Lake Chelan and the Okanogan river basin (Brown 1992). It is unclear how many bull trout used the mainstem of the Columbia and Snake rivers, but fish are still observed in counting windows of dams, primarily in the Columbia, upstream of the confluence of the Snake (Rieman et al. 1997).

2.7.2 Current Distribution

The Upper Columbia DPS of bull trout was listed as threatened under ESA on June 12, 1998 (63 FR 31647). In the draft recovery plan (USFWS 2002), bull trout were grouped into *DPSs*, *recovery units*, *core areas* or *local populations* (see above). They defined core areas as composed of one or more local populations, recovery units are composed of one or more core areas, and a distinct population segment is composed of one or more recovery units. The manner in which bull trout were grouped in the recovery plan represents an adaptive comparison of genetic population structure and management considerations. For the purposes of subbasin planning, our use of the term *independent population(s)* will be synonymous with the USFWS's use of the term *core area*.

While bull trout primarily inhabit colder streams (Pratt 1984, 1992), they are observed also in larger river systems throughout their range (Rieman et al. 1997). Bull trout are believed to occur primarily in fragmented habitat, although Williams et al. (1997) note that the distribution of bull trout has probably contracted and expanded periodically with natural climate changes.

Historically, there were most likely three life histories (or ecotypes) of bull trout within the CCP (adfluvial, fluvial and non-migratory; see discussion below in Life History section on *Potamodromy*), with distribution and population levels dictated by temperature and gradient (Mullan et al. 1992 CPa).

The USFWS's Upper Columbia Recovery Unit Team (UCRUT) identified three independent populations of bull trout currently in the CCP. These independent populations include the mainstem and tributaries of the Wenatchee, Entiat, and Methow Rivers (USFWS 2002). Based on survey data and professional judgment, the UCRUT also identified sub (local) populations of bull trout within each core area. Currently, the UCRUT felt that there are six sub populations in the Wenatchee Core Area, two in the Entiat Core Area, and eight in the Methow Core Area.

All three ecotypes of bull trout currently exist in the Wenatchee River Core Area (WDFW 1998). The six "migratory[4]" bull trout sub populations in the Wenatchee River are found in the Chiwawa River (including Chikamin, Phelps, Rock, Alpine, Buck and James creeks), White River (including Canyon and Panther creeks), Little Wenatchee River (below the falls), Nason Creek (including Mill Creek), Chiwaukum Creek, and Peshastin Creek (including Ingalls Creek). There may also be non-migratory subpopulations within some of these streams, as well as Icicle Creek.

In the Wenatchee subbasin, the adfluvial form matures primarily in Lake Wenatchee and ascends the White and Little Wenatchee rivers, and the Chiwawa River (Kelly-Ringold and DeLavergne 2003), where the young reside for one to three years. Fluvial bull trout populations spawn in the other streams identified above.

The USFWS (2002) has identified two sub populations of bull trout in the Entiat River, one fluvial population in the mainstem Entiat and one in the Mad River, a tributary to the Entiat. Primary bull trout spawning and rearing areas are in the Mad River and the mainstem Entiat River from the Entiat Falls downstream to the National Forest boundary (USFWS 2002).

In the Methow River system, the USFWS (2002) has identified bull trout in Gold Creek, Twisp River, Chewuch River, Wolf Creek, Early Winters Creek, the Upper Methow River,

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[4] "Migratory" bull trout are not defined within USFWS (2002). We assume they refer to ecotypes that exhibit some form of extended migration from either different "order" streams or between lakes and streams, and not those fish that inhabit a limited stream section (commonly known as "resident").

Lost River, and Goat Creek. In the Upper Methow River, sub populations have been identified in the West Fork and Trout Creek (USFWS 2002).

Two historically recognized populations of bull trout were extirpated in the Methow Basin through brook trout introgression (Eightmile and Beaver creeks). Brook trout probably represent the greatest immediate risk to the Methow Subbasin bull trout populations (Foster et al. 2002).

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 2002).

In conclusion, current distribution of bull trout within the CCP appears to be reduced from historic, especially in the lower Okanogan Basin where they are extirpated and Lake Chelan, where they have not been observed since the 1950s, but may exist in upper tributaries that have yet to be surveyed.

2.2 Westslope cutthroat trout

2.2.1 Historic Distribution

The primary historic distribution of westslope cutthroat trout (WSCT) occurred in the upper Columbia and Missouri River basins (USFWS 1999). WSCT were originally believed to occur in three river basins within Washington State; Methow, Chelan, and Pend Oreille, although only abundant in the Lake Chelan Basin (Williams 1998). From Williams (1998):

Apart from Lake Chelan and the Pend Oreille River where an abundance of relatively large cutthroat commanded the attention of pioneers, cutthroat trout in streams were obscured by their headwater location and small body size . . . Accordingly, the ethnohistorical record is mostly silent on the presence or absence of cutthroat. The picture is further blurred by the early scattering of cutthroat from the first trout hatchery in Washington (Stehekin River Hatchery, 1903) by entities (Department of Fisheries and Game and county Fish Commissions) dissolved decades ago along with their planting records. The undocumented translocation of cutthroats by interested non-professional starting with pioneers is another confusing factor that challenges determination of historical distribution.

Recent information, based on further genetic analyses (Trotter et al. 2001; Behnke 2002; Howell et al. 2003), indicates that the historic range of WSCT in Washington State is now believed to be broader. Historic distribution now includes the headwaters of the Wenatchee and Yakima River basins (Behnke 2002).

Overall, Behnke (1992) believed that the disjunct populations in Washington State probably were transported here through the catastrophic ice-age floods.

2.7.2 Current distribution

Through stocking programs that began with Washington state's first trout hatchery in the Stehekin River valley in 1903 (that targeted WSCT), WSCT have been transplanted in almost all available stream and lake habitat (Williams 1998). Extensive stocking of Twin Lake cutthroat trout in alpine lakes and mountain streams for decades has vastly increased the distribution of cutthroat in the Methow Subbasin (Williams 1998). Furthermore, the hatchery brood stock (indigenous Lake Chelan stock) used was felt by Behnke (1992) to be an excellent representation of pure westslope cutthroat trout. Another factor that most likely affected WSCT in the Chelan Basin was the introduction of *O. mykiss* in 1917.

Mullan et al. (1992 CPa) indicated pure or essentially pure westslope cutthroat trout were found above natural rainbow/cutthroat hybridization zones, and in alpine lakes with no history of non-native introductions in the Methow Basin.

Currently, in the CCP, WSCT are found throughout the Wenatchee, Entiat, Chelan, Methow, and Okanogan River basins (Williams 1998). WSCT are found within streams and lakes throughout these basins, but spawning (for stream populations) usually occurs in the upper portions of each basin.

In conclusion, westslope cutthroat appear to have expanded their range within the CCP from historic distribution, primarily from hatchery plants.

2.8 Redband trout

Redband trout (*Oncorhynchus mykiss gairdneri*), are indistinguishable from steelhead in the CCP. They are an exclusive ecotype of inland waters (Behnke 2002). For example, steelhead were not extirpated in the Methow River, as were coho, when a dam was constructed near its confluence with the Columbia, probably because headwater resident forms sustained the run (Mullan et al. 1992 CPa). This may have occurred in the Icicle Creek Basin too, where a barrier dam was erected in 1939 for the hatchery.

Anadromy is not obligatory in *O. mykiss* (Rounsefell 1958; Mullan et al. 1992). Progeny of anadromous steelhead can spend their entire life in freshwater, while progeny of rainbow trout can migrate seaward. Anadromy, although genetically linked (Thorpe 1987), runs under environmental instruction (Shapovalov and Taft 1954; Thorpe 1987; Mullan et al. 1992). It is difficult to summarize one life history strategy (anadromy) without due recognition of the other (non-migratory). The two strategies appear to co-mingle on some continuum with certain residency at one end, and certain anadromy on the other (see further discussion in Life History section). Upstream distribution is limited by low heat budgets (about 1,600 temperature units) (Mullan et al 1992). The response of steelhead/rainbow complex in these cold temperatures is they are “thermally fated” to a non-anadromous ecotype, presumably because growth is too slow within the time window for smoltification. However, these headwater rainbow trout contribute to anadromy via emigration and displacement to lower reaches, where warmer water improves growth rate and subsequent opportunity for smoltification.

2.8.1 Historic distribution

Redband trout originally occurred in the Fraser and Columbia River drainages east of the Cascade Mountains to barrier falls on the Pend Oreille, Spokane, Snake and Kootenai rivers (Behnke 1992). It is reasonable to assume that the historical distribution of redband trout was potentially wider than that of steelhead in the CCP because populations would have (and still do) occur in areas upstream of anadromous barriers. This would include all areas (downstream of temperature barriers; Mullan et al. 1992) in the Wenatchee, Entiat, Methow, and upper reaches of the Okanogan River basins.[5]

2.8.2 Current distribution

Currently, because of the admixture with hatchery fish (see below), *O. mykiss* is widespread throughout the CCP. *O. mykiss* is found virtually everywhere in the CCP below thermal barriers in the headwater areas within each major subbasin. To reiterate, in most areas of occurrence, it is not possible to distinguish between non-migratory and anadromous forms.

In conclusion, because it is not possible to distinguish anadromous from non-anadromous forms of redband trout, it is difficult to determine changes in distribution over historic times (regardless of hatchery plants, which have played an influence also; see below).

2.9 White sturgeon

2.9.1 Historic

Historically, white sturgeon moved throughout the mainstem Columbia River from the estuary to the headwaters, although passage was probably limited at times at large rapids and falls (Brannon and Setter 1992). Beginning in the 1930s, with construction of Rock Island, Grand Coulee, and Bonneville dams, migration was disrupted, because sturgeon do not pass upstream through fishways that were built for salmon, although they apparently can pass downstream (S. Hays, personal communication). Current populations in the Columbia River Basin can be divided into three groups: fish below the lowest dam, with access to the ocean (the lower Columbia River); fish isolated (functionally but not genetically) between dams; and fish in several large tributaries. In the CCP, construction of Wells, Rocky Reach, Rock Island, and Wanapum Dam have disrupted upstream movement of sturgeon.

2.9.2 Current Distribution

Construction of the dams has created what is believed to be “isolated” populations of white sturgeon. However, the population dynamics and factors regulating production of white sturgeon within these “isolated” populations are poorly understood. Because of this lack of understanding, Douglas, Chelan, and Grant PUDs have instigated studies for white sturgeon through their re-licensing processes (Golder Associates 2003 CPa, CPb; Shane Bickford, personal communication). This information will help us understand basic life history information, distribution and population sizes that currently exist within the CCP.

In conclusion, white sturgeon distribution has been affected by construction of mainstem Columbia River dams. What was believed to be a relatively continuous population, traveling the length of the mainstem Columbia River below migrational barriers, is now a number of ***potentially*** *disjunct populations between hydroelectric projects, although there does appear to be immigration and emigration from downstream recruitment.*

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[5] Redband (and steelhead) are not thought to have ever occurred in the Lake Chelan Basin (Dr. R. Behnke, personal communication; Brown 1984; Chelan PUD 2000).

3. Factors influencing the present population structure in the Upper Columbia populations

3.1 Grand Coulee Fish Maintenance Project (GCFMP)

In 1939, during construction of Grand Coulee Dam, the US Fish and Wildlife Service initiated a program to address the upcoming loss of over 1,100 miles of available habitat to Upper Columbia River salmonid populations (Fish and Hanavan 1948). Construction of the dam without fish passage facilities led to the program that centered on trapping at Rock Island Dam. During the GCFMP (1939-1943), all salmon and steelhead that reached Rock Island Dam were trapped there and mixed. These fish were either transplanted to spawning streams and "forced" to spawn there, or taken to newly completed hatcheries on the Wenatchee (Icicle Creek), Entiat, or Methow rivers.

Trapped and transported spring and late-run chinook and steelhead of mixed origins were allowed to spawn naturally in Nason Creek upstream from a rack 0.25 miles upstream from the creek mouth. Steelhead were also released in the upper Wenatchee River (upstream of Tumwater Canyon) and the Entiat River in 1939. The fish were released between two racks that forced the fish to spawn in the area selected by the biologists of the USFWS (Fish and Hanavan 1948). Sockeye and coho were raised in hatcheries and liberated in various places.

Trapping at Rock Island Dam extended over five brood years, 1939 through 1943. The last brood to spawn naturally in natal streams was that of 1938.[6]

Below, the activities of the GCFMP with respect to spring and summer/fall chinook, sockeye and coho salmon and steelhead are summarized.

Spring chinook and steelhead (Fish and Hanavan 1948; Chapman et al. 1994 CPa, 1995 CPa).

Brood Year **Description**

1938 - normal spawning, juveniles go to sea 1940 and beyond.

1939 - mixed-stock adult spring Chinook and steelhead released in Nason Creek and Entiat River (steelhead only).

1940 - 306 female spring Chinook artificially spawned. Records of fate of the progeny were combined with records of summer Chinook, of which 1,062 females were spawned artificially. About 135,000 parr released to Icicle Creek in October, 1941. About 640,000 parr released to the Entiat River and 182,000 in the Methow River in 1941.

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[6] Some spring chinook native to Nason Creek could have been among the fish released there upstream from the rack 1939-1943, although their contribution may have been small because spring chinook counts at Tumwater Dam in 1935-37 were very low (Craig and Suomela 1941). In addition, some resident age 2+ male spring chinook in Nason Creek may have contributed to fertilization of eggs of females that spawned in Nason Creek in the 1939, 1940, and 1941 broods.

1941 - About 239,400 spring Chinook fry of McKenzie River (Oregon) origin, and 444,000 fry from Entiat NFH were released to Icicle Creek. 831 steelhead spawned, and 371,768 parr released into the Wenatchee, Icicle, Entiat, and Methow rivers.

1942 - About 30,000 fingerlings, products of adults trapped at Rock Island Dam, released in the Methow River in August. About 118,000 parr released to Icicle Creek in October 1943. 591,000 parr released to the Entiat River in March, 1943. The brood year of these parr is in some doubt. 797 steelhead were spawned and 223,957 parr released in Icicle Creek and Entiat River.

1943 - About 1 million fry/fingerlings released to Wenatchee River tributaries, 591,000 to the Entiat River, and 654,000 to the Methow River. 1,560 steelhead spawned and 2,420,723 parr released in the Wenatchee, Entiat, and Methow rivers.

1944 - Four females and 121 male spring Chinook entered holding ponds at Winthrop; only two males entered the Leavenworth facility. Just 3,600 fry were released to Methow River. 434 steelhead spawned and 457,366 parr released. 1,068 adult steelhead trapped at Rock Island Dam, 213 collected at Lake Wenatchee, and 12 back to the holding pond at Leavenworth.

1945 - Eighteen female spring Chinook and 77 males spawned at Winthrop; 49,700 fry released in Methow River March 1946, and 549,000 fry released in Methow River in February 1947 (these juveniles probably reared at other mid-Columbia hatcheries, as the egg potential of 18 females would not support a release of that magnitude). Seventeen steelhead enter holding pond at Entiat (10 spawned), 56 enter pond at Leavenworth (all spawned). 95,899 parr released from steelhead eggs shipped from Carson Hatchery in Methow River and Icicle Creek. 72,936 steelhead parr from hatchery returns released in Icicle Creek and Entiat River.

1946 - Of 300 spring Chinook that entered Entiat holding pond, 128 were spawned and progeny transferred to Winthrop. Of 487 adult spring Chinook that entered Winthrop pond, 69 were spawned. Parr released totaled 804,000 in February, 1948 to the Wenatchee, 913,000 in February 1948 to the Methow River. Of the 80 steelhead that entered the Leavenworth pond, 32 fish that entered the Entiat pond, and 24 fish that entered the Winthrop pond, 36, 4, and 6 were spawned, respectively. 120,533 parr released in Icicle Creek and Methow River.

1947 - Of 459 adult spring Chinook returning to Leavenworth, 414 were spawned. 804,330 fingerlings released to Icicle Creek in the February, 1948. Of 363 adults that entered Winthrop pond, 348 were spawned and 912,889 fingerlings released to Methow River in February, 1948. Of the 71 steelhead that entered the Leavenworth pond, 77 fish that entered the Entiat pond, and 20 fish that entered the Winthrop pond, 43, 16, and 20 were spawned, respectively. 132,799 parr released in Icicle Creek, Methow, and Entiat river

Summer/fall chinook (from Fish and Hanavan (1948) as summarized in Chapman et al. 1994 CPb).

Brood Year	**Description**

1938 - Normal spawning, juveniles go to sea 1939 and possibly a few in 1940.

1939 - Trapping begins in May, no summer/fall chinook permitted to return to Wenatchee, Methow, Columbia or Okanogan rivers, trapped adults released into a racked 18-mile reach of the Wenatchee River just downstream from Lake Wenatchee. Adults were also released to a racked section of 15 miles of the Entiat River, where mortality was high.

1940 - Mixed stock juveniles introduced to Methow. Fingerlings of mixed origin released in Entiat River and Icicle Creek (Wenatchee River). Rack area reduced in Entiat and a small group of adults placed therein to evaluate mortality. Entiat rack holding area abandoned after this year. Fish culture began at Leavenworth in late August. Mixed adults released to racked Wenatchee River and Entiat River sections.

1941 - No returns allowed to Methow, Columbia, or Okanogan rivers, no juvenile introductions. Some mixed-origin fingerlings released to Entiat River. Mixed adults released to racked Wenatchee River section.

1942 - Mixed stock introduction of fingerlings to Methow River, Icicle Creek, and Entiat River. *Small lots* of mixed adult chinook were released upstream from Rock Island Dam to evaluate distribution. No information was obtained on distribution, but some probably went to the Methow or Okanogan. Tone of Fish and Hanavan is that these were small fish (jacks) from the egg take of 1939. Mixed adults released to racked Wenatchee River section.

1943 - Some introductions of mixed summer/fall fingerlings (mixed progeny of Rock Island trapping) to Icicle Creek and the Entiat River. *Small lots* of mixed chinook jacks were released upstream from Rock Island Dam. About 15% went to the Methow (Fish and Hanavan 1948). Distribution of the complementary 85% is unknown. Mixed adults released in racked Wenatchee River section.

1944 - River open to migration. Some returns from 1940 mixed stock planting. Some strays from Wenatchee mixed-stock natural spawners likely as well. Progeny of mixed Rock Island trapping released in Entiat River.

1945 - A few fish return from 1942 brood. Some strays likely from Wenatchee mixed-stock natural spawners. Mixed-origin fingerlings released to Entiat River.

1946 - Mixed stock returns. Mixed-stock summer/fall chinook fingerlings released to Icicle Creek, Methow River, and Entiat River.

No mention is made by Fish and Hanavan (1948) of delivery of summer/fall chinook juveniles to the Okanogan River system. Some mixed stock juveniles were delivered to the

Methow River. No mention is made of delivering adult summer/fall chinook to the Methow or Okanogan rivers.

The present Wenatchee, Entiat, Methow, Similkameen, Okanogan, and Columbia River spawning summer/fall chinook all originated from a mix of summer/fall chinook collected at Rock Island Dam 1939-1943. The only possibility that adults of unmixed stock might have escaped the GCFMP would have returned in 1944 of progeny of the 1938 brood that went to sea in 1939 and remained there for five years. This possibility seems remote. Not only is the fraction of age 0.5 fish (six years from parent brood return to progeny adult return; see below) very small in summer/fall chinook of the Columbia River (see below), but the likelihood that a 0.5 female would find a 0.5 male of the same natal origin rather than spawning with a colonizing mixed-origin adult is small also.

Since the mid-1940s, over 50 years have elapsed, the equivalent of about 12 generations of summer/fall chinook. This may be sufficient time for spawning populations to develop adaptive traits appropriate for each tributary upstream from Rock Island Dam (Quinn et al. 2000; Unwin et al. 2000).

Sockeye (from Fish and Hanavan 1948 as summarized by Chapman et al. 1995 CPb).

Brood Year **Description**

1938 – Normal spawning, most juveniles go to sea 1940. A few juveniles emigrate in 1941.

1939 – Trapping starts in May, no sockeye return to areas upstream of Rock Island Dam. Adult sockeye are released into lakes Wenatchee and Osoyoos upstream of outlet racks, and in the Entiat River. Eggs are taken from sockeye ascending the Little Wenatchee River, but there is no subsequent mention of release.

1940 – Adults released upstream of rack in Lake Wenatchee. Over 569,000 juveniles released into Lake Osoyoos, 414,016 into Lake Wenatchee, and 25,000 into Icicle Creek. The origin of these juveniles are fish trapped at Rock Island Dam.

1941 – Mixed origin adults released into Lake Wenatchee upstream of outlet rack.

1942 - Mixed origin adults released into Lake Wenatchee upstream of outlet rack. Quinault stock sockeye released into Entiat River, Lake Osoyoos, and Icicle Creek. Rock Island mixed stock juveniles released into Lake Wenatchee.

1943 - Mixed origin adults released into Lake Wenatchee upstream of outlet rack. Rock Island mixed stock juveniles released Lake Wenatchee, Lake Osoyoos, and Methow River.

1944 – River open to migration. Some adults return from 1941 brood mixed-stock adults that spawned in tributaries to Lake Wenatchee and some from juvenile plantings in 1940-41. Mixed stock juveniles released into Lake Wenatchee and Methow River. Kokanee from

Lake Chelan released as part of experiment to Entiat River. Kokanee (Lake Wenatchee origin) also released to Lake Wenatchee and Icicle Creek.

1945 – Returns to Entiat (59) and Leavenworth (64) spawned and combined with spawn taken from fish trapped at Little Wenatchee trap. Juveniles release into Lake Wenatchee.

1946 – Adults collected at Leavenworth (3,904) and Winthrop (99) spawned. Juveniles released into lakes Wenatchee and Osoyoos, and Methow River.

1947 – Fish trapped at Little Wenatchee (3,114) and Winthrop (41) spawned and raised.

Chapman et al. (1995 CPb) contains additional information concerning discrepancies of numbers of fish released.

The present independent populations of sockeye that return to the Wenatchee and Okanogan basins, and Methow River are descendants of mixed origin fish that were captured during the GCFMP. The origin of these fish was potentially from fish that originated from Lakes Wenatchee and Osoyoos, but most likely were from upper Columbia (upstream of Grand Coulee Dam) lakes (WDF 1938). This observation was based on low fish numbers observed in both the Wenatchee Basin (at Tumwater Dam) and in the Okanogan Basin (at Zosel Dam) in the 1930s (WDF 1938; see below). Other potential contributors to the present stocks from the GCFMP are from kokanee from Lake Chelan (originally from Lake Whatcom in western Washington), Lake Wenatchee, and potentially from lakes in the Okanogan Basin upstream from Osoyoos, and other lakes that empty into the Columbia upstream from Grand Coulee Dam. Lake Quinault sockeye may have contributed substantially to returns during the GCFMP also (Mullan 1986).

The extent of the contribution of these various stocks is somewhat moot, since the present two current independent populations (Wenatchee and Osoyoos) are easily separated genetically.

Coho (from Fish and Hanavan 1948 and Mullan 1984).

Brood Year **Description**

1938 – Normal spawning, most juveniles go to sea 1940.[7]

1939 – Fish and Hanavan report only 13 coho counted over Rock Island Dam. No report of their fate (i.e., whether they were used in the program or not)

1940 – A few adults received from Rock Island Dam, six of which are spawned at Leavenworth station.

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[7] Between 1933 and 1938, an average of 66 coho were counted ascending Rock Island Dam (range 0-182, with 5 of six years below 80 fish; Fish and Hanavan 1948).

1941 – Ten adults spawned of mixed origin (count at Rock Island = 29) origin at Leavenworth station.

1942 – Coho from Lewis River (count at Rock Island = 1) incubated at Leavenworth. Fish released from 1940 brood.

1943 - Coho from Lewis River (count at Rock Island = 22) incubated at Leavenworth. Fish released from 1940 brood in Icicle Creek.

1944 – River open to migration. Coho from Lewis River (count at Rock Island = 186) incubated at Leavenworth and Entiat. Fish released from 1942 brood in Icicle Creek and Entiat River. Coho from Carson Hatchery reared at Winthrop. 128 fish return to Leavenworth and 123 of which are spawned.

1945 – Mullan (1984) reports just under 2,000 fish raised from coho returning to the Icicle (Rock Island count = 166, but Fish and Hanavan note that these fish are descendants of Lewis River stock).

1946 – No fish raised. Fish released from 1945 brood from Leavenworth.

1947 – Fish returning to Leavenworth and Winthrop are raised and released from these stations in 1948 and 1949, respectively.

From Mullan (1984) on the fish released from the GCFMP:

. . . Dependence on non-native sources of eggs was because of the virtual depletion of the indigenous upriver runs. In 1940, 1941, 1942, and 1943 when the hatcheries became operation, only 12, 29, 1, and 22 native cohos, respectively, reached Rock Island Dam for interception and spawning. Two females were spawned from among the 12 adult coho salmon collected at Rock Island Dan in 1940. As a result, 5,470 smolts (11.4/lb) were released from Leavenworth Hatchery into Icicle Creek in the spring, 1942. Six females were spawned from among the 29 fish intercepted at Rock Island Dam in 1941, and 11,050 resulting smolts (11.4/lb) were released to Icicle Creek in spring, 1943. The run consisted of only one fish in 1942, and all 22 fish collected in 1943 died; therefore, no eggs were taken in those two years.

In summary, the GCFMP extensively homogenized spring and summer/fall chinook, steelhead, and sockeye that were of mid- and upper-Columbia river origin. Homogenization was both temporal and geographic. The manipulations of the GCFMP may have reduced the genetic uniqueness of any distinct populations, or subpopulations in the mid-Columbia.

While Fish and Hanavan (1948) concluded that the relocation of fish to the natural spawning areas “was successful to a degree exceeding expectations,” Ricker (1972) felt the program “was a salvage operation which in the long run seems to have salvaged nothing.” Mullan (1987) believed the program was successful in maintaining genetic diversity of the stocks to some unknown degree. Fish and Hanavan (1948) believed that the overall success of the artificial propagation part of the program was “only fair at best” which Mullan (1987) agreed with, pointing out that survival to adult for fish released was generally 1% or less. Regardless of the degree of success of the GCFMP, the current stocks of fish that spawn in the Upper-Columbia River basin are at least partially descended from the progeny of the program.

3.2 Other

3.2.1 Bull trout

A combination of factors that lead the USFWS to list bull trout as threatened (throughout their range) are: combined effects of habitat degradation, fragmentation and alterations associated with dewatering, road construction and maintenance, mining, and grazing; the blockage of migratory corridors by dams or other diversion structures; poor water quality; incidental (or targeted) angler harvest; entrainment (process by which aquatic organisms are pulled through a diversion or other device) into diversion channels; and introduced non-native species (63 FR 31647).

Within the CCP, the USFWS (2002) considered land use activities that have (and still do) impacted bull trout populations. Water diversions (primarily for irrigation), hydropower development, forest management practices, livestock grazing, residential development and urbanization, fish management (harvest regulations), and mining appear to be have reduced important fluvial subpopulations within the larger independent populations. One of the effects of all of these actions is to isolate and fragment habitat, which is another key effect.

Brown (1992) listed factors that influenced distribution of bull trout as hydropower construction, water storage and diversion dams, as well as overharvest, and probably introductions of exotic brook trout.

While there have been no hatchery programmatic releases of bull trout within the CCP, brook trout have been released in various locations, and are known to out-compete and hybridize with bull trout, eventually potentially eliminating bull trout from many areas (Markle 1992; Leary et al. 1993).

In Lake Chelan, bull trout have not been confirmed since the early 1950s, following the devastating floods of the spawning grounds in 1948, and potential disease problems (Brown 1984).

Factors that led to the extinction of bull trout in the lower Okanogan Basin are probably more to do with the heating of the mainstem Okanogan River, which may have led to less fish using the mainstem.

The sum total of these actions has led to the current population structure of bull trout in the CCP, and has affected the population status as well.

3.2.2 Westslope cutthroat trout

The USFWS (1999) identified various factors that may be affecting the WSCT habitat or range in the CCPO. These factors included channelization or stream alteration within the mainstem of the Methow River, increased sediment loading, erosion, and irrigation withdrawals. Other factors listed include past wild fire activity, flash flooding, timber harvest, and fragmentation of subpopulations by either man-made habitat alterations or natural barriers. Another potential threat mentioned was the introductions of non-native species within each drainage, especially brook trout, and non-native introductions of *O. mykiss* too (K. MacDonald, personal communication).

In the Chelan Basin, the establishment of a hatchery near Stehekin in 1903 was devastating to the WSCT population in the lake (Brown 1984). This hatchery was a good example of an "egg mining" hatchery, where many gametes were extracted from the population, but few fish were either planted back into the system, or aquaculture methods were so unsophisticated, that few fish survived and therefore did not replenish the founding population. The result was the eventual collapse of the population (Brown 1984). It appears that fluvial populations remained in the small feeder tributaries of the lake and the headwaters of the Stehekin River.

Another factor in the Chelan Basin that has recently been identified as potentially limiting WSCT production is how the lake level is operated by Chelan PUD (Chelan PUD 2001). In the Lake Chelan Fish Management Plan (Chelan PUD 2001), the PUD will operate the lake level differently, so when WSCT return to tributary streams in the spring to spawn, they will be able to enter them, which has been difficult in the past.

While most hatchery stocking of WSCT in the CCP has been from the Twin Lakes strain (originally Lake Chelan), there have been some stocking of other sub species of cutthroat (USFWS 1999, see below).

3.2.3 Redband trout

It is difficult to determine what factors may have affected the population structure of redband trout in the CCP. A history of stocking of other strains of rainbow trout, most notably coastal rainbow (*O. mykiss irideus*) has been documented by various sources (e.g., Chapman et al. 1995 CPa; Trotter et al. 2001).

Other habitat alterations have also affected the population structure of redband trout. Mullan et al. (1992 CPa) point out that anadromy of *O. mykiss* continues to exist in the Methow River, even when coho were extirpated by a dam in near the confluence with the Columbia because of headwater non-migrants, and that anadromy continues to exist in the Icicle River, after a blocking dam was built at the hatchery site in 1939 because of contribution of non-migrant forms of *O. mykiss* that continue to contribute to the anadromous population.

3.2.4 White sturgeon

The biggest influence on the white sturgeon population(s) in the CCP is the apparent upstream migratory blockage caused by the hydropower dams. As previously mentioned, this may be limiting the normal migratory ecotype and potentially affecting the productivity of the independent population(s) that occur in the CCP (see below).

In summary, habitat degradation to various extents has affected the population structure of *all non-anadromous focal species within the CCP. Displacement, inability to utilize former habitat, and interactions with exotic species have all contributed to the current population structure of bull, Westslope, and redband trout and white sturgeon.*

3.3 Introductions of non-indigenous fish

In addition to the non-indigenous introductions noted in the preceding subsection on the GCFMP, managers have injected several other exogenous groups of spring, summer/fall Chinook, sockeye, coho, *O. mykiss* (anadromous and non-anadromous forms), cutthroat trout, and brook trout into upper Columbia tributaries and mainstem. These fish originated primarily from lower Columbia River hatcheries such as the Mullan 1984, 1986, 1987, Peven (1992 CPa), Chapman et al. (1994 CPa, CPb, and 1995 CPa CPb), and Proebstel et al. (1998) all summarize the history of hatchery introductions in the Upper Columbia. The first hatcheries were built in the Wenatchee and Methow basins in 1899. Releases of fish from non-indigenous sources began in the 1940s (Peven 1992CPb).

The hatcheries that were built in the late 1890s apparently did not release Chinook salmon (Craig and Suomela 1941). Non-indigenous hatchery releases began in the 1920s, with most fish arriving from hatcheries from the lower Columbia River (Craig and Suomela 1941).

In addition to the non-indigenous introductions noted in the preceding subsection on the GCFMP, managers have injected several other exogenous groups of summer/fall chinook, sockeye, and especially coho into upper Columbia tributaries. Mullan (1984, 1986, 1987), Peven (1992 CPb), Chapman et al. (1994 CPb) and Chapman et al. (1995 CPb) summarized the history of these stocks of hatchery introductions in the Upper Columbia.

3.3.1 Spring chinook

Most of the exogenous spring chinook released into the Upper Columbia region were from or beyond the lower Columbia River (McKenzie, Spring Creek, Eagle Creek, Cowlitz, Simpson, Elokomin). The most persistent and extensive of these introductions involves the Carson Hatchery, on the Wind River (enters the Columbia River on the Washington side of the Bonneville Dam pool). This population was derived from spring-run fish destined for the Snake and the mid-Columbia region and intercepted at Bonneville Dam starting in 1955 (Ricker 1972).

A dependency of both the Leavenworth and Entiat hatcheries on Carson fish through the 1970s into the 1981 brood year ultimately gave way to full hatchery production from spring-run salmon returning to the respective hatcheries (Peven 1992b). Presumably, the current brood stocks of both hatcheries reflect a virtually 100% Carson Hatchery ancestry. The contributions of these massive releases and other exogenous releases to the wild populations of these drainages (Mullan 1987) are unknown.

Most of the populations represented in the exogenous releases appear to have left no detectable descendants (Chapman et al. 1995 CPa). Each population derived from or beyond the lower Columbia River (McKenzie, Spring Creek, Eagle Creek, Cowlitz, Simpson, Elokomin) represents lineages distinct from either of the resident groups produced upstream from Rock Island Dam (Utter et al. 1995). Presumably, these fish were poorly adapted to the habitats of their release and failed to make a permanent contribution to the Upper Columbia River gene pools.

In the Wenatchee Basin, it appears that there has been little influence of the Carson stock releases outside Icicle Creek , while in the Entiat Basin, the native population has been slightly more affected, and the picture is much more complicated in the Methow River Basin (Utter et al. 1995).

In summary, it appears that the releases of exogenous spring chinook has only been significant in regards to the long-term programs of the USFWS, and their reliance on Carson broodstock fish.

3.3.2 Steelhead

Peven (1992 CPb) and Chapman et al. (1994 CPa) list the extensive hatchery releases of steelhead and resident *O. mykiss* in the Upper Columbia Basin. Introduction of exogenous steelhead were from donor stocks from other parts of Washington State, primarily (e.g., Skykomish, Snoqualmie, Samish, Chambers Creek, Carson, Naches, Skamania, and Ringold), and made up winter- and summer-run populations.

Chapman et al. (1994 CPa) found no information that suggested that any of the exogenous broodstock releases in the Upper Columbia have had much of an effect on the population structure. The current naturally spawning populations appear to be mostly indistinguishable from the Wells Hatchery broodstock.

In summary, it appears that exogenous releases of steelhead have had no lasting impact on the naturally spawning populations.

3.3.3 Summer/fall chinook

The U.S. Fish and Wildlife Service released summer/fall chinook intermittently to the Methow River between 1947 and 1973 (Mullan 1987; Peven 1992 CPb). Some of these fish were obtained from adults in the Methow and Entiat rivers. From 1977 to 1982, yearling summer/fall juveniles were obtained from Wells Dam stock. The latter was a mix of Similkameen, Okanogan, and perhaps main Columbia River spawners and Wenatchee River “strays”.

In those same years, Rocky Reach Hatchery Complex produced summer/fall fish for release at Turtle Rock, in Rocky Reach pool. Those releases included fall chinook from Simpson and Elokomin hatcheries, Bonneville Dam[8] and Priest Rapids upriver brights, Wells summer/fall fish, and Snake River fall chinook. A few were fingerling releases, while most were yearlings. The degree to which those releases spawned on return with summer/fall

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[8] Bonneville Dam trapping of URB fall chinook almost certainly captured some Snake and Deschutes River fall chinook and summer/fall fish from the upper Columbia, along with Hanford Reach fall chinook.

chinook in the various tributaries and in the Wells Dam egg take likely varied from year to year.

Wells Dam Hatchery production through 1991 was released at Wells Dam, except for one group of presmolts released in the Methow River. In some years Wells Hatchery mined large portions (49% in 1969) of the summer/fall chinook destined for the Methow River and other upstream tributaries (Mullan 1987). Upriver bright fall chinook from Priest Rapids have entered the summer/fall chinook broodstock complement at Wells Hatchery. We assume that they have also spawned in areas where they may mix with adults from natural spawning in various tributary and mainstem areas. For several years, before the volunteer entrants at the Priest Rapids Hatchery trap became abundant enough to support broodstock needs, virtually all adult fall-run chinook destined for upriver spawning areas were trapped at Priest Rapids fishway trap. That "mining" of upriver fall-run fish probably took some summer-run fish that arrived after the cut-off date for summer chinook, and prevented late-run chinook from spawning upstream from Priest Rapids Dam. It thus mixed late-run chinook from the mid-Columbia region upstream from Priest Rapids Dam with Hanford Reach late-run chinook (Chapman et al. 1994 CPb).

Entiat Hatchery reared and released summer/fall chinook from the Methow River (1945), and Entiat River (1946-1964), and from Wells Dam, into the Entiat River. When liberations of summer/fall chinook ceased, the Entiat River run diminished to a large degree, but there currently appears to be a naturally reproducing population. The Entiat River is thought never to have produced a natural summer chinook run (Craig and Suomela 1941; Mullan 1987).

In summary, the recent and potentially current (see below) hatchery programs that release summer/fall chinook upstream from Rocky Reach Dam have led to extensive mixing of progeny of Wells broodstock with progeny of natural spawners in tributaries and mainstem areas used by summer/fall spawners. Hatchery programs downstream from Rocky Reach Dam have lead to extensive mixing of URB fall chinook and some mixing of Wenatchee River summer/fall chinook into Wells broodstock. The degree to which hatcheries downriver from Rocky Reach Dam have led to mixing in spawning areas upstream from Rocky Reach and in the Wenatchee River with naturally-produced summer/fall chinook is unknown.

3.3.4 Sockeye

It appears that most of the sockeye released as part of the GCFMP in the upper Columbia region were of Arrow Lakes, Canada origin (WDF 1938). Overall, most of the fish released in the program were released into the Wenatchee River basin, with lesser numbers released into the Okanogan basin, and a few into the Entiat and Methow rivers.

In the Wenatchee River Basin between 1941 and 1969, over 58 million juvenile sockeye were released (Mullan 1986). Most of the releases occurred in Lake Wenatchee, but some also occurred in Icicle Creek and the White River. Small numbers of sockeye occasionally return still to Icicle Creek today.

Most of the juveniles released into the Wenatchee basin by the USFWS were from Wenatchee-parent broodstock. Releases of exogenous fish occurred from 1936-1946 (excluding 1940)[9], and then periodically from 1949 through the end of the USFWS program in 1969. Most of the exogenous releases were from broodstock captured in the Entiat and Methow rivers, although fish from Lake Quinault, Carsen NFH, and one small group of fry from British Columbia were also released (see Chapman et al. 1995 CPb, Appendix 1 for details on releases).

In the Entiat River basin, there were four releases of sockeye in the Entiat River basin, mostly in the years of the GCFMP. Historically, sockeye did not use the Entiat Basin (WDF 1938; Craig and Suomela 1941), and fish released from the initial years of the GCFMP appear to have established a small run that still produces a few adults today. Since there is no nursery lake in the basin, it is assumed that these fish use the mainstem Columbia River as a surrogate lake for initial rearing.

Sockeye were released from the Winthrop NFH on the Methow River between 1943 and 1957 (Mullan 1986). Over 1.8 million fish were released. The origin of the early releases of fish were from fish captured at either Rock Island or Bonneville dams. Sockeye were not thought to have been native to the Methow River (Craig and Suomela 1941), and it is assumed they use the mainstem Columbia River as a surrogate lake. There appears to be a small naturally reproducing stock there today.

Adult sockeye were translocated to Lake Osoyoos in 1939 and 1940, as previously stated as part of the GCFMP. Juveniles were released there in only seven more years between 1941 and 1958 (Mullan 1986). Most of the fish released into the basin were from either Rock Island Dam or Wenatchee Basin origin. In 1947 and 1949, releases were from Methow River origin fish.

In the early 1990s, Douglas PUD sponsored a sockeye hatchery program that was operated by the Colville Confederated Tribes at the Cassimer Bar Hatchery (Chapman et al. 1995 CPb). Adult brood was captured at Wells Dam and rearing took place at Cassimer Bar. Resulting juveniles were released into Lake Osoyoos. Adult returns for this program were never documented and the program was abandoned in the late 1990s.

In summary, Mullan (1986) made three conclusions from the early (1940s-1960s) hatchery programs on sockeye:

(1) "contribution of hatchery sockeye to run size was substantial in some years;
(2) survival of hatchery juveniles to returning adults was about threefold greater in the 1940's than in the 1960's; and
(3) adults sacrificed for artificial propagation . . . showed no consistent increased efficiency, in point of returning adults, over natural recruitment based on spawner-recruit ratios . . ."

Chapman et al. (1995 CPb) concluded that the GCFMP were successful in reestablishing sockeye runs in the Wenatchee and Okanogan basins. They also felt that while the releases

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[9] Chapman et al. (1995 CPb) considered the releases from the GCFMP as exogenous because they were primarily made up of Arrow Lakes stocks (WDF 1938).

of sockeye in the 1950s and 1960s did not appear cost-effective in contributing to the commercial harvest, there was probably some benefit to the resource by adding numbers of fish to the spawning grounds.

3.3.5 Coho

The first hatchery in the Methow Basin was built in 1889 (Craig and Suomela 1941) and raised primarily coho salmon. Between 1904 and 1914, an average of 360 females were used for broodstock from this hatchery annually (Mullan 1984). With the building of a non-passable dam at the Methow River mouth in 1915, this hatchery was moved more towards the confluence with the Columbia. Between 1915 and 1920, an average of only 194 females were taken, suggesting a 50% decline in the run between this and the previous period. After 1920, no coho were taken from this hatchery and it closed in 1931 (in Mullan 1984).

No further releases of coho into the Methow River occurred until the GCFMP in 1945. Of the 17 years of releases of coho from the Winthrop NFH between 1945 and 1969, in only four of those years did the broodstock originate from the Methow River (which were admixtures of various stocks originally captured at Rock Island Dam; Mullan 1984). Most of the coho released at Winthrop originated from Lower Columbia River stocks from the Eagle, Lewis, and Little White Salmon hatcheries (Mullan 1984).

No further releases of coho occurred into the Methow River until the late 1990s (see below).

The first hatchery opened in the Wenatchee Basin in 1899 near Chiwaukum Creek. It closed 5 years later (Craig and Suomela 1941). Besides logistical problems (heavy snow, extreme cold, etc.), the hatchery was unable to obtain eggs of chinook, which were evidently, it's prime target. Mullan (1984) quotes from the 14th and 15th annual report of the State Fish Commissioners of Washington: *if it* [the hatchery] *had been below the Tumwater Canyon, the early chinook could have been secured; as it is, it takes only an inferior run of silversides (cohos).*

In 1913, a new hatchery was built, below Tumwater Canyon, near the town of Leavenworth. Very few spring chinook (target species) were collected here and this hatchery closed in 1931. Mullan (1984) reports that there were, at most, two plants of coho from this hatchery, utilizing lower Columbia River source fish.

No further releases of coho occurred in the Wenatchee River until the GCFMP, with the first release in 1942 (see above). Between 1942 and 1975, most of the coho released at Leavenworth originated from Lower Columbia River stocks from the Cascade, Quilcene, Eagle, Lewis, and Little White Salmon hatcheries (Mullan 1984).

3.3.6 Non-migratory *O. mykiss* and cutthroat trout

In the CCP, stocking of non-native fish is limited to cutthroat and redband trout. There have not been any introductions of hatchery sturgeon or bull trout at this time. There was one release of 14,500 Dolly Varden hatchery-origin fry from southeast Alaska into Lake Chelan in 1966, but these fish were never detected after release (WDFW 1998).

Chapman et al. (1994 CPa) document the introduction of rainbow trout in the CCP in their Appendix A2. Fish from various stocks from within and outside the Columbia River Basin have been released into the various streams and lakes within the CCP, most notably, the Mt. Whitney stock from California and some fish from Montana.

Trotter et al. (2001) reviewed hatchery release records from the WDFW (Crawford 1979) and concluded that the most likely non-native *O. mykiss* that they would encounter in their genetic mapping study would be from the coastal form (*O. mykiss irideus*).

Proebstel et al. (1998) documented the release of Yellowstone cutthroat (*O. clarki bouvieri*) in the CCP. Between 1930 and 1951, eggs of Yellowstone cutthroat were raised at Chelan Falls, Leavenworth, and "Wenatchee"[10] hatcheries.

Trotter et al. (2001) anticipated, based on their review of the stocking records, that they would encounter both coastal (*O. clarki clarki*) and Yellowstone cutthroat in their surveys.

Trotter et al. (2001) and Proebstel et al. (1998) found evidence of introgression of non-native trout on the native populations of WSCT and redband trout. This finding was not surprising in lieu of the history of hatchery plants within the CCP.

3.4 Current hatchery programs

3.4.1 Spring chinook

Currently, the WDFW and USFWS manage and operate various hatcheries throughout the CCP. In the Wenatchee Basin, the USFWS operates the Leavenworth National Fish Hatchery (NFH), built as part of the GCFMP, as a means to mitigate for lost fishing opportunities. The spring chinook that it has been more or less self-perpetuating since the early 1980s came from the Carson NFH on the Wind River (Peven 1992 CPb). This population was derived from spring-run fish destined for the Snake and mid-Columbia region and intercepted at Bonneville Dam starting in 1955 (Ricker 1972).

The WDFW managed program in the Chiwawa River is funded by Chelan PUD as mitigation for the operation of Rock Island Dam. Its goal is to supplement and increase the naturally spawning sub-population of spring chinook in the Chiwawa River (Chapman et al. 1995 CPa).

In the Entiat River, the Entiat NFH which is also part of the GCFMP complex, spring chinook are released, which are similar in origin to the Leavenworth NFH (Peven 1992 CPb).

Winthrop NFH, in the Methow River, was also built as part of the GCFMP. In the late 1970s, it began releasing spring Chinook with similar lineage to the other GCFMP NFHs (Peven 1992 CPb).

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[10] We assume this one shipment (100,000 eggs in 1932) was the hatchery that originated on Chiwaukum Creek and later moved near Leavenworth on the Wenatchee River. The current Leavenworth Hatchery was not built until about 1940.

WDFW manages a program in the Methow Basin that is funded by Chelan and Douglas PUDs as mitigation for the operation of their mainstem hydroelectric projects. The goals of this program are similar to the Chiwawa River program (Chapman et al. 1995 CPa).

In recent years, there has been a move to reduce the perpetuation of the Carson-origin spring chinook in the Methow River. Agreement has been reached between the various stakeholders that the Carson stock can be used in various situations (like re-introduction of spring Chinook into the Okanogan Basin), and used less so for broodstock purposes in the Methow Basin (Brian Cates, USFWS, personal communication).

3.4.2 Steelhead

For steelhead, a program began in the early 1960s, where broodstock was collected at Priest Rapids Dam, effectively mixing adults destined for all upstream tributaries and hatcheries. That practice continued until the early 1980s, although some of the broodstock was taken at Wells Dam periodically in the 1970s (Chapman et al. 1994 CPa). Beginning in 1982, all broodstock was captured at Wells Dam and fish from this program were released into all of the main tributaries upstream of Rock Island Dam, further homogenizing the populations.

Since the late 1990s, a change in the broodstock program has concentrated on initializing more tributary-specific hatchery programs.

3.4.3 Summer/fall chinook (additional details on the current hatchery programs can be found in Chapman et al. 1994 CPb).

3.4.3.1 Upstream of Wells Dam

Chelan PUD funds and WDFW operates the Similkameen (Okanogan Basin) and Carlton (Methow Basin) fish acclimation ponds. These acclimation ponds were built as mitigation for the operation of Rock Island Dam under the 1989 Rock Island Settlement Agreement between Chelan PUD and joint fisheries parties, made up of state and federal resource agencies, tribal entities and environmental groups.

The broodstock for these hatcheries is collected at Wells Dam, and it is an admixture of hatchery and naturally produced fish that originate upstream of Wells Dam, and “strays” from other, down-river stocks.[11] Fish are initially raised at the Eastbank Hatchery, which is immediately upstream of Rock Reach Dam, and then acclimated at the ponds beginning in October and February at Similkameen and Carlton, respectively. Fish are volitionally released in April-May.

The production numbers, goals and objectives, and evaluation of these hatcheries will be reviewed and potentially modified by a committee that will be formed through the HCP process (NOAA Fisheries 2002).

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[11] These fish are considered “strays” because they are collected in the broodstock. There is a potential that these fish would migrate naturally back to their natal areas if not collected in the broodstock. Managers are attempting to reduce the incidence of these fish in the broodstock at Wells.

3.4.3.2 Wells Dam

Douglas PUD funds and WDFW operates the hatchery at Wells Dam. This hatchery was built for mitigation for the construction and operation of Wells Dam. Hatchery operations and production goals are outlined in the 1990 Wells Settlement Agreement, and broodstock is made up of "volunteers" that enter the hatchery. Fish are raised and released at the facility. The program consists of releases of subyearling and yearling chinook.

The goals and objectives, and evaluation of this hatchery will be reviewed and potentially modified by a committee that will be formed through the HCP process (NOAA Fisheries 2002).

3.4.3.3 Rocky Reach Hatchery

Rocky Reach hatchery is made up of two components; Turtle Rock Island and the "Annex." Both are adjacent to Rocky Reach Dam. These facilities were built as mitigation for the construction of Rocky Reach Dam.

Broodstock for this program are taken at Wells Dam Hatchery. Fish are initially reared at the Annex and final rearing and release is on Turtle Rock Island. The program consists of releases of subyearling and yearling chinook.

The goals and objectives, and evaluation of this hatchery will be reviewed and potentially modified by a committee that will be formed through the HCP process (NOAA Fisheries 2002).

3.4.3.4 Wenatchee River – Dryden

Chelan PUD funds and WDFW operates the Dryden fish acclimation pond. This acclimation pond was built as mitigation for the operation of Rock Island Dam under the 1989 Rock Island Settlement Agreement.

Broodstock is captured primarily at Dryden Dam, and Tumwater Dam too, if necessary. Fish are initially reared at the Eastbank Hatchery and final rearing and release takes place from February through April.

The production numbers, goals and objectives, and evaluation of these hatcheries will be reviewed and potentially modified by a committee that will be formed through the HCP process (NOAA Fisheries 2002).

3.4.3.5 Priest Rapids Dam

Grant PUD funds and WDFW operates the Priest Rapids Dam Hatchery, which is located downstream of Priest Rapids Dam. This hatchery was built to mitigate the construction and operation of Wanapum and Priest Rapids dams.

Broodstock is taken from hatchery returns and the program is governed by interim settlement agreements between Grant PUD and the joint fisheries parties through the mid-Columbia proceeding.[12] Releases consist of subyearlings only.

Although this hatchery is located and fish are released downstream of the CCP, it is included because returning adult fish are observed on a regular basis upstream of the dam location (A. Murdoch, personal communication).

3.4.4 Sockeye

Currently, Chelan PUD funds and WDFW operates the Lake Wenatchee net pens, which is a satellite of the program to mitigate for the operation of Rock Island Dam, under the Rock Island Settlement Agreement.

Broodstock are captured at Tumwater Dam, and initial rearing takes place at Eastbank. Fry are transported to net pens in Lake Wenatchee in July and released as subyearlings in the fall. They over-winter in the lake and migrate downstream the following spring.

The production numbers, goals and objectives, and evaluation of this program will be reviewed and potentially modified by a committee that will be formed through the HCP process (NOAA Fisheries 2002).

3.4.5 Coho

The current coho reintroduction program is still in the feasibility stage. As such, it relies primarily on existing, or temporary facilities. The program began in 1996, and incubation and rearing sites have changed since then. Until the program is considered feasible, it is likely that changes will continue to occur (Scribner et al. 2002).

Broodstock are collected at Dryden and Tumwater dams and at the Leavenworth NFH in the Wenatchee Basin. For the Methow Basin, broodstock are collected at Wells Dam, or the Winthrop NFH. These fish were originally released from progeny of Lower Columbia River broodstock.

As previously mentioned, fish are incubated, raised and released from various facilities within the two basins. Extensive monitoring efforts are underway to determine the success of the project.

3.4.6 Non-migratory redband and WSCT

Current hatchery plants of cutthroat are from the Twin Lakes stock, which originated from Lake Chelan fish. For redband, the Spokane stock is primarily used.

In relicensing efforts for mid-Columbia River PUDs, discussions are underway for potential hatchery plants of white sturgeon to mitigate for continued dam operation

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[12] Grant PUD is now in the process of re-licensing their project (which includes both Wanapum and Priest Rapids Dams). Their future hatchery obligations are not known at this time, and may change under the re-licensing process.

4. Abundance

Chapman (1996) stated that large runs of chinook and sockeye, and lesser runs of coho, steelhead and chum historically returned to the Columbia River. Based on the peak commercial catch of fish in the lower Columbia River and other factors, such as habitat capacity, he estimated that approximately 588,000-spring chinook, 554,000 steelhead, 3.7 million summer chinook, over 2.6 million sockeye, and 618,000 coho were the best estimate of pre-development run sizes. Spring chinook, steelhead, summer/fall chinook, sockeye, and coho were relatively abundant in upper Columbia River tributary streams prior to the extensive resource exploitation in the 1860s. By the 1880s, the expanding salmon canning industry and the rapid growth of the commercial fisheries in the lower Columbia River had heavily depleted the mid and upper Columbia River spring and summer chinook runs (McDonald 1895), and eventually steelhead, sockeye and coho (Mullan 1984, 1986, 1987; Mullan et al. 1992 CPa). The full extent of depletion in upper Columbia River salmonid runs is difficult to quantify because of limited historical records, but the runs had been decimated by the 1930s (Craig and Suomela 1941). Many factors including construction of impassable mill and power dams, un-screened irrigation intakes, poor logging and mining practices, overgrazing (Fish and Hanavan 1948; Bryant and Parkhurst 1950; Chapman et al. 1982), and private development of the subbasins, in combination with intensive fishing, all contributed to the decline in abundance of Upper Columbia basin salmonids.

4.1 Spring Chinook

The numbers of spring chinook that entered the Columbia River averaged less than 102,000 in the first eight years after Bonneville Dam (1938) made it possible to estimate escapements at that point. Only after the mid-1970s did numbers again reach such low abundance. Since 2000, numbers have increased, eclipsing levels seen since Bonneville was built.

In the Upper Columbia region, spring chinook counting at Rock Island Dam began in 1935. Numbers (adults and jacks) in the period 1935-39 averaged just over 2,000 fish. Average counts fluctuated on a decadal average from the 1940s to 1990s from just over 3,200 (1940s) to over 14,400 (1980s), with recent counts (2000-2002) averaging almost 29,000. The long-term average of spring chinook passing Rock Island Dam is just over 8,900 (Table CP1).

Spring chinook have been counted passing Wells Dam since 1967. During the first three years of counts (1967-1969), the number of spring chinook (adults and jacks) averaged over 3,200. The average decadal numbers have fluctuated between 790 (1990s) to almost 3,000 (1970s), with recent counts (2000-2002) averaging over 7,000. The long-term average is over 2,600 (Table CP1).

4.1.1 Wenatchee River

In the Wenatchee River, redds counts have fluctuated widely since 1958, the earliest date for which systematic data were available. Spring chinook redd counts averaged 637, 564, 621 every ten years between 1958 and 1990 (Table CP2). In the 1990s, the average dropped to 232, but has increased to over 1,100 since 2000 (Figure CP1). The long-term average is 560 over the period 1958-2002.

Ford et al. (2001) recommended an interim recovery level for spring chinook of the Wenatchee River at an eight-year geometric mean of 3,750 natural spawners per year.[13] LaVoy (1994) estimated the average number of fish per redd as 2.2. Applying that expansion to the estimated (unadjusted for harvest prior to the 1970s) redd counts, escapement has ranged between 70 to over 4,100, with a long-term average of over 1,200 (Table CP2).

4.1.2 Entiat River

Redd counts in the Entiat River basin have been conducted since 1962. Decadal averages are 205, 143, 89, 33, and 81 between 1962 and 2002, with a long term average over the spanning years of 110 (Table CP2).

For the Entiat River, Ford et al. (2001) recommended an interim recovery level of 500 spawners per year. The historic redd counts suggest an escapement ranging from 2 to 845, and has averaged 215 since 1962 (Table CP2).

4.1.3 Methow River

Redd counts in the Methow River date back to 1958. Decadal averages are 494, 326, 306, 272, and 2,401 between 1958 and 2002, with a long term average of 454 (Table CP2).

Ford et al. (2001) recommended an interim recovery level of 2,000 naturally produced spawners per year. Escapement has ranged from 0 to over 9,700 spawners, averaging 954 (Figure CP2).

These data suggest that while the populations have fluctuated greatly since the late 1950s and early 1960s, there is a great resilience demonstrated in the populations to rebound from low numbers (Figure CP1).

It is important to remember that the long-term relative stability in upper Columbia spring chinook has been supported by drastic reductions in harvest of upriver spring chinook in zones 1-6. The harvest rate in lower Columbia River fishing zones 1-6, which had ranged from 40-85% before the 1960s, trended downward until 1974, and thereafter averaged less than 10%. Numerical harvest, which peaked, in the post-Bonneville Dam era, in the 1950s, also trended downward to 1974, and thereafter remained at negligible numbers (Chapman et al. 1995 CPa).

4.2 Steelhead

Steelhead counts began at Rock Island Dam in 1933, and annual counts averaged 2,800 between 1933 and 1939 (these numbers do not reflect large fisheries in the lower river that took place at that time, estimated by Mullan et al. (1992CPa) as greater than 60%). Average decadal numbers changed little in the 1940s and 1950s (2,600 and 3,700, respectively). Large hatchery releases began in the 1960s, and the average counts increased to 6,700. In the 1970s, counts averaged 5,700 and 16,500 in 1980s (record count of about 32,000 in 1985).

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[13] Ford et al. (2001) based their recommendation on values that fell within the range of habitat capacity estimates, historical run sizes (adjusted for lower river harvest, which ranged between 25-64% prior to the 1970s), and simple population viability analysis (McElhaney et al. 2000)

In the 1990s, counts decreased, following a similar trend as chinook, to 7,100, while, similar to chinook, they have increased substantially so far in the 2000s, with an average of over 18,000 (a high of 28,600 in 2001; Table CP3; Figure CP2).

These counts represent a "calendar year" count of fish over Rock Island Dam. A "cycle year" is a complement of fish in year X plus the number of fish ascending in the first two months (April and May) in year X+1. While this is a more accurate account of what the spawning population is in a given year, the annual count represents the spawning population reasonably well because the total number of steelhead ascending dams in the spring is low in comparison of the previous year's summer-fall counts (Figure CP3).

Counting of steelhead became possible at the Wells Dam fishway in 1967. Estimated wild run size above the dam was estimated at 1,500 to 2,000 fish in the late 1960s. Hatchery fish made up an increasing fraction of the steelhead run after the 1960s, as wild runs were already depleted (Chapman et al. 1994 CPa). Between 1982 and 1998, wild fish have made up an average of 7.4% and 16.3% of the steelhead ascending Wells and Priest Rapids dams, respectively (Figure CP4).

Mullan et al. (1992CPa) developed a spawner-recruit analysis that calculated the maximum sustainable yield (MSY) run size and escapement for the Methow Subbasin at 7,234 fish and 2,212 fish, respectively. Mullan et al. (1992CPa) demonstrated that the wild population appeared to be barely supporting itself and that hatchery additions are supplementing the natural production of fish. They felt that despite the natural production being sustained at threshold population sizes, the biological fitness of the hatchery spawners has allowed the population to meet pre-development MSY escapement and smolt production in most years (Mullan et al. (1992CPa). This does not mean that the hatchery fish are the "ecological equivalents of wild fish in all life history phases" (Chapman et al. 1994 Cpa), although Mullan et al. (1992CPa) found no difference in smolt to adult survival for hatchery versus wild steelhead. A portion of the hatchery-released steelhead remain in the freshwater for another winter (K. Williams, personal communication), increasing the fitness of returning adults (Chapman et al. 1994 Cpa). In addition, the resident form contributes to anadromy, at varying degrees, inversely related with the steelhead productivity.

In 2002, Murdoch and Viola (2003) found a total of 475 steelhead redds upstream of Tumwater Dam, with most of them found in the Wenatchee River. Jateff and Snow (2003) found 473 redds in the Methow Basin in 2002, most of which were found in the mainstem Methow River. Archibald (2003) has found between 0-38 redds in the Mad River since 1997 (excluding 1998), but the surveys were not conducted in the Entiat River, and thus do not reflect total abundance within the subbasin.

Ford et al. (2001) recommended interim recovery levels of about 2,500 naturally produced spawners each for the Wenatchee and Methow rivers, and about 500 for the Entiat, using similar criteria that was used for spring chinook (see above).

Since the 1930s, and particularly since the 1960s, construction of mainstem Columbia River dams has also affected fish abundance. While the dams on the mainstem may not have caused the original demise of the fish runs, they are a factor in reducing the resilience of the fish runs to handle natural perturbations.

In summary, both harvest rate and numerical harvest of spring chinook and steelhead appeared to have peaked in the last 15 years of the 1800s. Numbers of spring chinook and steelhead in the upriver run in the late 1930s and 1940s were depressed by decades of over fishing and habitat degradation. Runs increased in the 1950s, partly in response to somewhat reduced harvest rates. Favorable ocean productivity may also have been involved, as is evidenced in the recent increase of returns of spring chinook and steelhead in the Upper Columbia.

4.3 Summer/fall chinook

Chapman (1986) estimated peak runs (1881-1885) as about 3,700,000-summer/fall chinook. Historically, the late spring and summer components of the Columbia River chinook populations were the most abundant and heavily fished (Thompson 1951, Van Hyning 1968, Chapman 1986). Overfishing in the lower Columbia River rapidly depressed summer-run chinook. Spawning and rearing habitat extirpation and destruction accelerated the decline.

Decadal averages of summer/fall chinook escapements at Rock Island Dam from 1933 through 2002 show a rising trend (Table CP4; Figure CP5). Harvest rates in the 1930s and 1940s were very high in the lower river fisheries, and no doubt had a large impact on the escapement at Rock Island (Mullan 1987). In 1951, when harvest rates in zones 1-6 (lower Columbia River) were reduced, numbers increased dramatically. Between the 1930s (starting in 1933) and 1960s (excluding 1968 and 1969)[14], total (adults and jacks) decadal average numbers of summer/fall chinook rose from just over 7,000 to almost 28,000 (Table CP4). Numbers remained high in the 1970s until the mid-1980s, when they declined through the 1990s and have shown a sharp increase in the 2000s (Table CP4; Figure CP5).

In the 1960s, dam counts became available at Rocky Reach Dam (1962) and Wells Dam (1967). These project counts of total summer/fall chinook show a different trend than Rock Island (Table CP4; Figure CP5), which suggests the difference being the fish that spawn in the Wenatchee River were heavily affecting the trend at Rock Island Dam (see below).

Between the mid-1980s and through the 1990s, summer/fall chinook total numbers declined at Rock Island, Rocky Reach, and Wells dams (Table CP4; Figure CP5). The magnitude of the decline increased the further upstream the counts were. This suggests that the run into the Wenatchee River remained high or increased, while runs ascending upstream of Rocky Reach, and Wells did not (Table CP4; Figures CP6 and CP7). Figure CP6 shows that the run of summer/fall chinook into the Wenatchee River has continued to increase since redd counts

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[14] Unfortunately, there were no counts at Rock Island Dam between 1968 and 1972.

began in 1960.[15] Redd counts in the Methow River show a precipitous decline from the mid-1960s through the early 1990s (Figure CP6). Since the early 1990s, runs have increased sharply, partially due to the hatchery releases from the Eastbank Hatchery program (based on carcass sampling, e.g., Miller 2003), and in more recent years, high smolt-to-adult returns of hatchery and naturally produced fish.

Redd counts have been conducted in the Entiat River since 1957. Counts ranged from 0-55 between 1957 and 1991 (Peven 1992). Between 1994 and 2002, Hamstreet and Carie (2003) estimated the number of summer/fall chinook redds ranging between 15-218, averaging 75.

Redd counts in the Okanogan and Similkameen began in 1956, and similarly to the Methow, showed increasing escapement until the late 1960s, and then declined (Figure CP7). However, dissimilar to the Methow, the number of fish spawning in the Okanogan and Similkameen remained at very low numbers until the rise in the 1990s, which is believed to be due to the hatchery releases from Eastbank Hatchery primarily. The Eastbank satellite pond is located on the Similkameen River, and most of the spawning fish return to the short section of the Similkameen that is open to anadromous fish. This creates a problem of fish over-imposing redds on top of each other (A. Murdoch, WDFW, personal communication).

The escapement into the Wenatchee River appears to be still primarily composed of naturally produced fish based on carcass sampling. The Eastbank Hatchery program releases fish in the lower Wenatchee River (near Dryden), primarily for the purpose of reseeding the lower river habitat.

Dam counts in some cases may accurately reflect escapement, but caution needs to be applied when using only dam counts. For example, if the total (adults plus jacks) counts of summer/fall chinook from Rocky Reach Dam are subtracted from Rock Island Dam, the result, one would assume is a good estimate of escapement into the Wenatchee River (that enters the Columbia River between the dams). While there may be some mainstem spawners in that group of fish (especially the later-arriving ones), the correlation (between dam count differences and redd counts) is weak (Figure CP8). However, over Wells Dam, the estimate of fish escaping is easier to predict because of broodstock capture processes (Figure CP8).

In summary, the once great runs of summer/fall chinook that ascended into the mid- and upper Columbia River were initially depleted by over harvest and habitat modification and destruction in the latter part of the 19th century. When harvest rates were reduced in the lower Columbia River fisheries, an increase in escapement occurred at Rock Island Dam. This coincided with the GCFMP. Numbers continued to rebuild until the mid 1980s through the 1990s, and have shown huge (recent record) increases in recent years. The increase is due to a combination of factors, but primarily more favorable ocean conditions for fish entering the ocean, and possibly hatchery production.

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[15] It should be noted that historic (before 1987) redd counts were accomplished by flying over spawning areas and estimating the number of redds observed). Since 1987, ground counts have been done and those are used in this report.

4.4 Sockeye

Chapman (1986) estimated that peak run of sockeye entering the Columbia River could have been over 2.2 million fish in the 1880s. By the beginning of the twentieth century, it appears that most of the sockeye entering the Columbia River were headed to the Arrow Lakes region in British Columbia (WDF 1938). In the mid-1930s, WDF counted fish ascending Tumwater Dam in the Wenatchee River, and Zosel Dam in the Okanogan River. These counts suggested that 85-92% of the sockeye counted over Rock Island Dam in the same years where headed to spawning areas other than the Wenatchee and Okanogan basins (Table CP5). WDF (1938), through interviews with residents in the Arrow Lakes region and Native Americans at Kettle Falls, concluded that the sockeye were headed to Arrow Lakes. Chapman et al. (1995) point out that these percentages could be misleading because pre-spawning mortality was not figured in, but regardless, it is apparent that the vast majority of sockeye were not spawning in the Wenatchee or Okanogan basins by the 1930s.

Mullan (1986) quotes Rich (1940CPa, 1940CPb), who reviewed the sockeye fishery between 1892-1938, *the sockeye runs were greatly reduced as long ago as 1900, since which time there has been no marked change in the size of the catch*. Mullan (1986) suggests that the landings of sockeye may suggest otherwise, but that harvest rates in the lower river were undoubtedly high during that time; Rock Island Dam counts only accounted for 16% of the fish entering the Columbia River between 1933-1937, and in 1934 over 98% of the sockeye entering the river were harvested.

Mullan (1986) points out that commercial catches of sockeye after 1938 were still extreme, where escapement past the fisheries between 1938 and 1944 was mostly below 20%, and in 1941 was only 1%. In 1945, escapement increased and remained relatively high, between 25-50%. Since 1960, escapement has exceeded catch on a regular basis (Figure CP9).

While historic harvest rates, by all accounts were excessive, Mullan (1986) points to the “amazing tolerance to exploitation” of the sockeye stocks in the Columbia. He points out that runs apparently revived to some degree when harvest and escapement were brought more into balance in the later 1940s and 1950s. Declines since the 1960s point to other factors, besides harvest, that are responsible for current abundance levels.

Since 1938, the percentage of sockeye that has entered the Columbia River (minimum run) that have passed Rock Island Dam has varied from less than 1% (1941) to greater than 95% (1990s; Figure CP9). The mean percentage of fish ascending the Columbia past Rock Island Dam has increased since 1938. Between 1938 and 1944, only 14.5% of the sockeye estimated to have entered the Columbia River were counted at Rock Island Dam (see above). The percentage has steadily grown since then, approaching 100% in most recent years (Figure CP 9).

The percentage of adults returning to each basin fluctuates greatly between years. In some years, the Wenatchee population outnumbers the Okanogan population, but since 1962, most of the fish that are returning are headed to the Okanogan Basin (Figure CP6). Using adult sockeye accounted for in the tributaries, the percentage of adults in each drainage appears nearly equal (Table CP5; Figure CP10). Allen and Meekin (1980) caution against basing conclusions on the spawning ground counts however:

> *. . it appears that prior to 1952, the bulk of the run was produced in the Wenatchee system. This assumption appears reasonable because of the distribution of adults and the juvenile sockeye releases beginning in 1941. However, it should be noted that spawning ground surveys, including weir counts, were undoubtedly more efficient in the Wenatchee system than in the Okanogan. It is also evident . . . that large numbers of sockeye passing Rock Island Dam were unaccounted for on the spawning grounds of the two river systems. This is again partly related to the "efficiency" of the spawning ground surveys. . . This problem of adult loss has long been recognized and the Washington Department of Fisheries and Oregon Fish and Wildlife have established escapement goals of 80,000 sockeye over Priest Rapids Dam to ensure 25,000 average counts on the Okanogan River spawning grounds. Another point of interest was the lack of correlation between numbers of adult spawners and the resulting runs produced. For instance, spawning ground counts in the Wenatchee system exceeded those in the Okanogan for several years between 1951 and 1969, but the majority of the runs produced 4 years later still return to the Okanogan.*[16]

Since 1947, the percentage of adults observed on the spawning grounds has not comported well with the number of fish counted at different dams (e.g., Figure CP11). The differences observed between the dam counts and the spawning grounds may due to: 1) inflated dam counts, especially in years of large volumes of spill while adults are passing the dam causing an increase in the fallback rate, 2) inefficiencies of the spawning ground surveys due to the inability to make accurate counts for various reasons in the two basins, and 3) pre-spawning mortality, which may be a significant factor in the Okanogan Basin (Chapman et al. 1995 CPb). Allen and Meekin (1980; see above quote) mention how inefficient the counts can be on the spawning grounds, and this is exacerbated by the fact that most surveys have historically been once per year, hoping to coincide with peak spawning. The numbers of fish accounted for on the spawning grounds has been so low that 50% of the Wells Dam count has been used as an index of escapement to the Okanogan River (Pratt et al. 1991). Silliman (1947)[17] multiplied the number of spawners by five to derive an estimate to account for a greater proportion of fish counted over Rock Island Dam. This expansion was based on the average number of spawners observed in surveys, the duration of period that live fish are present in a section of stream, and the length of life of an individual fish after reaching a section of stream.

Even though there appears to be problems associated with the spawning ground counts, they may be used as an index of abundance in the two systems. In the Wenatchee, it appears the run may be stable, while in the Okanogan basin, the trend has been increasing since

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[16] Other factors, such as smolt size, may affect the survival of the two populations differently (see section on length at age). Another factor that may be different between the two populations is pre-spawning mortality (see section below).

[17] This expansion factor is usually attributed to Gangmark and Fulton (1952), but appears in Silliman prior to Gangmark and Fulton.

reconstruction of the runs (Figure CP12). However, if only dam counts are used, the long-term trend in the Okanogan run is decreasing slightly, but the Wenatchee run trend remains stable (Figure CP13).

Using the escapement estimates in both river systems (Table CP5), the numbers of fish returning seem to have a weak correlation (Figure CP14). Even though various factors are affecting smolt production in each individual system, and the distance the Okanogan fish travel is over 100 miles further upstream than the Wenatchee stock; survival trends appear to be generally similar between the two stocks, suggesting out-of-basin factors are dictating the yearly abundance of these populations.

Decadal averages have also shown a general increase in numbers of fish ascending Rock Island Dam (Table CP6). However, the slight decrease in the Okanogan run is demonstrated too.

Allen and Meekin (1980) report the escapement goal of 80,000 sockeye over Priest Rapids to ensure 25,000 fish on the spawning grounds of the Okanogan (see above). Currently, the escapement goal at Priest Rapids is 65,000 (Devore and Hirose 1988). The Columbia River Technical Advisory Committee (TAC) changed the goal in 1984 from 80,000 fish (1933-1966 at Rock Island, and from 1967 to the present at Priest Rapids) to the current 65,000, which under most conditions equates to 75,000 sockeye over Bonneville Dam. LaVoy (1992) showed the escapement goal of the Wenatchee population as 23,000. Using the various dam counts, escapement has been met in both systems in most years since 1970 (Figure CP13), but if spawning ground counts are used, the Wenatchee system is not meeting escapement goals in most years (Figure CP12). Improving pre-spawning mortality factors may increase the number of years that the stocks reach the escapement goals, especially for the Okanogan run.

In summary, the once large runs of sockeye that ascended the Columbia River were initially reduced from over-harvest in the mainstem coupled with habitat loss due to various factors including hydroelectric development. These stocks have shown a large resilience, having been reestablished from the low counts of the 1930s. Lower harvest rates and habitat improvements in the natal systems have contributed to the reestablishment. Hatchery practices may have aided the recovery in some time periods.

4.5 Coho

Chapman (1986) estimated that the peak run of coho entering the Columbia River in the 1880s was about 560,000 fish. Mullan (1984) pointed out that most coho spawned in the lower Columbia River tributaries. The furthest upstream coho were known to migrate in the Columbia River was the Spokane River (Fulton 1970).

Mullan (1984) estimated that between 120,000 to 166,500 coho historically ascended the mid- upper Columbia. Of those numbers, he estimated that 50,000 – 70,000 probably spawned in the Yakima Basin, 6,000 – 7,000 in the Wenatchee; 9,000 – 13,000 in the Entiat; 23,000 – 31,000 in the Methow; and 32,000 – 45,000 in the Spokane river basins.

Mullan (1984) points out that Craig and Suomela (1941) found the information on historic runs into the Entiat were sketchy and concluded that they were probably extirpated by the impassable dams in the river near the mouth that was built in1899.

Information concerning coho spawning in the Okanogan basin were conflicting, according to Craig and Suomela (1941). It is probable though, that did coho used some of the tributaries within the Okanogan historically (see Vedan 2002).

By the 1930s, the coho run into the mid- upper Columbia was virtually extirpated (see Rock Island Dam counts above). Tributary dams on the Wenatchee, Entiat, and Methow rivers appeared to be more destructive to coho than either steelhead (where genetic “storage” presided in resident forms) or sockeye (that appear to have benefited more than other species from the GCFMP and harvest reduction).

As previously mentioned, naturally reproducing stocks of coho have been extirpated in the mid- upper Columbia for at least 70 years. Recent (after GCFMP) programs to restore coho in the mid-upper Columbia began in the 1960s with releases from WDFW hatcheries for Rocky Reach Dam mitigation. Although this program did produce some initial promising results, (Figure CP15), it was determined that naturally producing runs were not establishing themselves, primarily because of the stock of fish used (Lower Columbia River stock – see Mullan 1984). In the early 1990s, this program was abandoned.

More recently, the Yakama Indian Nation has been trying different rearing techniques to establish naturally reproducing runs of coho in the Wenatchee and Methow basins. Initial results from the program look promising (Figure CP15).

In summary, the runs of coho that ascended the Columbia River were initially reduced from over-harvest in the mainstem. Habitat alteration, especially tributary dams in the Entiat and Methow rivers reduced the viability and capability of coho to rebuild themselves.

4.6 Pacific lamprey

Historical abundance of Pacific lamprey is difficult to determine because of the lack of specific information. However, lamprey were (and continue to be) culturally significant to the Native American tribes in the Columbia Basin.

Lamprey are excluded from large areas where they were assumed to be historically present, including upstream from Hells Canyon Dam on the Snake River and Chief Joseph Dam on the Columbia River. Landlocked populations have been found in areas from which the anadromous form has been precluded (Wallace and Ball 1978), but they have not persisted and Beamish and Northcote (1989) concluded that metamorphosed lamprey were unable, in such areas, to survive to maturity.

Close et al. (1995) describes the first data on the Willamette Falls (lower Columbia River tributary) commercial catch from Clanton (1913); 27 tons harvested in 1913. The commercial fishery for lamprey at Willamette Falls grew, and in the 1940s over 800 tons were captured, believed to be only 10-20 percent of the run (Close et al. 1995).

Dam counts on the Columbia became possible in the 1930s, and lamprey were counted along with salmonids as they ascended to their spawning grounds. In the first few years of counts at Bonneville Dam, counts were above 150,000. In the 1940s, counts ranged from approximately 50,000 to just under 150,000 (for one year; Close et al. 1995). In the late 1950s, counts rose dramatically over 350,000, and then dropped to less than 50,000 in the mid 1990s (no data is shown on Close et al.'s Figure 5 between 1969 and 1992; and we assume none exists).

In the upper Columbia, counts over Rock Island and Rocky Reach dams show a precipitous drop from the 1960s through the 1980s (Close et al. 1995), and appear to be rebuilding once again (see below).

There is little information on the abundance of Pacific lamprey in the upper Columbia region. Abundance estimates are limited to counts of adults and juveniles at dams or juvenile salmonid traps. There are no estimates of redd counts or juvenile and adult counts in tributaries.

Counts of adult lamprey at dams cannot be considered total counts because there was no standardized sampling across years and counting was restricted to certain hours (BioAnalysts 2000). For example, fish counters in the past counted for an 16-hr-day shift for the main part of the salmon runs (Close et al. 1995). Because the highest movement of lamprey occurs at night (Close et al. 1995), these day counts should be considered conservative estimates. Currently, fish counting occurs throughout the 24-hr period at most dams. At Rocky Reach and Rock Island dams, video tape or digital video record fish passage over 24 hours per day. This counting method began at Rock Island in 1992 and at Rocky Reach in 1996.

Additional problems with adult counts exist because some lamprey pass dams undetected. For example, adult lamprey can move near the bottom of the fish counting chamber making it difficult to detect them (Jackson et al. 1996). They can also bypass counting station windows by traveling behind the picketed leads at the crowder (Starke and Dalen 1995). Because of these shortcomings, adult counts at dams should only be viewed as crude indices of abundance.

Counts of juvenile lamprey at dams also suffer from sampling inconsistencies. Collection of juvenile lamprey at mainstem dams is incidental to sampling juvenile salmonids. Thus, numbers of migrants outside the juvenile salmonid migration period are unknown, since most of the literature suggests that migration occurs between fall and spring (Pletcher 1963; Beamish 1980; Richards and Beamish 1981). In addition, unknown guidance efficiencies of juvenile lamprey and unknown spill passage to turbine passage ratios reduce precise estimates of abundance (BioAnalysts 2000). Also, juveniles tend to hide in various locations in the bypass systems (Jackson et al. 1997). These problems, combined with highly variable sampling rates during periods of juvenile salmonid passage, confound estimates of juvenile lamprey abundance (BioAnalysts 2000). Juvenile counts at dams as should also be viewed as crude indices of abundance.

Large declines of adults occurred at most mainstem dams during the late 1960s and early 1970s. During the period between about 1974 and 1993, numbers of adult lamprey counted at Rock Island Dam was quite low (Figure CP16). Counts of adults have increased since that time; however, this increase corresponds closely with the time that the projects began day and night counts, which may have some effect on the comparison. However, recent increases in the last few years are far greater than those in the last 10, suggesting that a true increase in abundance is occurring (Figure CP 17).

Comparing counts among different projects is problematic because of sampling inconsistencies, the behavior of lamprey in counting stations, and the ability of lamprey to bypass counting stations undetected (BioAnalysts 2000).

In summary, while it is difficult to determine the historical abundance of lamprey in the Columbia Basin, and in the CCP, circumstantial evidence suggests that they have declined. Counts of juvenile and adult lamprey fluctuate widely. It is unknown whether these fluctuations represent inconsistent counting procedures, actual population fluctuations, or both. Although these factors may make actual comparisons difficult, it appears that lamprey in the upper Columbia are increasing.

4.7 Bull trout

Estimates of abundance specific to the CCP are not available until recent years through redd counts (begun in the 1980s in the Wenatchee and Entiat basins, and the 1990s in the Methow Basin), and mainstem Columbia River dam counts.

Bull trout once filled most every cold-water niche in the tributaries of the CCP. However, the presence of natural barriers such as waterfalls or small stream size blocked their access to many headwater streams. Bull trout spawning and early rearing is confined to streams cold enough (less than 1,600 C annual temperature units) to support them in the areas below blocking falls (Mullan et al. 1992 CPa). In most cases such reaches are very short (less than 5 miles). Adfluvial and fluvial ecotypes migrate through, or into warmer waters to increase trophic opportunities.

Because of the difficult nature of obtaining specific information, non-migratory (“resident”) numbers of bull trout are not considered.

Recent comprehensive redd surveys, coupled with preliminary radio telemetry work suggest that remaining spawning populations are not complete “genetic isolates” of one another, but rather co-mingle to some degree (Foster et al. 2002). This is primarily within each subbasin within the CCP, which comports with the belief of three independent populations (one in Wenatchee, Entiat, and Methow). It is possible that there are separate, local spawning aggregates, but more monitoring and DNA analysis is necessary to be able to empirically determine this. The chance of finding independent subpopulations within each subbasin would most likely found be in headwater areas upstream of barriers, which prevents immigration from downstream recruits, but not emigration to downstream areas during high water events occasionally.

Since non-migratory fish are difficult to enumerate, all estimates of current abundance should be considered underestimates of the true population size of bull trout within the CCP. This is based on the belief that "non-migratory" fish are most likely contributing to the "migratory" populations (like steelhead; see below for further discussion), and potentially vice versa, although there may not be very many non-migratory bull trout populations within the CCP (Archibald and Johnson 2002; K. MacDonald, personal communication).

4.7.1 Mainstem Columbia River

Fish counts at Rock Island and Rocky Reach dams prior to 1998 did not differentiate bull trout from other resident trout. Since then, bull trout counts at Rock Island Dam have averaged 126, while at Rocky Reach and Wells dams, the fishway counts have averaged 250 and 120 bull trout, respectively. Bull trout appear to use the mainstem Columbia to enhance feeding opportunities and over-winter (USFWS 2002). The mainstem also serves as a migration corridor to access tributary streams for spawning (USFWS 2002), and therefore is not considered a separate spawning aggregate.

Fewer bull trout have been counted at Rock Island Dam than at Rocky Reach Dam in all years from 1998 through 2002. This may be occurring because the major spawning areas are upstream of Rocky Reach Dam (Entiat and Methow basins), and only one between Rock Island and Rocky Reach (Wenatchee River).

4.7.2 Wenatchee River Basin

Redd surveys have been conducted by the USFWS, USFS, or WDFW in the various streams within the Wenatchee River Basin since the 1980s. The White and Little Wenatchee rivers have shown a fluctuating abundance of redds since 1983 (Table CP8; Figure CP18), averaging 34 redds.

Since 1989, the highest concentration of redds within the Wenatchee River Basin has been observed within the Chiwawa Basin, averaging over 300 redds per year, and showing a steady increase of abundance (Table CP8; Figure CP18). Lesser numbers of redds have also been observed within the Peshastin and Nason creek drainages, and in the upper mainstem Wenatchee River (Table CP8). Overall, the Wenatchee River Basin has average over 250 redds since the surveys began in the Chiwawa River in 1989, and has shown a steady increase (Figure CP19), although it should be noted that this trend may be a factor of increased effort in redd surveys in recent years (K. MacDonald, USFS, personal communication).

Hillman and Miller (2002) have observed between 76-900 bull trout in their snorkel surveys of the Chiwawa River between 1992 and 2002 (excluding 2000). They also state that because their surveys do not encompass areas outside of juvenile chinook salmon, or the entire lengths of all streams, so the estimates should be considered very conservative, since bull trout are known to extend beyond their survey boundaries.

4.7.3 Entiat River Basin

Bull trout redd surveys have been conducted by the USFS in the Entiat River Basin since 1989, primarily in the Mad River (Table CP8, Figure CP20). Since 1989, the number of redds observed has averaged 24, and has increased, primarily since 1997 (Table CP8, Figure CP20). Archibald and Johnson (2002) attribute the increase in bull trout redds in the Mad River to the closure of bull trout fishing in 1992 and the closure to all fishing (from the mouth to Jimmy Creek) since 1995.

4.7.4 Methow River Basin

Redd surveys began in the Methow River Basin in the early 1990s (Table CP8). The Twisp River basin is the largest producer of bull trout, averaging two- to three times more redds than any other spawning area within the Methow Basin (Table CP8; Figure CP21). The average number of redds within the basin has increased from less than 100 in the mid-1990s to greater than 150 since 1998.

Bull trout redd counts in all subbasins within the CCP show an increase since the mid-1990s, especially within the Methow Basin (Figure CP19) although it should be noted that this trend may be a factor of increased effort in redd surveys in recent years (K. MacDonald, USFS, personal communication). There are probably a multitude of factors for this increase, but the closure of steelhead angling in 1997 following the ESA listing of steelhead may have played a significant role in the increase in the Methow River redds since bull trout are very vulnerable to angling. Fishery management decisions may have also played an important role in the steady increase of bull trout observed within the Chiwawa River Basin too.

4.8 Westslope cutthroat

Numerical abundance has not been documented or estimated for WSCT. Westslope cutthroat were not thought to have been very abundant where they occurred in the headwater locations within the Methow, Entiat, and Wenatchee basins (Williams 1998; USFWS 1999; Behnke 2002).

Circumstantial information suggests that there was a large number of adfluvial WSCT in Lake Chelan prior to introductions of exotic species (kokanee and *O. mykiss*, primarily), extraction of fish for hatchery practices, and affects of Lake Chelan Dam (Brown 1984).

Currently, WSCT are distributed widely within the CCP. Thurow et al. (1997) used predictive models to estimate the range and status of WSCT throughout the Interior Columbia Basin. Their models suggest (from their Figure 3) that WSCT populations within the CCP headwater areas are currently "strong[18]" in most areas.

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[18] Thurow et al. (1997) used the criteria of Reiman et al. (1997) that determined a population was "strong" if it met the following criteria: 1) spawning and rearing occur within the subwatershed, 2) all major life histories that once occurred are still present in the subwatershed, 3) abundance is stable or increasing, and 4) the population, or

Williams (1998) documented that in the Wenatchee River Basin, WSCT sustain themselves in 82 streams (175 miles) and 83 alpine lakes (1,462 acres). In the Entiat, WSCT sustain themselves in 80 miles within 16 streams and 140 acres in 8 lakes. In the Methow Basin, Williams (1998) thought that WSCT are much more widely distributed now than they were historically, occupying some 60 streams (202 miles), and 43 alpine lakes (312 acres).

Lake Chelan is more complicated. Historically, Williams (1998) estimated that WSCT occupied 86 miles in 43 streams. Currently, they occupy 150 miles in the same number of streams. However, adfluvial WSCT appear to have been replaced in the lower 14.5 miles of the Stehekin River and another 2.5 miles of stream reaches that were formerly spawning areas of adfluvial WSCT, by *O. mykiss*.

Originally, there may have been one lake (besides Chelan) within the Chelan Basin that WSCT sustained themselves (Rainy Lake). Currently, of the 33 lakes that have been stocked, 25 (565 acres) sustain WSCT.

4.9 Redband trout

Determining historic distribution of redband trout within the CCP is difficult because of the lack of information and confusion over taxonomic classification (Behnke 2002) and separating potamodromous and anadromous ecotypes (Peven 1990; Mullan et al. 1992; Busby et al. 1996).

Abundance of allopatric populations of redband trout (those not occurring in sympatry with steelhead) have not been documented. As with WSCT, there has been various work done (e.g., Proebstel et al. 1998; Trotter et al. 2001) to document the distribution of redband trout, but these reports do not relate abundance. Thurow et al. (1997) used predictive models to determine strength of both allopatric and sympatric populations of redband trout throughout their range in the interior Columbia Basin. Their models predict that only Lake Chelan has a current allopatric population (introduced), which is "strong" in some areas. Where redband occur in sympatry with steelhead (their Figure 4), their models predict that redband are "strong" in most of their distribution.[19]

4.10 White sturgeon

Historic abundance of white sturgeon within the CCP is not known, and is further complicated because of the migratory behavior of white sturgeon.

Currently, through existing and future re-licensing of their hydroelectric facilities, Grant, Chelan, and Douglas PUDs are gathering information on white sturgeon on the mainstem Columbia River within the CCP.

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metapopulation of which this subwatershed population is part, supports an average of 5,000 individuals or 500 adults.

[19] It appears from Thurow et al.'s (1997) Figure 4, that some areas upstream from Chief Joseph Dam (the current anadromous barrier) are excluded in the "allopatric" category and are considered "sympatric." This would increase the area of "allopatry" if corrected.

In Wanapum Reservoir, Golder Associates (2003 CPa) estimated the current population at 351 (95% CI: 314-1,460) from data collected in mark and recapture studies between 1999 and 2001. In the Rocky Reach Reservoir, Golder Associates (2003 CPb) estimated the current population at 47 (95% CI: 23-237). There have been no estimates for Rock Island Reservoir, and Douglas PUD is still collecting information for Wells Reservoir (S. Bickford, personal communication).

5 Extinction Risks

5.1 QAR (from NMFS et al. 2002)

The Upper Columbia Quantitative Analysis Report (QAR) process was established to provide decision-makers with current assessments of the status of Upper Columbia spring-run chinook salmon and steelhead runs (Cooney et al. 2002; NOAA Fisheries et al. 2002). Upper Columbia River steelhead and spring-run chinook salmon were listed as endangered in 1997 and 1998, respectively. The purpose of the QAR was to provide hypothetical estimates of the relative risks of extinction for UCR steelhead and spring chinook under a range of alternative management and climatic/environmental scenarios and to estimate the survival gains necessary to meet interim recovery levels (IRLs) and reduce the risk of extinction to acceptable levels.

Simple population dynamics models were developed for independent populations of UCR spring- run chinook salmon (Wenatchee, Entiat, and Methow populations, based on redd counts) and summer-run steelhead (Wenatchee/Entiat and Methow populations, based on dam counts). Reconstructed spawner to spawner return ratios for historical years, estimated age at return data, and estimates of recent spawning escapements were used as input into a stochastic cohort run reconstruction (CRR) statistical model. The model was designed to generate hypothetical time trends in return levels and the effect of survival changes on those trends. Alternative assumptions regarding the effects of alternative future environmental conditions were analyzed for spring-run chinook salmon and the effectiveness of hatchery origin spawners were considered in the analysis for steelhead.

The focus of the analyses described in the QAR was on identifying levels of life cycle survival improvements necessary for the two Endangered Species Act-listed stocks to be self-sustaining. The report includes specific assessments of the potential benefits of meeting the passage survival and habitat objectives of the HCPs for each of the five Mid-Columbia projects (for analysis sake, the Grant PUD dams were included, although they do not have a HCP for their project). In the longer term, achieving conditions that result in survival levels high enough to support self-sustaining natural production is an important objective under the Endangered Species Act.

Under NMFS guidelines, hatchery production is explicitly not included in the assessment of long-term sustainability of a stock. However, hatchery supplementation can play a separate and important role in the overall approach to addressing particular Endangered Species Act-listed stock recovery issues. In the short term, hatchery supplementation can bolster weak stocks while survival improvement measures are implemented and play a major role in speeding up the rebuilding process.

The population models of Upper Columbia River spring-run chinook salmon and steelhead were used to explore five basic questions:

1. What are the relative risks of extinction to Upper Columbia River spring-run chinook salmon under alternative assumptions about future environmental conditions?

2. What are the relative risks of extinction to Upper Columbia River steelhead under alternative assumptions about the effectiveness of hatchery origin spawners?

3. How much improvement in survival across the life history of a particular run is necessary to meet extinction risk criteria and interim recovery levels?

4. What benefits in terms of life cycle survival would be gained by meeting the specific survival improvement goals in the Mid-Columbia HCP?

5. Assuming that the survival objectives set forth in the proposed Mid-Columbia HCP and the Federal Columbia River Power System Biological Opinion are met, would the cumulative improvement in survival meet or exceed population-specific survival improvement needs?

Because future environmental/climatic conditions cannot be accurately predicted, information was used from three different sets of years within the chinook salmon data series to capture a possible range of future conditions. Spawner-return data for the Upper Columbia River spring-run chinook salmon runs date back to about 1960. Annual spawner return rates were generally higher for broods originating in the 1960s than in later years (until the late 1990s). Return levels for broods originating in the early 1990s included several of the lowest rates in the historical time series. Model runs using three different sets of spawner return data from the historical series were used to characterize the relative extinction risks and survival needs under alternative environmental conditions.

Model runs incorporating the average and variance in spawner return rates across the entire historical series (1960 to 1994 brood years) represent an assumption that future environmental conditions are best represented by the longest historical series that can be generated and will result in some good survival years (similar to those observed in the 1960s) and some poor survival years (similar to the 1980s through the mid-1990s). This scenario would encompass assumptions that salmon survivals are strongly influenced by long-term (30- to 50-year) cycling in ocean/climatic conditions. Model runs incorporating the 1980 to 1994 period capture a time of relatively poor environmental/climatic conditions. If one assumes that these poor environmental/climatic conditions will continue into the future (a conservative view), then results based on the time series 1980 to 1994 would be most applicable. The period 1970 to 1994 may reflect an average condition that falls between the poor conditions represented by the 1980 to 1994 data series and the better conditions of the 1960 to 1994 series. The spawner-return data series for Upper Columbia River steelhead is relatively short (1976 to 1994); therefore, no attempt to generate alternative future survival and extinction risks for steelhead was made for spring-run chinook salmon.

The results from these simulations should not be viewed as specific predictions of future conditions or stock status. Rather, these models are tools intended to illustrate the potential response of the population to a range of future scenarios given a set of assumptions regarding population dynamics. While those assumptions are based on the best available information, there is considerable uncertainty associated with many of the estimates. This report includes sensitivity analyses designed to illustrate the influence of uncertainty in selected key assumptions on model results.

5.2 CRR

The CRR model estimated the relative risk of extinction of spring-run chinook salmon populations at 24, 48, and 100 years and for steelhead at 25, 50, 75, and 100 years. The majority of the extinction risk assessments described in the QAR are expressed in terms of absolute extinction—defined as the probability that chinook salmon or steelhead populations fall to one or fewer spawners in 5 or more consecutive years. Given the uncertainty associated with productivity at extremely low levels of escapement, quasi-extinction risk assessments were also applied to chinook salmon model populations.

Quasi-extinction risk was estimated as the probability that chinook salmon runs would fall to 50 or fewer spawners in the Methow and Wenatchee Basins and 30 or fewer in the Entiat Basin for 5 or more consecutive years (Ford et al. 2001). For each scenario analyzed, the model was run for 1,000 iterations. Relative extinction risk at each of the selected time intervals was expressed as the percentage of 1,000 runs projected to be at or below the selected extinction level.

5.3 Spring chinook

Extinction risks varied among the three Upper Columbia River spring-run chinook salmon population areas. In general, the modeling analysis indicated that the Wenatchee River population has the highest current risk of extinction of the three populations analyzed. Extinction risk levels were sensitive to the time period used to derive survival/production characteristics.

Annual return rates since 1980 have been highly variable, and until brood year 1995, have included the lowest estimated return per spawner rates in the record. Assuming that conditions into the future will continue at levels associated with the 1980 to 1994 brood year data series results in high probabilities of extinction in 50 to 100 years for all Upper Columbia River spring-run chinook salmon stocks.

Assuming that future conditions are best represented by the historical series extending back to brood year 1970 generally reduces extinction risks in the Wenatchee and Entiat analyses. For the Methow analysis, extending the series back to 1970 did not substantially change the projected extinction risk. Spawning escapements for spring-run chinook salmon in years 2000 and 2001 indicated relatively high return rates for the 1995 and 1996 brood years. Incorporating these brood years into the extinction analysis resulted in projections similar to those of the 1970 to 1994 data set. Assuming future conditions would include survivals like those observed in the early 1960s results in a large decrease in extinction risks relative to the assumption that survivals will remain at the lower levels seen since 1980. However, to meet extinction risk criteria, improvements in average population growth rate would still be necessary.

5.3.1 Carrying capacity

The estimated increase in survival is sensitive to assumptions regarding carrying capacity of the systems. If carrying capacity is substantially higher than the IRL level, the survival improvement required to rebuild from recent average escapements to IRL would be lower. For example, the requirement to meet the IRL escapement criteria for the Wenatchee (assuming future survivals are represented by the conservative1980 to 1994 data series) would be 170 percent assuming that maximum smolt production is reached at an escapement of 4,000 (approximately equal to the IRL level of 3,750).

The survival improvement necessary to reach IRL criteria would drop below 100 percent if the carrying capacity is roughly double the IRL level (7,500). If the carrying capacity (spawning level producing maximum smolt output) is very high relative to the IRL, the required survival improvement would be reduced to approximately 75 percent.

5.3.2 Stock-recruit model

The population modeling described in the QAR was based largely on a simple ‘broken stick’ model relating productivity to spawning population size. Under this approach, production per spawner is constant up to a carrying capacity threshold. At escapements above that threshold, average production is constant. An alternative population function, the Ricker spawner/recruit function, has been fit to historical data from the Upper Columbia stocks. The CRR model was modified to implement the Ricker function derived from the 1970 to 1994 brood year spawner/return series. Using the Ricker function resulted in lower projected extinction risks relative to the broken stick model assuming the 1970 to 1994 average survivals would continue. Reducing survivals to the equivalent of the more conservative 1980 to 1994 levels resulted in high extinction risk probabilities, similar to the broken stick model. Achieving the IRL levels took higher increments of survival improvements than were required using the broken stick model.

In summary, if future environmental conditions resemble the longer 1960 to 1994 or 1970 to 1994 data sets rather than the more conservative 1980 to 1994 data set, then the levels of additional survival needed for recovery metrics are reduced substantially or eliminated in certain scenarios. For spring-run chinook salmon, the addition of 2000 and 2001 adult returns (1995 and 1996 brood years) to the 1980 to 1994 brood year data yielded mean spawner/return rates similar to those of the 1970 to 1994 data series. This suggests that the 1970 to 1994 data set may best represent future environmental conditions for predicting extinction risks and the probability of achieving IRL criteria.

5.3 Steelhead

As described above, more limited trend data are available for Upper Columbia River steelhead. The parameters for the steelhead extinction risk model were derived from the 1986 to 1992 brood year data sets for the Wenatchee/Entiat and Methow steelhead runs. Significant proportions of returns to these areas are of hatchery origin. The relative effectiveness of hatchery origin spawners is a key scientific uncertainty. Extinction risk estimates were generated for a range of possible relative effectiveness values for naturally spawning fish of direct hatchery origin. As was the case with spring-run chinook salmon, the extinction risk assessments for steelhead were designed to evaluate the potential for runs to sustain production if hatchery supplementation were to be discontinued. The level of extinction risk was substantially influenced by assumptions regarding the historical effectiveness of hatchery contributions relative to spawners of natural origin. Extinction risk projections at 100 years were estimated to be approximately 28 to 35 percent under the assumption of low (25 percent) relative effectiveness of spawners. Under the assumption that the relative effectiveness of hatchery spawners is 50 percent or greater relative to wild fish, the projected extinction risks at 100 years for both groups was 99 to 100 percent.

In summary, the level of hatchery effectiveness determines the range of survival improvements needed to reach recovery metrics. Extinction risk projections at 100 years were estimated to be approximately 28 to 35 percent under the assumption of low (25 percent) relative effectiveness of spawners. Under the assumption that the relative effectiveness of hatchery spawners is 50 percent or greater relative to wild fish, the projected extinction risks at 100 years for both groups was 99 to 100 percent.

5.4 Summer/fall chinook

Various sources have assessed the potential future status of summer/fall chinook in the mid-upper Columbia. Chapman et al. (1994 CPb), Waknitz et al. (1995), and Meyers et al. (1998) are the most recent and up to date assessments.

From Chapman et al. (1994 CPb; edited):
Thompson (1991) examined criteria for deciding whether species should be designated as endangered or threatened. He suggested that an endangered designation would apply to a minimum viable population (MVP) that has a 95% chance of extinction over the next 100 years. He suggested that threatened status could apply to a population that had a 50% chance of reaching the endangered minimum viable population within 10 years. Thompson (1991) added some cautionary statements. He assumed that MVP would be assessed for populations qualitatively and spatio-temporally well distributed. Finally, he noted:

Endangerment is not necessarily the same as depletion. In the case of harvested fish stocks, for example, the fact that a stock may be below the abundance level corresponding to maximum sustainable yield does not necessarily mean that an ESA listing is in order. A population can be depressed and still be relatively stable. In the context of the ESA, the question is not whether the stock could be managed better, but whether the stock is in danger of extinction.

In fact, the compensatory mechanisms that underlie stock-recruit models specify higher stock:recruit ratios at parent generation abundance well below that at which maximum sustained yield occurs. Also in fact, mid-upper Columbia summer/fall chinook as a group, and summer-run fish alone, suffer heavy mortalities at all life stages from natural and anthropogenic factors.

In responding to the petition to list summer chinook under the ESA, the Alaska Department of Fish and Game (1993) ran the extinction model of Dennis et al. (1991) using three different approaches (see Chapman et al. 1994 CPb for detailed information). They predicted that the probability of decline to one fish in 100 years (abundance to trigger an *endangered* categorization using Thompson's definition) was estimated as 0.00001.[20] Probability of decline to 614 fish or less (abundance to trigger a *threatened categorization)* by the year 2003 was less than 0.00001.

Using other data, they estimated that the probability of decline to one fish by 2093 was less than 0.00001. Probability of reaching 946 fish or fewer (trigger for threatened status) by 2003 was less than 0.00001.

Using still one more method, they predicted the probability of decline to one fish by 2093 was less than 0.00001. Probability of decline to 1,477 fish by year 2003 was also less than 0.00001. Using the criteria of Thompson (1991), the ADFG staff concluded that all three estimates would not support endangered or threatened status.

Chapman et al. 1994 examined the sum of summer/fall chinook that spawned in the Wenatchee, Methow, Okanogan, and Similkameen rivers for each year 1973 through 1993. They estimated those numbers by multiplying the number of redds counted during aerial surveys by two, not 3.1 as others have done (based on Meekin (1967)). They assumed that each redd observed was built by one male/female pair. To inflate redd counts by 3.1 assumes that dead pre-spawn fish contribute to future production, which cannot be true. They considered the redd count numbers as minimum estimates because not all redds were counted, not all spawning areas were surveyed, and hatchery production was not included. Their modeling gave more conservative estimates than ADFG (1993; for more details, please see Chapman et al. 1994 CPb).

Chapman et al. found, from their modeling effort, that the probability of the population decreasing to 5,000 fish in 10 years is 0.02% (95% CI = 0-0.05%). The probability of a population decline to 10,000 fish in the same period is 3% (95% CI = 0-15%). In 50 years the probability of the population decreasing to 5,000 fish is 9% (95% CI = 0-50%), and to 10,000 fish is 26% (95% CI = 0-93%). In reviewing the results of the foregoing calculations, they found no biological justification for concluding that the populations of summer/fall chinook in tributaries of the upper-Columbia region are either threatened or endangered.

Waknitz et al. (1995) concluded:

Dam and redd count information indicated that although depression in some individual runs of late-run chinook salmon in the mid-Columbia River is cause for concern, the mid-Columbia River late-run, ocean-type chinook salmon ESU as a whole is relatively healthy, with little risk of extinction in the foreseeable future . . .While redd counts in two of the rivers

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[20] B. Dennis, personal communication, (in Chapman et al. 1994) states that it is unrealistic to calculate probabilities of reaching one fish in a given time.

(Okanogan and Methow) have exhibited substantial declines since the late 1960s, they have been relatively stable since 1980, and counts in both the Wenatchee and Similkameen Rivers have exhibited long-term (1956-93) increasing trends. Based on Rock Island Dam adult counts, this group of populations is certainly more abundant than it was in the 1930s and 1940s."

Meyers et al. (1998) agreed with this conclusion and did no further evaluation.

In summary, based on various evaluations, there is no indication that late-run, summer/fall chinook in the mid- upper Columbia River Basin are at risk of extinction, as a metapopulation. However, some tributaries that harbor historic habitat may need special management actions to increase use (and numbers). Recent (since 2000) counts of summer/fall chinook have surpassed historic (since the early 1930s) numbers of fish spawning in the area, which comports well with the conclusions above.

5.5 Sockeye

Gustafson et al. (1997) reviewed the current status of upper Columbia sockeye and concluded that they were not in eminent danger of extinction, nor did it appear that they would become so in the near future. However, they had concerns of the health of both independent populations in the area.

Trends of abundance for the Okanogan population could offer conflicting views, since when dam counts are used, the trend appears negative (Figure CP13), or positive when spawning ground counts are used (Figure CP12). A comparison of Wells Dam counts and subsequent spawning ground counts suggests that the number of fish counted at the dam is not always a good indicator of the spawning population, especially in extremely large escapements (Figure CP11).

For the Wenatchee population, trends are consistent between dam counts and spawning ground counts (Figures CP12, 13).

In the Okanogan Basin, channelization of the spawning habitat and warm water temperatures appear to be limiting factors. Mullan (1986) pointed out that for such a eutrophic lake, it was poor in converting its nutrients into sockeye production, while the oligotrophic Lake Wenatchee was very efficient in this manner.

Gustafson et al. (1997) felt that the Wenatchee population was limited by poor nutrient content in Lake Wenatchee, but as previously pointed out, Mullan (1986) felt that the conversion of low nutrients to sockeye production was actually quite high in that basin.

In summary, the two sockeye populations in the upper Columbia do not appear to be in danger of extinction. Both populations appear to be somewhat cyclic in nature, suggesting potential out-of-basin influences are dictating the overall abundance. However, management actions should consider improvement of production, if warranted, through various means.

5.6 Coho

As previously mentioned indigenous populations of coho are extinct within the CCP.

5.7 Pacific lamprey

Close et al. (1995) shows that the number of Pacific lamprey ascending dams is much lower than historical counts, where available. While they note that recent increases may be due, in part, to counts for adult salmon that now occur over 24 hours (see above), other reasons for the overall decline were: 1) reduction in oceanic prey, including “ground fish” such as walleye pollock (*Theragra chalcogramma*) and Pacific hake (*Merluccius productous*), and salmonids, 2) passage problems for adults and juveniles at hydro-system, and 3) further alteration and problems with freshwater habitat.

While part of the rise in numbers in recent years may be due to additional hours of counting at mainstem dams, Rock Island Dam has been counting for 24 hours per day since 1992, and there has been a steady (and steep) rise of Pacific lamprey since that time (Figure CP17). There may be a classic predator-prey relationship existing between lamprey and their prey species since the recent increase appears to coincide with increases in salmonid abundance (Figure CP16).

Not enough information is known of lamprey to predict the total health of the population or its extinction risk in the CCP.

In summary, more information needs to be gathered for Pacific lamprey before any determinations of extinction risks can be made.

5.7 Bull trout

Rieman et al. (1997) listed 144 watersheds within the “Northern Cascades” that had bull trout present within them. Their classification of Northern Cascades includes watersheds south of the CCP, including the Yakima, White Salmon, and Kickitat basins. This is almost 50% of potential historic range, using their criteria. While this complicates their assessment of the streams within the CCP, they state that within the Northern Cascades, 10 populations are “strong,” 22 are depressed, 90 were of unknown status, and 22 were transient (the watershed was used mostly as a migratory corridor; Rieman et al. 1997).

Within the Wenatchee River Basin, USFWS (2002) lists six local populations. Of those, the status of bull trout within Ingalls, Icicle, Chiwaukum, Nason creeks and the Little Wenatchee River are unknown. The status in the Chiwawa and White River basins is considered healthy (WDFW 1998)

Within the Entiat River Basin, bull trout appear to use the Mad River the most, and that local population is considered to be healthy (WDFW 1998).

The Methow River Basin has eight local populations (USFWS). Of these, only the Lost River is considered healthy; the rest are listed as unknown (WDFW 1998).

In summary, it appears that most of the local populations of bull trout, including, especially *non-migratory forms, have little or no information concerning their status. This is identified by USFWS (2002) as a major need to help recover bull trout.*

5.8 Westslope cutthroat trout

As stated above, WSCT appear to be more widely distributed now than they probably were historically. Since no census data are available, it is not possible to determine the status of these local (and independent) populations that occur in the various watersheds of the CCP.

5.9 Redband trout

There have been no census data collected for Redband trout. Further complicating the potential status is the complicated life history between potamodromous and anadromous local and independent populations. Status is not currently possible for this species with our current level of knowledge.

5.10 White sturgeon

While estimates of abundance have been obtained with the last few years in various sections of the mainstem Columbia River, baseline information is not available to determine if the population(s) are stable, increasing, or decreasing. However, it is reasonable to assume that the construction of the hydroprojects on the mainstem Columbia has significantly altered the population structure, and *potentially* the productivity of the white sturgeon population.

6 Life History Features

I. Anadromous species

6.1 Life history strategies in salmonids

6.1.1 Spring Chinook

Chapman et al. (1995) summarized the most current understanding of the life history of upper Columbia spring chinook. The following is primarily from that report.

Chinook salmon have two main life histories (Healey 1991). One form, designated stream-type by Gilbert (1913) is typical of northern populations and headwater tributaries of more southern populations. Stream-type chinook spend usually one year (sometimes more) in freshwater as fry or parr before entry into the ocean, they migrate extensively at sea, and return to the natal stream in the spring or summer, several months prior to spawning (Healey 1991). Occasionally, males mature in freshwater without ever migrating to the sea (Robertson 1957; Burck 1965; Mullan et al. (1992 CPb). The second behavioral form is known as ocean-type ("sea type," Gilbert 1913). This life history is common among North American populations south of 56° N (Healey 1991). Ocean type chinook generally migrate to the ocean in their first year of life, spend most of their ocean lives in coastal waters (although they may make extensive migrations), and return to their natal rivers in late summer or early fall (Healey 1991).

Different temperature regimes in natal areas cause the various in run timings that regulate incubation and emergence of fry (Miller and Brannon 1982; Brannon et al. 2002). In the

Upper Columbia region, spring (early-run) salmon spawn in the cooler headwater tributaries from July to mid-September. The later components of the chinook run (summer/fall) spawn in warmer downstream areas in the mainstem of the major tributaries and the mainstem of the Columbia River (Meekin 1967; French and Wahle 1965; Chapman et al. 1982). In essence, a time-window exists for egg deposition in a specific site as water temperatures decrease from upstream to downstream each fall. This time-space dimension was originally filled by successive waves of chinook salmon spawners.

For the above reasons the summer/fall components of the chinook run in the Upper Columbia basin can be referred to as ocean-type[21] and the spring component of the run as stream-type. The National Marine Fisheries Service (NMFS) recognized these distinctions in their grouping of the spring and summer components of the chinook run that enters the Snake River basin under the ESA listings of 1992, where the spring and summer components are stream-type and the fall component is ocean-type.

Matthews and Waples (1991), after review of the relationships of the different runs of chinook in the Snake and upper Columbia rivers state:

Life history information thus clearly indicates a strong affinity between summer- and fall-run fish in the upper Columbia, and between spring- and summer-run fish in the Snake River. Genetic data support the hypothesis that these affinities correspond to ancestral relationships.

So, based on life history patterns, spring chinook in the Upper Columbia basin and spring/summer chinook from the Snake basin are similar.

6.1.2 Adult migration timing

6.1.2.1 Mainstem Columbia River:

Adult spring chinook destined for areas upstream from Bonneville Dam (upriver runs) enter the Columbia River beginning in March and reach peak abundance (in the lower river) in April and early May (Peven 1992 CPb). Fifty percent of the spring chinook run passes Priest Rapids and Rock Island dams by mid-May, while most pass Wells Dam somewhat later (Howell et al. 1985; Chelan and Douglas PUD, unpublished data). Chinook that pass Rock Island Dam are considered "spring-run" fish from the beginning of counting (mid-April) through approximately the third week of June (French and Wahle 1965; Mullan 1987).

6.1.2.2 Tributaries:

Spring chinook enter the mainstem portions of tributaries from late April through July, and hold in deeper pools and under cover until onset of spawning. They may spawn near holding areas or move upstream into smaller tributaries. Spawning occurs from late July through September, usually peaking in mid- to late August.

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[21] However, some evidence exists that some summer/fall chinook of the mid-Columbia region can have stream-type scale patterns (Chapman et al. 1994). It appears that these fish rear in the mainstem Columbia River, not in natal tributaries (see below).

6.1.2.3 Juvenile migration

Fish and Hanavan (1948) reported the principal migration of chinook juveniles in the upper Wenatchee River was in the spring: *Young chinook fingerlings - progeny of naturally spawning fish - were found in greatest numbers in Nason Creek and the upper Wenatchee River during late April and early May . . .* While they report the principal early-spring movement, they note:.... *a second, smaller migration accompanies the early fall freshets of September and October*.

French and Wahle (1959) found that juvenile chinook migrated past Tumwater Dam on the Wenatchee River (RM 33) from spring through late fall. Yearlings and subyearlings were captured in the spring and only subyearlings were captured in the summer and fall months. During the summer and fall months, catches of subyearlings peaked in late August, mid-September, and mid-October (Figure 51).[22] Periodic sampling of Nason Creek and the Chiwawa River produced fish sizes and run timing that comported well with the catches at Tumwater Dam (French and Wahle 1959). This comports with recent information (Murdoch et al. 2000).

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). Similar run timing of smolts was observed in the Chewack River in 1994 (J. Hubble, YIN, personal communication, in Chapman et al. 1995 CPa).

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) 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).

From the above, it is apparent that some portion of each year class of spring chinook for a given year migrates downstream in the first year of life. These fish apparently rear

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[22] We believe, based on the timing of chinook past Tumwater Dam in the mid-1950s (French and Wahle 1959), that these fish were predominantly spring chinook, a thesis that agrees with Hillman and Chapman (1989) conclusion that fish in the upper reaches of the Wenatchee River that were present in the late summer-early fall were emigrants from the upper tributaries.

overwinter in the larger mainstem tributaries (e.g., Wenatchee, Methow rivers). The proportion that survives and migrates to the sea the following spring is unknown.

Since 1985, the average run timing of spring chinook has occurred between mid-April and the first week of June, peaking in mid May. Run timing of yearling chinook at Rock Island Dam is strongly related to the release of fish from Leavenworth NFH, which reach the dam generally two days after release. Most of the chinook sampled at Rock Island Dam are of hatchery origin, but based on sampling of migrants from the tributaries, we believe that the naturally-produced migrants have a run timing similar to that of the hatchery component of the run.

Peak movement of yearling chinook at Priest Rapids Dam usually occurs in mid-May. Movement at McNary Dam peaks about mid-May. The peak moves to about the third week of May at John Day Dam, and to the last week of May at Bonneville Dam. More than half of the daily movement of spring chinook past dams occurs at night.

6.1.3 Age structure

Age structure

Age at smoltification is thought to have both genetic and environmental influences (Ricker 1972; Randall et al. 1987). Environmental control of smoltification is evidenced by the fact that growth conditions in freshwater determine smolt age (Randall et al. 1987). The physiological factors that determine smoltification (Hoar 1976), and marine survival (in Randall et al. 1987), appear to be size dependent for some stocks. Elson (1957) observed that the "physiological age" of parr in their pre-smolt year appeared to be a more important factor in parr-smolt transformation than the chronological age. This suggests that unless a fish reaches a certain size within an appropriate time frame (window), then it will remain longer in freshwater before emigrating to the sea.

Randall et al. (1987) summarized data that suggest genetics influence smoltification. They conclude that, ... *the age of migration must have a genetic component, but that it is also strongly influenced by environmental conditions*. Mullan (1987) suggests that adult life history patterns in chinook salmon, although having some hereditary component, may be controlled by environmental priming in freshwater. Ricker (1972) inferred that one of the factors influencing the evolutionary fitness of the population (measured by the reproductive potential of the returning adults) was determined by, ...*the natural selection of hereditary factors that produced smolts of the best size for the prevailing conditions; and that on the average, cooler temperatures northward tend to require a longer period of freshwater life to get the smolts to the most favorable size*. Ricker's observation of north-south temperature differences could be applicable to the temperature differences observed between upstream and downstream areas in the tributaries upstream from Rock Island Dam (Mullan et al. 1992CPa). This postulate would explain the consistent difference in freshwater ages between the spring (predominantly stream-type) and late-run (predominantly ocean-type) chinook that spawn in these areas.

Ricker (1972) concludes that there is a strong genetic influence on the age at maturity in chinook salmon. The evolutionary adaptive benefit of migrating to the ocean is greater for females than for males because of the higher energy cost in developing female gonadal tissues (reviewed in Peven 1990).

6.1.3.1 Juveniles:

Juvenile spring chinook generally spend one year in fresh water before they enter the sea (Mullan 1987; Healey 1991). French and Wahle (1959) sampled downstream migrating chinook captured at Tumwater Dam in 1955. Of the fish sampled in April and May, two size groups were sampled. Twenty-one percent (n=3,318) were categorized as fry (some may have been summer chinook that spawned upstream from the sampling site). French and Wahle (1959) read scales from 79 juveniles that were of the larger size group. Seventy-eight of the scales indicated the fish were in their second year of life (1.)[23], while the remaining one was in the third year of life (2.). Healey (1991) reports that some populations in more northern rivers produce smolts that spend an additional year in fresh water, but the vast majority of stream-type chinook spend no more than one winter in fresh water before they enter the sea.

Fryer et al. (1992 CPa) summarized age information of spring chinook sampled at Bonneville Dam from 1987 through 1991. They found no adult scales with two stream annuli (2.x), although in every year there were some fish estimated to have entered the ocean in their first year of life (0.x; probably from the Snake River basin). Adults sampled in the Upper Columbia tributaries have shown no 0.x or 2.x life histories.

6.1.3.2 Adults

Most Columbia River adult spring chinook spend two years in the ocean before migrating back to their natal streams (Mullan 1987; Fryer et al. 1992 CPa; Tonseth 2003). Adults sampled from Upper Columbia tributaries predominantly spend two years in the ocean, and are four years old (1.2). Both females and males are predominantly four years old. The estimates of age of adult spring chinook sampled in the Upper Columbia comport well with those for fish sampled at Bonneville Dam and other Columbia basin tributaries. These data suggest that over 50% of spring chinook in the Columbia River basin spend one year in fresh water and two in salt water. About 20-40% spend an extra year in saltwater before returning to the river. Tonseth (2003) found that in 2001 (a recent record run into the Wenatchee Basin), that over 90% of the fish sampled on the spawning grounds in the Chiwawa River broodstock were four-years-old, while 8% had spent three years in the ocean, and only 1% were jacks. Most stream-type chinook throughout their geographic range average approximately four years of age, except those from the Yukon River, Alaska.

Individuals that never migrated to the sea make up some portion of the spawning population (Healey 1991; Mullan et al. 1992CPb). The state of sexual maturation of male chinook is considered precocious when it occurs any time before normal maturation in the ocean (Mullan et al. 1992CPb). Thus, we consider male chinook to be precocious if they mature at

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[23] For age estimations, we use the "European Method" for describing age, where two digits are used, separated by a period. The first digit represents the number of winters the fish has spent in freshwater, and the second digit the number of winters in saltwater. We also use the total age (e.g., a fish designated as 1.2 is four-years-old).

the end of their first or second summer, regardless if they lived their second summer in fresh or salt water. Mullan et al. (1992 CPb) indicate that precocious maturation of male spring chinook is common in the upper Columbia basin and is characteristic of both hatchery and wild stocks. Generally the largest males show evidence of early maturity (Rich 1920). This may be why large numbers of hatchery fish mature precociously.

The proportion of males that mature precociously is mostly unknown. Mullan et al. (1992CPb) examined 20,000 wild juvenile chinook in tributaries of the upper Columbia River during 1983-1988 and found that precocious males made up about 1% of the sample. Examination of 3,443 juveniles from the Lemhi River, Idaho, showed that precocious development existed in 2.6% of the sample (Gebhards 1960). Burck (1993) believes that precocious males in Lookingglass Creek, a Grande Ronde tributary in Oregon, *...could amount to several percent of the total production of juveniles for a brood year*. His trap catch peaked in the last week of August or the first week of September, and amounted to 158 to 575 fish in the years 1964-1968. We do not know what fraction of the male population consisted of precocious males in the above studies. Actual percentages of precocious males in the male populations would be considerably higher, as the samples in their studies consisted of both juvenile males and females. In the McCloud River, California, Rich (1920) found that precocious males constituted 10-12% of the male population. These studies consider only males that mature in freshwater. If we include jacks (age-2 males that return after 1 year in the ocean), the percentage of males that mature precociously would be much greater than 10%.

The extent that precocious males contribute to reproduction is unknown. In the Upper Columbia Basin, males that mature in freshwater during their first or second summer may contribute to reproduction, and may contribute more than jacks under certain conditions. For example, Leman (1968) and Mullan et al. (1992CPb) observed only precocious males attending large female chinook in small headwater streams that were accessible only at high water. In Marsh Creek and Elk Creek, Idaho, precocious males occurred most frequently where there was active spawning (Gebhards 1960). These fish usually lay within the depression of the redd with an adult female, or male and female pair. Gebhards (1960) reports seeing between 4 and 30 precocious males within redds. Apparently these fish frequent spawning areas to reproduce, not to forage on eggs. Gebhards (1960) analyzed the stomach contents of several precocious males and found that only 5% had consumed eggs. Furthermore, most (85.1%) of the dead precocious males that he found were partly or completely spent.

Although jacks are less common among spring chinook (<13%) than among summer/fall chinook (>35%) in the Upper Columbia basin (Mullan 1987), they probably contribute to reproduction in the basin. Reproduction of jacks has been considered inferior to the larger, older males, but Gross (1987) indicates that jacks successfully reproduce and that their strategy appears to be evolutionarily stable. Thus, jacks have the potential for obtaining equal reproductive success.

The mechanism that dictates the life history tactic of chinook is not well understood (Gross 1991). The tactic, probably determined in the fry stage, is apparently related to body size, since larger, faster growing juveniles tend to mature precociously and smaller, slower growing males mature at an older age. Juvenile size is determined by many variables, such as genotype, egg size, time of hatching, water flow, water temperature, territory quality, stream productivity, predation pressure, and population density. Changes in these variables may therefore affect the life history of chinook. In addition, hatcheries can increase the number of precocious males by accelerating the growth rates of chinook (Mullan et al. 1992CPb). Lastly, selective harvest of larger chinook can increase the occurrence of precocious males. This can have two effects (Gross 1991): (1) a decline of larger, older males on the breeding grounds (frees jacks to employ either fighting or sneaking tactics), and (2) selective harvest of large chinook provides an immediate increase in the probability that jacks, relative to larger males, survive to breed. Thus, selective removal of individuals that adopt the late-maturing life-history tactic should result in an evolutionary response toward more jacks (Ricker 1981; Gross 1991).

We believe that precocious males may play a significant role in reproduction in the Upper Columbia Basin, spawning successfully not only as "sneakers" in the presence of older males, but as the sole male present in some areas and in some years when spawner numbers are very low. They probably play a greater role in spawning in years like 1994 and 1995, when numbers of spawners were so low that adult females were widely dispersed.

6.1.4 Length at age

6.1.4.1 Juveniles:

Fish and Hanavan (1948) sampled juvenile chinook emigrating from the "upper" and "lower" Wenatchee River during 1940 and 1941. The only yearlings they found were in the samples collected in May and June in the "lower" river. The yearlings sampled in May and June (June yearlings were grouped in the May samples) averaged 127 mm (assumed fork length). Yearlings sampled at Tumwater Dam in 1955 by French and Wahle (1959) averaged 95 mm in April and May (note no sampling in June because of high water). Murdoch et al. (2000) found that yearling chinook averages ranged from 91 to 97 mm FL during the main smolt migration out of the Chiwawa River in 2000. They state that these data comport well with observations made at the same trap between 1993 and 1999 and with those observed by French and Wahle (1959).

In the 1950s, Edson (1958) found that juvenile chinook salmon collected in the water cooling screens at Rock Island Dam averaged between 90 and 110 mm in April and May. In the 1970s, yearling juvenile chinook sampled in April and May averaged 120 mm.[24] There appears to be some discrepancy between the size of juveniles sampled from the water cooling screens from the 1950s and the 1970s, but this may be due to sample error (more units were sampled in 1956, 1957 than during the 1970s), to an increased proportion of hatchery smolts released at relatively large size, or possibly differences in run timing that may have developed. In April and May, 1993, yearling chinook collected at the second powerhouse bypass trap (for both naturally- and hatchery-produced individuals) averaged 138 mm FL.

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[24] Juvenile chinook in the 30-40 mm range are probably from late-run chinook that spawned in the mainstem of the Columbia River upstream from Rock Island Dam (Edson 1958; French and Wahle 1965).

Subyearlings measured by Fish and Hanavan (1948) had average lengths that ranged from 37 mm (April 1941 - upper Wenatchee) to 137 mm (November 1940 - lower Wenatchee). French and Wahle (1959) found subyearling average lengths that ranged between 41 mm in April and 79 mm in October. Murdoch et al. (2000) found subyearlings average length increased from a mean of 36-mm FL in April to 84 mm FL in October, 2000 in the Chiwawa River. These lengths comport well with those observed from French and Wahle (1959).

Lengths of juveniles measured in the Chiwawa River comport well with lengths of juvenile chinook measured in the Chewuch River in 1993, and the Naches River (Yakima basin) in 1985, and in Lookingglass Creek in Oregon (Burck 1993). In all four drainages, larger migrants were observed in the spring, then smaller migrants were observed from July through the fall.

6.1.1.2 Adults:

Over half of the adults return to the Upper Columbia basin in their fourth year (see above), averaging around 60 cm hypural length. There appears to be little difference in the average length per age group between streams for both sexes, and females are approximately the same average size per age group as males within streams (Tonseth 2003). Mullan (1987) observed that males were larger for a given age group for fish returning to the Leavenworth NFH, but the data collected on the spawning grounds between 1986 and 1993, and 2001 do not show this. There may be more sampling bias in fish sampled on the spawning grounds than the possibly more random sample collected at the hatchery. For all fish sampled, length averaged 66 and 67 cm, for females and males, respectively. These distributions are different from those measured in the 1950s by French and Wahle (1965).

The average length for females was exactly the same between the late 1950s and more recent samples, but the males measured in the late 1950s were smaller than males in the more recent samples. This discrepancy may be due to sampling bias, or the differences in the number of jacks present on the spawning grounds. Most of the jacks collected by French and Wahle were from the Twisp River in 1957 and the Chewuch River in 1958. The years 1957 and 1958 were years of very high jack counts for spring and summer chinook salmon at Rock Island Dam.[25] It is curious that French and Wahle were able to capture so many jacks, since we are unable to do so from the spawning grounds in recent years (C. Peven, personal communication).

6.1.5 Sex ratios

Mullan (1987) presented data compiled from Howell et al. (1985) on the number of returning male and female hatchery spring chinook in the mid-Columbia. From those data, we calculated the sex ratios for Leavenworth, Entiat, and Winthrop populations. The range (female to male) for the three stocks was 1.27:1 to 1.86:1. These estimates are similar to data

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[25] We mention summer chinook jacks because the arbitrary date at which fish are designated "spring" or "summer" would bias the number of fish being categorized as either. In 1957, the summer chinook jack count was almost 7,000 and the spring chinook jack count was nearly 3,000, both very high numbers compared to the historic record at Rock Island Dam. The spring chinook jack count has not been over 1,000 fish since 1977.

compiled within the Upper Columbia for wild fish collected during carcass surveys for the periods of 1957-1960, and 1986-1993. For the period of 1957-1960, the ratio was 1.55:1. For the period of 1986-1993, the ratio was 1.07:1. Although these estimates are fairly close, it is likely that the actual ratio for the wild fish collected on the spawning ground is closer to 1:1. This is because there is a greater likelihood of recovering females on the spawning ground than males (Chapman et al. 1994 CPa). Data from the Yakima River basin between 1980 and 1992 and Wenatchee River in 2001comport well with Mullan's observation (J. Hubble, YIN, personal communication; Tonseth 2003). French and Wahle (1965) found mostly females on the spawning grounds in the late 1950s, as has been the case in recent years. Year-to-year returns may vary. Males can outnumber females on the spawning grounds (from Howell et al. 1985), but overall, it appears that the reverse is true.

6.1.6 Fecundity

Fecundity from wild spring chinook salmon has been measured in recent years in the upper Columbia basin as part of newly developed hatchery supplementation programs. In the Chiwawa River, the estimated fecundity has ranged from 4,600 - 5,980 between 1990 and 1994.[26] In the Methow River basin, fecundity (hand counted) averaged 5,100 (range: 2,600-8,100) between 1992 and 1994. In the Methow River, four-year-old females averaged 4,200 eggs, while five-year-old fish averaged 5,400 eggs. Differences in length explained 44% of the variation in eggs per female measured from the Methow River basin.

Healey and Heard (1984) found that length usually explained less than 50% of the variation observed in fecundity of chinook. Variation in age, seasonal runs, and life history (ocean- or stream-type) were not significant predictors of differences in fecundity. In the majority of populations that Healey and Heard (1984) examined, variation between years was significant, but not large, and when annual variation was taken into account, the variation in fecundity only increased from 34 to 45%. They conclude: *clearly, a great deal of variation in fecundity within populations remains to be explained.*

Rounsefell (1957) felt that there was a relationship between the number of eggs per female and latitude, with populations from lower latitudes having more eggs for a given length than more northerly populations. Healey and Heard (1984) disagreed with Rounsefell (1957), and concluded that the trend toward higher fecundity increased at higher latitudes. We found that fecundity also appeared to increase in populations that were farther upstream from the mouth of the Columbia River. This relationship could be an evolutionary response to the probable higher mortality of migrants (both upstream and downstream) that would accrue going to and coming from the ocean. It could also be explained by differences in sampling techniques or years sampled. Healey and Heard (1984) speculated:

. . the differences in elevation reflect local adaptation to spawning and rearing conditions. Most of the high-fecundity populations, for example, are stream-type

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[26] Fecundity estimates for years 1989 and 1992 were not used in this report because fish were gaffed off the spawning grounds, and a large portion of the females were partially spent. The fecundity reported for 1994 (5,979) was hand-counted and should be viewed as the best estimate, although it was derived from only six fish (K. Petersen, personal communication).

chinook and for these populations high fecundity may be necessary to offset high pre-reproductive mortality and older age of maturity.

6.2. Steelhead

Summer steelhead native to the Upper Columbia is the exclusive ecotype of the inland waters. Anadromy is not obligatory in *O. mykiss* (Rounsefell 1958; Mullan et al. (1992 CPa). Progeny of anadromous steelhead can spend their entire life in freshwater, while progeny of rainbow trout can migrate seaward. Anadromy, although genetically linked (Thorpe 1987), runs under environmental instruction (Shapovalov and Taft 1954; Thorpe 1987; Mullan et al. 1992CPa). It is difficult to summarize one life history strategy (anadromy) without due recognition of the other (non-migratory). The two strategies co-mingle on some continuum with certain stream residency at one end, and certain anadromy on the other. Upstream distribution is limited by low heat budgets (about 1,600 temperature units) (Mullan et al 1992 CPa). The response of steelhead/rainbow complex in these cold temperatures is residualism, presumably because growth is too slow within the time window for smoltification. However, these headwater rainbow trout contribute to anadromy via emigration and displacement to lower reaches, where warmer water improves growth rate and subsequent opportunity for smoltification.

6.2.1 Adult migration

Steelhead destined for the Upper Columbia enter the Columbia River between May and September and pass Rock Island Dam from July through the following May. All steelhead spawn in the spring, and those that pass Rock Island Dam in the spring have over-wintered in the mainstem of the Columbia River (French and Wahle 1959).

Peven (1992 CPb) showed that the run timing of steelhead passing Rock Island Dam has changed in the last 70 years. In the 1930s and 1940s, more fish passed the dam in the spring. This change may be due to different flow regimes in the Columbia River.

Steelhead are classified into two distinct races, or runs (Smith 1960; Withler 1966; Everest 1973; Chilcote et al. 1980). Winter-run fish ascend streams between November and April, while summer-run fish enter rivers between May and October. In Washington state, winter-run fish are found primarily west of the Cascade Mountains, although both summer- and winter-run fish inhabit certain west side streams (Kendra 1985; Pauley et al. 1986). Winter-run steelhead are not found above of the Deschutes River in the Columbia River Basin (Pauley et al. 1986). In Washington, the Klickitat River is the uppermost tributary where winter-run fish are found (Kendra 1985). Steelhead runs on the Columbia River above the Deschutes River, and the entire Snake River are made up of exclusively summer-run fish. There are two groups of summer-run steelhead that ascend the Columbia River: an early segment known as the "A" group, which enters the Columbia River in June and July, and the "B" group, which enters the river during August and September. The "B" group is made up of larger fish that are produced primarily in the Clearwater and Salmon river drainages (Chrisp and Bjornn 1978).

6.2.2 Juvenile migration

Smolts typically leave the tributaries in March to early June (Peven et al. 1994). The timing of smolt migration is regularly indexed at Rock Island dam as part of a smolt monitoring program (Chapman et al. 1994 CPa) since 1990. The majority of the composite (wild + hatchery) steelhead smolts pass Rock Island in May (Chapman et al. 1994 CPa).

6.2.1 Age structure

6.2.1.1 Juveniles:

Steelhead smolts have been shown to migrate at ages ranging from 1-5 years, with most populations smolting at ages 2 or 3 (Shapovalov and Taft 1954; Withler; 1966; Hooton et al. 1987; Loch et al. 1988). In the Upper Columbia region, Peven et al. (1994) observed smolt ages ranging from 1-7 years, with the highest percentages at ages 2 and 3. Female smolts (63% of fish sampled) were older and larger for most age classes than males.

6.2.1.2 Adults:

Steelhead grow rapidly after reaching the ocean, where they feed on crustaceans, squid, herring, and other fishes (Wydoski and Whitney 1979; Pauley et al. 1986). The majority of steelhead spend 2 years in the ocean (range 1 - 4) before migrating back to their natal stream (Shapovalov and Taft 1954; Narver 1969; Ward and Slaney 1988). While the majority of adult hatchery steelhead destined for the Upper Columbia are comprised of fish that have spent 1 year in salt water, it appears that the majority of naturally produced fish spend 2 years in salt water before they ascend the river (Mullan et al. 1992CPa). Once in the river, steelhead apparently rarely eat, and grow little, if at all (Maher and Larkin 1954).

Most of the naturally produced adults that have been sampled in the Upper Columbia have spent 2 years in freshwater and two years in the ocean (Chapman et al. 1994 CPa). It appears that repeat spawners were never a large proportion of the spawning population (Chapman et al. 1994 CPa).

6.2.2 Length at age

6.2.2.1 Juveniles:

Steelhead smolts average 160 - 175 mm fork length (FL) on their downstream migration (Chrisp and Bjornn 1978; Peven 1987 CPa, 1988, 1989 CPa; Peven and Hays 1989; Loch et al. 1988; Ward and Slaney 1988), although variation occurs among streams (Narver 1969; Barnhart 1986; Pauley et al. 1986; Loch et al. 1988). Mullan et al. (1992CPa) found that the average smolt length was 173 mm, and 95% of the smolts fell within 143-207 mm.

Most studies (e.g., Shapovalov and Taft 1954; Bjornn 1978; Chrisp and Bjornn 1978) have concluded that the parr/smolt differentiation is around 140 mm FL, although some smolts of lesser size (e.g., Wydoski and Whitney 1979; Loch et al. 1988; Ward and Slaney 1988). Smolt survival seems to depend on the size, not the age of the fish entering the estuary (Elson 1957; Fessler and Wagner 1969; Hoar 1976; Ward and Slaney 1988).

In the Upper Columbia Basin, naturally produced steelhead smolts sampled at Rock Island Dam have averaged between 163-188 mm FL (Peven and Hays 1989; Peven et al.1994).

6.2.2.2 Adults:

Withler (1966) reported that steelhead length at maturity varies between streams, and increases northward in their range. Howell et al. (1985) found from creel census and other studies in the Wenatchee, Entiat, and Methow rivers averaged 59.3-63.8 cm and 67.0-75.8 cm for fish that had spent one and two years in the ocean, respectively. Chapman et al. (1994 CPa) reported that female steelhead sampled at Wells from 1982-1992 ranged from 57-81 cm and 67-75 cm for fish spending one and two years in the ocean, respectively. Males ranged from 59-66 cm and 69-77 for one and two ocean fish.

6.2.3 Sex ratios

Most authors report equal numbers of males and females in the spawning population (e.g., Withler 1966; Sheppard 1972). Williams (personal communication reported in Chapman et al. 1994 CPa) found that females made up 65% of the adults sampled at Wells Dam between 1982 and 1993. This comports well with Peven et al. (1994) finding of 63% of the smolts sampled in the downstream migration made up of females.

6.2.4 Spawning

Spawning grounds have historically not been surveyed for steelhead because the adults generally spawn over a 4-5 month period coinciding with high spring flows when water visibility is low and discharge high. Since 2001, WDFW have conducted surveys for steelhead in the Wenatchee and Methow rivers. Spawning surveys have started around the first part of April and ended towards the end of May. Peak spawning in both the Wenatchee and Methow rivers occurred in the last part of April. Steelhead appear to spawn at temperatures between 4 and 8 degrees C (Murdoch and Viola 2002; Jateff and Snow 2003).

Spawning and rearing distribution correlate closely (Mullan et al. 1992CPa). Unlike other species in the *Oncorhynchus* genus, steelhead eggs incubate at the same time temperatures are increasing. Fry emerge in July through October (Chapman et al. 1994 CPa), with time of hatching varying largely with water temperature, region, habitat and season (Bjornn and Reiser 1991).

6.2.5 Fecundity

Fecundity of steelhead ranges from 2,000 to over 9,000, depending on the size of the fish and geographic origin; most steelhead average around 3,500 eggs (Shapovalov and Taft 1954; Bulkley 1967; Pauley et al. 1986). Females' average 94 eggs per cm body length, with an egg diameter of approximately 5.3-mm (Shapovalov and Taft 1954; Rounsefell 1957).

In the Upper Columbia region, steelhead have the second highest fecundity reported (Mullan et al. 1992CPa), averaging over 5,500 eggs per female.

6.3 Summer/fall chinook

6.3.1 Adult migration timing

Summer/fall chinook destined for the upper Columbia region, enter the Columbia River from June through September. They pass Rock Island Dam primarily between late June through November (French and Wahle 1959). The earlier individuals in the run generally spawn in the mainstem tributaries, and usually begin spawning during the later part of September, progressing downstream into the mainstem Columbia through November (Mullan 1987).

6.3.2 Juvenile migration

Chapman et al. (1994 CPb) viewed the migration of summer/fall chinook in the area upstream from McNary pool as a continuum. All summer/fall subyearlings leave areas where they incubated, in both tributaries and in the main Columbia River, within days to several weeks after they emerge from the redd. Fry emerge mostly in April and May. Some fry move downstream many miles to rear. Others rear for a time in natal spawning areas before they move extensively.

Most subyearling summer/fall chinook leave the Wenatchee River within a few weeks after emergence. Beak (1980) operated a Kvichak trawl just upstream from the Dryden Canal intake in the Wenatchee River. 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), who estimated age 0 chinook salmon abundance in the Wenatchee River in 1987 as about 41 fish/100 m^2 in June, 4.6 fish/100 m^2 in July, and 1.1 fish/100 m^2 in August; a 97% decline from June to August. Hillman and Chapman (1989) also demonstrated that the rate of emigration of subyearling chinook was highest in June, then declined through the summer. Most fish that they marked with fin dyes disappeared from marking sites quickly. Hillman and Chapman (1989) found that mean size of subyearlings in the Wenatchee River increased very slowly or not at all in 1986 and 1987, consonant with disappearance through emigration of larger subyearlings.

The migrational timing of subyearling chinook salmon is regularly indexed at Rock Island Dam (RIS) as part of the Smolt Monitoring Program. Fish that enter the collection system are enumerated by species and reported as the daily passage index for that site. This is the only site in the upper Columbia where such information is regularly acquired.[27] At this sampling location in the river system, the subyearling chinook population is comprised of chinook from hatcheries and wild production sites. It is not possible to identify individual stocks within the admixture arriving at RIS, except for a segment of the Wells Hatchery population that has been freeze branded in many years, and more recently PIT tagged fish from Turtle Rock Hatchery. The apparent pattern of emigration from the Wenatchee River within a few weeks after emergence comports with the seasonal distribution of juvenile chinook salmon captured in the Rock Island bypass trap (Mullan 1987), which lies a few miles downstream from the mouth of the Wenatchee River. Fish continued to trickle through the bypass through August. Averaged over the seven-year period 1985 through 1991, the middle 80% of the migration passed RIS from 3 June through 3 August (Truscott 1992).

In years between the late 1980s and 2002, hydroacoustic equipment was used to monitor the smolt migration at Wells Dam. This sampling technique does not provide species-specific information. This limits our ability to accurately identify the migratory timing of any particular salmonid species. During the summer when subyearling chinook are passing through the system, other non-salmonid species are present in considerable numbers at times.

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[27] This information is also recorded at the smolt trap near Monitor on the Wenatchee River.

6.3.3 Age structure

Chinook have historically been separated into two different basic ecotypes; ocean- and stream-type (Gilbert 1912, Healey 1991). The usual paradigm for these life histories dictates that ocean type generally migrate to the sea as subyearlings, while stream type spend one winter in freshwater prior to migrating to the ocean. These two life histories are apparent in the Columbia Basin. Stream-type chinook usually spawn in the upper tributaries of large river systems, and the ocean-type chinook spawn either in coastal streams or in the lower tributaries of larger systems (Ricker 1972; Healey 1991). In the upper Columbia basin, what are commonly referred to as “spring” chinook usually exhibit a stream-type life history, while the later-running chinook (“summer/fall-run”) usually exhibit an ocean-type life history (Mullan 1987). In contrast, “spring” and “summer” run chinook in the Snake River Basin generally exhibit a stream-type life history, while “fall” run fish are ocean-type (Matthews and Waples 1991).

Fish emerging from natal gravels in the spawning areas above Rock Island Dam encounter varied habitats (Mullan et al. 1992 CPa). As Chapman (1993) surmised, the summer/fall chinook that hatch in the Similkameen River most likely emigrate shortly after emergence to the Okanogan, a warm, relatively fertile river. These fish encounter growing conditions that are more favorable than those found by fish that originate from the Methow and Wenatchee drainages (or even the mainstem Columbia River). Consequently, fish from the Similkameen River may achieve the physiological size of smoltification sooner than their conspecifics in the other drainages and thus emigrate at a faster rate to the ocean. Fork lengths from naturally produced subyearling chinook caught at Wells Dam (McGee et al. 1983) were larger than fish measured at Rock Island Dam (Peven 1989 CPb, 1991; Peven and Fielder 1988; Peven and Duree 1990) for the same time periods throughout the summer. These data would comport with the postulate that fish that rear in the waters of the Okanogan drainage may be obtaining larger sizes quicker than fish that originate in the waters in other drainages. The large size of fish by late July in Wells pool may also reflect growth opportunity in Wells pool. Only 26% of the observed redds of the brood of adults that produced the fish examined by McGee et al. (1983) were found in the Similkameen River. The remainder were in the Methow River and in the main Okanogan River. The total observed in the Okanogan system was 37%. Summer/fall chinook may also have spawned in the main Columbia River downstream from Chief Joseph Dam without being observed. If the Okanogan subyearlings had grown in the Okanogan to large size, while Methow River subyearlings grew in the Methow River to smaller sizes, we might expect a bimodal size distribution, or at least a broad mode, in the data of McGee et al. (1983). The length distribution appears unimodal.

Hillman and Chapman (1989) observed that most of the newly emerged summer/fall chinook fry exited the Wenatchee River shortly after emergence. This suggests that the late-run fish that have a stream-type life history on their scales spend their first year in the mainstem of the Columbia River. Park (1969) found that a few chinook subyearlings that were marked in the summer of 1966 at Priest Rapids Dam were recaptured the following year at The Dalles Dam, and Wagner and Hillson (1992) reported late fall migration at McNary Dam of some known subyearling summer/fall chinook. It is of no surprise, therefore, that some fish from the area upstream from Rock Island Dam would spend one winter in the mainstem of the Columbia River before reaching the sea.

The fact that fish with a stream-type scale pattern were consistently shorter than fish with an ocean-type pattern for the same age (Chapman et al. 1994 CPb) is further evidence that these fish reach the ocean later in life than their conspecifics. One must ask if there is an evolutionary adaptive benefit to longer fresh water residence? This question is not easily answered for it is not possible to determine the relative number of individuals that stay longer in freshwater compared to individuals that do not.

Another conclusion could be drawn. It *is* possible that summer/fall chinook from the mid-Columbia River basin have always had individuals that reached the ocean later in life than most of the juveniles. A common theory (e.g., Park 1969; Raymond 1979) is that, with the onslaught of dam construction on the mainstem of the Columbia River, migration of juvenile salmonids to the ocean has been delayed. Since no empirical data on migration rates exist for the period before dam construction, there is no way to scientifically evaluate this theory. Rich (1920) observed that juvenile chinook were present throughout the year in the Columbia River, with many yearling migrants (stream-type) present in the estuary by June. Subyearlings (ocean-type) were abundant by late summer to early fall. From these observations, it is difficult to definitively say if juveniles are being delayed in their migration now, compared to pre-development of the river. Since no age estimation data exist for the period before the late 1980s, we will never know if summer/fall chinook from the upper-Columbia basin have always exhibited a stream-type life history for at least a segment of the population. McIsaac (1990) notes that about 4% of adult scales from Lewis River bright fall chinook had a stream annulus. Chapman et al. (1994) suspected that upper-Columbia summer/fall fish always had a higher proportion of stream-annulus adults present in spawning populations than have, for example, Lewis River bright fall chinook. About 5% of scales from spawners from the Hanford Reach have a stream annulus (Chapman et al. 1994 CPb).

J. Sneva (WDFW, pers. comm.), who has read many scales from the area, notes that the pattern associated with the "stream-type" late-run chinook looks neither like a regular stream-type (spring) chinook, nor like a normal ocean-type chinook. Sneva claims that the circuli spacing on the scales suggests regular growth, usually associated with a hatchery environment, but that these scales do not show a normal hatchery pattern. This supports the hypothesis that these fish are rearing in reservoirs, where the temperature regime and productivity would be more favorable than in natal tributaries (Mullan 1987).

6.3.3.1 Juveniles

Summer chinook in the upper Columbia region have long been considered as the ocean-type (Fryer and Schwartzberg 1993CPa; TAC 1991). However, Park (1969) reported that three juvenile chinook salmon, marked at Priest Rapids Dam in August 1966, were captured at downriver dams in spring of 1967; two at Bonneville Dam and one at The Dalles Dam. Wagner and Hillson (1992) recorded counts of subyearling chinook in collection facilities at McNary Dam. Those data demonstrate a late downstream movement of subyearlings into December. The movement may continue at a low level through the winter, for about 2,000 fish were counted per week in the first half of December. Wagner and Hillson (1992) sampled three branded fish in the late fall: a Wells Hatchery subyearling (November 4), a Priest Rapids Hatchery subyearling (November 18), and a wild subyearling from the Hanford Reach (December 1). One PIT tagged wild fall chinook from the Snake River was detected on November 17. Thus, at least some summer/fall subyearlings appear to winter in the Columbia River. Their scales will show a fresh-water annulus. That annulus may have characteristics that differ substantially from annuli of, say, spring chinook and hatchery-reared summer/fall fish.

Dawley et al. (1982), in estuarine sampling in 1981, recovered one juvenile chinook that had been released at Priest Rapids as a subyearling in late June, 1979. That juvenile, 157 mm at recovery, had spent two winters between Priest Rapids and the estuarine recovery point. McIsaac (1990) found that 5 and 4 tagged fish from the 1978 and 1979 broods, respectively, were recaptured in the Columbia River estuary in 1980 and 1981. Those fish, subyearlings when tagged in the Lewis River, spent one winter between the tagging point and the estuary.

Percentages of reservoir annuli chinook make up the majority of the population sampled on the spawning grounds in some years (Figure CP22 and CP23; Hillman and Ross 1992; Langness 1991; Fryer and Schwartzberg 1993 CPa; Chapman et al. 1994 CPb). In 2001, stream-annulus summer/fall chinook made up over 30% of the broodstock captured at Wells Dam (for the Methow/Okanogan stocks) and Wenatchee stock (Tonseth 2003).

6.3.3.2 Adults

Between 1986 and 1992, 1,526 summer/fall chinook were sampled for scales and lengths from the Wenatchee, Methow, and Similkameen rivers (Chapman et al. 1994). The majority of these fish (76.1%) were sampled from the Wenatchee River, and were female (61%).

Scales from males were interpreted as having a wider range of age classes than scales from females, with most estimated at 4-year olds (Figure CP22; age class 0.3, 1.2). Females were predominantly five years old (0.4, 1.3). In general, males were younger than females. We compared the age structure of summer/fall chinook from 1986-1992 to more recent data (1998-2001). The comparison suggests that the overall distribution of ages is similar to previous years, but there is a higher proportion of age class 1.x in all populations (Figure CP23).

The occurrence of more freshwater annulus (primarily “reservoir-reared”) may be a function of scale interpretation than an actual phenomenon. In the late 1980s, most scale readers assumes that summer/fall chinook were overwhelmingly only 0-aged juvenile migrants (i.e., reached the ocean in their first year of life; C. Peven, personal communication). See discussion above for more empirical information on freshwater annulus summer/fall chinook.

Between rivers, the modal ages discussed above held true except in the Methow River, where there were equal numbers of age 4 and 5 males. A large portion of the males sampled in the Similkameen were three years old (1.1; Figure CP22), sampled in 1992. They originated from the Carlton Hatchery. In recent years, the proportion of this age group has diminished, relative to the total population (Figure CP23).

Possible biases occur from estimating and comparing age compositions from scales. These may result from different sex and size recovery rates from spawning grounds, age-related differences in scale regeneration rates, and scale-reader criteria for rejecting scales with slight regeneration. Chinook scales, particularly those from summer/fall chinook in the Columbia River, are perhaps the most difficult to interpret with respect to their first year of growth (J. Sneva, personal communication).

6.3.4 Length at age

6.3.4.1 Juveniles

Juvenile summer/fall chinook from the upper Columbia have been measured since the late 1980s at Rock Island Dam (Peven 1989 CPb). As the sampling season progresses (juveniles are present at Rock Island from generally mid-May through August), fish size increases (Figure CP24). For example, the mode of subyearling sizes in May, 1991 was about 45 mm. Two size modes were present in June at the bypass trap. By August, the two modes became blurred, but the most pronounced mode lay at 125 mm.

6.3.4.2 Adults

For fish sampled upstream from Rock Island Dam, there were virtually no differences in mean length per age class among fish sampled in the three tributaries (Figure CP25). For all fish sampled, females had a greater degree of overlap of length between age groups than males. For a given total age, fish that had spent less time in freshwater (more time in saltwater) were larger than those that did not (Figure CP25).

6.3.5 Sex ratio

Of the 1,526 chinook carcasses sampled between 1986 and 1992 in tributaries upstream from Rock Island Dam, 61% were female (ratio of 1:1.6) (Chapman et al. 1994 CPb). The sex ratios varied from 1:1.2 in the Okanogan system to 1:1.7 in the Wenatchee River. The male-to-female ratio in the Methow River was 1:1.4. By comparison, the sex ratio of chinook salmon in the Hanford reach on the Columbia River was 1:1.2 between 1987 and 1992 (Chapman et al. 1994 CPb).

6.3.6 Spawning

Historically in the CCP, summer/fall chinook salmon spawned in the Columbia, Wenatchee, Okanogan, and Similkameen rivers (Craig and Suomela 1941). Apparently they also spawned in the Chelan River because Chapman (1941) observed them spawning downstream from the powerhouse on the Chelan River as early as 1937. In the Columbia River, Chapman (1943) found chinook spawning near Kettle Falls, upstream from Grand Coulee Dam. Fish and Hanavan (1948) reported chinook redds in the Columbia River upstream from the confluence of the Chelan River to Grand Coulee Dam. Meekin (1967) documented chinook salmon redds in the Columbia River between Brewster and Washburn Island. Apparently, summer/fall chinook did not spawn in the Entiat River (Craig and Suomela 1941; Mullan 1987). Also, Craig and Suomela (1941) found no evidence that summer/fall chinook salmon spawned in the Methow River; although, they indicate that it was possible that a few spawned in the lower Methow River. Meekin (1967) also believes that no summer/fall chinook historically spawned in the Methow River.

Since 1972, five years after the completion of Wells Dam, survey crews have found redds of summer/fall chinook salmon in the Columbia, Wenatchee, Methow, Okanogan, Similkameen, Chelan, and Entiat rivers (Peven 1992 CPb; Chapman et al. 1994 CPb; Grassel 2003; Miller 2003). In the Columbia River, Peven (1992 CPb) reports redds of summer/fall chinook between Rocky Reach and Wells dams. In 1990 and 1991, Giorgi (1992) found them on a gravel-cobble shelf located on the west side of the Columbia River (between RM 515-514) just downstream from Wells Dam.

Summer/fall chinook salmon typically spawn in the Wenatchee River between RM 1.0 and Lake Wenatchee (RM 54). Within that area the distribution of redds of summer/fall chinook has changed. Peven (1992 CPa) notes that, since the early 1960s, numbers of redds have decreased downstream from Dryden Dam (RM 17.5), while they have increased upstream from Tumwater Dam (RM 32.7). On a smaller scale, Peven (1992 CPa) reports that, since at least 1975, densities of redds (i.e., redds/mile) were highest near Leavenworth (RM 23.9-26.4) and in Tumwater Canyon (RM 26.4-35.6).

In the Methow River, summer/fall chinook salmon spawn between RM 2.0 and the Winthrop hatchery diversion dam (RM 51.6). Chinook redds are scattered throughout that area, with a redd found within almost every river mile (Hillman and Miller 1993). The overall distribution of redds of summer/fall chinook in the Methow River has changed little since 1987, when ground surveys began. During that period, redds were most abundant between Carlton and Twisp (RM 27.2-39.6), and least abundant between Winthrop and the hatchery diversion dam (RM 49.8-51.6) (Hillman and Miller 1993; Miller 2003).

In the Okanogan Basin, summer/fall chinook salmon spawn in both the Okanogan and Similkameen rivers. In the Okanogan River, chinook usually spawn between RM 14.5 (just downstream of Malott) and Zosel Dam (RM 77.4). In the Similkameen River, chinook spawn between its mouth and Enloe Dam (RM 8.9). In both rivers, redds are highly clumped, and those distributions have not changed since 1987 when ground surveys were first conducted (Hillman and Miller 1993). During that period, densities of redds in the Okanogan River were highest between Okanogan and Omak (RM 26.1-30.8), McLoughlin Falls and Tonasket (RM 48.9-56.8), and the Similkameen River confluence and Zosel Dam (RM 74.1-77.4); they were lowest between Tonasket and the Similkameen River confluence (RM 56.8-74.1) (Hillman and Miller 1993). In the Similkameen River during the same period, densities of redds were highest between the mouth and the county road bridge (RM 0-5). Unlike in other mid-Columbia streams, Hillman and Miller (1993) found that summer/fall chinook in the Okanogan Basin constructed most of their redds near islands, i.e., in braided segments.

A small number of summer/fall chinook salmon spawn in the Chelan and Entiat rivers (Peven 1992 CPb). Spawning in the Chelan River is limited to the short segment below the Chelan powerhouse. In 1990 and 1991, Giorgi (1992) found chinook redds in the Chelan River between the boat ramp and about 150 feet downstream from the railroad bridge. Spawning of summer/fall chinook salmon in the Entiat River was an artifact of the Entiat National Fish Hatchery, which released chinook into the river between 1941 and 1976 (Mullan 1987). Since 1980, few to no summer/fall chinook spawned in the Entiat River. Those few that did, used the lower eight miles of the river. In 1991, Giorgi (1992) observed chinook redds in the first riffle at about RM 0.5.

6.3.7 Fecundity

Age-specific fecundity (number of eggs produced by a female of given age) has not been assessed for summer/fall chinook salmon that reproduce naturally in the Wenatchee, Methow, or Okanogan systems. There are various reports from broodstock captured during hatchery practices, however. Wells Dam Hatchery reports for 1978 to 1982 indicate a mean fecundity of 4,935 eggs for females that average 90.4 cm long (Howell et al. 1985). Mathews and Meekin (1971) describe a length-fecundity relationship for summer chinook in the Methow River where the number of eggs produced by a female equals 214 times her fork length (inches), minus 2,234. That corresponds roughly to fecundities of 2,284 for 4-year-olds, 4,306 for 5-year-olds, and 4,980 for 6-year-olds.

Average fecundity for 1991 brood stock from the Wenatchee River was 4,333 eggs (n=57) for a mix of age classes. Wells Hatchery broodstock in 1991 averaged 4,819 eggs/female, for mostly ages 4 and 5 (Eltrich et al. 1992). These data suggest that the relationship of Mathews and Meekin (1971) does not accurately describe present fecundities.

Fecundity in chinook salmon is highly variable. Healey and Heard (1984) summarized data on the fecundity of 16 populations of chinook and found high intra- and interpopulation variation in fecundity. They report that fecundity was correlated significantly with female size in all but one of the populations examined. Size, however, explained 50% or less of the variation in fecundity among individuals within a population. Age contributes little to variation in fecundity beyond that predicted by the difference in sizes between ages. Healey and Heard (1984) speculate that this high variation may reflect an uncertain trade-off between egg size and egg number. We are unaware of any data on egg size in chinook that demonstrate that the more highly fecund fish within a size class produce smaller eggs. It appears, therefore, that fecundity is less determined by body size in chinook than in other species of fish.

6.4 Sockeye

6.4.1 Adult migration

Sockeye enter the Columbia River primarily in June and July and pass Bonneville Dam during late June and July. Spawners reach the Wenatchee and Osoyoos lakes generally in July and August and begin spawning in September, peaking approximately one month later in the Okanogan basin (Peven 1992 CPb).

6.4.2 Juvenile migration

In the mid-Columbia basin, Fish and Hanavan (1948) reported that sockeye smolts migrating downstream in April and May, but were not more specific. Between 1946 and 1954, juvenile sockeye were monitored at Tumwater Dam (Mullan 1986). Mullan (1986) shows the first, last, and peak passage dates of the migrating juveniles. French and Wahle (1959) collected juveniles at Tumwater Dam in 1955 and 1956.

Run timing of juvenile sockeye in the 1950s can also be inferred from fish collected from the water cooling screens at Rock Island Dam. The run was bimodal in the 1950s, with Edson (1958) reporting that larger fish made up the majority of the fish sampled in mid-April. Edson's findings comport well with the run timing reported at McNary Dam in 1957 (Oligher 1958), and run timing in the 1940s and 1950s at Bonneville Dam (Anas and Gauley 1956). Run timing of juvenile sockeye at Bonneville Dam varied over the years that Anas and Gauley (1956) report, with the peak of the run fluctuating between late April to mid May.[28] They also found the larger fish migrating earlier.

Run timing of juvenile sockeye was probably influenced by releases of fish from the hatcheries in the mid-Columbia basin in the 1940, 1950s, and 1960s.[29] Since fish were released in various places (Lake Wenatchee, Icicle Creek, Entiat and Methow rivers, Lake Osoyoos, Columbia River at Pateros; Mullan 1986; Peven 1992 CPb), at different sizes, and different times of the year, it is difficult to assess the influence of the releases on the run timing of juveniles measured at various places such as Tumwater, Rock Island, McNary, or Bonneville dams. It may be that the differences observed in the run timing between the 1950s and more recently may be due to hatchery releases in the earlier years. Anas and Gauley (1956) did show that hatchery fish could influence the timing of migration at Bonneville Dam. Hatchery fish moved at an average rate of between 12 and 25 d. They based their conclusions on the recapture of marked fish from the Winthrop and Leavenworth NFHs.

In the 1970s, juvenile sockeye collected from the water screens from the turbine intakes at Rock Island Dam showed variation in run timing over a five-year span. Some years showed more than one node, but on average, over the five years, the run timing was basically unimodal. In recent years, with the ability to capture more fish on a regular basis, the run timing of juveniles past Rock Island Dam has been bimodal, with Wenatchee origin fish migrating past the dam in April, and Okanogan origin fish migrating past the dam in May (Peven 1987 CPb, 1991 CPb).

Peven (1987 CPb, 1991 CPb) used length frequency to estimate the relative run timing of each stock migrating past Rock Island Dam. He found that, in general, fish originating from the Wenatchee River were shorter (< 100 mm FL) than fish originating from the Okanogan River system (> 100 mm FL). Fish transportation studies conducted by Grant PUD in the late 1980s, supported with empirical evidence that the earlier arriving, smaller migrants originated from the Wenatchee River system (Carlson and Matthews 1990, 1992). Carlson

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[28] Chapman et al. (1995 CPb) believed the majority of smolts sampled at Bonneville Dam were from the mid-Columbia basin based on adult run size estimates, harvest, and counts at Rock Island Dam (summarized in Mullan 1986). Bjornn et al. (1968) found most the smolts leaving Redfish Lake from late April - mid-May, and assuming the run timing was the same in the 1940s and 1950s, would probably be sampled at Bonneville in late May - early June considering their extensive migration (almost 900 miles). The run timing estimates at Bonneville Dam from Anas and Gauley (1956) do not appear to be influenced to any great degree by the Snake River sockeye smolts.

[29] Hatchery releases ceased in 1968 (Mullan 1986).

and Matthews (1990, 1992) marked juvenile sockeye collected from the gatewells at Priest Rapids Dam and recovered them x years later from the spawning grounds.

Park and Bentley (1968) marked juvenile sockeye emigrating from the Wenatchee and Okanogan rivers in the spring of 1967. They subsequently recovered a percentage of the fish from the gatewells at Priest Rapids Dam. They found that juvenile sockeye marked from the Okanogan River arrived, on average, 10 days earlier than sockeye from the Wenatchee River, in contrast to more recent findings (Peven 1987 CPb, Carlson and Matthews 1990, 1992).

Hays et al. (1978) captured juvenile salmonids in the gatewells at Rocky Reach Dam in May 1977. These data suggest the peak of the sockeye outmigration occurred in mid-May.

Based on run timing estimates at Rock Island Dam in recent years, and sampling in the tributaries and at the dam from past years, the run timing of smolts past Rock Island Dam appears to be earlier now than it use to be (Chapman et al 1995 CPb). It appears that the unimodal run was probably composed of Wenatchee fish initially, and Okanogan fish slightly later. But, in recent years there has been more divergence of the two stocks with respect to arrival at Rock Island Dam, with both stocks apparently arriving earlier than in past years, and particularly so for the Wenatchee origin fish.

6.4.3 Age structure

6.4.3.1 Juveniles

Residence in the nursery lake is usually one year, but may be two (or more) in some lakes (Ricker 1972; Miller and Brannon 1982; Burgner 1987). Burgner (1987) reviewed various factors that affected the age at seaward migration. He concluded:

Among lakes there are large differences in juvenile growth rate and in age composition of seaward smolts. While fast-growing fish tend to smoltify at an earlier age, age at seaward migration quite obviously has a racial, or genetic, component apparently related to historical conditions for success in the nursery lake and the ocean. . .

Ricker (1972) tried to explain the differences in age at migration of sockeye smolts and concluded,

. . . with evidence so varied and conflicting, what hypotheses are possible? The easiest one is to postulate that age at migration is determined by an unknown factor or factors that sometimes just happens to be positively correlated with the size of the fish, sometimes negatively. This is not particularly helpful.

Ricker did find that there did appear to be a north-south cline in mean smolt age, and concluded that,

. . . for each stock there has been natural selection of hereditary factors that produce smolts of the best size for the prevailing conditions; and that, <u>on the average</u>, cooler temperatures northward tend to require a longer period of freshwater life to get smolts to the most favorable size. More exactly, what would be maximized is the combination of sizes and

numbers at each smolt age that produces the maximum reproductive potential among the returning adults.

In lakes Wenatchee and Osoyoos, most of the juveniles spend one year in freshwater and migrate downstream in their second year of life (Figure CP26; designated as 1., or 1+; Allen and Meekin 1980; Schwartzberg and Fryer 1988, 1989, 1990; Fryer and Schwartzberg 1991, 1993CPb, 1994; Fryer et al. 1992; Peven 1987 CPb, 1991 CPb, 1992 CPb). Small numbers of fish spend 2 years in the lakes before emigration to the sea (mostly from the Wenatchee Basin), while no fish have been observed migrating in their first year (subyearlings; Chapman et al. 1995 CPb)
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Anas and Gauley (1956) observed that 93% of the sockeye smolts they captured at Bonneville Dam between 1946 and 1953 were yearlings, while the percentage of subyearlings ranged up to 2% of the catch, and two-year-old fish represented between 3-7% of the catch. Chapman et al. 1995) found that 86% of the sockeye smolts sampled at Rock Island Dam between 1986 and 1993 were yearlings (1+), and 14% were in their third year of life (2+). No smolts in their first year of life (0+) were observed. From data obtained from J. Fryer and D. Pederson (CRITFC, personal communication), Chapman et al. (1995 CPb) found from adult scale samples that the majority of sockeye spend one year in the lake before emigrating to the sea, and no adult scale patterns showed any fish with less than one year freshwater life history.

Anas and Gauley (1956) found virtually no difference in the run timing of 1+ and 2+ juvenile sockeye at Bonneville Dam between 1949 and 1953. The few subyearling fish that were captured at Bonneville Dam in the 1940s and 1950s appeared there later in the season than the older fish. Chapman et al.'s (1995 CPb) data from Rock Island Dam suggests that 2+ fish migrate earlier than 1+ fish. This would comport well with other observations that larger fish (2+ are larger than 1+ juveniles) migrate earlier, in general, than the smaller members of the population (Burgner 1987, 1991).

Mullan (1986) theorized that the occurrence of outlet spawning in the Wenatchee system in the late 1940s - early 1950s may have been because of the introduction of Arrow Lake stocks, which probably spawned primarily in inlets and outlets of streams because of the nature of the Arrow Lakes. The fry produced from these spawners did not ascend the river to the lake, but moved downstream (Tuttle 1950). Gangmark and Fulton (1952) erroneously thought that the fry moved upstream into the lake because adult scale samples of fish spawning in the lake outlet and Nason Creek showed one year of freshwater growth, similar to the scale samples of fish from the Little Wenatchee and White rivers. Fry sampled by Chelan County PUD (1980) in the Dryden irrigation canal may have been from fish that spawned in Icicle Creek or Tumwater Canyon. Fry sampled by Weitkamp and Neuner (1981) in the Okanogan River may have been from fish spawned in the Similkameen River.

It appears that the number of subyearlings produced from the major spawning populations in the Wenatchee and Okanogan basins is trivial, and that subyearlings that have been observed in past years are probably from the small riverine populations. This suggests that the production of subyearlings may be maladaptive, which is evidenced by the disappearance of the spawning populations in the outlet of Lake Wenatchee and Nason Creek. Adult scale patterns have never shown any fish to have entered the ocean in their first year of life.[30] But Mullan (1986) makes a compelling argument that the maturity of the mainstem reservoirs may have led to the decline of the riverine populations also. The fact that distinct populations still spawn in the Methow and Entiat rivers (and possibly Icicle Creek) suggest that the riverine life history is not entirely maladaptive in the mid-Columbia.

Mullan (1986) discussed the tendency of Lake Wenatchee sockeye to be mostly age-4 at return. This means that the smolts departed the lake at age 1 and adults returned after two winters at sea, and that most progeny returned to spawn four years after the parents had spawned. He contrasted that pattern to the varying but generally large fraction of Lake Osoyoos sockeye of age 3 (mostly two years in freshwater and one at sea). He noted that Lake Osoyoos smolts tended to be large when they left the lake, relative to smolts from Lake Wenatchee, and that large smolts tend to spend less time at sea than small smolts.

6.4.3.2 Adults

Sockeye mature from their third to eighth year of life (Healey 1986). Throughout their range, sockeye display 22 mature age categories (over six different ages) after the variations in the length of fresh- and salt water residence are considered (Healey 1986). Only five of the age categories (1.2, 1.3, 1.4, 2.2, 2.3) are observed in any significant proportions within populations, though. Two or three age categories tend to dominate any individual population (Healey 1986). Age class 1.2 appears to make up the largest percentage of the returning adults, followed by age classes 1.4, 2.3, 2.2, and 1.3 (Healey 1986).

Healey (1987) postulated that the reason there are so many different life histories in Pacific salmon is due to their continual adaptation to achieve "maximum fitness." He states:

If we assume that each population of sockeye is adapted to the particular environment within which it lives and reproduces, then we must also accept that evolution has operated, and is still operating, so as to increase the fitness (i.e., contribution of genetic material to future generations) of individuals within each population. Even though it may never get there, we can think of the population as constantly moving toward some maximum fitness. Thus, the variation in parameters of reproduction among populations reflects adaptations to maximize fitness in local environments. From an evolutionary perspective, therefore, it is appropriate to ask several questions about the reproductive tactics of female sockeye, such as:
1) What age and size at maturity will maximize female fitness?
2) What number and size of eggs will maximize female fitness?
3) What allocation of surplus food energy among competing processes of somatic growth, egg production, spawning, and survival activities will maximize female fitness?

Age at maturity has been shown to vary year-to-year both within and between populations of sockeye (Ricker 1972; Peterman 1985; Healey 1987). Theories to explain these variations fall under two main categories: environmental and genetic. Environmental conditions

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[30] This may lend credence to the theory of juveniles rearing in the reservoirs, though.

affecting growth rates and survival rates in both fresh- and salt water are considered the largest factors (Peterman 1985). Ricker (1972) concluded that the age at maturity was at least partially controlled by genetics, and felt that the effects of variations in environment should not be excluded, but "*are probably weak in comparison with the hereditary effect*." Rogers (1987) observed that freshwater age was most often determined by environmental factors, but ocean age was primarily innate (determined by the ocean age of the parents). Peterman (1985) found the age of maturity was primarily influenced by early marine growth, an idea supported by Ricker (1972):

As regards environmental influence, this is suggested by the occasional large percentage of jacks observed . . . which it seems impossible to account for on genetic grounds. Only in one case do these occur in the same year in different rivers: the 1951 year-class on the Columbia and Fraser. However, both of these are sufficiently outstanding to warrant a search for unusual oceanographic conditions in the area . . . 1953 was the year having the greatest southerly component of the Ekman transport for January-August off southern California . . . The year 1953 was the first season of ocean growth of the 1951 year-class, during which its percentages of early maturation might well have been determined. However, it is not wise to make too much of a single coincidence . . .

It appears that age at maturity is based on both environmental and genetic components. The extent of the importance that each factor exhibits may be stock-specific. Chapman et al. (1995) postulated that genetics may be a more important factor when environmental conditions (both freshwater and oceanic) remain stable for a certain time period. When environmental conditions fluctuate greatly (from "normal"), age at maturity may show more variation.

Sockeye from the upper Columbia region show year-to-year variation in their age at maturity (Chapman et al. 1995 CPb). In most years, the predominant age class is 1.2 (Figure CP16), agreeing with what is observed for most stocks, but in some years, the percentage of 3-year-old (1.1) fish is large. It has been long known (Major and Craddock 1962) that the vast majority of the 3-year-old fish originate from the Okanogan River system (Figure CP16). Chapman et al. (1995 CPb) showed the year-to-year variation in the percentage of 1.1 fish returning to the Okanogan Basin. In some years, the percentage of these fish is quite high (1970), while in others, it dropped dramatically (1971), not showing any regular pattern. In most populations, fish maturing after one year in the ocean are usually males (jacks), but 3-year-old sockeye from the Okanogan are both male and female (Major and Craddock 1962). Since females that have only spent one year in the ocean are smaller than two-ocean fish, the reproductive potential of the stock is reduced in years when 3-year-old fish predominate the run (Major and Craddock 1962). Major and Craddock (1962) demonstrated that not accounting for the reduced reproductive potential of the 3-year-old fish could lead to a serious distortion of spawner-recruit relationship.

Major and Craddock (1962) felt that the occurrence of 3-year-old fish in the Okanogan was environmentally based since there was a lack of a significant correlation between the number of 1-ocean fish in year n compared to year n+3, and the lack of 1-ocean fish in the Wenatchee Basin, since both stocks were developed from the same brood stock during the

Grand Coulee Fish Maintenance Program (outlined earlier in this report). Selective harvest (Bilton 1970; Healey 1986) would also not fully explain the occurrence of 1-ocean fish in the escapement, although Major and Craddock (1962) do report how selective the harvest was in the 1950s. If selective harvest was a factor, then 1-ocean fish would be occurring in the Wenatchee Basin also, which they do not in any significant degree . Mullan (1986) concludes after reviewing the same information above that:

Lake Wenatchee qualifies as classic sockeye-rearing habitat in being cold and well oxygenated but infertile. Lake Osoyoos, on the other hand, poses the environmental hazards of hypolimnetic oxygen depletion, lethal epilemnetic heating, and predation and competition by warmwater fish . . . But for the sockeye that survive such perils, or in years when such perils are less acute or non-existent due to climatic variability, the lake offers relatively abundant food. Consequently Lake Osoyoos in some years produces some of the largest sockeye smolts reported in the literature, whereas those from Lake Wenatchee are average . . . Accelerated rearing of smolts to a large size before release characteristically increases the number of one-year ocean salmon and steelhead. Bilton (1978, 1980) demonstrated that atypically large coho salmon smolts released into a stream on Vancouver Island, British Columbia, returned relatively more as jacks than did corresponding typical (smaller) smolts. Stockner (1979) reported that since fertilization of Great Central Lake, also on Vancouver Island, the proportion of jacks in sockeye runs progressively increased over pre-enrichment levels.

In the upper Columbia, Wenatchee fish are older, on average, than the Okanogan fish (Figure CP16). Okanogan adults have the lowest average age of the populations Chapman et al. (1995 CPb) looked at. The Okanogan population has a slightly lower age at maturity for fish that migrated to the ocean as yearlings, but show nearly a one year difference for fish that migrated in their third year (2+) of life. Since, it is believed that these fish behave the same in oceanic waters (i.e., enter the ocean at approximately the same time and migrate to the same areas to rear), then the differences observed must be due to the differences in freshwater life before emigration to the sea.

In conclusion, Okanogan River sockeye have the youngest age at maturity known for sockeye throughout their range. This is at least in part due to the preponderance of 1-ocean fish in some years. The occurrence of 1-ocean fish in the Okanogan stock appears to be related to the size of smolts, which is in turn driven by conditions in Lake Osoyoos. Wenatchee River sockeye have a higher occurrence of fish that have spent two years in Lake Wenatchee before emigrating to the ocean.

6.4.4 Length at age

6.4.4.1 Juveniles

Fish and Hanavan (1948) reported that juvenile sockeye left lakes Wenatchee and Osoyoos as yearlings between March and May, ranging in size from 89 to 127 mm (assumed fork length).

Allen and Meekin (1980) found only two smolts (n = 504) from their samples of Okanogan River fish that had spent more than one year in Lake Osoyoos before emigration to the sea. They concluded that the fish from the Wenatchee system were also primarily 1+ smolts.

Periodic sampling of juveniles has occurred since the 1950s (Allen and Meekin 1980; Mullan 1986). The length frequency of Wenatchee River smolts measured in 1955 and 1956 comport well with the earlier, smaller arriving smolts at Rock Island Dam (Chapman et al. 1995 CPb). Smolts originating from the Okanogan Basin are larger than smolts from the Wenatchee system, and larger than most sockeye salmon smolts throughout their range (Figure CP27). From sampling at the Rock Island Dam bypass trap since 1986, Okanogan River smolts can be distinguished from Wenatchee River smolts by general being larger than 105 mm FL, and Wenatchee smolts being smaller than 105 mm FL (Peven 1987). The average length of smolts sampled at Rock Island Dam increases as the season progresses, showing that the Okanogan River smolts arriving later in the season (generally mid- late May) than the Wenatchee River fish. This observation was confirmed by the recapture of tagged fish (tagged as juveniles) on the spawning grounds in the late 1980s (Carlson and Matthews 1990, 1992). This also comports with observations of juvenile sockeye run timing at Rocky Reach Dam.

The larger size of the Okanogan smolts is mostly due to the growth opportunities in the lake (Mullan 1986). Chapman et al (1995 CPb) compared the average size of smolts leaving the lake with the number of fish that spawned two years previous (this assumes most smolts are 1+). They found that as the number of spawners increased, smolt size decreased. This relationship suggests that food and or space may be limited in Lake Osoyoos, in at least some years.

Hatchery fish released from the Eastbank Hatchery program, are larger on average than either the Wenatchee or Okanogan age 1+ smolts observed at Rocky Reach and Rock Island, although lengths overlap to a large degree (Chapman et al. 1995 CPb).

In conclusion, juvenile sockeye originating from the Okanogan River basin are some of the largest smolts reported in the literature. They arrive at Rock Island Dam generally in May, after most of the juvenile sockeye from the Wenatchee River have passed. There are two modes of length for both age groups observed at Rock Island Dam. The larger of these modes is from the Okanogan River stock, as suggested by sampling at upstream locations.

6.4.4.2 Adults

As shown above, smolts originating from the Okanogan River are larger than smolts from the Wenatchee system for both life histories (i.e., 1+ and 2+). Since larger smolts are known to have a faster rate of maturity (see above), it is not surprising that Okanogan fish have a higher percentage of 1-ocean life history (for both 1+ and 2+), than Wenatchee fish

Since 1952, the average length of adults (all year classes included) returning to the mid-Columbia has varied between years (Chapman et al. 1995 CPb). Sockeye originating from the Okanogan show a much greater degree of variation in length between years than the Wenatchee population. This is probably due to the large percentage of 1-ocean fish returning in some years, although on the average, both populations have similar lengths per age group (37-57 cm, over all ages and between sexes; Table CP8; Chapman et al. 1995).

Average length between year classes of adults varies more in the Okanogan population than in the Wenatchee population (Table CP8; Chapman et al. 1995 CPb). There is little variation between length at maturity between the Wenatchee and Okanogan systems within age classes, discounting the relationship between smolt size and size of returning adults.

For both males and females, the average length increases as age increases (Chapman et al. 1995 CPb). Wenatchee River adults appear to vary less between age groups than Okanogan River fish. For all age groups, for fish of the same total age (e.g., a fish designated as 1.2 or 2.1 is 4-years-old), fish that have spent an extra year in the ocean (migrated as 1+ smolts) are larger than fish that spent an extra year in the nursery lake (and migrated as 2+). For age classes that were represented in both populations, average length is virtually the same (Chapman et al. 1995 CPb). For most of the age classes there is considerable overlap of length, especially for the Wenatchee stock. For all age classes and both sexes combined, Wenatchee fish are larger.

In conclusion, Wenatchee sockeye are larger than Okanogan fish, although they are smaller (for both juvenile age classes) when migrating to the ocean. Within age classes, there is little variation in length between stocks or sexes. There is a wide overlap of length between age groups, especially for fish that have spent more than one year in the ocean. Upper Columbia sockeye appear to be the smallest per age group recorded throughout the range of sockeye.

6.4.5 Sex ratios

Sex ratios of adult sockeye returning to the mid-Columbia has varied over the last 50 years (Chapman et al. 1995 CPb). From the available data, it appears that on average, there are more male spawners in the Okanogan system, and more females in the Wenatchee system. In years past, this may have been at least partially an effect of the gill net fishery in the lower river, which selected for larger fish (Major and Craddock 1962), but if this were the sole reason, one would expect to see similar ratios in the Wenatchee River system, since males for a given age are similar in size.

6.4.6 Spawning

Sockeye exhibit many different life history strategies that are worth noting and discussing. These life history strategies may explain their continued relatively healthy status in the CCP.

6.4.6.1 Sockeye and kokanee (from Chapman et al. 1995 CPb)

Sockeye and kokanee often inhabit the same lakes and lake areas, and eat the same foods (Scott and Crossman 1973). Foote et al. (1989) were unable to find genetic differences between sockeye and sympatric kokanee. No genetic characteristics were found by which the forms could be separated consistently. However, Brannon et al. (1992) indicate existence of two distinct demes of kokanee in Fishhook Creek, tributary to Redfish Lake, Idaho, on the basis of differing rates of development of early and late spawning segments. Furthermore, they note sufficient temporal separation of beach-spawning sockeye and Fishhook Creek kokanee to isolate resident kokanee from anadromous *O. nerka*.

Anadromous sockeye and resident kokanee live sympatrically in many British Columbia lakes and in some cases they spawn together. Taylor and Foote (1991) hypothesized that divergent selective pressures of the marine and freshwater environments may have led to genetic differentiation in saltwater adaptability of the anadromous and resident forms. Pure and mixed crosses of sockeye and kokanee from Shuswap Lake were raised in constant water temperature and natural photoperiod from fall 1986 through spring 1988, the natural duration of sockeye freshwater residence. Kokanee displayed the physiological smolting response typical of anadromous salmonids, but its onset was retarded and more variable than in sockeye.

Contribution of resident kokanee to anadromous sockeye was suggested by Rounsefell (1958) as the only logical source for the large number of adult sea-run sockeye that have attempted at times to ascend the impassable falls below Lake Chelan (Lake Chelan kokanee) or at Enloe Dam on the Similkameen River (Palmer Lake kokanee).

Ricker (1972) summarizes data from a manuscript of Hanavan and Fulton that describe experiments with sockeye and kokanee in Lake Wenatchee (also see Fulton and Pearson 1981). Kokanee of the 1944 brood year from the lake were reared at Leavenworth Hatchery and released in Icicle Creek in March, 1946 and in Lake Wenatchee in November, 1945. The Icicle Creek releases survived at 0.27%; the lake releases at 0.50%. These survivals can be compared with sockeye releases from the 1942 brood year at Lake Wenatchee, which survived at 0.40-2.03%. Unfortunately, no marked sockeye were released from the 1944 brood for comparison with the kokanee smolts. Dorsal and one ventral fin were removed as marks for the kokanee releases. Adipose and ventral, or dorsal and ventral combinations were used on the sockeye releases. Fin removal, perhaps excluding removal of the adipose fin, probably reduced survival of all marked groups. Forester (1954) calculated a differential mortality of 62% for fin marking, which would result in adjustment of adult returns upward for fin-marked sockeye or kokanee by a factor of 2.63. Ricker (1976) re-examined this issue and concluded that a 37% handicap was appropriate. Hence, marked fish survivals would be multiplied by 1.37. Weber and Wahle (1969) estimated effects of fin-clipping on survival of sockeye by marking equal numbers of sockeye with fin clips and with tetracycline fed to the paired groups. Upon adult return, 39% more tetracycline-marked fish were found than fin-marked sockeye. The authors showed that tetracycline did not cause mortality. The 1.39 multiplier is very close to the 1.37 multiplier used by Ricker (1976).

Mullan (1986) summarized survival, adjusted for mark bias, for all hatchery sockeye released from broods 1940-1944 at Leavenworth, Entiat, and Winthrop hatcheries. The mean recovery in fisheries and spawning areas for all releases was 1.62%. Hatchery sockeye released at Leavenworth hatchery in brood years 1960-1963 survived from smolt to adult at rates of 0.30-0.96% (mean=0.67%, which would equal 0.92% if adjusted by a mark handicap constant of 1.37). Those fish passed six hydroelectric projects. Thus, the survival of kokanee smolts to adult return at 0.50% (if adjusted by 1.37 x 0.50 would equal 0.69%) for a fall release to Lake Wenatchee is somewhat lower than survival of sockeye. Weights of age 3+ anadromous kokanee on return were 1.27 kg in downriver fisheries, compared to 1.45 kg in sockeye but, once again, returns occurred in different years that may reflect differing ocean growth rates for either sockeye or kokanee.

It reasonable to assume that kokanee have contributed to some of the anadromous sockeye that have been counted over mainstem dams, especially Wells Dam.

6.4.6.2. Prespawning mortality (from Chapman et al. 1995 CPb)

Egg voiding has been examined in stocks of sockeye in the Fraser River since the 1940s. Voiding grades have been "essentially unspawned (0-25%)," "half-spawned (25-75%)," and "nearly to completely spawned (75-100%)." Cumulative stress, not ascribable to any single cause, is deemed responsible, although disease may be the ultimate cause of death before spawning (Gilhousen 1990). Fraser River sockeye probably have higher prespawning mortality rates than sockeye in other river systems because of higher water temperatures and more difficult migration conditions. Those descriptions apply to Columbia River sockeye as well.

Burgner (1991) notes that delay in migration, high stream temperatures, high spawner density, or predation can increase failure of sockeye to spawn successfully. Prespawning mortality has reached 90% in the Chilko River in 1963 and 62% in sockeye in the Horsefly River in 1961 (Williams 1973). Various pathogens and parasites have been epidemic in some prespawning mortalities, but may only have been the final cause of death, while other factors predisposed sockeye to premature death.

Allen and Meekin (1980) examined carcasses in the Okanogan River system to determine the fraction of females that had fully spawned in the years 1952-1974. The percentage fully spawned ranged from 45% to 95% (mean=85%). Totally unspawned females ranged from 0% to 43% (mean=8.0%). Thus, another 7% of carcasses had partially spawned. Prespawning mortality with respect to unvoided eggs thus amounted to a minimum of 8% and a maximum between 8% and 16%.

Hansen (1993) sampled 148 female sockeye carcasses in the Okanogan River spawning areas in 1992, and found that 73.6% of the fish had voided all eggs (95-100% voided), 25.7% had partially spawned (24-94% voided), and 0.7% had not spawned at all (0-25% voided). Hansen used an average fecundity of 2,000 eggs, from Allen and Meekin (1980). Egg-voiding was more successful in the Wenatchee River system than in the Okanogan River. Allen and Meekin (1980) examined 348 females in 1971. Only 2.6% of the females had not spawned completely. In 1972, 6.6% of 289 females had not voided all eggs. In 1973, only 1.7% of 350 female carcasses had not spawned completely. Thus, average failure to void eggs amounted to about 3.6% over the three years. This is about one-fourth the voiding failure recorded in the Okanogan system. Water temperature during the migration and maturation season may likely contribute to the higher rate of unvoided eggs in the Okanogan Basin.

The loss represented by failure to void eggs represents only part of total prespawning loss, however, for it does not include fish that die between, say, passage at the last dam traversed and arrival on the spawning grounds. It does not include fish that die near the spawning grounds while maturing.

Chapman et al. (1995 CPb) surmised that total prespawning loss of all types exceeded 25%. It is probably much higher in some years in the Okanogan system when river and lake temperatures are high. Hatch et al. (1993) used a video system to estimate that 25,172-42,410 sockeye passed Zosel Dam in 1991, a range that one can compare to the Wells Dam count of 47,158 sockeye. However, the range can also be used to estimate that 10-47% of the sockeye that passed Wells Dam failed to pass Zosel Dam.

Hansen (1993) used mark-recapture of carcasses to estimate total escapement of 22,587 sockeye on the spawning grounds in 1992. This estimate suggests a "loss" of about 46% of the Wells Dam count of sockeye. Hansen notes that about 220 sockeye were reported caught in a Colville tribal C&S fishery downstream from Chief Joseph Dam and on the Okanogan River. A few hundred sockeye may have been taken in total by sport fisheries in Wells pool and by Canadian native fisheries. A few hundred sockeye probably spawned in the Methow River. Still, the prespawning loss of sockeye between Wells Dam and the spawning areas upstream from Lake Osoyoos appears to have been greater than 40% in 1992.

6.4.6.3 Spawning time:

Sockeye appear to be ascending the mainstem Columbia and Wenatchee (and possibly the Okanogan) rivers earlier than in past years (Chapman et al. 1995 CPb). Chapman et al. (1995 CPb) attempted to see if there have been any corresponding earlier spawning times. They found no evidence for earlier spawning in either river basin, and the fluctuation between peak spawning appeared to be generally within a two week period in each basin, probably corresponding to annual fluctuations in stream temperature, which initiates spawning (Miller and Brannon 1982). Swan et al. (1994) found that adult sockeye began their exodus from Lake Osoyoos to the spawning grounds when flow increased and temperatures decreased in early September. It is reasonable to assume that those conditions will vary somewhat between years, explaining the slight variation in peak spawning.

6.4.7 Fecundity

Average fecundity for sockeye ranges from 2,000 to 5,000 eggs per female (Burgner 1991). The primary determinant in fecundity in females is believed to be the size of the female and the number of years spent in the ocean. Foerester (1968) noted that racial or genetic characteristics might also help determine the number of eggs per female. Rounsefell (1957) also found that fluvial anadromous *Oncorhynchus nerka* showed a lower number of eggs for their weight than lacustrine anadromous sockeye. He further notes that, because egg size is sacrificed by number, *in each ecological situation there is some point at which, on the average, the forces favoring size are exactly balanced by those favoring number*. Females show no consistent or significant difference in fecundity in relation to the length of freshwater life as juveniles, given the same juvenile freshwater life history type (i.e., lacustrine or fluvial).

WDF (1938) measured 52 female sockeye that were captured at Rock Island Dam in 1937. The average fecundity was 2,668 (range: 1,479-6,224). These fish represented the composite original population of sockeye returning to the upper Columbia River. Most of these fish were probably destined to return to the Arrow Lakes region in Canada (see above).

Since 1944, fecundity has been estimated from upper Columbia sockeye, mostly in conjunction with hatchery operations. Average fecundity of the Wenatchee population (~2,500) appears greater than the Okanogan population (~2,400). The data does show that the Okanogan average fecundity can be greatly affected by the presence of 1-ocean females in the spawning population. Major and Craddock (1962) showed that 1-ocean females were 50% less fecund than 2-ocean females, although Burgner (1991) concluded that fecundity per kg for the 1-ocean fish was greater. Foerster (1968) observed that for females of the same size that had spent a shorter time in the ocean, the younger fish were more fecund, relating to the presumed faster growth rate of the younger fish. Chapman et al. (1995) summarized data from Major and Craddock (1962) that showed that overall, for upper Columbia sockeye, 1-ocean fish were 30% less fecund then 2-ocean fish, but the differences varied from year to year, when age information was available.

While the average fecundity of the 1937 sample is comparable to the average fecundity estimated since then (Chapman et al. 1995 CPb), 8% of the fish had greater than 3,800 eggs (greater than most fish today), and one fish had fecundity greater than 6,200 eggs, higher than any reported in the literature. This suggests that at least in some of the populations that originally returned to the area upstream of Rock Island Dam, fish had a higher fecundity than fish that have adapted to lakes Wenatchee and Osoyoos since the GCFMP in the 1940s. Length and fecundity from fish sampled in 1937 also suggest that 1-ocean females were represented in the sample (fecundity and length less than 2,000 eggs and 43 cm, respectively).

Rounsefell (1957) investigated the relationship between latitude and fecundity. No conclusive results were presented, but the data suggested higher fecundity in the southern most population looked at (although only five populations were compared). Foerster (1968) concluded that more data needed to be looked at to determine if there was a relationship between latitude and fecundity. Chapman et al. (1995 CPb) looked at 13 different populations to compare fecundity estimates with increasing latitude northward. Those data suggests an increase in fecundity for more northern populations, but the relationship was not strong. Comparing length and fecundity for the same populations did not show any consistent pattern, but again, the data suggests a weak correlation between latitude and fecundity.

Sockeye returning to the Columbia River (upper Columbia and Redfish Lake) have the lowest fecundity of any populations Chapman et al. (1995 CPb) looked at, even though their average length is comparable to other populations. Manzer and Miki (1985) found that coastal stocks of sockeye were 18% more fecund than interior stocks of sockeye in British Columbia for females of the same length. They conclude that,

It may by hypothesized that these differences represent adaptive mechanisms for maintenance of stocks utilizing markedly different environments. To elaborate, coastal lakes are extremely unstable as a result of winter discharge and are mainly oligotrophic . . .

Consequently, smolts from these lakes are generally small compared with most interior lake smolts (1-2 vs. 4-6 g) . . . Since marine survival of smolts is positively correlated related to size . . . in general, coastal smolts presumably experience lower marine survival rates than interior lake smolts. For coastal stocks to maintain populations under these conditions, high egg production is advantageous. Alternatively, interior lakes are more stable and productive, but stocks utilizing these lakes are faced with longer and more arduous migration routes than coastal stocks. Somatic material which otherwise could be directed into egg production is expanded in physical energy.

Chapman et al. (1995 CPb) proposed that the hypothesis proposed by Manzer and Miki (above) could be applied to upper Columbia sockeye, since they have to travel greater than 500 miles from the ocean to their natal spawning areas. Their hypothesis may also be applied to the differences observed between the Wenatchee population and the Okanogan population too. Wenatchee fish are older, and slightly more fecund. They produce smaller smolts, which probably survive at lower rates than the larger Okanogan smolts.

In conclusion, sockeye from the upper Columbia have some of the lowest fecundity reported in the literature. Upper Columbia sockeye may produce fewer eggs because of their longer migration than most sockeye stocks. This may be an evolutionary "trade-off" between energy needed for migration (somatic growth) compared to energy needed for reproduction (gonadal growth).

6.5 Coho

6.5.1 Adult migration

Two coho ecotypes ascend the Columbia River; early and late run. The early-run coho enter the Columbia River during August and September and generally spawn in October and November. Later running coho enter the main river between October and November and generally spawn between October and March (Mullan 1984).

The extinct populations from the upper Columbia appear to have been the earlier running types (Mullan 1984). Currently, coho from the reintroduction program begin appearing at Rock Island Dam in August and peak in September (Chelan PUD, unpublished data). Spawning begins in October and goes through December (K. Murdoch, personal communication).

6.5.2 Juvenile migration

Most coho smolts begin their ocean migration in spring, from February through May (Sandercock 1991). The beginning of the migration appears to coincide with the size of the fish, flow conditions, water temperature, day length, and potentially the availability of food (Shapovalov and Taft 1954).

Smolts appear at Rock Island Dam primarily in May from the coho reintroduction program (A. Murdoch, personal communication).

6.5.3 Age structure

6.5.3.1 Juveniles

Coho spend at least one year in fresh water before emigrating to the sea, as no returning adult coho salmon have been observed without a freshwater annulus (scale mark). It appears that all coho salmon must find some freshwater habitat for their first year of life or perish (Shapovalov and Taft 1954; Mason 1974).

Data for the CCP is presently lacking, but some should be coming forth within the next few years, if the YIN program is successful. However, it is reasonable to assume that coho will behave similarly in this region as they do in others. We anticipate them using rearing habitat within the Wenatchee and Methow drainages for one year prior to emigrating to the sea.

6.5.3.2 Adults

Adult coho usually spend 5-20 months in the ocean prior to returning to freshwater to spawn (Godfrey 1965). Early-run Columbia River coho appear to have a tendency to migrate south after leaving the river, where later-run coho mostly migrate north, although there is considerable overlap (Mullan 1984). In general, it appears that Columbia River coho do not migrate very far offshore, and are usually harvested off the west coast (Landers and Henry 1973).

Data from the CCP is lacking except what is captured from Mullan (1984). However that information is primarily based on hatchery origin fish that originated from lower Columbia River stocks, and therefore may or may not represent a naturalized, or original population of coho. As stated previously, within the next few years, the YIN program should yield information concerning the life history of a naturalized population(s) of coho in the CCP.

6.5.4 Length at age

6.5.4.1 Juveniles

Coho smolts range in size from approximately 75-165 mm, but average around 10 cm (Sandercock 1991). Since there are no data for native coho in the CCP, we assume that naturally produced fish will average near Sandercock’s (1991) average, which spanned all age classes and geographic areas coho spawn.

6.5.4.2 Adults

Adults range in size upon return from 50-70 cm throughout their range (Sandercock 1991). Various studies have show that the size at time of return varies and appears to be influenced by sex (males are generally larger), age (older fish are larger), time of position in the run (one study documented that fish sampled at the peak of the migration were larger), and potentially other factors (reviewed in Sandercock 1991).

6.5.6 Sex ratio

Sandercock (1991) reports that for various reasons, females outnumber males on the spawning grounds, although in some years more males appear on the spawning grounds because of the presence of jacks.

6.5.7 Spawning

Spawning time for coho is generally between November and January (Sandercock 1991). Mullan (1984) was able to estimate that native coho spawned in the Wenatchee River in late

October to early November during the GCFMP. This information was determined from relatively few fish, since coho were virtually extirpated by that time (see above).

Sandercock (1991) reviews information that suggests that late spawning coho may have an adaptive advantage over either earlier spawning populations, or other species within the same drainage. Late-running fish may dig up the redds of the earlier spawning fish.

Coho ascending Rock Island Dam in recent years, as part of the YIN reintroduction program, begin appearing in August and peak in mid-late October, which suggests a November-December time frame for spawning.

6.5.8 Fecundity

Sandercock (1991) noted that there is a tendency for fecundity in coho to increase from southern to northern populations, and that North American populations have a higher number of eggs than Asian populations. For North American populations, Sandercock (1991) reported that average fecundity was approximately 2,000 to 4,700, with the higher range from Alaskan populations. For populations in British Columbia, Washington and Oregon, all populations averaged lower than 3,000 eggs per female.

Mullan (1984) summarized data from the coho hatchery releases as part of the GCFMP. The average number of eggs per female was about 3,000, suggesting that native coho in the upper Columbia may have had higher fecundities than current coastal populations (as reported in Sandercock 1991).

This may be an adaptive advantage of anadromy (to compensate for higher mortality of migration) for populations that have to travel over 500 miles from the ocean to spawn (similar to steelhead, but dissimilar to sockeye and lamprey).

6.6 Pacific lamprey

6.6.1 Adult migration

At Bonneville Dam, the run begins in May and generally goes through October, peaking towards the end of June-mid July (Columbia River DART webpage).

Beamish (1980) suggested lamprey enter fresh water between April and June, and complete migration into streams by September. It is not clear how flow impacts freshwater immigration. Pacific lampreys are considered weak swimmers compared to other fish Burst swimming speed was calculated to be approximately 2.1 m/sec for lamprey (Bell 1990). On the Fraser River in British Columbia, Pacific lamprey were estimated to migrate 8 km/day (Beamish and Levings 1991). In the Columbia River, the lamprey were estimated to migrate 4.5 km/day (Kan 1975).

Pacific lamprey overwinter in fresh water and spawn the following spring (Beamish 1980). Pacific lamprey do not feed during the spawning migration. The fish utilize carbohydrates, lipids, and proteins for energy (Read 1968). Beamish (1980) observed 20% shrinkage in body size from the time of freshwater entry to spawning. Lamprey over-winter in freshwater and commence spawning the following spring, similar to summer-run steelhead.

6.6.2 Juvenile migration

After metamorphosis in October and November, young adults migrate to the ocean between late fall and late spring (Close et al. 1995). Fyke net sampling at Wells Dam indicates that lamprey pass the dam during most months that sampling occurs, but the greatest numbers usually pass during April through July (BioAnalysts 2000). Most pass Rocky Reach Dam in late May and June (CPUD 1991). Young adults are sampled from March to June in collection facilities at John Day and Bonneville dams (Hawkes et al. 1991; Hawkes et al. 1992; Hawkes et al. 1993). In the Nicola River, British Columbia, Beamish and Levings (1991) found that 99% of all young adults migrated by April and May.

At the beginning of the migration, most young adults leave the substrate over a short period during the night (Beamish and Levings 1991). Initially, migration is mostly nocturnal (Moursund et al. 2000). As the migration proceeds towards salt water, more groups amalgamate, resulting in a more uniform migration that continues day and night.

Downstream migration appears to correlate with increased discharge but not temperature (Hammond 1979; Potter 1980; Beamish and Levings 1991; Close et al. 1995). In the Fraser River system, 99% of the young adults left the substrate and began migration during the night with increased flows (Beamish and Levings 1991). In the Methow River, McGee et al. (1983) found that catches of lamprey increased with rapid increases in flow. Young lamprey rely on currents to carry them downstream (Beamish and Levings 1991). They do not actively swim downstream; rather, they drift downstream tail first.

It is unknown how long young adult lamprey spend in the estuary. Beamish and Levings (1991) noted that young adults migrated both day and night near the mouth of the Fraser River. Beamish (1980) believes that young adults move quickly through the estuary into deeper water and start feeding immediately.

6.6.3 Age structure

6.6.3.1 Juveniles

Eggs can hatch within the gravel within 19 days at 15 degrees C (Pletcher 1963). The larvae leave the gravel approximately two or three weeks after hatching and drift downstream usually at night. The larvae settle in slow backwater areas such as pools and eddies (Pletcher 1963). The larval stage has been estimated to range from four to seven years (Richards 1980; Kan 1975; Pletcher 1963; Hammond 1979; Beamish and Northcote 1989). The size of the larvae varies but ranges from 3-5 g and 13-20 cm in length (Mallatt 1983). During the larval stage, ammocoetes are blind, sedentary, and survive by filtering food particles. Ammocoetes possess a high entrapment efficiency due to mucus secreted by the walls of the pharynx and goblet cells within the gill filaments. The high entrapment efficiency is coupled with low food assimilation. Larvae digested only 30-40% of the food intake while passing large amounts of undigested food (Moore and Mallatt 1980).

After the juveniles complete metamorphosis in October and November, young adults migrate to the ocean between late fall and spring. In the upper Columbia, it appears most juveniles migrate downstream in the spring and early summer (BioAnalysts 2000). The young adults from some populations can stay in freshwater up to 10 months after metamorphosis, although different populations in British Columbia vary in their ability to survive in freshwater (Beamish 1980).

6.6.3.2 Adults

The ocean phase has been estimated to last for periods of up to 3.5 years for Pacific lamprey in the Strait of Georgia in British Columbia (Beamish 1980). Off the coast of Oregon, the duration of the ocean phase was estimated to range from 20 to 40 months (Kan 1975). Kan (1975) suggested that coastal populations enter salt water in the late fall, while inland populations enter in the spring. After entrance into salt water, Pacific lamprey move into water greater than 70 m in depth. Young adults have been captured off the Pacific coast of Canada at depths ranging from 100 to 250 m (Beamish 1980). Pacific lamprey have been collected at distances ranging from 10 to greater than 100 km off the Oregon coast and up to 800 m in depth (Kan 1975). Despite- the occurrence of deep water collections, Pacific lamprey are generally considered to be mid-water fish associated with plankton layers (Beamish 1980).

6.6.4 Length at age

6.6.4.1 Juveniles

Mallet (1983) found that the size of ammocoetes range from 13-20 cm. After metamorphosis into macropthalmia, lamprey are usually between 12.2-30.3 cm (Scott and Crossman 1973). No information is currently available from the CCP.

6.6.4.2 Adults

Beamish (1980) estimated that adult lamprey are between 12 and 72 cm upon entry into freshwater. He also estimated that they loose approximately 20% of their body size prior to spawning.

6.6.5 Sex ratios

We were unable to find information on sex ratio of Pacific lamprey

6.6.6 Spawning

Pacific lamprey that migrate inland in the Columbia River spawn later than those in coastal streams (Close et al. 1995). Pacific lamprey along the Oregon coast generally spawn in May at temperatures between 10° and 15°C. In the Columbia River basin, lamprey typically spawn during June and July (Wydoski and Whitney 1979; 2003). Kan (1975) collected both spawning and pre-spawning fish in the John Day River system in July. Mattson (1949) described lamprey spawning in the Willamette River during June and July. In the Babine River system in British Columbia, Pacific lamprey spawned from June through the end of July (Farlinger and Beamish 1984). They most probably spawn in the mid-Columbia region in June and July.

Pacific lamprey usually select low-gradient stream sections for spawning (Kan 1975; Close et al. 1995). They construct nests at the tail areas of pools and riffles (Pletcher 1963; Scott and Crossman 1973; Kan 1975), and, if given a choice, prefer spawning in gravels (Pletcher 1963). Pacific lamprey generally select spawning sites with water velocities and depths that range from 0.5 to 1.0 m/s and 0.4 to 1.0 m, respectively (Pletcher 1963; Kan 1975). In the Babine River system, lamprey spawned at depths that ranged from 0.3-4.0 m, although most spawned at sites with depths less than 1.0 m (Farlinger and Beamish 1984).

No one has documented the spawning sites selected by lamprey in the upper Columbia region (BioAnalysts 2000). They likely spawn in the lower reaches of the Wenatchee, Entiat, and Methow rivers. Quite possibly they spawn in the Wenatchee River near Leavenworth (RM 23.9-26.4), because both adults and ammocoetes occur there. This area consists of well-sorted gravels and cobbles. Lamprey may also spawn in the Gunn Ditch near Monitor (K. Petersen, NOAA Fisheries, personal communication).

Although rare, Pacific lamprey may spawn in lakes (Close et al. 1995). In the Babine Lake system, Russell et al. (1987) observed lamprey spawning in shallow water in two areas of the lake system. Nests were subject to wave action but not an obvious unidirectional flow. It is unlikely that Pacific lamprey spawn in lakes in the upper Columbia region. Spawning in Lake Wenatchee is unlikely because lamprey have not been seen or documented upstream from Tumwater Canyon. Lake Chelan is off limits because of migration barriers in the Chelan River. It is also unlikely that they spawning in Lake Osoyoos because lamprey apparently do not currently exist in the Okanogan basin.

6.6.7 Fecundity

Lamprey fecundity varies widely and is probably related to female size and migration distance (Scott and Crossman 1973; Close et al. 1995). The mean number of eggs produced by a female is about 34,000, but can be as many as 106,000 for a 16-inch female (Wydoski and Whitney 1979; 2003). The absolute fecundity for lamprey in Oregon ranged from 98,000 to 238,400 eggs (Close et al. 1995). The relative fecundity was significantly different between lamprey from coastal Oregon and the John Day River (Kan 1975). Kan (1975) suggested that the lower fecundity for lamprey in the John Day may be related to a higher cost of migration

II. Non-anadromous species

Migration

Many independent and local populations of bull, cutthroat, and redband trout exhibit various life history forms. The types of migrations a fish makes throughout its life can determine most of these life histories. Migrations are usually undertaken for trophic opportunities, reproduction, or survival (e.g., thermal refuge). While white sturgeon are believed to be anadromous if given access to the sea, healthy populations of wholly freshwater forms are known. Since all of these focal species migrations occur in strictly freshwater, we use the term *potamodromous* (Gresswell 1997). Other terms have been used to convey the same meaning (reviewed in Gresswell 1997), but for sake of clarification, we follow the example of Gresswell.

Forms of potamodromous life histories are (from Northcote 1997):

- Fluvial – spawning, feeding, and survival habitats is in mainstem streams and rivers only.
- Fluvial-adfluvial – spawning habitat is in stream of river tributaries, and feeding and survival habitats are in streams, rivers, and tributaries.
- Lacustrine-adfluvial – spawning habitat is in lake tributaries, and feeding and survival habitats are in lakes.
- Allacustrine – spawning habitat is in lake outlets streams or rivers and feeding and survival is in lakes.

Fish that do not migrate over a substantial distance we term “non-migratory.” Another term that is commonly used in the CCP to describe this life history form is “resident,” but as Gresswell (1997) points out, this term has different meanings depending on where it is used. It is commonly used to describe a type of fluvial life history, indicating that the fish does not travel very far from its natal area (i.e., can it accesses the whole stream system, or do barriers restrict it?).

6.7 Bull trout

Differing potamodromous forms of bull trout may be found together in sympatry, and either form may give rise to offspring exhibiting either non-migratory or migratory behavior (Rieman and McIntyre 1993). This phenomenon is also seen within the redband trout complex of *O. mykiss*. Factors affecting the expression of one ecotype or the other are probably related to temperature and trophic opportunities, as they are for *O. mykiss*.

Bull trout have more specific habitat requirements than other salmonids. The habitat components required by bull trout are often summed up by the “Four C’s” - cold, clean, complex, and connected. Because even under pristine conditions the required habitat components are not ubiquitous throughout river basins, bull trout exhibit patchy distributions. Bull trout do not, and should not, be expected to simultaneously occupy all available habitat (USFWS 2002).

6.7.1 Adult migration

Bull trout are known to migrate long distances (Northcote 1997). Fraley and Shepard (1989) found bull trout in the Flathead River system migrated up to 250 km (155 miles). In the CCP, radio tagged bull trout were found to migrate over 160 km one way (~ 100 miles; BioAnalysts 2002, 2003).

6.7.1.1 Mainstem Columbia River

A 3-year radio telemetry study was initiated in 2001 (BioAnalysts 2002, 2003) to track bull trout movement within the CCP. A total of 79 bull trout were tagged in 2001 and 2002 (15, 45, and 19 fish at Rock Island, Rocky Reach, and Wells dams, respectively) during May and June. All of the tagged fish, despite their release location, migrated into the Wenatchee, Entiat, or Methow rivers, by the beginning of August, although most entered in June and July. Only one fish entered the Okanogan River; where it stayed briefly, then swam back downstream and entered the Methow River.

After entering tributaries, most bull trout remained within them until October-November, when they migrated back to the mainstem Columbia River (BioAnalysts 2002, 2003). This time period overlapped with spawning timing (see below) and most fish were presumed to have spawned within the tributary areas that they “held” in during August through October.

After the fish exited the tributaries, they moved various distances both up- and downstream of the tributary mouths. Of special note, some appeared to take up residence in the hatchery outfall at Wells Hatchery (immediately downstream of Wells Dam). Since temperatures were not greatly different from ambient Columbia River temperatures, it is assumed that fish were staying there for feeding opportunities, instead of seeking thermal refugia (BioAnalysts 2002, 2003).

As previously indicated, most bull trout pass counting windows at mainstem dams on the Columbia during May and June (Chelan PUD, unpublished data). Diel timing of migration at the dams indicates that fish pass primarily during day light hours (Figure CP28).

6.7.1.2 Tributaries

Between 2000 and 2003, Kelly-Ringel and DeLaVergne (2003) tagged 62 bull trout within the Wenatchee River with radio telemetry tags to follow their movement patterns. Many of the tags that were used had a battery life of 2 years so they were able to track them for extended periods.

Various patterns of movement were observed. Of the fish tagged in Lake Wenatchee, most of the fish migrated to the Chiwawa River Basin, and others to the White River Basin. Many of the fish that were tagged used either the Wenatchee River of Lake Wenatchee to over-winter. Other patterns were observed throughout the Wenatchee Basin, and no one strong patterns emerged from the study.

In summary, bull trout tagged in the Wenatchee River basin showed various movement patterns that were most likely related to feeding, spawning, and overwintering.

6.7.2 Juvenile migration

Depending on age, size, and habitat availability, juvenile bull trout (migratory types) appear to migrate out of natal streams from spring to fall (Goetz 1989; Pratt 1992). Goetz (1989) suggested that over-seeding of rearing habitat may displace fry downstream either by competition or high spring flows. In the Flathead River system in Montana, Fraley and Shepard (1989) found juvenile bull trout migrated from tributaries into the Flathead River from June through August. These fish appeared to move rapidly downstream to Flathead Lake.

McPhail and Murray (1979) suggested two migration periods for juvenile bull trout: a spring migration of newly emerged fry, and a fall migration of larger age 1+ and 2+ fish. These fish may be migrating because of high flows (in the spring), or survival (thermal refugia) in the fall, which may be different than the “smolt” behavior of migratory fluvial or adfluvial fish.

At mainstem dams on the Columbia River within the CCP, very low numbers of juvenile bull trout pass between April and August, primarily in June (Chelan PUD, unpublished data).

In the Chiwawa River, Hillman et al. (2002) have observed 79-505 (usually with large standard error) juvenile bull trout within the upper reaches and tributaries of the Chiwawa River. These surveys are conducted in August, a time when captures are usually low in the juvenile salmonid “screw” trap near the mouth (Figure CP29; Murdoch et al. 1998CPa, 1998CPb, 1999, 2000, 2001).

Murdoch et al. (1998CPa, 1998CPb, 1999, 2000, 2001) have observed juvenile bull trout emigrating from the Chiwawa River between March and December (Figure CP29), which comports well with what other researchers have found (Goetz 1989; Pratt 1992). Most appear to leave the Chiwawa River in the fall, which they postulate may be due to the amount of over-winter habitat, or trophic opportunities (Figure CP29).

6.7.3 Age structure

The size and age of bull trout at maturity depends upon life-history strategy (Platts et al. 1993). Non-migratory fish are usually smaller than migratory populations and may live up to 20 years (Mullan et al. 1992 CPa; Brown 1994). Bull trout normally reach sexual maturity in 4 to 7 years (reviewed in Platts et al. 1993).

Within the CCP, Mullan et al. 1992 report some populations that did not mature until 9 years of age in the Methow Basin. They found that headwater male bull trout (potentially non-migratory ecotype) in the Methow River began to mature at age 5, and were all mature by age 6. Females from the same area began to mature at age 7 and were all mature by age 9. Brown (1994) found that most migratory bull trout within the Wenatchee River basin were between 5 and 7 years old. The bull trout that Mullan et al. (2002 CPb) found *that did not mature* until 9 years of age are the oldest (at first maturity) reported within the literature. The oldest bull trout sampled in the Methow River was 12 years (Mullan et al. 1992 CPb).

Migratory juveniles usually rear in natal streams for 1-4 years before emigration (Goetz 1989; Fraley and Shepard 1989; Pratt 1992). Methow Subbasin juvenile bull trout rear in the coldest headwater locations until they reach a size that allows them to compete with other fish (75-100 mm; Mullan et al. 1992 CPb). Non-migratory forms above barrier falls probably contribute a limited amount of recruitment downstream, nevertheless, this recruitment contributes to fluvial and adfluvial productivity. The fluvial forms migrate to the warmer mainstem Methow and Columbia rivers (e.g. Twisp River, Wolf Creek), while the adfluvial populations (e.g. Lake Creek, Cougar Lake) migrate to nearby lakes.

6.7.4 Length at age

In the Wenatchee River, migratory bull trout are usually between 460 and 600 mm, although some up to 813 – 915 (32-36 inches) and 5.4-6.8 kg (12-15 pounds) have been observed (Brown 1992). Non-migratory, stream-resident bull trout usually mature between 150 to 300 mm (6-12 inches; Wallis 1948; Goetz 1989; Mullan et al. 1992 CPa).

Length at age of bull trout found in Methow River tributaries by Mullan et al. (1992 CPa) were the shortest by age group of any other lengths reported in the literature (Goetz 1989; Wydoski and Whitney 2003).

6.7.5 Sex ratios

The only literature found on sex ratio for bull trout was in Mullan et al. (1992 CPa). In their Table 12 (Appendix K), they show that the overall female to male ratio was 1.11:1, but for mature fish, they found almost twice the percentage of the population of males was mature (14.6 % of the females and 24.3% of the males).

6.7.6 Spawning

As previously mentioned, bull trout are strongly influenced by water temperature during all life stages and for all ecotypes. Most bull trout spawn from mid-September through October, with timing related to declining water temperatures. Spawning sites are commonly found in areas of ground water interchange, both from the subsurface to the river, and from the river to the subsurface. Association with areas of ground water interchange can promote oxygen exchange and mitigate severe winter temperatures including the formation of anchor ice.

Within the CCP, spawning begins in headwater streams in late September and continues through October, with commencement closely tied to water temperature between 11 and 9 °C (Brown 1994). After spawning, fluvial and adfluvial kelts return to their more moderate environments, while resident forms seek winter refuge. In Methow drainage tributaries, bull trout spawning and early rearing is confined to streams cold enough (less than 1,600 C annual temperature units) to support them in the areas below the falls (Mullan et al. 1992 CPa). In most cases such reaches are very short (less than 5 miles).

Repeat- and alternate-year spawning has been reported, although repeat-spawning frequency and post-spawning mortality are not well documented (Leathe and Graham 1982; Fraley and Shepard 1989; Pratt 1992; Rieman and McIntyre 1996).

6.7.7 Fecundity

Fecundity of bull trout varies with size. Fraley and Shepard (1989) found that fecundity averaged almost 5,500 eggs (up to over 12,000 in one individual) for migratory bull trout from the Flathead River. Martin et al. (1992) noted females between 271-620 mm long produced 380 to over 3,000 eggs in southeastern Washington streams. Mullan et al. (1992 CPa) found one bull trout in the Methow Basin had a fecundity of fewer than 200 eggs that was 300 mm.

6.8 Westslope cutthroat trout

Differing potamodromous forms of WSCT may be found together in sympatry throughout their range (reviewed in Behnke 2002; Wydoski and Whitney 2003). Historically, most populations within the CCP were strictly fluvial (non-migratory) or fluvial-adfluvial ecotypes, although lacustrine-adfluvial forms existed in the Lake Chelan Basin (Williams 1998). Current lacustrine populations (primarily high mountain lakes) are primarily a result of hatchery plantings (Williams 1998).

From Foster et al. 2002 (edited)):

Allopatric cold-water species such as cutthroat can flourish in much warmer environments than in sympatry, but they are vulnerable to displacement by species better suited to warmer temperatures such as the rainbow trout (Mullan et al. 1992 CPa). Westslope cutthroat trout reside in cold-water refugia where interactive threats from other species are absent because many populations are protected from invasion by barrier falls and most invaders are competitively debilitated by cold temperature. The brook trout is the lone exception. Brook trout, a cold-water species itself, may replace cutthroat in low gradient streams with sandy substrates. The threat from brook trout results from stocking them above an existing cutthroat trout population. The replacement of native westslope cutthroat trout in Eightmile Creek (Methow Basin) was due to stocking brook trout in a small, flat stream, ideally suited to the latter. Brook trout co-inhabit a number of streams with cutthroat, but the effect in production decreases for both species, not elimination of either. Hybridization with steelhead/rainbow trout results from the natural spawning interaction of cutthroat and steelhead/rainbow at their distributional point of contact where water temperature favors neither species (Mullan et al. 1992; Williams 1998). These hybridization zones are short, limiting the negative impact to either species.

Howell et al. (2003) found that genetically “pure” WSCT were found in suspected allopatric zones, which were usually limited to a few km in the upper reaches of WSCT distribution.

6.8.1 Adult migration

WSCT may migrate long distances, depending on the ecotype (Schmetterling 2001; Wydoski and Whitney 2003). Fish in the St. Joe River in Idaho were found to migrate up to 214 km (132 miles; Trotter 1987). In the Blackfoot River, Schmetterling (2001) found WSCT moved an average of 39 km (24 miles), and ranged from 12-72 km (20-45 miles) in 1998. No information is available for WSCT in the CCP for adult migration. However, given the size of some WSCT in the Methow River in recent years (> 500 mm (20 inches); Mazama Fly Shop, personal communication, photos), it seems reasonable to assume that these fish are most likely adfluvial ecotypes that probably spawn in the Upper Methow, Twisp and Chewuch rivers (and other tributaries). If this assumption is true, then fish may be easily migrating the average 39 km that Schmetterling (2001) found in the Blackfoot River.

Non-migratory ecotypes usually do not migrate over 1 km within the Blackfoot River (Schmetterling 2001), and usually appear in the CCP in areas upstream of physical or temperature barriers (Williams 1998; Wydoski and Whitney 2003).

6.8.2 Juvenile migration

Depending on life history, juveniles may move to a lake shortly after emergence if adfluvial-lacustrine (Behnke 2002), or may reside in tributaries for up to four years (Wydoski and Whitney 2003). Fluvial-adfluvial may either move quickly, or spend up to three years in a stream before moving to a larger stream (Shepard et al. 1984; Liknes and Graham 1988; Behnke 2002). For juveniles that had reared in streams for extended time periods (years), most moved to either lakes or larger streams during high stream flows (Wydoski and Whitney 2003).

6.8.3 Age structure

6.8.3.1 Adults

WSCT usually mature at 4 or 5 years of age (Downs et al. 1997; USFWS 1999), and the maximum life span is typically 6 to 8 years (Behnke 2002). Most fluvial-adfluvial ecotypes appear to mature at an earlier age than non-migratory forms (Downs et al. 1997; Schmetterling 2001; Wydoski and Whitney 2003). The oldest fish ever recorded was 13 years old in Wolf Creek, a tributary of the Methow River (Mullan et al. 2002 CPa) although Downs et al. (1997) cite personal communication with N. Horner of IDFG of stating they have found fish to this age in Idaho too.

From Foster et al. (2002):

The oldest westslope cutthroat trout ever reported in the literature (Mullan et al. 1992 CPa) flourished for 13 years amidst summer parades of visitors to the Gardner Meadow campsite at the head of Wolf Creek because there was little demand for this 6.3 inch trout. In addition, the state regulation minimum size of 8 inches, precluded retention.

6.8.3.2 Juveniles

As previously stated, juveniles may reside for very short time periods in their natal area before migrating to larger streams or lakes, or spend up to four years prior to migrating. While empirical information is limited, if the hypothesis that non-migratory ecotypes may give rise to migratory ones, there may be occasions when fish may begin their migratory life style after 4-5 years, as has been observed in steelhead (Peven 1990; Mullan et al. 1992 CPa).

6.8.4 Length at age

6.8.4.1 Adults

Non migratory adults fish are generally 150-250 mm (6-10 inches; Mullan et al. 1992 CPa; Downs 1997; Behnke 2002). Fluvial-adfluvial forms generally reach maximum sizes of between 410-470 mm (16-18.5 inches; Schmetterling 2001; Behnke 2002; Wydoski and

Whitney 2003), although Wydoski and Whitney have observed larger lacustrine forms (introduced) over 510 mm (20 inches).

Behnke (2002) notes that the relatively smaller size of adults of the WSCT compared to other cutthroat subspecies may be due to their coevolution with two highly piscivorous species, bull trout and northern pikeminnow. WSCT are rarely piscivorous and usually consist on aquatic and terrestrial insects.

6.8.4.2 Juveniles

Wydoski and Whitney (2003) reviewed length at age information for WSCT. At the end of their second year of life, WSCT ranged between 74-145 mm (3-5.8 inches). By the end of their 5th year, WSCT ranged from 140-320 mm (5.5-12.6 inches). WSCT from the CCP (Methow Basin) were consistently smaller at age (represented by the low end of the range at each age class) than WSCT lengths reported elsewhere in the literature.

6.8.5 Sex ratios

Downs et al. (1997) found the average sex ratio for WSCT in headwater streams in Montana to be 1.3 males per female across streams (n=8) that they sampled. In the CCP, Mullan et al. (1992 CPa) found 0.9 males per female in the 412 fish sampled in the Methow River, which comports well with values between 0.2-0.9 males per female reported in other studies (Bjornn 1957; Johnson 1963; Lukens 1978; Thurow and Bjornn 1978; May and Huston 1983; and Shepard et al. 1984). Downs et al. (1997) postulated that the differences in their findings compared to others may have been due to angling pressure (males were more readily removed from the population), and their samples were from non targeted populations. This may be true, however, Mullan et al.’s samples were primarily from fish that experience very little (if any) angling pressure. Another potential explanation is that it is possible that there are environmental differences that dictate the differences observed between sex ratios of different populations.

6.8.6 Spawning

WSCT spawn generally from March to July, when water temperatures rise in the range of 6-9 °C (43-48 °F; Behnke 2002; Wydoski and Whitney 2003). Individual fish may spawn in alternative years (Shepard et al. 1984; Liknes and Graham 1988). Schmetterling (2001) found that WSCT entered spawning tributaries when the flow began to increase. While spawning, he found that fish did not move more than 200 m within the spawning tributary.

6.8.7 Fecundity

Average fecundity reported in Downs et al (1997) for Montana headwater populations ranged from 227-459 eggs per female, and showed a relationship to length at maturity (length ranged from 162-218 mm (6.3-8.9 inches)). Brown (1984) reported fecundity of WSCT taken in the early hatchery on Lake Chelan for years 1916 through 1927. Fecundity ranged from 667-1,107 for fish that were estimated to be between 221-363 mm (8.7-14.3 inches) long. The probable reason for the difference observed in average size is most likely due to the differing life history of fluvial-lacustrine Chelan fish compared to the fluvial ecotype from Montana.

6.9 Redband trout

In the CCP, redband trout make up two life history ecotypes; anadromous and potamodromous (Behnke 2002; Wydoski and Whitney 2003). The two ecotypes are thought to be "interchangeable" if access to the ocean is available (Peven 1990; Mullan et al. 1992). Mullan et al. (1992 CPa) believed the life history of redband trout was dictated by the environment the fish rears in; it becomes "thermally fated" to a non-migratory life history if the physiological development does not match the timing to migrate to the ocean.

Some of the categories below will not be separated by adult and juvenile because this section addresses the non-migratory ecotype of redband trout.

6.9.1 Adult migration

In the Alagnak River in Alaska, Meka et al. (2003) found that rainbow trout exhibited varying life history ecotypes within the same basin, as determined by their migration patterns. They were able to determine and separate migratory behavior for spawning, refuge and trophic reasons. They determined that rainbow (*O. mykiss irideus* in this case) migrated 4-35 km (2.5-22 miles) for spawning migrations, 4-72 km (2.5-45 miles) to reach summer feeding habitat, and 3-60 km (2-37 miles) to reach suitable overwintering habitat.

Hockersmith (1995) estimated redband trout migrations in the Yakima River. The distance migrated during the spawning migration ranged from 0.3-87 km (.18-54 miles), with the majority of fish migrating less than 15 km (9 miles) from the tagging site. This behavior was similar to what Bjornn and Mallet (1964) found in the Salmon River Basin, Idaho in their study.

Both of the above studies demonstrate that non-anadromous forms of redband trout are capable of extensive and complex migratory behavior. We assume that some populations within the CCP most likely perform similar types of migration.

Because of the sympatric relationship between redband and steelhead, it is difficult to define adult migration of redband (non-migratory) in the CCP, but most likely follows the same queues and timing as described by Hockersmith et al. (1995).

6.9.3 Age structure

Most redband are thought to live 4-6 years (Behnke 2002). However, in the CCP, Mullan et al. (1992 CPa) found many individual fish age 8+ and one 9+, which is the oldest ever reported in the literature for North American stocks, but comports with Asian stocks (in Mullan et al. 1992). Most individuals that Mullan et al. sampled did not exceed 6 years of age. The few that exceeded this age were from the coldest headwater locations.

6.9.4 Length at age

Most of the non-migratory, stream dwelling redband trout grow to 150-250 mm (6-10 inches; Behnke 2003). This comports well with the findings of Mullan et al. (1992 CPa) in cold headwater sections of the Methow River Basin, but is much lower than other "rainbow trout" reported in Wydoski and Whitney (2003) for a given age class.

6.9.5 Sex ratios

In the colder, headwater streams of the Methow River Basin, Mullan et al. (1992 CPa) found that there were 0.86 females per male, which comported with the overall Methow basin of 0.91.

6.9.6 Spawning

Spawning usually occurs between February and June (Wydoski and Whitney 2003). Hockersmith et al. (1995) found that redband trout of the Yakima River Basin began their spawning migration in March and April in response to increased water temperature and flow.

6.9.7 Fecundity

Fecundity ranges from 200 to over 9,000 eggs per female (Wydoski and Whitney 2003). Peven (1990) used data from Hartman (1959) and regressed fork lengths of 239-464 mm (9.4-18 inches) to obtain fecundity estimates of 536-2,142. This comports well with data from the Yakima River, where fish ranging from 292-393 mm (11.5-15.5 inches) long and had fecundities of 703-1,411 eggs per female (reported in Wydoski and Whitney 2003).

6.10 White sturgeon

Little information is known of white sturgeon within the CCP. In recent years, more information is being collected through various relicensing processes for the three PUDs.

6.10.1 Adult migration

It appears from sonic tagging studies that white sturgeon appear mostly inactive during the late fall to spring (Golder Associates 2003CPa, 2003CPb). Spawning migration in the Wanapum Reservoir occurred between April and June. Since movement is primarily limited by the dams (apparently in the lower Columbia River, adult sturgeon have been documented to use the ladders, but it is inconsistent; Golder Associates 2003CPa), no large movements are believed to occur in the reservoirs of the CCP.

6.10.2 Juvenile migration

Juvenile white sturgeon appear to migrate downstream during winter and early spring, and the movements are thought to be primarily to increase trophic opportunities (in Golder Associates 2003CPa).

6.10.3 Age structure

Sturgeon are known to live in excess of 100 years (Beamesderfer and Nigro 1995). The median age of maturity of lower Columbia River sturgeon is 24 years, and 95% were mature between the ages of 16 and 35 years (Wydoski and Whitney 2003). This comports well with the data collected on fish in the Wanapum and Rocky Reach reservoirs of the CCP (Golder Associates 2003CPa, 2003CPb).

In the recent studies by Golder Associates (2003CPa, 2003CPb), ages of sturgeon sampled are estimated between 3-50 years. This suggests successful spawning is occurring in the

CCP of white sturgeon. However, younger age classes could be emigrating from upstream areas, although successful spawning has been documented within the CCP (see below).

6.10.4 Length at age

Sturgeon can attain lengths of greater than 381 cm (12.5 feet; Wydoski and Whitney 2003). Some white sturgeon reach sexual maturity at about 120 cm (4 feet) for males and 180 cm (6 feet) for females, however, most fish mature at a larger size (Wydoski and Whitney 2003).

In the CCP, sturgeon caught in the Wanapum and Rocky Reach reservoirs appeared to have two length modes; one roughly between 45-100 cm (1.5-3.3 feet), and the other from about 150-250 cm (5-8 feet; Golder Associates 2003CPa, 2003CPb). This comports well with the information presented in Wydoski and Whitney (2003), where white sturgeon throughout the west coast ranged 48-81 cm (1.5-27 ft) for 5-year-old fish to 160-241 cm (5.3-8 ft) 30 year old fish.

6.10.6 Sex ratios

For fish captured in the Wanapum and Rocky Reach reservoirs, the overall sex ratio was 1:1 (Golder Associates 2003CPa, 2003CPb). Because of relatively small sample sizes (especially in the Rocky Reach reservoir), this may or may not be representative of the total population.

6.10.7 Spawning

In the lower Columbia River, McCabe and Tracy (1993) found the spawning period extended from late April or early May through late June or early July of each year. Spawning occurred primarily in the fast-flowing section of the river downstream from Bonneville Dam, at water temperatures ranging from 10 to 19 °C. Freshly fertilized white sturgeon eggs were collected at turbidities ranging from 2.2 to 11.5 NTU, near-bottom velocities ranging from 0.6 to 2.4 m/s, mean water column velocities ranging from 1.0 to 2.8 m/s, and depths ranging from 3 to 23 m. Bottom substrate in the spawning area sampled was primarily cobble and boulder. White sturgeon deposit their eggs by “broadcast” spawning. Only a small percentage of white sturgeon spawn on a given year. Intervals between spawning have been estimated to be between 3 and 11 years (Wydoski and Whitney 2003).

Sturgeon appeared to begin their spawning migration in May in the Wanapum Dam reservoir when water temperatures were between 8-13 °C (Golder Associates 2003CPa). This comports with spawning in the lower Columbia River (Wydoski and Whitney 2003).

Spawning has been documented in the CCP only in the tailrace of Rock Island Dam (Wanapum Reservoir; Golder Associates 2003CPa), but has not been ruled out in the Rocky Reach reservoir because of a strong showing in the samples of the 1997 brood (Golder Associates 2003CPb).

6.10.8 Fecundity

Mature white sturgeon commonly produce between 100 and 300 thousand eggs, although larger fish may produce up to 3 million eggs (Wydoski and Whitney 2003). No data has been collected to date in the CCP for fecundity of white sturgeon.

In conclusion, Table CP9 summarizes pertinent life history information for all focal species of the CCP.

7 Potential unique population segments

7.1 Genetic subdivisions among spring-run collections

Each of the three cluster analyses discussed in Chapman et al. 1995 CPa and Utter et al. 1995 suggests the existence of some degree of genetic distinctness among the spring-run fish. Collections of wild fish from the Entiat River and White River diverged at respective distances of 0.01 and 0.007 from two less distinct groups of collections joining at a distance of .005.

7.2 Genetic conclusions for spring-run collections

The much smaller magnitude of difference among the spring-run collections than between these and the summer/fall-run fish requires a more cautious approach to deriving genetic conclusions about apparent relationships within this group. At this level, distinctions may be based on one or more possibilities other than a real genetic divergence; including non-random sampling, year-class variation, and problems in recording raw data. The following tentative conclusions were derived with such alternative possibilities in mind, drawing in additional information from source where appropriate.

The most obvious distinctions among the spring-run fish are the outlying collections in each of the dendrograms that were presented in Chapman et al. (1995 CPa). The outlying Entiat collection contrasts with a different Entiat collection, which does not suggest a distinction of this group within other spring-run fish. The data for another collection were considered more representative in view of the extensive history of translocation and hatchery influence (discussed below) in this basin. The data for one of the collections recorded seven sampling areas over a three-mile stretch. Nevertheless, most of the fish could have been progeny of a few matings taken at a single area, and the aberrant data a reflection of the inevitable biases arising from such a "bottleneck".

A similar explanation is suggested for the consistent divergence of one of the juvenile collections from the other collections of Chiwawa River fish. The juvenile progeny of Chiwawa River adults were sampled during hatchery rearing for one collection. The observed differences are primarily attributed to one or more possible sources of bias (Marshall and Young 1994) including limited numbers of parents, differential family survival, and non-random sampling of juveniles. The spring chinook salmon of the Chiwawa River, then, like those of the Entiat River, are not considered strongly diverged from other groups upstream from Rock Island Dam. White River collection diverged from the clusters comprising most of the spring-run populations. The collection of adult fish is considered less vulnerable to potential sampling biases affecting juveniles. However, attempts to minimize these biases, coupled with the concurrence of allelic data with other regional groups, preclude an easy dismissal of one of the collections data as artifactual. The independent distinction of the one collection with data not available for another collection, favors consideration of the adult collection as representative of this drainage, but indicates a need for testing this conclusion with further sampling. Chinook of the White River are therefore tentatively considered a divergent group from other spring-run fish of this region.

Finally, a somewhat divergent group of Methow River wild fish is suggested, based on the collections from the Twisp River, the Chewuch River, and the Lost River, aggregating within a common cluster (where the inclusion of Chiwawa R. collection is disregarded as an artifact based on previous discussion). The magnitude of these distinctions is slight. Further sampling is needed to determine whether persisting wild spring chinook populations exist that are distinguishable from hatchery-maintained populations of the Methow drainage, and other wild spring-run populations of this region.

7.3 Influences of management activities

This section addresses management activities over the past 60 years that have had actual or potential influences on the genetic structure of spring-run chinook salmon populations upstream from Rock Island Dam. This information is reviewed in Utter et al. (1995) and much of this section is taken directly from this source.

Two related activities drastically changed the population structure of mid-Columbia River chinook salmon during the 1930s and 1940s. The impoundment of Grand Coulee Dam in 1939 permanently blocked access of anadromous salmonids to over 1,000 miles of upstream spawning and rearing habitat. In compensation for this loss, the GCFMP intercepted upstream migratory salmonids at Rock Island Dam from 1939 through 1943 for relocation in tributaries downstream from Grand Coulee Dam. Details of these events relating to spring chinook salmon were outlined earlier in our report. These interceptions, translocations and admixtures permanently transfigured the populations of anadromous salmonids upstream from Rock Island Dam, providing a foundation for the present population structures.

The extreme modifications on population structures initiated by the GCFMP have been complicated by subsequent cultural activities persisting through the present. The most obvious manipulations involve introductions of fish from regions beyond the Upper Columbia River. A review of such introductions indicates a continual influx of exogenous populations of diverse geographic and ancestral origins (e.g., Peven 1992 CPb).

The most persistent and extensive of these introductions involves the Carson Hatchery, on the Wind River (enters the Columbia River on the Washington side of the Bonneville Dam pool). This population was derived from spring-run fish destined for the Snake and the mid-Columbia region and intercepted at Bonneville Dam starting in 1955 (Ricker 1972). The spring-run fish of the adjacent Little White Salmon River Hatchery were derived at least in part from Carson fish (Howell et al. 1985). A dependency of both the Leavenworth and Entiat hatcheries on Carson fish through the 1970s into the 1981 brood year ultimately gave way to full hatchery production from spring-run salmon returning to the respective hatcheries (Peven 1992 CPb). Presumably, the current brood stocks of both hatcheries reflect a virtually 100% Carson Hatchery ancestry. The contributions of these massive releases and other exogenous releases to the wild populations of these drainages (Mullan 1987) are unknown.

The above account of the GCFMP and of subsequent hatchery activities on chinook salmon populations of the mid-Columbia River are but a brief synopsis of the overall and continuing influence of these activities. Nevertheless, the material presented is sufficient to document profound actual and potential effects on these populations.

7.4 Synthesis from genetic and historical information

Joint consideration of the genetic and historical information provides additional insights into the current status of spring-run chinook salmon populations upstream from Rock Island Dam. The major points from these preceding sections include:

- spring-run populations are genetically distinct from summer/fall fish;
- the strongest evidence for genetic isolation within the spring-run fish came from adult collections of the White River, and the existence of isolated wild populations was suggested within the Methow drainage;
- both of these possibilities require verification with further sampling;
- the basis for all current distributions upstream from Rock Island Dam lies in relocations and mixing of populations over five consecutive years under the GCFMP;
- releases of cultured fish under the GCFMP included possible crosses between late spawning spring-run and early spawning summer/fall fish;
- extensive subsequent releases have included origins from gene pools beyond the mid-Columbia River;

Further conclusions can be derived from this combined information: First, there are no detectable residual effects from the mixed spring-summer releases under the GCFMP. No intermediate groups are evident to suggest persistence of a hybridized spring-run x summer/fall ancestry. Inspection of the allelic data of the presumed distinct White River spring-run population indicates a recent (i.e., post GCFMP) divergence from pure spring-run ancestry; no alleles or allele frequencies are apparent that tend toward the summer/fall group.

Similarly, most of the populations represented in the exogenous releases appear to have left no detectable descendants. Each population derived from or beyond the lower Columbia River (McKenzie, Spring Creek, Eagle Creek, Cowlitz, Simpson, Elokomin) represents lineages distinct from either of the resident groups produced upstream from Rock Island Dam (Utter et al. 1989). Presumably, these fish and the above-noted hybrid progeny were poorly adapted to the habitats of their release and failed to make a permanent contribution to the Upper Columbia River gene pools.

The lower river populations that derived from mixed upriver ancestry tell a different story. The continued infusion of Carson-derived spring-run fish ultimately resulted in self-sustaining mid-Columbia River hatchery populations, and is discussed in greater detail in a subsequent section of this report.

There seems little doubt that chinook salmon populations can adapt quickly to new environments. Quinn and Unwin (1993) discuss the rapid apparent adaptation of chinook salmon liberated in New Zealand about 1905. They point out that if the differences (freshwater age, marine age, length at age, weight at length, fecundity at length, and timing of migration and spawning) are caused by genetic divergence, such rapid evolution would provide a new perspective on the stock concept in salmon. Populations would be seen as more plastic than commonly believed.

7.5 Genetic effects of hatchery fish on wild spring chinook

Waples et al. (1990) described the potential for hatchery salmonids to interact with wild fish, arguing that it has increased in recent decades. He listed three issues: (1) direct genetic effects caused by hybridization and introgression; (2) indirect genetic effects largely due to altered selection regimes or reduced population size caused by competition, predation, disease, or other factors; and (3) genetic changes to hatchery stocks through selection, drift, or stock transfers, which magnify consequences of various management options.

7.6 Direct genetic effects:

Homing permits local adaptation. If hatchery fish, such as Leavenworth or Winthrop hatchery fish with extensive Carson Hatchery background, strayed extensively into tributaries used by wild spring chinook, one might expect hybridization to occur with detectable consequences. No direct evidence exists that such hybridization has occurred in Wenatchee or Methow tributaries used by wild chinook in spite of similar allele frequencies of Leavenworth Hatchery fish and wild stocks of the Chiwawa River and Nason Creek. Chapman et al. (1991) extensively reviewed information on homing in spring chinook. They noted that carcass checks in the Upper Columbia region revealed very limited Leavenworth Hatchery strays among tags sampled in 967 carcasses examined within Wenatchee River tributaries (excluding Icicle Creek) or in the Entiat and Methow rivers. Many hatchery tags were recovered from Icicle Creek, into which Leavenworth Hatchery fish are released.

For the Chiwawa Hatchery program, there have been some years where a large portion of the returning adults have spawned in the Upper Wenatchee River basin outside of the Chiwawa River, making up a substantial proportion of the spawners in some years (A. Murdoch, WDFW, personal communication). However, it should be noted that during the GCFMP, chinook were not introduced into any tributary in the Upper Wenatchee Basin outside of Nason Creek. All current tributary spawning aggregates besides Nason Creek have been formed by “strays” from those plants in Nason Creek in the early 1940s.

Quinn and Fresh (1984) reported that straying was higher in older spring chinook, reaching over 3% in fish five years old, but for all combined ages equaled only about 1.4%. They also found that straying rate was higher in small escapements than in large ones. Straying was 3.8% for an escapement of about 4,500, 2.3% for an escapement of 6,134, and 1.6% and 0.3% for respective escapements of 12,384 and 18,069.

Information is very limited on negative effects of hybridization of wild and hatchery chinook. Williams (1990) reported that declines in chinook salmon redds in hatchery-supplemented streams have exceeded those in unsupplemented streams. Nickelson et al. (1986) reported declines in coho (*O. kisutch*) populations where hatchery coho were used to supplement natural production. As Waples et al. (1990) points out, such declines are doubly damaging if wild runs are "mined" to produce hatchery fish with lower survival than progeny of wild adults.

7.7 Indirect genetic effects:

Large numbers of hatchery fish, mixed with wild ones, can lead to excessive harvest on the wild run component. Where excessive escapement of hatchery fish occurs, even a small percentage of straying can lead to a high fraction of hatchery fish in wild production areas. Hatchery fish of Carson origin, released in the main Grande Ronde River, strayed to, or colonized, wild fish sanctuary areas in the Wenaha and Minam rivers, and made up over 70% of spawners in those areas in at least two years (ODFW et al. 1989).

Another indirect effect of hatchery fish on genetics is ocean carrying capacity. Ocean carrying capacity may be limited and density-related interactions may occur at sea (Beamish and Bouillon 1993). To the extent that hatchery-produced fish reduce carrying capacity of ocean rearing areas for wild fish, an indirect genetic effect can occur.

Any factor that affects abundance of wild populations can also alter selective pressures and cause directional genetic change in wild stocks (Waples et al. 1990). Examples include selective fishing pressure caused by propensity of wild Snake River chinook to stay at sea more often for three years instead of two years (Chapman et al. 1991). In the Upper Columbia region, hatchery and wild spring chinook do not differ materially in number of years that they spend at sea. Longer time at sea could expose wild fish to relatively more incidental catch and hooking-related mortality, as well as natural mortality. Gill nets may tend to take larger fish, selecting against three-ocean wild fish. Both fisheries would appear to be minor in potential effect at present harvest rates.

7.8 Genetic changes in hatchery stocks:

Waples (1991) cited Utter et al. (1989) and Waples et al. (1990) as demonstrating no trend toward reduced heterozygosities in hatchery chinook salmon in comparison with wild chinook in the same region. Waples and Teel (1990) and Waples and Smouse (1990) found unexpectedly high allele frequency changes and gametic disequilibrium in hatchery, but not wild, chinook stocks from the Oregon coast. Those authors suggested that the explanation lay in the low effective number of breeders (N_b) < 50). Waples (1991) suggests that a figure in this range is possible for many of the hatcheries included in the study by Waples and Teel (1990).

Genetic data collected from samples of the Winthrop National Fish Hatchery (NFH) population in 1992 (n=100) and Winthrop Hatchery-origin adults intercepted at Methow Hatchery in 1994 (n=25), and from Twisp and Chewuch rivers naturally produced adults in 1992, 1993, and 1994 (n=112 and n=158 in total, respectively) showed significant genetic differentiation among the wild and hatchery populations. Methow River mainstem natural spawners sampled in 1993 and 1994 showed significant genetic differentiation from Twisp and Chewuch populations, but were less differentiated from the Winthrop NFH population. Some of the Methow mainstem spawners were found to have hatchery scale patterns, and were believed to be Winthrop NFH-origin. In general, the three naturally reproducing populations, prior to start-up of Methow Hatchery supplementation operations, were more closely aligned with each other than with the Winthrop NFH population, which was genetically closer to Leavenworth, Entiat and Carson NFH populations. Twisp River spring chinook were the most highly divergent among the three naturally reproducing Methow Basin populations.

The following excerpt from Ford et al. (2001) adds additional information concerning the delineation of populations in the Upper Columbia:

Spring chinook salmon population structure:
As a group, we discussed a variety of hypotheses about Upper Columbia River spring chinook salmon population structure, including scenarios with as few a single independent population and as many as eleven or more independent populations. Based on the data and analyses discussed above, we suggest that historically there were probably at least three independent populations of spring chinook salmon in the Upper Columbia River area. These spawned in the Wenatchee, Entiat and Methow River Basins. There is some anecdotal evidence that the Okanogan River Basin may have also contained an independent spring chinook salmon population. There are two primary lines of evidence supporting a three or four independent population hypothesis: 1) The spring chinook spawning grounds in these four major tributaries are geographically isolated from each other by lower reaches of the tributaries and sections of the mainstem Columbia River. Chinook salmon are generally not expected to stray at substantial rates between rivers of this size (reviewed by Quinn et al. (1991)); 2) Mark/recapture studies with hatchery reared spring chinook released in the Upper Columbia River area provide direct evidence that rates of straying among the major tributaries are low. Other evidence supporting this conclusion includes: 1) Trends in redd counts are somewhat less correlated among the major tributaries than within the major tributaries; 2) There are significant differences in length-at-age between fish sampled from the different major tributaries; and 3) The major tributaries differ with respect to several environmental variables, which could promote reproductive isolation. The low level of genetic divergence observed between spawners in the major tributaries is consistent with this scenario if populations were substantially homogenized during the GCFMP. There is still some uncertainty about whether or not there are (or were) multiple independent populations within one or more of these major tributaries. Some particular areas of uncertainty are discussed below:

White River/Little Wenatchee River
We concluded that there is uncertainty about whether spawners in the White River (possibly combined with the Little Wenatchee due to its geographic proximity) should be considered an independent population in their own right or a subpopulation of a greater Wenatchee River population. The evidence pointing toward demographic independence is: 1) The White River samples are the most distinctive in terms of allozyme allele frequencies, and based on these frequencies the estimated rate of gene flow from other areas is quite low; 2) Very few marked Chiwawa Hatchery fish have been recovered in the White River; and 3) Lake Wenatchee may geographically separate the spawning grounds in the White and Little Wenatchee Rivers from other areas in the Wenatchee River Basin.

The evidence pointing toward non-independence is: 1) During the GCFMP (1939-1943) adult spring chinook trapped at Rock Island Dam were planted only in Nason Creek or were artificially spawned. Planted adults in Nason Creek were fenced in to keep them from spawning elsewhere, and artificially propagated fish were not released in the White River or any other tributaries other than Nason Creek (Chapman et al. 1995). Assuming that these actions had the effect of eliminating spawning in the White River for at least several years, this implies that the current White River (sub)population resulted from recolonization soon after the GCFMP ended. This suggests that the spawners in the White River are effectively demographically connected to other spawning groups, because if the White River spawners were to go extinct they could be rapidly recolonized by fish from other areas; 2) The estimated spawning abundance in the White and Little Wenatchee Rivers has never been particularly large, and has always been far lower than simple population viability guidelines of several thousand spawners per year. An estimate of the potential spawning abundance in the White River based on habitat area also suggests that this (sub)population does not have the potential to be very large (D. Chapman, pers. com.). Together, these data suggest the possibility that even if it is independent, the White River population might not have a negligible risk of extinction over a 100 year time frame; 3) Even prior to the GCFMP, spring chinook spawning abundance in the Upper Wenatchee River Basin was very low (Fish and Hanavan 1948; Mullan et al. 1992), further suggesting that current patterns of population structure in Wenatchee River are of relatively recent origin. The level of genetic differentiation between the White River sample and other samples is consistent with the hypothesis that the White River (sub)population diverged from the other groups after 1943.

Icicle Creek
We concluded that the spawners in Icicle Creek are probably currently part of an independent population that also includes spawners in Leavenworth NFH. Mark/recapture data and the lack of abundance correlations with any other index area support this conclusion. However, this independence may be due to the strong influence of Leavenworth NFH. The historical degree of isolation between spring chinook spawning in Icicle Creek and other spawning groups in the Wenatchee River Basin is not known, although the mark/recapture data suggest that Chiwawa River spring chinook do not stray in large numbers to Icicle Creek. The Icicle Creek spawning area may be geographically separated from other areas in the Wenatchee River Basin by Tumwater Canyon, but we do not know if this potential geographic isolation would result in substantial reproductive isolation from other areas in the Wenatchee River Basin over 100 year time frames. In any case, the stock currently being propagated at the Leavenworth NFH is not considered to be part of the Upper Columbia spring chinook ESU, so the current Icicle Creek population cannot be 'counted' for recovery purposes (NMFS 1999).

Twisp River
Samples from the Twisp River are nearly as genetically distinctive as those from the White River at the allozyme loci surveyed, and the estimates of divergence time and gene flow suggest that spawners in the Twisp River could be substantially reproductively isolated from other groups. On the other hand, the spawning areas in the Twisp River are not geographically disjunct from other spawning areas in the Methow River Basin, and

mark/recapture experiments suggest that homing fidelity of hatchery fish released in the Twisp River is not particularly high. During the GCFMP, neither adults nor juveniles were released into the Twisp River (Chapman et al. 1995), suggesting that the current (sub)population there may be the result of recolonization shortly after the GCFMP ended. If so, this suggests that recolonization would occur quickly following extinction, suggesting a demographic connection to other spawning groups in the basin.

Summary and conclusions for spring chinook salmon

We believe that the weight of the evidence suggests that there are (or historically were) three or four independent populations of spring chinook salmon in the upper Columbia River Basin, inhabiting the Wenatchee, Entiat, Methow, and (possibly) Okanogan River basins. There appears to be considerable population substructure within one or more of these major tributaries (see, e.g., discussion on the White and Twisp Rivers above), however, and this population substructure should be considered when evaluating recovery goals and management actions. Spring chinook spawning in Icicle Creek and Leavenworth NFH are an independent population, but this population is not considered part of the Upper Columbia spring chinook ESU (NMFS 1999).

Steelhead population structure

A complete understanding of the historical population structure of Upper Columbia steelhead appears impossible to achieve. However, based primarily on current and historical spawning distributions and the assumption of reasonably accurate homing rates, we believe that historically there were at least three (possibly four) major populations of steelhead in the Upper Columbia River area, one each in the Wenatchee, Entiat, Methow, and Okanogan River Basins. Due to lack of detailed data on spawning locations and straying patterns, the very limited nature of the existing genetic data, and long history of extensive artificial propagation of Upper Columbia River steelhead, it is impossible rule out the possibility that one of more of these major tributaries could have historically contained more than one independent population.

Since the late 1960s (and perhaps since the 1940s), steelhead in the Upper Columbia River area may have been functionally part of the same population, due to very large scale supplementation from a common hatchery subpopulation. The existing genetic data are consistent with this conclusion, but they do not rule out the possibility that independent populations have persisted despite large-scale supplementation. Even if large-scale supplementation has resulted in a single independent population, this does not preclude multiple independent populations from existing in a recovered ESU.

8 Conclusion

Current information suggests that there are at least three independent populations of Upper Columbia spring chinook and four populations of summer steelhead. For summer/fall chinook, there is one large metapopulation in the upper Columbia River. There are two independent populations of sockeye in the upper Columbia. Coho are extinct in the CCP, but the recent feasibility study by the YIN has shown promise. The population structure of

Pacific lamprey in the CCP is not known, but we assume the potential for one large metapopulation with subpopulations within each tributary. Currently, there appears to be three independent populations of bull trout within the CCP, although recent telemetry information blurs this distinction. An accurate understanding of the population dynamics of westslope cutthroat and non-migratory redband trout does not exist, and has been further complicated because of past hatchery plants. Sturgeon that once migrated the entire Columbia River are now thought to reside in somewhat isolated populations between dams, although some movement is know to occur, especially downstream.

Recent (since the 1960s and 1970s) evaluations have shown that spring chinook and steelhead runs have fluctuated greatly, but total numbers have increased over this time. However, the composition of the runs has changed from primarily naturally produced fish to a reliance (steelhead) on hatchery fish. Current (since 2000) run sizes suggest overall improvements in smolt-to-adult survival since both hatchery and naturally produced fish have increased (to recent record numbers). Currently, the metapopulation of summer/fall chinook appears to be healthy, with recent-record historic high numbers in the CCP. Sockeye numbers are highly volatile, but overall, they do not appear in danger of extinction. The YIN coho reintroduction program has shown promise, and the hope is that they can "build" a naturally reproducing population in the CCP. Pacific lamprey, while apparently reduced in number from historical levels, appears to be rebuilding in recent years. Additional information on the status of WSCT and non-migratory redband trout is needed. For management purposes, habitat improvement and conservation of tributary spawning and rearing habitat will increase the likelihood of improving and sustaining populations of bull, westslope, and redband trout. Work is on-going on the mainstem Columbia River to identify life history and conservation measures for white sturgeon.

The area upstream of Rock Island Dam was historically a good producer of these salmonids and lamprey. From all available information, the original decline occurred at the end of the 1800s. Factors such as degradation of spawning and rearing areas, un-screened irrigation channels, and over-fishing in the lower river all contributed to the original reduction of the runs. When Grand Coulee Dam was being built, a program implemented by the USFWS captured all fish stocks at Rock Island Dam (no mention of lamprey) and co-mixed them and planted them in designated tributaries or raised and released them from newly built hatcheries. While the conclusions vary as to the degree of success of this program, it had a profound influence on the make up of current stocks (with the potential exclusion of Pacific lamprey). Coho were so severely depleted by the time of the GCFMP, efforts were made to introduce fish from exotic broodstocks, which were unsuccessful.

The current hydrosystem on the Columbia River reduces the resiliency of these of most of these populations. Management actions should focus on meeting survival goals through the hydrosystem and improving habitat conditions within spawning and rearing areas.

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