FACTORS FOR DECLINE

3.4.5 EFFECTS OF HYDROELECTRIC DAMS ON VIABILITY OF WILD FISH

The existence and operation of the Columbia River Hydrosystem poses risks to wild populations of anadromous salmonids. Run-of river dams present passage obstacles to both adult and juvenile migrants, and the water management of storage reservoirs for hydropower production has reshaped the seasonal hydrograph. Both of these elements have had deleterious effects on salmon resources in the basin. This section focuses on Upper Columbia River populations, but in some cases refers to data from the Snake River or lower Columbia to illustrate basic principals.

Effects on Juvenile Life Stages

Migrating smolts of all species traverse the impounded mainstem Columbia during their seaward journey, most notably the two ESUs of Upper Columbia spring chinook and summer steelhead. Also, egg-through-smolt life stages of ocean-type summer/fall chinook incubate, rear, and migrate through the upper and lower Columbia River segments. During downstream migration smolts encounter two general classes of effects, those associated with passage at the dams and those experienced within the reservoirs.

Smolt travel time and survival through a series of projects (dam & pool) are two key indices used to assess the effects of the hydrosystem on the performance of salmon populations. Typically PIT-tagged hatchery fish or a mixture of hatchery and wild fish are used as indicator stocks. In the Snake River, known wild fish are used on a regular basis, but in the Upper Columbia there has been no concerted effort to tag known wild fish. Therefore, in the Upper Columbia, managers must rely on hatchery and mixed populations to generate performance indices. However, the hatchery and mixed populations have generally proved to be adequate surrogates for representing the migratory characteristics of wild populations…… within the impounded Columbia-Snake River system (Cite NMFS and USFWS studies). Herein, this section relies on the same complex of populations for representing wild stocks from the Upper Columbia.

Salmon Migration and Survival

As noted elsewhere in this plan, both Mullan et al. (1992) and Chapman et al. (1994, 1995) identified the construction and operation of the Columbia River hydrosystem as a primary agent contributing to the decline of spring chinook and steelhead populations in the upper Columbia. Chapman et al. (1994, 1995) arrived at the same conclusion for sockeye and summer/fall chinook as well…Our discussions focus on spring chinook and steelhead, but in most cases will apply to sockeye as well. Ocean-type summer/fall chinook populations that migrate during the summer face unique conditions. We do not discuss details for ocean-type chinook at his time.

Smolts

Dam Passage Effects

Smolts passing each dam incur effects that result in elevated mortality. Survival rates differ among passage routes and dams. Skalski & Giorgi summary here

Migration Rate Effects

The emplacement of nine dams on the mainstem Columbia has slowed river velocities considerably. This has resulted in slower migration rates through the impounded system. To illustrate this, Ebel and Raymond (1976) and Bentley and Raymond (1976), for example, estimated that after dam emplacement, travel times of yearling chinook salmon and steelhead increased at least two-fold over pre-impoundment conditions. Slower migration seaward can affect smolt survival inriver and perhaps at seawater entry. Inriver, smolts have increased exposure time to predatory species and changing water conditions. Both of these can result in higher mortality than realized under pre-impoundment conditions. The physiological process of smoltification continues during seaward migration (Rondorf old work, Muir & Giorgi photoperiod). A protracted migration may result in suboptimal development and compromise seawater adaptation and survival, although this remains to be definitively demonstrated. Clearly, evidence for steelhead indicates that exposure to warming inriver temperatures depresses the smoltification process and promotes recidivism when temperatures exceed 12-13˚C.

Also, slower migration may result in other types of delayed effects that could be manifested in the form of poor marine survival. Congleton et al. (2002) monitored the physiological condition of stream type spring/summer chinook salmon migrating from Lower Granite Dam to Bonneville Dam during 1998-2002. They found that body lipid and protein masses decreased significantly and with increased travel time. Slower migration forces juveniles to use caloric reserves beyond levels expected to occur under a free-flowing river, yielding swift migration speed. Such a tax on body reserves could compromise smolt survival, particularly during early seawater residence.

Adults

Dam Passage Effects

Chief Joseph Dam lacks an adult fishway and has blocked passage to spawning and rearing areas above that site since …. When the dam was completed. Spring chinook & steelhead……( ). All Other dams from Wells to Bonneville are equipped with adult fishways that permit upstream passage. Although these dams are obstacles, they do provide effective fish passage ways in most cases. Some fishways have been found to be problematic because their specific location or configuration exacerbates fallback. ……………………..

Migration Rate Effects

ECOLOGICAL RELATIONSHIPS

2.4.1 FISH AND WILDLIFE THAT INTERACT WITH FOCAL SPECIES

The biotic communities of aquatic systems in the Upper Columbia Basin are highly complex. Within communities, assemblages and species have varying levels of interaction with one another. Direct interactions may occur in the form of predator-prey, competitor, and disease- or parasite-host relationships. In addition, many indirect interactions may occur between species. For example, predation of one species upon another may enhance the ability of a third species to persist in the community by releasing it from predatory or competitive constraints (e.g., Mittelbach 1986; Hillman et al. 1989a). These interactions continually change in response to shifting environmental and biotic conditions. Human activities that change the environment, the frequency and intensity of disturbance, or species composition can shift the competitive balance among species, alter predatory interactions, and change disease susceptibility. All of these changes may result in community reorganization.

Our purpose in this section is to identify species that are likely to interact with chinook and steelhead in the Upper Columbia Basin. A more detailed description of the effects of interactions on chinook and steelhead is presented in the section on Factors For Decline.

Community Structure

Few studies have examined the fish species assemblages within the Upper Columbia Basin. Most information available is from past surveys (e.g., Dell et al. 1975; Dobler et al. 1978; McGee et al. 1983; Burley and Poe 1994; Hillman 2000; Duke Engineering 2001), dam passage studies (e.g., Mullan et al. 1986; Tonseth and Petersen 1999; Chelan PUD unpublished data), and northern pikeminnow studies (e.g., Burley and Poe 1994; West 2000). The available information indicates that about 41 species of fish occur within the Upper Columbia Basin (from the mouth of the Yakama River upstream to Chief Joseph Dam) (Table 1). This is an underestimate because several species of cottids (sculpins)[1] live there. Of the fishes in the basin, 15 are cold-water species, 18 are cool-water species, and 8 are warm-water species. Most of the cold-water species are native to the area; only four were introduced (brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), lake whitefish (*Coregonus clupeaformis*), and Atlantic salmon (*S. salar*)). Four of the 18 cool-water species are exotics (pumpkinseed (*Lepomis gibbosus*), walleye (*Stizostedion vitreum*), yellow perch (*Perca flavescens*), and smallmouth bass (*Micropterus dolomieu*)), while all warm-water species are exotics (Table 1).

Anadromous species within the upper basin include spring and summer/fall chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), steelhead (*O. mykiss*), and Pacific lamprey (*Lampetra tridentata*). Atlantic salmon (*Salmo salar*) are also anadromous, but their status in the basin is largely

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[1] At least three species of sculpins have been identified in the Upper Columbia Basin. They include Prickly sculpin (*Cottus asper*), torrent sculpin (*C. rhotheus*), and shorthead sculpin (*C. confuses*).

unknown. White sturgeon (*Acipenser transmontanus*), which may have been anadromous historically, are present as a resident population.

About half of the resident species in the upper basin are piscivorous (eat fish) (Table 1). Ten cold-water species, seven cool-water species, and five warm-water species are known to eat fish. About 59% of these piscivores are exotics (Table 1).[2] Before the introduction of exotics, northern pikeminnow (*Ptychocheilus oregonensis*), sculpin (*Cottus* spp.), white sturgeon, bull trout (*Salvelinus confluentus*), rainbow trout (*O. mykiss*), cutthroat trout (*O. clarki*), and burbot (*Lota lota*) were the primary piscivores in the region (Li et al. 1987; Poe et al. 1994). Presently, burbot are rare in the upper basin (Dell et al. 1975; Burley and Poe 1994) and probably have little effect on the abundance of juvenile chinook and steelhead in the region. The status of white sturgeon in the upper basin is mostly unknown, although their numbers appear to be quite low (DeVore et al. 2000).

Introduced species such as walleye, smallmouth bass, and channel catfish (*Ictalurus punctatus*) are important predators of chinook and steelhead in the Columbia River (Poe et al. 1994). Channel catfish are rare (Dell et al. 1975; Burley and Poe 1994) and likely have little to no effect on abundance of chinook and steelhead. Other piscivores, such as largemouth bass (*M. salmoides*), black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), brown bullhead (*Ameiurus nebulosus*), yellow perch, and pumpkinseed are either rare or not known to prey heavily on juvenile anadromous fish (Dell et al. 1975; Burley and Poe 1994).

What follows is a brief summary of interactions of fish, birds, and mammals with spring chinook and summer steelhead in the Upper Columbia River Basin.

Competition

Competition among organisms occurs when two or more individuals use the same resources and when availability of those resources is limited (Pianka 2000). That is, for competition to occur, demand for food or space must be greater than supply (implies high recruitment or that the habitat is fully seeded) and environmental stresses few and predictable. Two types of competition are generally recognized: (1) interference competition, where one organism directly prevents another from using a resource through aggressive behavior, and (2) exploitation competition, where one species affects another by using a resource more efficiently. Salmonids likely compete for food and space both within species (intraspecific) and between species (interspecific). Interspecific interactions are more likely to occur between native and exotic species, rather than between species that coevolved together.

Although coevolved sympatric species should segregate (i.e., partition resources in space or time or both), native species may still interaction along the margins of their spatial and temporal distributions. An example of this may occur between chinook salmon and

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[2] Although 59% of the piscivores are exotics, these exotics constitute a small fraction of the total fish biomass within the project area (S. Hays, Chelan PUD, personal communication).

steelhead. This interaction was studied in the Wenatchee Basin by Hillman et al (1989a, 1989b) and found to be relatively unimportant in limiting the production of the species. Interaction between the species was minimized because of disparate times of spawning, which tended to segregate the two species. Both chinook and steelhead may interact competitively with other natives, such as bull trout, westslope cutthroat trout, or redside shiners. Currently, there is no evidence that the focal species interact with bull trout or westslope cutthroat trout. Indeed, Martin et al. (1992) indicated that juvenile bull trout and chinook have different habitat preferences and thus do not interact competitively.

Significant interaction between redside shiners and chinook and steelhead may occur as a result of changes or modifications in water quality (e.g., temperature). In both field and laboratory studies, Hillman (1991) found that redside shiners displaced chinook salmon from rearing areas at temperatures greater than 18°C. In fact, at these warmer temperatures, shiners negatively affected the distribution, behavior, and production of chinook salmon. Reeves et al. (1987) documented similar results with redside shiners and juvenile steelhead. Thus, if water temperatures increase within the basin, one can expect increased interactions between shiners and chinook and steelhead.

Exotic species may be more likely to interact with chinook and steelhead because exotics have not had time to segregate spatially or temporally in their resource use. For example, there is a possibility that brook trout interact with chinook and steelhead in the upper basin. Welsh (1994), however, found no evidence that brook trout displaced chinook salmon. On the other hand, Cunjak and Green (1986) found that brook trout were superior competitors to rainbow/steelhead at colder temperatures (9°C), while rainbow/steelhead were superior at warmer temperatures (16°C). A potentially important source of exploitative competition occurring outside the geographic boundary of the ESUs may be between the exotic American shad (*Alosa sapidissima*) and juvenile chinook and steelhead. Palmisano et al. (1993a, 1993b) concluded that increased numbers of shad likely compete with juvenile salmon and steelhead.

Although coho salmon were native to the upper basin, they have been absent for many decades. Recently, there have been efforts to re-establish them in the upper basin (Murdoch et al. 2002). Thus, there is the potential that reintroduced coho will interact negatively with chinook and steelhead. However, studies conducted in the Wenatchee Basin indicate that there is little to no interaction between the species (Spaulding et al. 1989; Murdoch et al. 2002).

Predation

Fish, mammals, and birds are the primary natural predators of chinook and steelhead in the Upper Columbia Basin. Although the behavior of chinook and steelhead precludes any single predator from focusing exclusively on them, predation by certain species can nonetheless be seasonally and locally important. Recent changes in predator and prey populations along with major changes in the environment, both related and unrelated to development in the Upper Columbia basin, have reshaped the role of predation (Mullan et al 1986; Li et al 1987).

Although several fish species can consume chinook and steelhead in the upper basin, northern pikeminnow, walleyes, and smallmouth bass have the potential for significantly affecting the abundance of juvenile anadromous fish (Gray and Rondorf 1986; Bennett 1991; Poe et al. 1994; Burley and Poe 1994). These are large, opportunistic predators that feed on a variety of prey and switch their feeding patterns when spatially or temporally segregated from a commonly consumed prey. Channel catfish also have the potential to significantly affect the abundance of juvenile chinook and steelhead (see e.g., Gray and Rondorf 1986; Poe et al. 1994), but because they are rare in the upper Columbia (Dell et al. 1975; Burley and Poe 1994), they likely have a small effect on survival of juvenile chinook and steelhead there. Native species such as sculpins and white sturgeon also prey on juvenile anadromous fish (Hunter 1959; Patten 1962, 1971a, 1971b; Mullan 1980; Hillman 1989).

Most adult salmonids within the upper basin are opportunistic feeders and are therefore capable of preying on juvenile chinook and steelhead. Those likely to have some effect on the survival of chinook and steelhead include adult bull trout, rainbow/steelhead trout, cutthroat trout, brook trout, and brown trout. Of these, bull trout and rainbow trout are probably the most important. These species occur together with chinook and steelhead in most tributaries, hence the probability for interaction is high. The presence of both fluvial and adfluvial stocks of bull trout in the region further increases the likelihood for interaction there.

Predation by piscivorous birds on juvenile anadromous fish may represent a large source of mortality. Fish-eating birds that occur in the upper basin include great blue herons (*Ardea herodias*), gulls (*Larus* spp.), osprey (*Pandion haliaetus*), common mergansers (*Mergus merganser*), American dippers (*Cinclus mexicanus*), cormorants (*Phalacrocorax* spp.), Caspian terns (*Sterna caspia*), belted kingfishers (*Ceryle alcyon*), common loons (*Gavia immer*), western grebes (*Aechmophorus occidentalis*), black-crowned night herons (*Nycticorax nycticorax*), and bald eagles (*Haliaeetus leucocephalus*) (T. West, Chelan PUD, personal communication). These birds have high metabolic rates and require large quantities of food relative to their body size. In the Columbia River estuary, avian predators consumed an estimated 16.7 million smolts (range, 10-28.3 million smolts), or 18% (range, 11-30%) of the smolts reaching the estuary in 1998 (Collis et al. 2000). Caspian terns consumed primarily salmonids (74% of diet mass), followed by double-crested cormorants (*P. auritus*) (21% of diet mass) and gulls (8% of diet mass). The NMFS (2000) identified these species as the most important avian predators in the Columbia River basin.

Mammals may be an important agent of mortality to chinook and steelhead in the upper basin. Predators such as river otters (*Lutra Canadensis*), raccoons (*Procyon lotor*), mink (*Mustela vison*), and black bears (*Ursus americanus*) are common in the upper basin. These animals, especially river otters, are capable of removing large numbers of salmon and trout (Dolloff 1993). Black bears consume large numbers of salmon, but generally scavenge post-spawned salmon. Pinnipeds, including harbor seals (*Phoca vitulina*), California se lions (*Zalophus californianus*), and Stellar sea lions (*Eumetopia jubatus*) are the primary marine mammals preying on chinook and steelhead originating from the Upper Columbia basin (Spence et al. 1996). Pacific striped dolphin (*Lagenorhynchus obliquidens*) and killer whale (*Orcinus orca*) may also prey on adult chinook and steelhead. Seal and sea lion predation is primarily in saltwater and estuarine environments though they are know to travel well into freshwater after migrating fish. All of these predators are opportunists, searching out locations where juveniles and adults are most vulnerable.

Disease and Parasitism

Chinook and steelhead can be infected by a variety of bacterial, viral, fungal, and microparasitic pathogens. Numerous diseases may result from pathogens that occur naturally in the wild or that may be transmitted to wild fish via infected hatchery fish. Among these are bacterial diseases, including bacterial kidney disease (BKD), columnaris, furunculosis, redmouth disease, and coldwater disease; virally induced diseases, including infectious hepatopoietic necrosis (IHN), infectious pancreatic necrosis (IPNV), and erythrocytic inclusion body syndrome (EIBS); protozoan-caused diseases, including ceratomyxosis and dermocystidium; and fungal infections, such as saprolegnia (Bevan et al. 1994).

Chinook in the Columbia River have a high incidence of BKD (Chapman et al. 1995). Incidence appears higher in spring chinook (Fryer 1984) and can be a major problem in hatchery-reared chinook in the upper Columbia region (Chapman et al. 1995). Viral infections such as IPNV have been detected in hatchery steelhead in the upper Columbia region (Chapman et al. 1994). Other epizootics, including *Ceratomyxa shasta* and tuberculosis, are endemic to the Columbia River basin, but it is unknown if these affect the production of chinook and steelhead in the upper Columbia region.

Generally one thinks of epizootics killing fish outright. However, sublethal chronic infections can impair the performance of chinook and steelhead in the wild, thereby contributing secondarily to mortality or reduced reproductive success. Fish weakened by disease are more sensitive to other environmental stresses. Additionally, they may become more vulnerable to predation (Hoffman and Bauer 1971), or less able to compete with other species. For example, both Hillman (1991) and Reeves et al. (1987) found that water temperature affected interactions between redside shiners and the focal species. Both researchers noted that outcomes of interactions were, in part, related to infection with *F. columnaris*. In their studies, most chinook and steelhead were infected at warmer temperatures, whereas shiners showed a higher incidence of infection at cooler temperatures.

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Table 1. List of fishes that occur in the upper Columbia Basin (between the mouth of the Yakama River and Chief Joseph Dam). Temperature classification follows Zaroban et al. (1999) and trophic guilds follow Li et al. (1987). Table is from Hillman (2000).

			Feeding location in water column			Primary prey				
Common name	Species	Native (N) or Exotic (E)	Surf	Mid	Bot	Plant	Detrit	Mic	Mac	Fish
Cold-water species:										
White sturgeon	*Acipenser transmontanus*	N			x	x	x	x	X	x
Chinook salmon (juv)	*Oncorhynchus tshawytscha*	N	X	x	x				X	
Coho salmon (juv)	*Oncorhynchus kisutch*	N	X	x	x				X	
Sockeye/kokanee (juv)	*Oncorhynchus nerka*	N	x	X	x			x	X	
Steelhead/rainbow	*Oncorhynchus mykiss*	N	x	X	x				X	x
Cutthroat trout	*Oncorhynchus clarki*	N	X	x	x				X	x
Brown trout	*Salmo trutta*	E	x	X	x				X	x
Atlantic salmon	*Salmo salar*	E	x	X	x				X	x
Bull trout	*Salvelinus confluentus*	N	x	x	X				X	x
Brook trout	*Salvelinus fontinalis*	E	x	X	x				X	x
Mountain whitefish	*Prosopium williamsoni*	N	x	x	X				X	
Lake whitefish	*Coregonus clupeaformis*	E		x	X				X	x
Burbot	*Lota lota*	N		x	X				X	x
Longnose sucker	*Catostomus catostomus*	N			X	x	x	x	x	
Sculpins	*Cottus spp.*	N			X				X	x

Common name	Species	Native (N) or Exotic (E)	Feeding location in water column			Primary prey				
			Surf	Mid	Bot	Plant	Detrit	Mic	Mac	Fish
Cool-water species:										
Longnose dace	*Rhinichtys cataractae*	N			X				X	
Peamouth	*Mylocheilus caurinus*	N			X				X	x
Chiselmouth	*Acrocheilus alutaceus*	N			X	X			x	
Northern pikeminnow	*Ptychocheilus oregonensis*	N	x	x	X				X	x
Redside shiner	*Richardsonius balteatus*	N	x	X	x				X	
Sand roller	*Percopsis transmontana*	N			X				X	
Bridgelip sucker	*Catostomus columbianus*	N			X	X			x	
Mountain sucker	*Catostomus platyrhynchus*	N			X	X	x	x	x	
Largescale sucker	*Catostomus macrocheilus*	N			X	X	x	x	x	
Pacific lamprey (juv)	*Lampetra tridentata*	N			X	x		X	x	
River lamprey (juv)	*Lampetra ayresi*	N			X	x	X	x		
Western brook lamprey (juv)	*Lampetra richardsoni*	N			X	x	X	x		
Threespine stickleback	*Gasterosteus aculeatus*	N	x	X	x				X	
Pumpkinseed	*Lepomis gibbosus*	E		X	x				X	x
Walleye	*Stizostedion vitreum*	E		x	X				x	X
Yellow perch	*Perca flavescens*	E	x	X	x				X	x
Smallmouth bass	*Micropterus dolomieu*	E	x	x	X				X	x
Sculpin	*Cottus spp.*	N			X				X	x

Common name	Species	Native (N) or Exotic (E)	Feeding location in water column			Primary prey				
			Surf	Mid	Bot	Plant	Detrit	Mic	Mac	Fish
Warm-water species:										
Channel catfish	*Ictalurus punctatus*	E			X				X	x
Black bullhead	*Ameiurus melas*	E			X	x			X	
Brown bullhead	*Ameiurus nebulosus*	E			X	x	x	x	X	x
Tench	*Tinca tinca*	E			X	x			X	
Common carp	*Cyprinus carpio*	E			X	x	x	x	X	
Bluegill	*Lepomis macrochirus*	E	x	X	x				X	x
Black crappie	*Pomoxis nigromaculatus*	E	x	X	x				X	x
Largemouth bass	*Micropterus salmoides*	E	x	X	x				x	X

*Surf = surface feeder; Mid = midwater feeder; Bot = bottom feeder; Detrit = detritus; Mic = microinvertebrate; Mac = macroinvertebrate. Capital letters denote dominant mode.

POLICY, SOCIAL, AND CULTURAL FACTORS

3.1.1 POLICY, SOCIAL, AND CULTURAL FACTORS FOR DECLINE[1]

Humans and salmon colonized and expanded their range in the Columbia River Basin after the most-recent Ice Age (10,000-15,000 years BP). American Indians developed a culture that relied extensively upon anadromous fish for sustenance in some portions of the area (Craig and Hacker 1940). Their catches must have increased as their populations rose and techniques of fishing developed. Particularly at partial obstacles for passage, Indians captured large numbers of fish for both sustenance and trade.

Native Americans had access to an abundant fish resource comprised of spring, summer, and fall runs of chinook salmon, coho and sockeye salmon, and steelhead, as well as Pacific lamprey and white sturgeon. Estimates of pre-development (late 1700s) abundance of Columbia River salmon and steelhead ranged from about 8 million (Chapman 1986) to 14 million (NPPC 1986) fish. Estimates of pre-development salmon and steelhead numbers were based on maximum catches in the latter part of the 1800s and assumed catch rates by all fishing gear. Inherent in such calculations is the assumption that fish populations in the late 1800s represented a reasonable expression of average effects of cyclic variation in freshwater and ocean habitat conditions. No one currently has determined validity of that assumption. It is, however, quite certain that salmon and steelhead have declined to a small fraction of their former abundance (Figure 3-2 in NRC 1996). Peak catches in the 1800s by all fishers may have included 3-4 million salmon and steelhead (Chapman 1986). Total run size for all salmon and steelhead recently has ranged from 1 to 2 million fish. About three-quarters of recent spring chinook and summer steelhead runs have consisted of fish cultured to smolt size in hatcheries.

While actual numbers of adult spring chinook salmon and steelhead produced by the upper Columbia River basin in the pre-development period are not available, one can attempt to estimate them, albeit roughly. From Fulton (1968, his Table 2), one can total formerly-used spring chinook salmon habitat throughout the Columbia River basin as 10,002 km, and upper Columbia habitat (upstream from the Yakima River) as 899 km, or about 9% of the total. Chapman (1986) estimated that about 500,000 spring chinook returned to the Columbia River in the latter portion of the 1800s. Nine percent of that total would be about 45,000 spring chinook salmon attributable to the upper Columbia River.[2]

Anadromous fish of the upper Columbia area must have fluctuated because of variable environmental conditions. Certain combinations of freshwater and ocean habitat

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[1] The following discussions treat "factors for decline" as holistic issues not confined to the upper Columbia River. Multiple political jurisdictions, stakeholders, and ecological systems have influenced upper Columbia salmon and steelhead as they reared and migrated in streams and the sea.

[2] This does not include ocean-annulus summer chinook. Stream-annulus chinook salmon predominated in the Snake River basin, but ocean-annulus chinook salmon, both "summer-run" and "fall-run," were much more abundant than spring chinook in the upper Columbia River (Chapman and Chandler 2003).

conditions appear to have caused very low salmon returns in some years well before non-Indians degraded habitat or began fishing intensively (Mullan et al. 1986), and probably "bonus" returns in others (as, recently, in 2002 and 2003).

Numbers of spring chinook that escaped to the Columbia River at Priest Rapids Dam in the most-recent decade have averaged about 15,800 (adults plus jacks). This escapement would convert to approximately 21,000 fish downstream from Bonneville Dam (adjusting for 4% loss of adults for each dam between the estuary and counting station at Priest Rapids Dam, and a fishing rate of about 5%, mostly upstream from Bonneville Dam). Hatcheries had contributed about 75-80% of these fish. Thus naturally-produced spring chinook salmon abundance[3] in the upper Columbia area can be estimated to have declined to about 5,000 fish; a decrease of 89%[4]. Estimation of the percentage decline in wild summer steelhead produced in the upper Columbia River would indicate a similar major decline. Salmon and steelhead genetic diversity has also declined as a result of artificial propagation and widespread stock transfers.

Both spring chinook and summer steelhead in the upper Columbia River[5] have been listed under provisions of the Endangered Species Act (ESA) of 1972. Factors that depressed numbers of wild spring chinook and steelhead sufficiently to lead to ESA listing include range extirpation, fishing, artificial propagation, and habitat degradation caused by dams, irrigation, channelization, overgrazing, and public policy. Lackey (2001) wrote:

> "The depressed abundance of wild stocks was caused by a well known but poorly understood combination of factors, including unfavorable ocean or climatic conditions; excessive commercial, recreational, and subsistence fishing; various farming and ranching practices; dams built for electricity generation, flood control, and irrigation, as well as many other purposes; water diversions for agricultural, municipal, or commercial requirements; hatchery production to supplement diminished runs or produce salmon for the retail market; degraded spawning and rearing habitat; predation by marine mammals, birds, and other fish species; competition, especially with exotic fish species; diseases and parasites; and many others."

Lackey (2001) also wrote that "technocrats" who represent various organizations have developed estimates of the proportions of wild fish declines attributable to one or more of the above-mentioned factors for decline. He pointed out that models that resulted in that work usually ended up supporting the favored policy position of the supporting organization.

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[3] It is important to note here that "naturally-produced" fish includes progeny of hatchery fish that spawn in the wild. Currently, natural production is intentionally stimulated in some streams (e.g., Chiwawa River) and serendipitously in others (e.g., Icicle Creek and Entiat River).

[4] Fishing downstream from Bonneville Dam has not taken enough upriver spring chinook in the most recent decade to justify adjustment of adult numbers to the mouth of the Columbia River.

[5] Upper Columbia River here means upstream from the Yakama River.

Fishing as a cause of decline

It seems quite unlikely that aboriginal fishing was responsible for run declines in the Columbia River (Craig and Hacker 1940; Chapman 1986; Lackey 1999). Their artisanal fishing methods (Craig and Hacker 1940) were incapable of harvesting upper Columbia River spring chinook and summer steelhead at rates that approached or exceeded optima for maximum sustained yield (probably 68% and 69% for spring chinook and steelhead, respectively, as estimated in Chapman (1986)).

An intense industrial fishery in the lower Columbia River, employing traps, beach seines, gillnets, and fishwheels, developed in the latter half of the 1800s. In the early 1900s, troll fisheries developed to catch salmon even before they reached the Columbia River. The late-spring and early-summer chinook salmon returns, which constituted the heart of the Columbia River runs, were decimated by the early 1900s (Thompson 1951).
As these run components rapidly declined, fishing shifted earlier, later, and to other species, changes that, for a time, numerically masked the precipitous decline in the sought-after late-spring and early-summer fish.

By the early 1930s, mean escapement of spring chinook into the upper Columbia River upstream from Rock Island Dam had declined to fewer than 3,000 fish. That escapement would represent perhaps 12,000 fish arriving in the lower Columbia River, inasmuch as fishing rates exceeded 75% in that period. Only Rock Island Dam (1933) lay athwart the Columbia River. Mean returns of summer steelhead to the upper Columbia River were lower than 4,000 fish in the first part of the 1930s. Harvest rates of 70%, and probably higher, were common before the 1940s. If one assumes a 70% rate, returns of upper Columbia summer steelhead to the estuary may have amounted to about 13,000 fish.

By the 1930s and 1940s, restrictions on fishing time and gear had increased. For example, purse seines were outlawed in 1917, whip seines in 1923, fish wheels in 1927 (in Oregon), seines and traps east of Cascade Locks in Oregon in 1927, drag seines, traps, and set nets in 1935 (Washington), and seasons were gradually shortened. Catch rates almost certainly were much higher than those appropriate for maximum sustained yield or populations for several decades before then.

It is important to remember that fishing intensity, unless pursued to stock extinctions, can be relaxed by management action. If habitat remains intact, stocks can rebound.[6] Presently, fishing rates have been reduced well below 10% for spring chinook and 13% for summer steelhead (see section on harvest), yet wild and natural components of the respective runs in the upper Columbia River have not responded markedly. Currently, factors other than fishing depress these fish of the upper Columbia River.

Mainstem dams as a factor for decline

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[6] However, extirpation of habitat upstream from Chief Joseph Dam militates against rebound of populations to levels that should have been attainable earlier.

Spring chinook and steelhead production areas in the pre-development period included the Wenatchee, Entiat, Methow, Okanagan, and limited portions of the Spokane, San Poil, Colville, Kettle, Pend O'reille, and Kootenay rivers[7]. The Grand Coulee Dam project and Chief Joseph Dam eliminated access to the Columbia River upstream. The Grand Coulee Fish Maintenance Project (GCFMP), designed to transfer populations formerly produced upstream into remaining habitat downstream from Grand Coulee, trapped fish at Rock Island in 1939-1943. Managers placed some adults in tributaries (e.g., Nason Creek) to spawn naturally, and artificially propagated others. Spring chinook from outside the upper Columbia were introduced. The extreme changes in population structures permanently transfigured populations of spring chinook and steelhead of the upper Columbia River (Chapman et al. 1995).

The era of mainstem multi-purpose dams downstream from the Grand Coulee project began with Rock Island Dam in 1933 and culminated with completion of Wells Dam. Seven mainstem dams lie between the Wenatchee River and the sea, eight downstream from the Entiat River, and nine between the Methow/Okanagan systems and the estuary. Dam-related losses are substantial. For example, adult salmon and steelhead mortality in the reaches between projects has been estimated as 4% or more in some years (Chapman et al. 1994 and 1995), and juvenile losses at each project can amount to about 10%.[8] Some of the losses result from physical effects of adult and smolt passage. Others derive from altered limnological conditions that increase predation by fish and birds, or cause gas-bubble trauma. Whatever the direct causes, losses for Wenatchee adults and juveniles could accumulate to an estimated 25% and 52%, respectively. For Methow River fish, which must pass two additional dams, losses may accumulate to an estimated 31% and 61% for adults and juveniles, respectively.[9] In a very real sense, dam-related mortality appears to have replaced mortality rates once caused by intensive mainstem fishing. The cumulative loss rates also explain why so much mitigative effort has been allocated to project-related mortality rates.

Dams for storage, like Grand Coulee, and mainstem multipurpose dams have had other effects on ecology of salmon and steelhead. Estuarine limnology has shifted from a basis of macrodetritus and benthos to a microdetrital, planktonic trophic structure that favors non-salmonids. Spring freshet flows and turbidity have declined in the river and estuary, and the Columbia River plume has been reduced seasonally (Ebbesmeyer and Tangborn 1993, Chapman et al. 1994 and 1995, NRC 1996) with potential but largely unknown effects on survival of salmon and steelhead in the estuary and nearshore ocean.

Tributary habitat degradation as a factor for decline

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[7] Natural falls blocked salmon and steelhead access to most of the Spokane, Colville, Kettle, Pend O'reille, and Kootenay rivers.

[8] Estimates of smolt mortality (per project and cumulative) rely more on PIT tag recovery data for spring chinook and steelhead in the lower Snake River than on estimates for fish produced in the upper Columbia River. Chapman et al. (1995) discussed uncertainties associated with interdam conversion rates for adults.

[9] Whether the loss rates per project are slightly higher or lower than shown, the cumulative loss rates provide an impression of the importance, relative to other factors, of mainstem dams as a factor for decline. The pre-dam loss rates for adults and smolts that pass through each project reach are unknown, but unlikely to have come close to post-dam mortality rates.

Perhaps the most important habitat influence on wild spring chinook and steelhead in the upper Columbia River involves water diversion, withdrawal, and application to crops. The Columbia Basin Project, operated by the U.S. Bureau of Reclamation, constitutes the largest single water diversion and application system in the area. In the Wenatchee, Okanagan, and Entiat River basins, water diversion for orchards is important. In the Methow River system, crops and pasturage divert tributary and mainstem water.

For wild spring chinook and summer steelhead, diversions on tributaries of the Wenatchee, Entiat, Okanagan, and Methow rivers must be considered a factor for decline. Instream flows have been depleted downstream from irrigation diversion dams, reducing instream habitat and improving predator access to rearing juvenile fish. Diversions were unscreened for many decades, permitting downstream migrants to pass into, and perish in, fields and orchards. Today some fish diversion screens are less than 100% effective. Diversion dams were built in some cases without adequate provision for adult passage.

Cattle pastures adjacent to tributaries can and have denuded riparian vegetation and permitted nutrients from fecal material, and fine sediment, to enter salmon and steelhead habitat. Overgrazing by sheep and cattle has locally increased runoff of fine sediments and increased streamflow peaks (Mullan et al. 1992).

Channelization reduces instream habitat by straightening meanders, increasing water velocity, and eliminating or reducing riparian cover and input of large woody debris. It can and has occurred associated with roads and railroad grades, residential encroachment, and protection of agricultural land. Diking and channel-bank riprap prevents stream lateral movements across alluvial floodplains; particularly in the Methow and Okanagan drainages.

Roads for logging access and log skidding can and have locally introduced fine sediments to spring chinook and summer steelhead habitat. Riparian communities have at times been disrupted, reducing shade and availability of large woody debris. Timber removal alters hydrology of tributaries until regrowth occurs.

Of the foregoing habitat factors, diversions and associated diversion dams probably constitute the most important factors for decline. Mullan et al. (1992) concluded, after reviewing habitat conditions in the tributaries of the upper Columbia River:

> “Despite some abuse from the recent activities of humans, there appears to be little or no net loss of the functional features of mid-Columbia River tributaries. In large part this is a fortuitous outcome from the lack of human interplay, a result of the formidable topological and climatic barriers that restrict settlement. To be sure, there are problems in sustaining populations of salmonids, but, for the most part, these are minor, localized, and controllable compared to the mainstem Columbia River.”

Hatcheries as factors for decline[10]

NRC (1996) and Flagg et al. (2001) discussed at length the risks and problems associated with use of hatcheries to compensate for, or supplement, fish produced in the wild. NRC (1996) noted demographic risk, pointing out that large-scale releases of hatchery fish exacerbate mixed-stock harvest problems. Wild fish cannot sustain harvest rates that would be appropriate for hatchery fish. Demand is essentially unlimited for salmon and steelhead, and advocacy groups for various fisheries often clamor to have access to ever-more harvestable fish from hatcheries.

Solutions to the mixed-stock fishing problem are elusive. Gillnets, for example, have only limited potential for releasing wild spring chinook and steelhead unharmed. Terminal fisheries, particularly for spring chinook after they enter waters that contain only hatchery fish, are impractical for commercial fisheries because fish quality there has declined greatly. Steelhead are somewhat easier to manage in sport fisheries, where fish known to be of wild origin (identifiable by an intact adipose fin) can be released with minimal mortality and hatchery fish (with adipose intact) kept.

Genetic and evolutionary risks for hatchery fish and interacting populations include inbreeding depression, loss of population identity and within-population diversity, and domestication selection (NRC 1996). Recognition of these possible factors has increased in recent decades. Unfortunately, measures used in the GCFMP and steelhead management in the upper Columbia (until recently) almost certainly realized some of the listed risks and contributed to decreased genetic diversity of wild fish. Steelhead adults were collected at Priest Rapids, and later at Wells Dam, their progeny reared in hatcheries and released as smolts to the various tributaries without regard to fostering local adaptation in tributaries.

Foraging, social behavior, time of spawning, and predator avoidance can differ for fish reared in the hatchery and in the wild (Flagg et al. 2001). While resulting differences may primarily reduce survival of hatchery-produced salmon and steelhead, negative effects may carry into the wild population where adults of hatchery origin spawn with wild fish. Effects of disease on released hatchery fish and on wild fish are poorly understood, but likely to be negative (Flagg et al. 2001, tables 10-11 summarize these).

Also poorly understood are ecological effects of hatchery programs. NRC (1996) noted that 5.5 billion salmon smolts of all species are released to the wild each year around the Pacific rim, with potential trophic effects that may lead to altered body size and survival of wild fish. Emphasis on hatchery fish denies marine nutrients to infertile rearing streams used by relatively few wild spring chinook salmon and steelhead.[11]

Public policy as a factor for decline

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[10] "Agriculture" here includes farming for various crops, including fruit, livestock production, and grazing.

[11] While responsibility for emphasis on hatchery fish as compensation for other factors for decline belongs in the province of the latter, the practical result would nevertheless be reduction of marine nutrient inputs.

The Marine Mammals Protection Act of 1976 afforded seals and sea lions complete protection from killing by humans. These animals increased sharply in abundance thereafter (Fresh 1996). NRC (1996) discussed the potential for effects on salmon and steelhead. They concluded that such predation was "probably not a major factor in the current decline of salmon in general." Chapman et al. (1994 and 1995) suggested a need for adaptive management, including population control through selective harvest and/or sterilization of live-captured seals on haul-out beaches. They pointed out that although pinnipeds and salmon coexisted long before man interfered ecologically, contrary views hold that it is unrealistic for man to manage and prey upon salmon without managing one of their principal predators.

The Corps of Engineers dredges shipping channels in the lower Columbia River and has created artificial islands with the spoils. Caspian terns have exponentially increased in the Columbia River estuary after dredge spoils created near-ideal nesting sites within the boundaries of a U.S Fish and Wildlife Service refuge. Many PIT tags have been found on artificial island sites, demonstrating that terns may be very important predators on smolts that must pass through the estuary to reach the sea.

Public policy clearly has more ubiquitous influences, both direct and indirect, than the foregoing examples (NRC 1996). Mainstem dams are a direct outgrowth of public policy, constructed by the federal government (Chief Joseph, Grand Coulee, and four mainstem Columbia River dams downstream from the Snake River) or by public utilities licensed by the Federal Energy Regulatory Commission (Wells, Rocky Reach, Rock Island, Wanapum, and Priest Rapids dams).

Human population growth in the Pacific Northwest, often fostered by local government boosters, places more pressure every year on salmon and steelhead. Lackey (1999, 2001) eloquently described the ramifications for salmon of human population growth and public policies and decisions. He noted that the Pacific Northwest has a population increase rate that rivals many developing third-world nations. Public policies affect water diversions, instream flows, water temperature, dam operations, manufacturing, urban development, national defense, fishing, hatchery outputs, and transportation of people and goods. All of these factors and more, some of greater influence than others, have depressed salmon and steelhead abundance and potential for restoration of depressed fish populations.

Marsh (1994) may have inadvertently captured an essence of the effects of public policy on salmon when he wrote:

> "…the process is seriously, significantly, flawed because it is too heavily geared towards a status quo that has allowed all forms of river activity to proceed in a deficit situation – that is, relatively small steps, minor improvements and adjustments – when the situation literally cries out for a major overhaul."

He was referring to salmon restoration and management. But the underlying question was identified by Lackey's papers: Given human population growth and perceived needs, is Pacific Northwest society prepared to make the sacrifices necessary to restore wild listed spring chinook and steelhead in the upper Columbia River (and elsewhere in the Columbia River basin)? The answer to date appears to be “no.”

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ltMORTALITY OUTSIDE THE ESU

3.3.1 MORTALITY ASSUMPTIONS

- Decadal scale climate-driven fluctuations in marine conditions are a dominant factor influencing salmonid survival in marine waters. This factor appears to account for the greatest amount of change in survival from smolt through return as adults documented over the decades.

  NOAA Fisheries (Williams et al. 2003-draft) recently characterized the importance of marine-based processes on the abundance of Columbia River salmon as follows:

  > *"Increasing evidence points to dramatic changes in the marine ecosystem of the northern Pacific Ocean resulting from shifts in climate over the past 2000 years (Finney et al. 2002, Moore et al. 2002). Throughout this region, changes in ocean-climate conditions have influenced zooplankton, benthic invertebrate, seabird, and fish populations (McGowan et al. 1998). In particular, analyses of data from the last 100 years demonstrate a strong relationship between ocean conditions and the production of Pacific salmon (Oncorhynchus spp.) across a range of spatial and temporal scales (Mantua et al. 1997, Beamish et al. 1999). The varied response of salmon to these past environmental changes likely reflects their complex life history and the wide diversity of freshwater and marine habitats that they occupy (Hilborn et al. 2003).*
  >
  > *Recent evidence links chinook salmon from the Columbia River basin to cyclic changes in ocean-climate conditions. Modeling exercises directed at explaining the negative effects of various anthropogenic activities on the productivity of Snake River spring-summer (SRSS) chinook salmon identified the estuary and ocean environments as important sources of unexplained variation in stock performance (Kareiva et al. 2000, Wilson 2003). Using catch records from commercial fisheries, Botsford and Lawrence (2002) found reasonable correlations between the inferred survival of Columbia River chinook salmon and physical attributes of the ocean, such as sea-surface temperature and coastal upwelling. Building upon these previous studies, Scheuerell and Williams (in review) found that they could actually forecast changes in the smolt-to-adult survival of SRSS chinook from changes in coastal ocean upwelling over the past 37 years, including the rapid decline in the 1960-70's and the increase in the late 1990s. All of these analyses highlight the important effects of the ocean in determining smolt-to-adult survival, and further support Pearcy's {, 1992 #307} assertion that the primary influence of the ocean on salmon survival occurs early within the first year that juveniles occupy coastal waters."*

- Smolt and adult mortality associated with passage through the hydrosystem is still problematic, but efforts are underway to improve passages conditions and evaluate progress.

  System survival studies conducted during the 1980s revealed that the survival of spring-migrating smolts was poor. Skalski and Giorgi (1999) summarized results from seven studies conducted by either the Public Utility Districts or the Fish

Passage Center that decade. Four studies used yearling spring chinook and three used steelhead. The average annual per-project survival across all studies was 86.2% (range = 83.4 to 88.7 %). This equates to only 47.6 % survival for smolts passing through five hydroelectric projects, from Wells Dam to Priest Rapids Dam. Today the HCP for Douglas and Chelan County PUDs specifies a smolt survival goal of 93% per project for all species of smolts. If this goal can be realized through passage improvements currently being implemented or explored at all five dams, then the smolt survival through that system would equate to 69.6%. If these passage survival goals can be achieved they would provide a substantive contribution to the recovery of ESA-listed spring chinook and steelhead ESUs in the Upper Columbia.

- The existence and magnitude of delayed effects associated with passage through the hydrosystem remains unresolved and constitutes a critical uncertainty in the context of ESU recovery.

  It has been hypothesized that cumulative effects may be incurred as smolts migrate through the hydrosystem, which are not expressed until smolts enter saltwater. Such a scenario has proved difficult to test and verify. NOAA Fisheries established the Plan for Analyzing and Testing Hypotheses (PATH) in 1995. For five years this issue was one of many key ones that were investigated. Consensus was never reached. Subsequent to PATH, a number of papers were published, some supporting and some contesting the hypothesis. The debate still continues today and is a prominent topic treated in a recent draft technical memorandum published by NOAA Fisheries (Williams et al. 2003-draft).

- The condition of smolts migrating from a watershed can influence survival in subsequent life stages. Thus, improving habitat conditions may realize benefits beyond those reflected in egg to smolt survival.

3.3.2 TOTAL MORTALITY OUTSIDE THE SUBBASIN

The most comprehensive and instructive index of ESU survival beyond the watershed is smolt to adult return rate (SAR). It is a common survival index used to characterize the performance of salmonid populations throughout the Pacific Northwest. This survival index reflects all sources of mortality affecting migrating smolts through returning adults. These include effects associated with:

- Hydrosystem operations.
- Migration conditions in the mainstem, including both natural and anthropogenic causes (e.g., actions associated urbanization and industrialization).
- Fish condition that can vary annually by hatchery or rearing stream.
- Marine/estuarine conditions and processes influenced by natural and anthropogenic factors.
- Harvest in marine and riverine waters.
- Predation.

SARs can be calculated in different ways. Juvenile salmonids implanted with either PIT tags or CWT can be used to estimate SAR, if returning adults can be sampled at strategic locations. Alternatively, the survival index can be calculated by estimating smolt abundance passing some site (a dam or the mouth of a tributary), then subsequently estimating adult returns to that location for a specific brood year. Often times SARs are expressed in terms of return rates to the mouth of the Columbia River. This calculation requires additional information such as estimates of inriver harvest and adult passage mortality.

Upper Columbia Smolt to Adult Survival

Spring Chinook

Historical estimates of SAR for naturally produced spring chinook in the upper Columbia River have been reported by Mullan et al. (1992) and Raymond (1988). Mullan et al. estimated the smolt to adult return rate for the collective populations produced in the Wenatchee, Entiat, and Methow rivers for the years 1967 -1987. Over that period SAR ranged from 2.0 to 10.1%. They noted that the estimates reflect corrections for adult passage mortality as well as marine and inriver harvest.

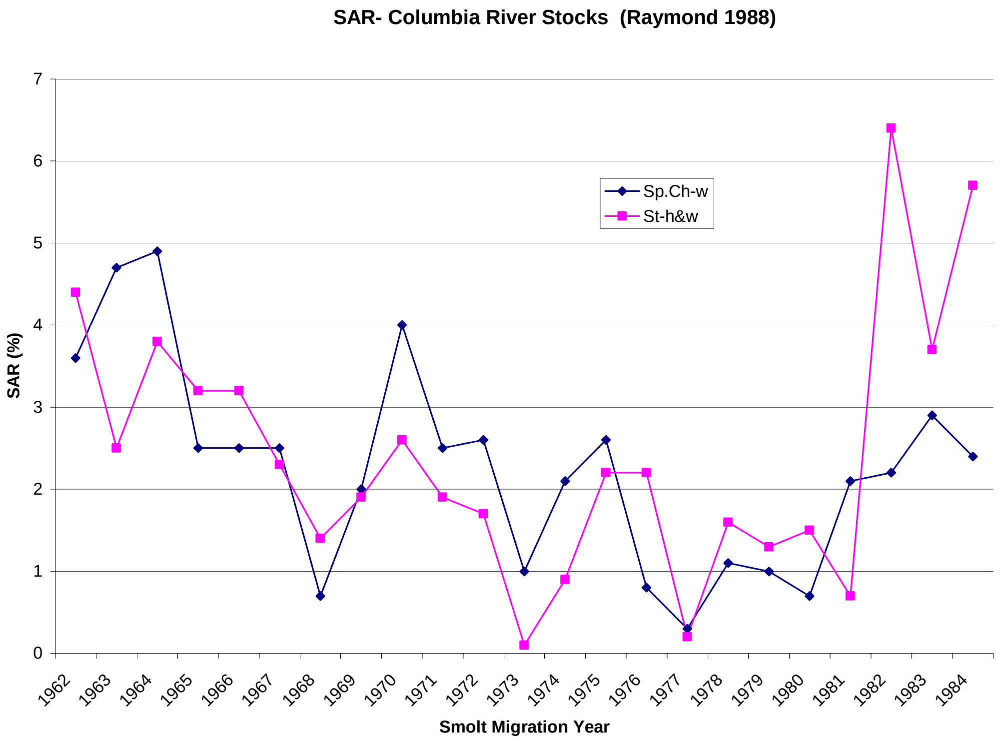
Raymond (1988) estimated the percent returning adults to the uppermost dam on the upper Columbia River for the years 1962 through 1984. Values for wild spring chinook ranged from 0.7 to 4.9 % over those years. One reason Raymond’s values are generally lower than those reported by Mullan et al. (1992) may be that his estimates are not adjusted for adult passage mortality and marine harvest, whereas Mullan et al. (1992) were. Also, the reference locations for calculating SARs differed, with Raymond focusing on the upper dam and the other investigators referencing the spawning grounds. This raises an important point. When comparing SAR values among investigators, the locations where smolts and adults are enumerated must be known.

SAR estimates for the most recent decade have not been calculated and published by any other investigators. Thus the historical estimates provide the only guidance on this matter.

Steelhead

Raymond (1988) estimated smolt to adult return percentages for the combined wild and hatchery steelhead population, 1962-1984. Adult return rates to the upper dam ranged from a low of 0.2% for the smolt migration of 1977 to a high of 6.4% for the 1982 smolt migration. Mullan et al. (1992) reported SARs for only one stock, Well Hatchery steelhead, and 1982-1987. The percent return to the mouth of the Columbia River averaged 6.38%, ranging from 1.32 to 14.28%. Survival back to Wells Dam averaged 3.01% and ranged from 0.72 to 7.31. These estimates aligned closely with Raymond’s estimates for the overlapping years 1982-1984. Chapman et al. (1994) compiled data from three hatcheries in the upper Columbia (Chelan, Entiat, and Leavenworth) for the years 1961-1991. Smolt to adult survival averaged 1.7%, with a range from 0.16-7.54%.

Figure. Survival from smolt to returning adult for upper Columbia wild spring chinook and steelhead stocks as estimated by Raymond (1988). The reference point for smolt abundance is the upper dam on the Columbia and estimated return of adults to that location. Years refer to smolt migration years.



Selecting Values for SAR to Use in ESU-Level Habitat Effectiveness Evaluations

Clearly SAR estimates for both spring chinook and steelhead vary greatly across years. Over the decades changes spanning at least an order of magnitude were commonly observed. Thus, no single survival index value is satisfactory for accurately representing the performance of an ESU beyond the watershed. But accuracy may not be a central requirement for selecting a standard SAR that can be applied universally in habitat evaluations that use models like EDT. In years when smolt to returning adult survival is low, survival from pre-spawner through parr in the tributaries carries more weight in terms of overall lifecycle survival. Conversely, when SARs are high the contribution of survival during the subbasin residence stages contributes less proportionately to overall gravel-to-gravel survival.

What is the importance in establishing the magnitude of survival expressed outside the boundaries of a subbasin? When resource managers wish to compare the effectiveness of tributary habitat actions among subbasins or across ESUs, then effects beyond the bounds of the subbasin or watershed become an issue. For example, if analysts in Subbasin A assume a high SAR index and they use adult abundance as a performance measure in modeling analyses, then the contribution from tributary-resident life stages is diluted. In contrast if analysts in Subbasin B assume a low SAR index, then the contribution of tributary survival is magnified in importance. One could imagine that funding agencies may prefer to invest in habitat projects where the bang for the buck might be greatest. This will be difficult to determine unless a standard out-of-subbasin survival index is adopted by all parties.

Is it practical to ignore effects outside the subbasin and not incorporate them in quantitative analyses? Not if performance measures like productivity and adult abundance are of interest; these are sensitive to hydro, marine, and harvest effects. Thus an SAR-like component should be incorporated into whatever analytical model is employed. However, it may not be practical to run a series of model analyses over a range of SARs to reflect the sensitivity of every watershed population to variable marine or hydrosystem conditions. Therefore, this is another reason why it is advantageous if a standard SAR value and approach can be selected for application when analyzing various populations emanating from different subbasins.

Out-of-Subbasin Effects (OOSE) Approach

Since subbasins enter the mainstem Columbia at differing distances from the point of ocean entry, each subbasin population will incur different levels of hydrosystem-related mortality. Mobrand Biometrics in conjunction with the NPCC has devised an approach to generically treat all populations entering the mainstem. They refer to the composite mortality through the hydrosystem and marine waters including harvest removals as “out-of-subbasin-effects” (OOSE). We propose adopting that approach at this time.

Under this OOSE approach, a hypothetical generic situation forms the blueprint. There is one SAR reference value selected for each species. The maximum value of this SAR index value stock is realized for a generic stock of smolts entering the mainstem from tributaries downstream from Bonneville Dam. In modeling analyses, that generic stock of smolts is moved upstream to subbasins that enter the mainstem above an increasing number of dams. The SAR index value is then reduced by incremental amounts to reflect the number of dams the generic stock now has to pass en route to the mouth of the Columbia River. The values initially selected as the SAR index does not need to represent the “truth”, nor do values representing dam passage survival, but they should fall within an accepted range of observed values. The purpose is to prescribe a standard OOSE that can be applied to all ESUs or populations entering the mainstem at different locations.

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FACTORS FOR DECLINE

3.4.2 ARTIFICIAL PRODUCTION PROGRAMS

Artificial production programs (hatcheries) can have a negative effect on wild stocks of anadromous fish. In general, hatchery problems stem from their goals of increasing anadromous fish runs to mitigate for human-induced mortality (dams, habitat and water quantity and quality reduction, etc.) and these goals are often based on insufficient genetic, evolutionary, and ecological baseline information required in the planning, operation, and monitoring of hatcheries. In addition to direct effects, hatchery management practices and operations, including broodstock extraction, out-of-basin population transfers, overfishing wild stocks in a mixed fisheries on hatchery and wild fish, building of hatchery dams and weirs, removal of salmon carcasses from streams, and mixing of spawning hatchery and wild fish in the natural environment, can have negative effects on wild populations.

In their review of hatchery programs in the Columbia River Basin, the Scientific Review Team (SRT) agreed to seven conclusions (Brannon et al. 1999):

- Hatcheries have generally failed to meet their objectives.
- Hatcheries have imparted adverse effects on natural populations.
- Managers have failed to evaluate hatchery programs.
- Rationale justifying hatchery production was based on untested assumptions.
- Supplementation should be linked with habitat improvements.
- Genetic considerations have to be included in hatchery programs.
- More research and experimental approaches are required.

More specifically, the SRT report summary concluded that:

1. Hatcheries have failed to mitigate for the effects of habitat loss and damage in the Columbia River Basin.
2. Past hatchery practices have failed to take into account the biological diversity of salmonids and the role of environmental factors in their life history.
3. Hatcheries will likely continue to have a role in the development and conservation of salmonids in the Columbia River Basin, but a radically different production model (objectives and rearing strategies) is needed. Hatcheries should be considered experimental and carefully monitored to minimize impacts on natural populations and for effective management.
4. Future hatchery practices need to recognize the importance of the genetic structure and diversity in salmonids, the importance of maintaining adaptability to future environmental changes, and how to integrate this production within the emerging ecological framework that is to guide management of resources in the Columbia River.
5. Hatcheries must be considered in the context of functioning ecosystems. Production from hatcheries cannot be considered independent of natural systems. The success of a hatchery program will depend on the fitness of the stock, the

quality and constraints of the natural habitat, and how well the hatchery production is integrated with the natural ecosystem.

6. The region, through the Council, needs to implement a scientifically valid monitoring program for assessment of hatchery procedures, production, impact on natural populations, and achievement of goals. Given the extensive annual investment in hatchery programs within this basin, and the reliance implied on these programs to conserve and enhance salmonid production, we must recommend more quantitative evaluations of production and studies of interactions with natural populations.

Presently, there are 10 hatcheries or programs in the Upper Columbia Basin operated by the USFWS or WDFW, releasing 4,087,000 spring chinook salmon and 950,000 summer steelhead in the Entiat, Methow, Okanogan, and Wenatchee subbasins (Table 1). Hatchery programs are integrated, except for the segregated USFWS Entiat and Leavenworth spring chinook salmon hatcheries. Also, the Confederated Colville Tribes have plans for a new chinook salmon hatchery in the Okanogan River basin.

Table 1. Hatcheries or artificial production programs in the Upper Columbia Basin producing spring chinook salmon and summer steelhead (data are from the HGMP's).

Subbasin/Hatchery (Operator)	**Smolts released**	
	Spring chinook salmon	**Summer steelhead**
Entiat (USFWS)	400,000	-
Methow/Methow Hatchery (WDFW)	550,000	-
Methow/Winthrop NFH (USFWS)	600,000	100,000
Methow/Wells Hatchery (WDFW)	-	350,000
Okanogan/Lake Similkameen (WDFW)	-	50,000
Okanogan/Okanogan Hatchery (WDFW)	-	50,000
Wenatchee/Chiwawa River (WDFW)	672,000	-
Wenatchee/White River (WDFW)	240,000	-
Wenatchee/Leavenworth NFH (USFWS)	1,625,000	-
Wenatchee/Wenatchee River (WDFW)	-	400,000
Total	**4,087,000**	**950,000**

The origin of most spring chinook released from 1940 to the late 1960s into the Wenatchee, Entiat, and Methow rivers from Upper Columbia hatcheries descended from co-mingled upriver stocks intercepted at Rock Island Dam. Also, there were juvenile releases from lower Columbia River broodstock (mixtures of Mckenzie and Cowlitz rivers, Eagle Creek, Carson, and Little White Salmon stocks) (Mullan 1987). The primary spring chinook broodstock was from the Carson NFH. The USFWS hatcheries programs producing spring chinook salmon and steelhead in the Entiat, Methow, and Wenatchee rivers contribute to fulfilling tribal trust responsibility mandates and treaty rights, as described in applicable agreements such as under U.S. v. Oregon. The program also contributes to mitigation requirements as stated in the Columbia River Fish Management Plan and the U.S. v. Oregon decision.

The purpose of most Upper Columbia hatcheries is either for harvest or contribution to conservation and recovery to mitigate for hydroelectric impacts and/or loss of spawning and rearing habitat. An important limitation to building self-sustaining populations of anadromous fish in the Upper Columbia is smolt and adult mortalities incurred at downstream hydropower facilities, which reduce the number of naturally produced adults that return to spawn and reseed available habitat.

Spring Chinook Salmon Production

The goal for spring chinook salmon is to maintain its high biological significance and improve its viability from poor to healthy in the long-term. The use of an integrated hatchery program as part of the recovery strategy is consistent with the current status and long-term goals for the stock.

Artificial propagation activities for spring chinook salmon are included within the Mid-Columbia Mainstem Conservation Plan (MCMCP)[1], a conservation planning initiative designed to bolster the productivity of salmonid populations in a manner that is compatible with self-sustaining populations. The MCMCP includes approaches for hatchery production that should contribute to the rebuilding and recovery of naturally spawning stocks throughout the Upper Columbia region to the point that those stocks can be self-sustaining and support harvest, while maintaining genetic and ecologic integrity (MCMCP 1998). A Biological Assessment and Management Plan (BAMP), assembled as a part of the MCMCP, describes approaches to be applied within the region under a Mid-Columbia River Hatchery Program. This program is a consensus plan by fish co-managers for development, operation, and evaluation of anadromous salmonid hatcheries in the Columbia River upstream of the Yakima River confluence (BAMP 1998). The co-managers include National Marine Fisheries Service (NMFS), U. S. Fish and Wildlife Service, Washington Department of Fish and Wildlife, Yakama Indian Nation, Colville Confederated Tribes, the Confederated Umatilla Tribes, and Chelan, Douglas, and Grant County Public Utility Districts (PUDs).

The hatchery programs are part of an application for the 50-year multi-species MCMCP and relicensing agreement for the PUDs. The plan has two objectives: (1) to help recover natural populations throughout the Upper Columbia region so that they can be self-sustaining and harvestable, while maintaining their genetic and ecologic integrity; and (2) to compensate for a 7% mortality rate at three PUD-owned, upper-Columbia River mainstem dams (Wells, Rocky Reach, and Rock Island) in a manner that is consistent with the first objective. The first objective (recover populations that are at risk of extinction) takes precedence, and will guide the strategies used in the initial years of the hatchery program. Once it appears that populations have recovered, and if it can be done in a manner that will not jeopardize them, hatchery production of these populations will increase to meet the second objective (compensation for hydropower-related mortalities).

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[1] Here “Mid-Columbia” refers to the Upper Columbia region.

The WDFW intent for all their hatcheries is to ensure that supplementation activities proposed in this permit application are consistent with the Mid-Columbia River Hatchery Program and with NMFS policy for artificial propagation under the Endangered Species Act (Hard et al. 1992). It is recognized, however, that the success of the supplementation program depends upon remedy of all factors responsible for the species decline. The successful establishment of self-sustaining, wild spring chinook populations is highly dependent on habitat rehabilitation and protection of spawning and rearing areas, and on the correction of factors affecting spring chinook migration.

In addition to maintaining consistency with the MCHCP hatchery plan, allowable annual spring chinook production levels must also be consistent with ESA protective requirements for other ESA-listed salmonid species in the Columbia River Basin, fulfillment of federal treaty obligations to Native Americans, fulfillment of court approved actions developed under the auspices of United States v. Oregon, the discharge of fisheries mitigation responsibilities incurred as a result of water development authorizations, and achievement of U.S./Canada Pacific Salmon Treaty obligations (CBFWA 1996). Production levels described in this application will also be compatible with allowable levels defined through the basin-wide annual production ceiling set by NMFS (NMFS 1995). Existing policies affecting hatchery operation and maintenance protocols in the Columbia River Basin are detailed in the 1994 Integrated Hatchery Operations Team (IHOT) Annual Report (IHOT 1995). The mid-Columbia re-licensing agreement sets forth specific program performance indicators (fish size and release numbers, survival, etc.) that are explicitly monitored and evaluated as part of an adaptive management policy.

Three other spring chinook salmon hatcheries, the Entiat, Winthrop (Methow River Basin), and the Wenatchee are run by the USFWS and funded by the Bureau of Reclamation. These hatcheries were constructed as mitigation facilities to compensate for the loss of spawning and rearing habitat due to the construction of Grand Coulee Dam.

Hatchery spring chinook may affect wild chinook in several ways. Naturally spawning populations may be subject to genetic interactions through interbreeding. Ecological interactions through predation and competition may occur between the hatchery population and natural populations, and natural populations may be incidentally harvested in fisheries targeting a more abundant hatchery stock. Abundant hatchery stocks may also mask the status of natural populations. Conversely, an increase in the number of artificially produced fish may improve the ecological function of a watershed through their contribution of marine derived nutrients.

A number of factors are known to affect the likelihood and severity of such interactions, among them the abundance of the hatchery population relative to other populations; the time, size, and life stage at which hatchery fish are released; and the quantity and quality of habitat available to the co-mingled stocks. Table 2 lists hatchery factors that may affect the abundance and survival of natural populations of spring chinook in the Upper Columbia region.

The proposed Colville Tribal Hatchery for the production of chinook salmon in the Okanogan River watershed has the following conceptual objectives:

1. Manage genetic risks to all stocks from management of the fishery;
2. Conserve and/or expand Okanogan and Methow river chinook salmon;
3. Conserve and/or expand the Okanogan stocks of chinook salmon;
4. Optimize natural production of spring chinook salmon with respect to abundance and distribution;
5. Optimize natural production of chinook salmon while managing adverse impacts from interactions between and within species and stocks;
6. Maintain Okanogan chinook salmon natural production at a level that would contribute an average of X number of fish to the Okanogan River basin adult return;
7. Maintain natural escapement of chinook salmon (hatchery and wild) at a average of X number of adult returns and consistently greater than X number spawners per year;
8. Learn to use supplementation as defined by the RASP, ISAB and Council to increase natural production of Okanogan River chinook salmon and increase harvest opportunities;
9. Increase harvest opportunities for all fishers consistent with requirements of genetic, natural production, and experimental objectives.

Summer Steelhead Production

The goal for the Upper Columbia summer steelhead stock is to maintain its high biological significance and improve its viability from poor to healthy in the long-term. A further goal for the stock is to provide harvest opportunity. The use of an integrated hatchery program as part of the recovery strategy is consistent with the current status and long term goals for the stock.

WDFW addresses this concern in the Wild Salmonid Policy (WDFW 1997), which states that even with a high level of genetic similarity between hatchery and wild fish, the hatchery component should not comprise more than 10% of the naturally spawning population, except in the case of supplementation programs intended to sustain the stock for reasons other than harvest (e.g., habitat degradation, hydropower dams, and unforeseen catastrophic loss). Under present circumstances, the proportion of hatchery fish rarely is less than 50% in the upper Columbia River tributaries.

Conversely, if hatchery steelhead are essential for recovery, the degree of use of hatchery fish must be reassessed to accommodate hatchery strategies. This includes selecting fish to reflect the most appropriate return and spawn timing, the use of acclimation ponds to imprint juvenile steelhead to return as adults to specific sites, and the removal of excess hatchery fish by a combination of methods including recreational harvest and removal at fish passage and collection facilities. The 10% level identified in the Wild Salmonid Policy may be useful as a guideline, but cannot be given strict adherence because of mortalities attributed to hydropower facilities in the Columbia River, and in situations of low run sizes caused by poor freshwater and marine survival. Such impacts can put this stock in jeopardy because wild fish cannot replace themselves given the cumulative impacts from hydropower projects.

Traditional approaches of hatchery programs have imposed different types of biological problems on salmon and steelhead populations including demographic risks; genetic and evolutionary risks; problems due to behavior, health status, or physiology of hatchery fish; and ecological problems (CPMPNAS 1996).

Table 3 shows hatchery factors, operations, and risk aversion measures that will be applied to minimize the likelihood for adverse genetic and ecological effects to listed steelhead during incubation, broodstock selection and collection, mate selection, propagation, incubation and rearing, releases, and monitoring and evaluation.

Possible Negative Effects of Artificial Production Programs

Demographic Risks:

In the Upper Columbia region, high numbers of hatchery spring chinook salmon and summer steelhead may be causing problems as these adults mix with wild returning fish in natural spawning areas. To lessen the potential risk of negative genetic effects of straying hatchery fish spawning with wild stocks, managers should only allow a minimum level of hatchery fish to escape upstream for natural spawning; they should plant hatchery-acclimated smolts in desired locations where adult returns will help minimize straying to other streams; and they should mark of all hatchery chinook and steelhead with a CWT and visual mark. Mass marking will allow for ready differentiation between hatchery and wild fish on spawning grounds. NOAA Fisheries evaluation of current monitoring reveals that the Chiwawa (Wenatchee River) and Twisp (Methow River) spring chinook hatchery programs are increasing the abundance of natural-origin fish, while the Methow River and Chewuch (Methow River) programs are decreasing the number of natural-origin fish.

Hatchery stocks produced for harvest are being reared and released in a manner enabling effective harvest, while avoiding over-harvest of non-target species. In addition, release groups are sufficiently marked in a manner consistent with information needs and protocols enabling determination of impacts to natural and hatchery-origin fish in fisheries.

Genetic and Evolutionary Risks:

Numerous studies involving the comparison of hatchery and wild population productivities in a natural environment have shown that hatchery fish have a lower productive capability than wild fish (Chilcote 1983, 1986, 1998, 2001; Campton 1991). Also, the use of wild fish as hatchery broodstock has not solved the genetic problem, with a possible main problem being an unknown environmental impact where hatchery rearing produces a hatchery adult that is less able to produce viable offspring under natural conditions (Chilcote 1998). Chilcote (1998) found that when hatchery fish mix with wild fish in natural production areas, the overall productivity of the population decreases and the population's vulnerability to extinction increases. NOAA Fisheries believes this may have occurred in the Entiat and Methow river basins, where natural-origin stocks have been replaced by federal hatchery stocks.

Population Identity and Variability—Straying of hatchery fish in spawning streams in the Upper Columbia has the potential to erode the genetic diversity of the few wild spawners, especially where lower-Columbia River hatchery stocks (e.g., Mckenzie and Cowlitz rivers, Eagle Creek, Carson, and Little White Salmon stocks) were mixed with wild spawners in the Upper Columbia basin. Hatchery volitional release timing may interact with natural spawners through interbreeding. Predation and competition may occur between natural and other stocks and natural populations may be harvested in fisheries of the target hatchery stock. In addition, the abundance of hatchery fish may mask the status of natural populations. Some factors are known to affect the likelihood and severity of such interactions including: the proportion of hatchery population to natural populations; the time, size and life stage at which hatchery fish are released; and the quantity and quality of habitat available to the co-mingled stocks. Straying of federal hatchery spring chinook salmon in the Wenatchee, Entiat, and Methow river basins has been identified by NOAA Fisheries as a problem.

To maintain genetic diversity/identity and population variability, hatchery operations in the Upper Columbia are now using only native, adapted broodstock; reducing the number of wild fish used for broodstock; and follow acceptable guidelines for contribution of hatchery fish to natural spawning fish (Tables 2 and 3).

Domestication of Wild Stocks—Domestication, the nonrandom collection of hatchery broodstock over the duration of the run, can change the genetic adaptations of a stock in two ways: (1) with the infusion of hatchery stocks shifting to earlier run timing and (2) altered selection pressures due to differences between the natural and hatchery environments.

To minimize domestication and effects on wild spring chinook salmon broodstock, spring chinook encountered in hatchery broodstock collection operations are held generally less than 24 hours in traps; spring chinook trapped in excess of broodstock collection goals are released upstream immediately without harm; rearing and release strategies are designed to limit adverse ecological interactions through minimizing the duration of interaction between newly liberated hatchery chinook and naturally produced fish; smolt releases are timed with water budget releases from upstream dams, to further accelerate seaward migration of released hatchery fish, further reducing the duration of any interactions with wild fish; and the most discrete population units possible are targeted for supplementation, after balancing logistical limitations of terminal area collection and release of populations, maintenance of genetic integrity and local adaptation, and management of discrete populations.

However, hatcheries producing spring chinook salmon and summer steelhead are still not releasing fish in a manor that simulates natural seasonal migration patterns. Volitional releases to match outmigration timing are only conducted at Methow, Chiwawa and White rivers (Wenatchee) for spring chinook salmon, and in the Methow River for summer steelhead (Tables 2 and 3).

Disruption of Natural Selection by Artificial Matings—Artificial matings in hatcheries can disrupt natural patterns of sexual selection, negatively affecting fitness of hatchery fish in natural environments. Under natural selection, the relatively small number of adults that survive the life history challenges to spawn represents a process of natural sexual selection. The hatchery selection process is non-selective and has no method to determine which breeders would be the best in a natural environment. For spring chinook in Upper Columbia programs, adults are mated randomly only in the Entiat and Leavenworth (Wenatchee) hatcheries, gametes are not pooled in any hatchery, backup males are used in spawning, and precocious males used are generally a set percentage of the run (Table 2). For Upper Columbia summer steelhead programs, adults are not mated randomly and gametes are not pooled, while backup males are always used in spawning and precocious males used are not generally a set percentage of the run (Table 3).

Effects of Physical Hatchery Conditions on Probability of Selection—Physical and environmental conditions in hatcheries differ greatly from those conditions in natural environments. Hatcheries lack diverse habitat conditions, flows and temperature regimes, and exposure to natural prey and predators. In the Upper Columbia region, only the Entiat spring chinook salmon and Methow spring chinook salmon and steelhead hatcheries have rearing facilities that attempt to mimic natural environments (Tables 2 and 3).

Synopsis—Overall, the current effects of hatchery practices on genetics are much reduced compared to historical practices. All hatcheries conform to Integrated Hatchery Operations Team (IHOT), Pacific Northwest Fish Health Protection committee (PNFHPC), and federal and other fish culture guidelines and standards. Protocols in IHOT are intended to address fish health practices, genetic effects, ecological interactions, fish cultural practices, and hatchery operations (IHOT 1995). Also, all hatcheries in the Upper Columbia follow IHOT fish health guidelines to prevent transmission between lots of fish on site or transmission or amplification to or within the watershed and vaccines are not used.

Fish Behavior:

Hatchery fish behavior is markedly different than wild fish, including foraging, social interactions, and predator-avoidance. These differences have lead to more aggressive hatchery fish and a higher mortality of hatchery fish in the natural environment. Currently in all Upper Columbia hatcheries, programs try to produce fish that are similar in morphology, behavior, and physiological status and health compared to natural fish (Tables 2 and 3).

Fish Health:

The incidence of disease outbreaks in hatcheries is common. Disease concerns can interact with genetic risks with a stock losing inherited modes of combating disease (O'Brien and Evermann 1988). All hatchery fish released from Upper Columbia hatcheries are certified by Fish Health professionals prior to release to minimize the risk of disease transference from hatchery fish to wild fish.

Physiology of Hatchery Fish:

Hatchery fish are sometimes released at a suboptimal physiological state and incomplete smoltification of hatchery fish results in lack of strong downstream migration behavior and longer residence in stream habitats compared to wild fish (Snelling and Schreck 1992). Hatchery spring chinook are reared to sufficient size, such that smoltification occurs within nearly the entire population, reducing residence time in the streams after release and promoting rapid seaward migration (Table 2). For all Upper Columbia hatcheries, summer steelhead are not being released at sizes similar to natural fish or in a manner that simulates natural outmigration timing (Table3).

Ecological Problems:

The ability of hatchery fish to survive and integrate into natural habitats without affecting changes in wild salmonid populations depends on the numbers and sizes of fish released, their physiological state, their behavior and health status, and the locations and timing of releases. In the Upper Columbia, most hatcheries producing spring chinook (except the Methow) and two hatcheries producing summer steelhead (Methow and Wenatchee) are now determining some ecological factors, such as the carrying capacity of stream environments and density-dependent interactions within and between species (Tables 2 and 3). In general, a potentially positive effect of high numbers of hatchery fish spawning naturally would be the increase in marine derived nutrients from additional salmon carcasses. Some hatchery practices, however, can lead to a lack of carcasses in streams and rivers (Cedarholm et al. 1989). In the Upper Columbia, only the USFWS Leavenworth Hatchery on Icicle Creek currently prevents upstream migration of naturally producing adults. Another indirect ecological problem of hatcheries is lower numbers of wild spawning adults, with lower redd numbers reducing redd superimposition and egg drift thereby reducing a food source for other indigenous and listed fish, such as bull trout.

Future Role of Salmonid Hatcheries in the Upper Columbia Basin

First and most importantly, hatchery programs have to be linked to rehabilitation strategies and the long-term sustainability of natural salmonid habitats. Hatchery programs should not be used as a substitute for rehabilitating the natural capacity of an ecosystem. Hatcheries can be used to reduce the human-induced causes of the decline of anadromous salmonids and adopt a goal of maintaining genetic resources that exist in naturally spawning and hatchery populations. Hatcheries can be used to prevent the extinction of severely depressed populations and rebuild these populations to a self-sustaining status. Hatcheries also can be used to restore recreational, commercial, and traditional (treaty-protected) fishing.

New or modified programs in the Wenatchee and Entiat River basins, which splits the Chiwawa program into two tributary programs, changes the progagated spring chinook salmon stock in the Wenatchee and Entiat river basins, and relocates releases in areas outside the Entiat River to support a terminal fishery, should reduce harm to native populations.

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Table 2. Hatchery factors and/or operations that can potentially affect or interact with wild spring chinook salmon (based on HGMP information)

Hatchery Factors and/or Operations	Hatchery/Programs					
	Entiat R. (USFWS)	Methow R.(WDFW)	Methow R.(USFWS)	Wenatchee R. (Chiwawa R.)	Wenatchee R. (White River)	Wenatchee R. (Leavenworth)
Is the program stock listed	N	Y	Y	Y	Y	N
Program has Section 7 or 10 and NPDES permit	Y	Y	Y	Y	Y	Y
Hatchery operates to allow all migrating species of all ages to by-pass or pass through hatchery related structures.	Y	Y	Y	Y	Y	Y/N
Incubation water can be heated or chilled to approximate natural water temperature profiles	Y	Y	Y	Y	Y	Y
Adequate flows are maintained to provide unimpeded passage of adults and juveniles in the by-pass reach created by hatchery water withdrawals	Y	Y	Y	Y	Y	Y
Rearing water has a chemical profile significantly different from natural stream conditions to provide adequate imprinting of hatchery fish and minimize the attraction of naturally produced fish into the hatchery.	Y	Y	Y	Y	Y	Y
Naturally produced fish access to intake screens	Y	Y	Y	N	N	N
Water used provides natural water temperature profiles that results in hatching/emergence timing similar to naturally produced stock	N	N	N	N	N	Y
Broodstock represents natural populations native or adapted to the watersheds where hatchery fish will be released	N	Y	N	Y	Y	N
A collection plan for natural origin adults is in place that prevents collection of surplus fish and 10% or less of the brood stock is derived from wild fish each year	Y	Y	Y	Y	Y	Y
All hatchery fish are tagged or clipped	Y	Y	Y	Y	Y	Y
Sexes randomly mated, gametes pooled, backup males used, precocious males set % of run	Y/N/Y/Y	N/N/Y/Y	N/N/Y/Y	N/N/Y/Y	N/N/Y/Y	Y/N/Y/Y
Program has guidelines for acceptable contribution of hatchery fish to natural spawning	Y	Y	Y	Y	Y	Y
Juveniles rearing area mimics a natural environment	Y	Y	Y	N	N	N
Juveniles are released on station	Y	Y/N	Y/N	Y	Y	Y/N
Program uses a diet and growth regime that mimics the natural seasonal growth patterns	Y	N	Y	N	N	Y
Excess adults are used for seeding habitat	Y	Y	Y	Y	NA	Y
Fish produced are qualitatively similar to natural fish in morphology , behavior , physiological status and health	Y	Y	Y	Y	Y	Y
Fish are released at sizes similar to natural fish of the same stage and species	Y	Y	Y	Y	NA	Y
Fish are released in a manner that simulates natural seasonal migration patterns	N	N	N	N	NA	N
Volitional release is practiced during natural out-migration timing	N	Y	N	Y	Y	N
Fish are released in the same subbasin as the rearing facility.	Y	Y	Y	Y	Y	Y
Fish are released within the historic range for that stock	Y	Y	Y	Y	Y	Y
Carrying capacity of the subbasin has been taken into consideration in sizing	Y	N	Y	Y	Y	Y
Fish produced are effective for harvest, while avoiding overharvest of non-target species	Y	NA	Y	NA	NA	Y
Is monitoring and M&E research conducted	Y/Y	Y/N	Y/Y	Y/Y	N/N	Y/Y

Table 3. Hatchery factors and/or operations that can potentially affect or interact with wild summer steelhead (based on HGMP information).

Hatchery Factors and/or Operations	Hatchery				
	Methow R. (Winthrop)	Methow R. (Wells)	Okanogan R. (L. Similkameen)	Okanogan R. (Okanogan)	Wenatchee R. (Wenatchee)
Is the program stock listed	Y	Y	Y	Y	Y
Program has Section 7 or 10 and NPDES permit	Y	Y	Y	Y	Y
Hatchery operates to allow all migrating species of all ages to by-pass or pass through hatchery related structures.	Y	Y	Y	Y	Y/N
Incubation water can be heated or chilled to approximate natural water temperature profiles	Y	Y	Y	Y	Y
Adequate flows are maintained to provide unimpeded passage of adults and juveniles in the by-pass reach created by hatchery water withdrawals	Y	Y	Y	Y	Y
Rearing water has a chemical profile significantly different from natural stream conditions	Y	Y	Y	Y	Y
Naturally produced fish access to intake screens	N	N	N	N	N
Water used provides natural water temperature profiles that results in hatching/emergence timing similar to naturally produced stock	N	N	Y	N	N
Broodstock represents natural populations native or adapted to the watersheds where hatchery fish will be released	Y	Y	Y	Y	Y
A collection plan for natural origin adults is in place that prevents collection of surplus fish and 10% or less of the brood stock is derived from wild fish each year	Y	Y	Y	Y	Y
All hatchery fish are tagged or clipped	Y	Y	Y	Y	Y
Sexes randomly mated/ gametes pooled/ backup males used/ precocious males set % of run	N/N/Y/N	N/N/Y/N	N/N/Y/N	N/N/Y/N	N/N/Y/N
Program has guidelines for acceptable contribution of hatchery fish to natural spawning	Y	Y	N	N	Y
Juveniles rearing area mimics a natural environment	Y	N	N	N	N
Juveniles are released on station	Y	N	N	N	N
Program uses a diet and growth regime that mimics the natural seasonal growth patterns	Y	N	N	N	N
Excess adults are used for seeding habitat	Y	Y	Y	Y	NA
Fish produced are qualitatively similar to natural fish in morphology , behavior , physiological status and health	Y	Y	Y	Y	Y
Fish are released at sizes similar to natural fish of the same stage and species	N	N	N	N	N
Fish are released in a manner that simulates natural seasonal migration patterns	N	N	N	N	N
Volitional release is practiced during natural out-migration timing	Y	Y	N	N	Y
Fish are released in the same subbasin as the rearing facility.	Y	N	N	N	N
Fish are released within the historic range for that stock	Y	Y	Y	Y	Y
Carrying capacity of the subbasin has been taken into consideration in sizing	Y	N	N	N	Y
Fish produced are effective for harvest, while avoiding overharvest of non-target species	Y	Y	NA	NA	NA
Is monitoring/ M&E research conducted	Y/N	N/N	N/N	N/N	Y/Y

FACTORS FOR DECLINE

3.4.3 FISH AND WILDLIFE INTERACTIONS WITH FOCAL SPECIES

As described in the section on Ecological Interactions, there are several species that can affect the production and survival of spring chinook salmon and summer steelhead in the Upper Columbia Basin. This section describes in more detail specific interactions that may affect chinook and steelhead in the basin. Here the focus is on competition and predation.

Competition

As noted in the Ecological Interactions section, competition among organisms occurs when two or more individuals use the same resources and when availability of those resources is limited (Pianka 2000). Although competition is difficult to demonstrate, a few studies conducted within the Upper Columbia Basin indicate that competition may affect the production of chinook salmon and steelhead in the basin.

Chinook/steelhead:

It is possible that interspecific[1] competition may occur beween juvenile chinook and steelhead along the margins of their spatial and temporal distributions. Hillman et al. (1989a, 1989b) investigated the interaction between these species in the Wenatchee River between 1986 and 1989. They reported that chinook and steelhead used dissimilar daytime and nighttime habitat throughout the year. During the daytime in summer and autumn, juvenile chinook selected deeper and faster water than steelhead. Chinook readily selected stations associated with brush and woody debris for cover, while steelhead primarily occupied stations near cobble and boulder cover. During winter days, chinook and steelhead used similar habitat, but Hillman et al. (1989a) did not find them together. At night during both summer and winter, Hillman et al. (1989b) found that both species occupied similar water velocities, but subyearling chinook selected deeper water than steelhead. Within smaller streams, Hillman and Miller (2002) found that chinook were more often associated with pools and woody debris during the summer, while steelhead occurred more frequently in riffle habitat. Hillman et al. (1989a, 1989b) concluded that interaction between the two species would not strongly negatively affect production of either species, because disparate times of spawning tended to segregate the two species. This conclusion is consistent with the work of Everest and Chapman (1972) in Idaho streams.

Redside shiners:

Under appropriate conditions, interspecific interaction may also occur between redside shiners and juvenile chinook and steelhead. Hillman (1991) studied the influence of water temperature on the spatial interaction between juvenile chinook and redside shiners in the field and laboratory. In the Wenatchee River during summer, Hillman (1991) noted that chinook and shiners clustered together and that shiners were aggressive toward salmon. He reported that the

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[1] Interspecific competition is interaction between different species. Intraspecific competition is interaction among individuals of the same species.

shiners used the more energetically profitable positions, and that they remained closer than chinook to instream and overhead cover. In laboratory channels, shiners affected the distribution, activity, and production of chinook in warm (18-21°C) water, but not in cold (12-15°C) water (Hillman 1991). In contrast, chinook influenced the distribution, activity, and production of shiners in cold water, but not in warm water. Reeves et al. (1987) documented similar results when they studied the interactions between redside shiners and juvenile steelhead. Although Hillman (1991) conducted his fieldwork in the lower Wenatchee River, shiners are also present in the Entiat, Methow, and Okanogan rivers and are abundant in the mainstem Columbia River. At warmer temperatures, shiners likely negatively affect the production of chinook salmon and steelhead in the upper basin.

Coho salmon:

It is possible that the re-introduction of coho salmon into the Upper Columbia Basin may negatively affect the production of chinook and steelhead. One of the first studies in the upper basin that addressed effects of coho on chinook and steelhead production was conducted by Spauling et al. (1989) in the Wenatchee River. This work demonstrated that the introduction of coho into sites with naturally produced chinook and steelhead did not affect chinook or steelhead abundance or growth. However, because chinook and coho used similar habitat, the introduction of coho caused chinook to change habitat. After removing coho from the sites, chinook moved back into the habitat they used prior to the introduction of coho. Steelhead, on the other hand, remained spatially segregated from chinook and coho throughout the study. More recent studies conducted by Murdoch et al. (2002) found that juvenile coho, chinook, and steelhead used different microhabitats in Nason Creek, and at the densities tested, coho did not appear to displace juvenile chinook or steelhead from preferred microhabitats. These studies indicate that the re-introduction of coho should have little to no effect on the production of chinook and steelhead.

Various salmonids:

It is possible that juvenile chinook and steelhead interact with bull trout, brook trout, and cutthroat trout if they occur together. Hillman and Miller (2002) observed chinook, bull trout, and brook trout together in several tributaries of the Chiwawa River and in the Little Wenatchee River. In tributaries of the Chiwawa River, Hillman and Miller (2002) observed chinook and juvenile bull trout in the same habitat. They report seeing bull trout and chinook nipping each other in Big Meadow, Rock, and Chickamin creeks. Usually the aggressive interactions occurred in pools near undercut banks or in woody debris. In contrast, Martin et al. (1992) investigated the interaction between juvenile bull trout and spring chinook in the Tucannon River, Washington, and found that the two species have different habitat preferences. Juvenile spring chinook occurred more often in open, slow-water habitat without complex hiding cover. Bull trout, on the other hand, more frequently used riffle and cascade habitat. Bull trout numbers inversely correlated with amounts of woody debris and the two species did not compete for food because food was not limiting in the Tucannon River (Martin et al. 1992).

Although Hillman and Miller (2002) observed juvenile chinook and brook trout together in many tributaries of the Chiwawa River and in the Little Wenatchee River, they did not see aggressive interaction between the two species. Welsh (1994), on the other hand, studied the interaction between the two species in Idaho streams and found that when chinook were introduced into a stream with brook trout, the latter was displaced into marginal habitat. Over a six-year period, Welsh (1994) notes that brook trout vanished from his study sites. We can find no studies that address the interaction between chinook and cutthroat trout. Although chinook and steelhead may interact with bull trout, brook trout, and cutthroat trout, there is no evidence that they will negatively affect the production of chinook and steelhead in the Upper Columbia basin.

American shad:

A potentially important source of exploitative competition occurring outside the geographic boundary of the ESUs may be between the exotic American shad and juvenile chinook and steelhead. Changes in streamflow in the Columbia River system have resulted in increased plankton production, which has apparently increased the success of introduced shad. Shad prey on the most abundant foods (Walburg 1956; Levesque and Reed 1972). Shad in the Columbia River estuary consume amphipods, calanoid copepods (*Neomysis mercedis*), cladocerans (*Daphnia* sp.), and insects (Durkin et al. 1979). Juvenile salmonids eat the same foods (McCabe et al. 1983). Palmisano et al. (1993a, 1993b) concluded that increased numbers of shad likely compete with juvenile salmon and steelhead.

Predation

Fish, mammals, and birds are the primary natural predators of chinook and steelhead in the Upper Columbia basin. Although the behavior of chinook and steelhead precludes any single predator from focusing exclusively on them, predation by certain species can nonetheless be seasonally and locally important. Below is a discussion on the importance of specific predators on the production of chinook and steelhead in the Upper Columbia basin.

Smallmouth bass:

Smallmouth bass were introduced into the Columbia River before 1900 (Poe et al. 1994). Given their behavioral characteristics, it is assumed that they could significantly affect the abundance of juvenile chinook and steelhead. In spring and early summer they inhabit rocky shoreline areas that are also used by juvenile salmonids (Scott and Crossman 1973; Wydoski and Whitney 1979). Studies in Columbia basin reservoirs and Lake Sammamish, Washington, showed that smallmouth bass were highly predacious on outmigrating juvenile salmonids (Gray et al. 1984; Gray and Rondorf 1986). In contrast, studies by Bennett et al. (1983) and Zimmerman (1999) found that even though salmonids were present in Snake and Columbia River reservoirs, they were less important in the diets of smallmouth bass than other fish. Smallmouth bass commonly consumed sculpins, minnows, suckers, and troutperches in impounded and unimpounded reaches of the lower Columbia and lower Snake rivers during the outmigration of juvenile anadromous salmonids (Zimmerman 1999).

Sampling in the Upper Columbia Basin indicates that smallmouth bass are relatively rare (Dell et al. 1975; Burley and Poe 1994). Burley and Poe (1994) described studies that assessed the relative abundance of northern pikeminnow, walleye, and smallmouth bass in the Rocky Reach project area. Smallmouth bass constituted only 5% of the catch; northern pikeminnow and walleye made up 91% and 4% of the respective catch. Most (63%) smallmouth bass resided in the tailrace. Very few (3%) were captured mid-reservoir. Mullan (1980), Mullan et al. (1986), and Bennett (1991) suggested that few smallmouth bass occur within the Upper Columbia because of low ambient water temperatures. Optimum growth temperatures for smallmouth bass range from 26-29°C (Armour 1993a). Because Upper Columbia reservoirs function as a cold-tailwater to the reservoir of Grand Coulee Dam, optimal temperatures for bass occur primarily in warm backwaters (Mullan et al. 1986; Bennett 1991). The typical low water temperatures in the project area result in late spawning times, slow fry and fingerling growth, and small body size of smallmouth bass entering the first winter. This contributes to high over-winter mortality of juvenile smallmouth bass (Bennett 1991).

One could theorize that if sustained removals of northern pikeminnow significantly reduce mortality of juvenile salmonids in the project area, predation by smallmouth bass may be enhanced because of increased availability of juvenile salmonid prey. Studies in the lower Columbia and Snake rivers found that smallmouth bass did not respond to sustained removals of northern pikeminnow (Ward and Zimmerman 1999). Smallmouth bass density, year-class strength, consumption of juvenile salmonids, survival, growth, and relative weight did not increase concurrent with removals of northern pikeminnow. Likewise, it is unlikely that smallmouth bass will respond to sustained removals of northern pikeminnow in the Upper Columbia basin.

Because smallmouth bass are not abundant in the upper Columbia, they probably have a minor influence on the survival of juvenile chinook and steelhead. Of the anadromous fish in the project area, subyearling summer/fall chinook may be consumed more readily because their habitats overlap seasonally with smallmouth bass, and the subyearlings are ideal forage size for adult smallmouth bass (Poe et al. 1994).

Walleye:

According to Li et al. (1987), walleye recently invaded the Columbia River from the reservoir of Grand Coulee Dam, where they are now very abundant. This fish is a large, schooling predator, unlike the native fauna, and its affect on juvenile chinook and steelhead could be significant because of the potential for depensatory predatory-prey interactions[2]. Gray et al. (1984) found a high frequency of occurrence (42%) of juvenile salmonids in the stomachs of walleyes collected in the John Day tailrace during spring. In John Day Reservoir, however, Maule (1982) reported that walleyes ate few juvenile salmonids, and suggested that the probable reason was the spatial and temporal segregation of the species when walleyes were feeding most actively. Perhaps the reason that walleyes eat more juvenile salmonids in the tailrace is because the dam creates habitat that increases potential for spatial overlap, and therefore predation, between the species. This is supported by the high occurrence of juvenile salmonids in walleye stomachs collected between 1800 and 2400 hours (Gray et al. 1984), when the greatest fraction of smolts move through the powerhouse at John Day Dam (Sims et al. 1981), and when walleyes feed most heavily (Maule 1982).

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[2] Depensatory predation means that prey mortality is highest at the lowest density.

Work by Zimmerman (1999) in impounded and unimpounded reaches of the lower Columbia River indicated that walleyes, like smallmouth bass, more commonly consumed sculpins, suckers, minnows, and troutperches during the outmigration of juvenile salmonids. This comports with the observations of Vigg et al. (1991), who estimated that nonsalmonid consumption rates of walleye were similar to those of smallmouth bass and exceeded those of northern pikeminnow in John Day reservoir.

Walleyes are relatively rare in the upper Columbia (Dell et al. 1975; Burley and Poe 1994). Burley and Poe (1994) reported that walleyes made up only 4% of the catch of the major predators in the Rocky Reach project area; the other two major predators, northern pikeminnow and smallmouth bass, made up 91% and 5% of the respective catch. Most of the walleyes were captured in the tailrace. Few were captured in the forebay or mid-reservoir. The abundance of walleye appears to be limited by poor recruitment and low turbidity (Bennett 1991). Bennett (1991) reported that the most significant factor limiting abundance of walleyes is the short reservoir retention times (5.5-0.7 days), especially at the time of larvae abundance. High mortality and low food abundance for larvae probably limits recruitment of walleyes in reservoirs. In addition, low water turbidity likely affects the temporal and spatial distribution of feeding and reproduction of walleyes. Walleyes attain maximum population sizes in shallow, large, turbid waters (Scott and Crossman 1973). They prefer turbid water because their eyes are sensitive to bright light. In clear waters, walleyes retain contact with the substrate during the day (Ryder 1977) and increase activity as light conditions decrease in the evening. Peak periods of activity in clear waters are dusk and dawn (Kelso 1976).

Mullan et al. (1992) believed that low water temperatures may limit recruitment of walleyes in the upper Columbia. Optimal water temperatures for embryo incubation range from 9-15°C (Armour 1993b). Optimal growth temperatures for juveniles and adults range from 22-28°C and 20-28°C, respectively (Armour 1993b). These thermal requirements suggest that water temperatures in the project area may not increase sufficiently fast or high enough for successful incubation, hatching, and rearing (Mullan et al. 1986; Bennett 1991). Successful incubation, hatching, and rearing may occur in backwater areas.

Because walleyes are not abundant in the upper Columbia, they probably do not significantly reduce the abundance of juvenile chinook or steelhead in the area. Walleye predation on juvenile salmonids is probably greatest on subyearling summer/fall chinook. Gray et al. (1984) found that about 80% of the juveniles identified in walleye stomachs were subyearlings, probably a result of their smaller size. Subyearling chinook spend more time in shallower water than yearling spring chinook, also increasing the likelihood of encountering walleyes.

Northern pikeminnow:

The northern pikeminnow is a native cyprinid widely distributed throughout the Columbia River system (Mullan et al. 1986). It is the dominant predator of juvenile salmonids in the system, and predation by this species is clearly important compared to other sources of mortality (Poe et al. 1991; Rieman et al. 1991; Vigg et al. 1991; Ward and Zimmerman 1999; Zimmerman 1999). Petersen (1994) estimated the annual loss of juvenile salmonids to predation by northern pikeminnow in John Day Reservoir to be 1.4 million, approximately 7.3% of all juvenile salmonids entering the reservoir. Predation varies throughout the system and is often highest near dams (Ward et al. 1995). Although the work by Gadomski and Hall-Griswold (1992) suggests that northern pikeminnow prefer dead juvenile chinook to live ones, Petersen (1994) found that 78% of juvenile salmonids eaten by northern pikeminnow near a dam were consumed while alive. Ward et al. (1995) estimated that 48% of predation occurs in mid-reservoir areas away from dams, where juvenile salmonids are presumably alive and uninjured when consumed. Of the estimated 200 million juvenile salmonids that emigrate annually through the Columbia River system, about 16.4 million (8%) are consumed by northern pikeminnow (Beamesderfer et al. 1996).

Northern pikeminnow are abundant in the Upper Columbia Basin (Dell et al. 1975; Mullan 1980; Mullan et al. 1986; Bennett 1991; Burley and Poe 1994) and large numbers pass through the fishways at dams. Of the three major predators in the Rocky Reach project area (northern pikeminnow, smallmouth bass, and walleye), northern pikeminnow made up 91% of the catch (Burley and Poe 1994). These fish were most abundant in the mid-reservoir (45% of the total catch of northern pikeminnow), with the remaining catch of northern pikeminnow split equally between the forebay and tailrace. At other dams in the Upper Columbia basin, Burley and Poe (1994) found larger numbers of northern pikeminnow in the tailrace areas. Northern pikeminnow in the Rocky Reach project area averaged 296 mm fork length (range, 115-515 mm) (Burley and Poe 1994). Vigg et al. (1991) reported that juvenile salmonids are the major dietary component of northern pikeminnow larger than 250-mm fork length. Therefore, one would assume that northern pikeminnow could significantly affect the abundance of juvenile chinook and steelhead in the upper basin.

Burley and Poe (1994) summarize studies that assessed the significance of northern pikeminnow predation in the Upper Columbia region. They reported that northern pikeminnow in the Rocky Reach project area consumed primarily fish during the spring and summer; crustaceans, molluscs, insects, and plants were also consumed. Typically, the highest percentage of gut contents consisting of fish occurred in pikeminnows feeding in the tailrace and forebay areas. Juvenile salmonids were a significant component of northern pikeminnow diets, especially in tailrace areas.

The concern that northern pikeminnow could significantly affect the abundance of chinook and steelhead in the upper basin resulted in the initiation of a pikeminnow population reduction program. Since its initiation (1994), the program has removed well over 75,000 northern pikeminnow from Rocky Reach and Rock Island project areas (West 2000). At Rocky Reach, the program removed 44,743 (average, 6,400 per year; range, 2,482-9,633) pikeminnow. The number of northern pikeminnow ascending fish ladders at both dams has declined and catch rates have decreased (West 2000).

It is reasonable to assume that the reduction in numbers of northern pikeminnow has increased survival of juvenile chinook and steelhead in the upper basin. In the lower Columbia and Snake rivers, potential predation on juvenile salmonids by northern pikeminnow decreased 25% after a pikeminnow removal program was implemented there (Friesen and Ward 1999). Friesen and Ward (1999) estimated a reduction in potential predation of 3.8 million juvenile salmon (representing 1.9% of the total population). Knutsen and Ward (1999) found no evidence that the surviving pikeminnow compensated for removals. That is, estimates of relative weight, growth, and fecundity of pikeminnow were similar to estimates made before pikeminnow removals. Zimmerman and Ward (1999) concluded that consumption of juvenile salmonids by surviving pikeminnow has not increased in response to pikeminnow removal. It is likely that similar results occur within the Upper Columbia basin.

Northern pikeminnow are abundant in the Upper Columbia basin and have the potential to significantly affect the abundance of juvenile chinook and steelhead. They consume large numbers of juvenile salmonids, primarily those concentrated in the tailrace and forebay areas during the spring outmigration. They also consume large numbers of juvenile salmonids (probably summer/fall chinook) during summer. Currently, the factor limiting the abundance of northern pikeminnow in the upper basin is the sustained population reduction program. The program has removed large numbers of northern pikeminnow from the project area. As a result, dam passage counts of pikeminnow have decreased. This has likely resulted in increased survival of juvenile anadromous fish in the project area.

Sculpins:

Sculpins are native and relatively common in the upper basin (Dell et al. 1975; Mullan 1980; Burley and Poe 1994). Although sculpins are not considered a major predator of outmigrating anadromous fish, they do prey on small chinook and steelhead (Hunter 1959; Patten 1962, 1971a, 1971b; Hillman 1989). In the Wenatchee River, Hillman (1989) noted that large concentrations (20 fish/m^2) of juvenile chinook and steelhead occupied inshore, shallow, quiet-water positions on the streambed during the night. Hillman (1989) found that many sculpins moved into these areas at night and preyed heavily on chinook and steelhead fry. Predation on fry appeared to be limited to sculpins larger than 85 mm and ceased when prey reached a size larger than 55 mm. The number of fry eaten per night appeared to be related to sculpin size, with the largest sculpins consuming the most fry per individual.

Because sculpins are abundant in Upper Columbia River tributaries, they are likely an important agent of mortality of chinook and steelhead eggs and fry. As chinook and steelhead fry grow, they are released from this source of mortality. It is unknown what fraction of the chinook and steelhead population is removed by scuplins.

White sturgeon:

White sturgeon, a native species, are not abundant in the upper basin (Mullan 1980; Mullan et al. 1986; Gray and Rondorf 1986; DeVore et al. 2000). According to Mullan (1980), sturgeon were perhaps the most important predator on young and adult salmon, as well as other fishes. This is not the case now because of greatly reduced sturgeon abundance. Using setlines and gill nets, DeVore et al. (2000) found few sturgeon in the Upper Columbia River. In Rock Island Reservoir, a total of 95 overnight setlines captured only four sturgeon. The researchers did not sample in Rocky Reach Reservoir and used only setlines in Rock Island Reservoir. Sturgeon in Rock Island Reservoir ranged in lengths from 144-192 cm and in weight from 31-57 kg. The researchers aged two fish, one at 17 years and the other at 30 years. White sturgeon are occasionally captured during the northern pikeminnow reduction program. For example, anglers collected two sturgeon in 1998, one at Rocky Reach Dam and another at Rock Island Dam (West 1999). Angling in 1999 captured three sturgeon at Rock Island Dam (West 2000). No sturgeon were captured at Rocky Reach Dam in 1999. All sturgeon captured during the northern pikeminnow control program were 91 cm or larger (T. West, Chelan PUD, personal communication).

White sturgeon are opportunistic bottom feeders, as indicated by morphological adaptations that include ventral barbels and a ventral, protrusible, sucker-like mouth (Wydoski and Whitney 1979; Ford et al. 1995). Juveniles predominantly eat chironomids and to a lesser degree, zooplankton, molluscs, and immature mayflies, caddisflies, and stoneflies (Scott and Crossman 1973). In the lower Columbia River, juveniles primarily ate the tube-dwelling amphipod *Corophium salmonis* (McCabe et al. 1993). Individuals larger than 48 cm in length eat primarily fish (Scott and Crossman 1973; Ford et al. 1995). In the Kootenai River, white sturgeon larger than 80 cm fed on fish (whitefish, suckers, and other unidentified fish), aquatic insects, snails, clams, leeches, and chironomids (Partridge 1983).

DeVore et al. (2000) concluded that the white sturgeon in the Upper Columbia region are recruitment-limited because spawning habitat appears to be absent and no juveniles were found. Spawning coincides with peak flows during spring and early summer. Mature adults typically spawn in swift water (mean water column velocity, 0.8-2.8 m/s) over large substrate (cobble, boulder, or bedrock) (Parsley et al. 1993; Ford et al. 1995). In the upper basin these conditions likely exist just downstream from Wells Dam and Rocky Reach Dam. It is unknown if white sturgeon spawn in these areas.

Because white sturgeon are rare in the upper basin, they probably do not significantly affect the abundance of juvenile chinook or steelhead. Small chinook that rear in the Columbia River may be vulnerable to predation by white sturgeon. Theoretically, this would occur primarily at night when chinook and steelhead are stationed on the streambed.

Various salmonids:

Most adult salmonids within the upper basin are capable of preying on juvenile chinook and steelhead. Those likely to have some effect on the survival of chinook and steelhead include adult bull trout, rainbow/steelhead trout, cutthroat trout, brook trout, and brown trout. Because brown trout are rare in the region, they probably have little effect on the survival of chinook and steelhead. The other salmonids often occur in the same areas as chinook and steelhead and are known to be important predators of chinook and steelhead (Mullan et al. 1992). Of these, bull trout and rainbow trout are probably the most important. These species occur together in most tributaries; hence the probability for interaction is high. The presence of both fluvial and adfluvial stocks of bull trout in the region further increases the likelihood for interaction there.

Bull trout are opportunistic feeders and will eat just about anything including squirrels, birds, ducklings, snakes, mice, frogs, fish, and insects (Elliott and Peck 1980; Goetz 1989), although adult migrant bull trout eat primarily fish. Because adult migrant bull trout occur throughout the upper basin, including the mainstem Columbia River (Stevenson et al. 2003), they likely prey on juvenile chinook and steelhead. In the upper Wenatchee basin, Hillman and Miller (2002) noted that juvenile chinook and steelhead were rare in areas where adult bull trout were present. Like northern pikeminnow, adult bull trout frequent the tailrace areas of upper Columbia dams. These areas provide concentrated prey items, which include juvenile chinook and steelhead. It is likely that adult bull trout prey heavily on migrant salmon and steelhead in these areas. Indeed, Stevenson et al. (2003) found bull trout staging near the Wells Hatchery outfall, apparently seeking opportunistic feeding opportunities. As the number of bull trout increase in the upper basin, the interaction between them and chinook and steelhead will increase.

Rainbow/steelhead trout feed on chinook fry in the upper basin. In the Wenatchee River, for example, Hillman et al. (1989a) observed both wild and hatchery rainbow/steelhead feeding on chinook fry. Predation was most intense during dawn and dusk. At these times, rainbow/steelhead occupied stations immediately adjacent to aggregations of chinook. Hillman et al. (1989a) noted that within the prey cluster, the largest, light-colored chinook were closest to shelter and seldom eaten. Small, darker-colored chinook were farther from escape cover and usually eaten by predators. Hillman et al. (1989a; 1989b) suggest that predator-mediated interaction for shelter was strong and contributed to the rapid decline in chinook numbers in May. Although this work was done in the Wenatchee River, the results probably hold for other tributaries where the two species occur together.

Although adult salmonids prey on juvenile chinook and steelhead in the upper basin, the predation rate is unknown. Because of the abundance of both bull trout and rainbow/steelhead trout in the upper basin, it is reasonable to assume that large numbers of fry are consumed by these fish.

Birds:

Predation by piscivorous birds on juvenile anadromous fish may represent a large source of mortality. Birds have high metabolic rates and require large quantities of food relative to their body size. In the Columbia River estuary, avian predators consumed an estimated 16.7 million smolts (range, 10-28.3 million smolts), or 18% (range, 11-30%) of the smolts reaching the estuary in 1998 (Collis et al. 2000). Caspian terns consumed primarily salmonids (74% of diet mass), followed by double-crested cormorants (21% of diet mass) and gulls (8% of diet mass). The NMFS (2000) identified these species as the most important avian predators in the Columbia River basin.

Currently, there is little information on the effects of bird predation on the abundance of juvenile chinook and steelhead in the upper basin. Fish-eating birds that occur in the region include great blue herons, gulls, osprey, common mergansers, American dippers, cormorants, Caspian terns, belted kingfishers, common loons, western grebes, black-crowned night herons, and bald eagles (T. West, Chelan PUD, personal communication). According to Wood (1987a, 1987b), the common merganser limited salmon production in nursery areas in British Columbia. He found during smolt migrations that mergansers foraged almost exclusively on juvenile salmonids (Wood 1987a). Maximum mortality rate declined as fish abundance increased (i.e., depensatory mortality) and did not exceed 10% for any salmonid species. Wood (1987b) also estimated that young mergansers consumed almost one-half pound of subyearling chinook per day. Thus, a brood of ten ducklings could consume between four and five pounds of fish daily during the summer.

The loss of juvenile chinook and steelhead to gulls is potentially significant. Ruggerone (1986) studied the consumption of migrating juvenile salmon and steelhead below Wanapum Dam and found that the foraging success of gulls averaged 65% during bright light conditions and 51% during the evening. The number of salmonids consumed ranged from 50 to 562 fish/h. Ruggerone (1986) estimated that the number of salmonids consumed by gulls foraging downstream from the turbines during 25 days of peak salmonid migration was about 111,750 to 119,250 fish, or 2% of the estimated spring migration. Ruggerone (1986) noted that gulls consumed some salmonids that had been killed when passing through the turbines.

Cormorants may take large numbers of juvenile chinook and steelhead in the upper basin. Roby et al. (1998) estimated that cormorants in the estuary consumed from 2.6 to 5.4 million smolts in 1997, roughly 24% of their diet, and most were hatchery fish. Although Caspian terns are not common in the upper basin, there is evidence that they consume fish from the area. Bickford (Douglas PUD, personal communication) found both PIT-tags and radio tags at a Caspian Tern nesting area near Moses Lake. Tag codes indicated that consumed fish were from the Upper Columbia region.

Although there are no estimates of the losses associated with bird predation in the Upper Columbia basin, it appears that bird predation can significantly affect the survival of juvenile chinook and steelhead. Accordingly, the PUDs have implemented bird harassment measures and in some cases placed piano wire across tailraces. The degree to which these measures have reduced predation on juvenile anadromous fish is unknown at this time, but they have reduced bird predation on fish in the region (T. West, Chelan PUD, personal communication).

Mammals:

No one has studied the effects of mammals on numbers of chinook and steelhead in the Upper Columbia basin. Observations by BioAnalysts (unpublished data) indicate that river otters occur throughout the region. BioAnalysts (unpublished data) found evidence of otters fishing the Wenatchee, Chiwawa, Entiat, and Methow rivers, and Icicle Creek. Otters typically fished in pools with large woody debris. According to Hillman and Miller (2002), juvenile chinook are most abundant in these habitat types; thus, the probability for an encounter is high. Dolloff (1993) examined over 8,000 otoliths in scats of two river otters during spring 1985 and found that at least 3,300 juvenile salmonids were eaten by them in the Kadashan River system, Alaska. He notes that the true number of fish eaten was much higher, as it is unlikely that searchers found all the scats deposited by the otters. Other predators, such as raccoon and mink also occur in tributaries throughout the Upper Columbia basin. Their effects on numbers of chinook and steelhead are unknown.

Black bears are relatively common in the upper Columbia basin and frequent streams used by spawning salmon during autumn. Studies have shown that salmon are one of the most important meat sources of bears and that the availability of salmon greatly influences habitat quality for bears at both the individual level and the population level (Hilderbrand et al. 1999; Reimchen

2000). Observations by crews conducting chinook spawning surveys in the upper basin indicate that bears eat chinook, but it is unknown if the bears remove pre-spawned fish or are simply scavenging post-spawned fish. Regardless, there is no information on the roll that bears play in limiting survival and production of chinook and steelhead in the upper basin.

Pinnipeds, including harbor seals, California se lions, and Stellar sea lions are the primary marine mammals preying on chinook and steelhead originating from the Upper Columbia basin (Spence et al. 1996). Pacific striped dolphin and killer whale may also prey on adult chinook and steelhead. Seal and sea lion predation is primarily in saltwater and estuarine environments though they are know to travel well into freshwater after migrating fish. All of these predators are opportunists, searching out locations where juveniles and adults are most vulnerable.

Although there are no estimates of the losses associated with mammal predation in the Upper Columbia basin, it appears that mammals can significantly affect the survival of chinook and steelhead, especially in the estuary and near-shore ocean environments.

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FACTORS FOR DECLINE

3.4.4 HARVEST FACTORS AND THREATS

Pre-development harvests and effects

Until 7,000 to 10,000 B.P., glacial ice blocked upper reaches of many rivers of the Pacific Northwest (Lackey 1999). Improved ecological conditions for salmon likely developed about 4,000 years ago, and aboriginal fishermen benefited. Lackey (1999) speculated that salmon populations reached their highest levels within the last few centuries.

Craig and Hacker (1940) described artisanal fishing methods and Native American utilization of catch for subsistence and trade. Methods often depended upon capturing fish at natural obstacles like waterfalls that concentrated passage points, or upon man-made weirs. As noted in the material on factors for decline, it is very unlikely that catch rates attainable by Native Americans approached those appropriate for maximum sustained yield or populations. Hence escapement rates probably exceeded optima.[1]

Indian populations declined sharply about 100-500 years ago, attacked by smallpox, measles, sexually-transmitted diseases, cholera, and other pathogens imported from Europe. Fishing rates likely declined in concert.

Fisheries of the late 1800s

The population of humans in the Columbia River Basin developed rapidly with extensive immigration from the eastern U.S., beginning in the mid-1800s. Efficient fishing techniques, and preservation methods such as canning, set the stage for overexploitation of Columbia River salmon stocks. The onslaught of techniques included gillnets, traps, horse-pulled beach seines, purse seines, and fish wheels.

Intense fishing first targeted the abundant late-spring and summer components of what was a bell-shaped abundance function for chinook salmon. Spring chinook entered first, and in relatively small numbers (Chapman 1986). The late-spring and summer runs formed the central bulk of the abundance timing function. Finally, fall chinook arrived in lesser numbers. Thompson (1951) showed that fishing had all but extirpated the central bulk of the return distribution by 1919. As that fishery disappeared, industry shifted to sockeye, steelhead, coho, and fall chinook. These shifts partially masked the decline of overfished run components.

Although governmental agencies existed with nominal responsibility for fishery management (e.g., U.S. Bureau of Fisheries, Oregon Fish Commission), demand for fish

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[1] "Optima" refers to long-held adherence to theories of fishing rates associated with the Ricker or Beverton and Holt yield models. "Optimum rate" usually means that harvest rate that maximizes physical yield generation after generation. Current thinking has begun to focus on delivery of marine nutrients to spawning streams and riparian communities by large escapements. It is also possible that high escapements (even "overescapements") foster competition for spawning sites and for mates.

and gear competition, chiefly among commercial fishermen brooked little interference with seasons and fishing intensity. Washington passed its first gear restriction in 1866, some six years after commercial fishing became an important Columbia River industry. Oregon's first restriction came in 1878. Not until 1899 did Oregon and Washington begin to jointly manage Columbia River fisheries.

There can be little doubt that the relentless fishing intensity in most of the latter half of the 1800s and early 1900s substantially exceeded optimum rates. Chapman (1986) assumed that extant rates were 80-85% on spring and summer chinook, 88% on fall chinook, and 85% on steelhead.

The 1900s - decades of change

In 1909, Oregon and Washington instituted joint consistent fishing seasons. About 1910-12, as reasonably dependable internal combustion engines became available, troll fishing for salmon developed, enabling offshore fishing on Columbia River stocks mixed with fish from other rivers. Some inflation of early Columbia River landing statistics likely occurred as a result of troll-caught salmon sales inside the Columbia River mouth.

In 1917, purse seines were prohibited in the Columbia River. These regulations, as several others later, likely resulted in part from gear wars rather than conservation. Whip seines became illegal in 1923, and fish wheels in Oregon were prohibited in 1927. Fish wheels in Washington remained legal until 1935. Washington prohibited drag seines, traps, and set nets in 1935, while Oregon waited until 1949 to so act.

Washington law prohibited commercial take or sale of steelhead from the Columbia River after 1934, while Oregon continued to permit take and sale of steelhead by non-Indians until 1975.

Meanwhile, upriver dams began to deny salmon access to habitat. Swan Falls Dam on the Snake River was the first mainstem obstacle (1910). On the Columbia River mainstem, Rock Island Dam was completed in 1933, Bonneville Dam in 1938. These facilities provided the first consistent numerical assessments of fish passage (only harvest data were available formerly). Grand Coulee Dam denied fish access to salmon and steelhead that formerly used Canadian tributaries and the Spokane and San Poil rivers. Small irrigation dams also chipped away at fish habitat, beginning in the 1800s.

The year 1957 marked a major change in Native American fisheries. The Dalles Dam, completed in that year, flooded the most important traditional and important Indian fishing dipnetting site in the Columbia River, at Celilo Falls. Catch rates in 1957 in Zone 6 dropped dramatically, and did not increase until the early 1960s after Indians shifted to set gillnets.

Commercial fishing, and most Native American subsistence fishing in the latter half of the 1900s, was confined to gillnets. Downstream from Bonneville Dam, in zones 1-5, only drift nets were employed. In Zone 6, set gillnets were used. Gillnets do not facilitate release of gilled fish alive. Hence, the principal means for protecting weak stocks of salmon and steelhead are area and time closures. Large mesh sizes in the 1990s afforded some protection for upper Columbia A-group steelhead (most upper Columbia summer steelhead are in this group of smaller steelhead), although some larger steelhead that spent two years at sea were taken during late summer during the fall chinook season.

As upriver spring chinook populations declined sharply in the last quarter of the 1900s, managers reduced commercial fishing seasons in zones 1-5 and tribes reduced harvest rates in Zone 6. Hatchery-produced salmon and steelhead increasingly dominated runs.

Effects of harvest on wild/natural spring chinook and steelhead of the upper Columbia River are very difficult to control in mixed-stock fisheries of zones 1-5 (Columbia River mouth to Bonneville Dam) and Zone 6 (upstream from Bonneville Dam, concentrated in Bonneville, The Dalles, and John Day pools). Gillnets are the most-utilized fishing technique, indiscriminate in selecting one stock or another or hatchery fish over wild ones. Mixed-stock fisheries are particularly detrimental to naturally small populations or those depressed by human activities (Spence et al. 1996; NRC 1996).

Only through virtual elimination of fishing on weak stocks can managers achieve protection for them. Fisheries in zones 1-6 have been curtailed sharply to protect ESA-listed stocks, chiefly destined for the Snake and upper Columbia rivers. This has led to excess[2] escapements of spring chinook of hatchery origin, leading to public policy conflicts with respect to management use of the excess returns when they arrive at the hatchery.

Near elimination of harvest on weak stocks can be accomplished by fishery closures, restrictions on area and times of fishing, limitations on gillnet mesh sizes, sometimes combined with net modifications (e.g., trammel nets that entangle rather than gill fish). Sport and Native American subsistence catches have been confined largely to areas short distances downstream from hatcheries where managers expect sufficient returns (e.g., on Icicle Creek downstream from Leavenworth National Fish Hatchery).

Columbia River fishery management in the last third of the 1900s was based in large measure on the concept of maximum sustained yield (MSY) (NRC 1996). At least two important issues make that concept obsolete for future management. The first is that stock-recruit models, from which MSY was determined, are based on historical adult and progeny adult information obtained under past environmental conditions.[3] Those conditions changed, or re-set, as successive mainstem dams came on line, especially after the early 1950s. They may also change markedly over time with cyclicity of the ocean environment.[4] Furthermore, MSY management does not acknowledge value of "excess"

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[2] "Excess" with respect to escapement requirements for hatchery culture objectives.

[3] The models implicitly or explicitly assume dynamic equilibrium in environmental conditions, and predictions of MSY based on the models must assume that such equilibrium will remain the same in the future as they were in the past.

[4] For example, a 15-year data set obtained during a period of low ocean productivity will provide a yield model very different from that assessed from a similar time period of high ocean productivity.

escapement as (1) a means of augmenting nutrient levels by bringing marine nutrients to the infertile streams of the upper Columbia River, or (2) important in fostering competition for mates and spawning sites. The MSY paradigm now does not well serve managers, especially for upriver anadromous stocks.

Current fisheries

Extremely restrictive fisheries are allowed in the lower Columbia River for spring chinook and steelhead in order to protect listed fish (including upper Columbia River spring chinook and steelhead). For example, a federally-established limit of 2% incidental kill of wild spring chinook and wild steelhead was set in 2004 for non-tribal fisheries; of that allowance, a maximum kill of 1.2% was set for the recreational fishery and 0.8% for the commercial fishery in zones 1-5. These conservative impacts were emplaced in spite of an expected spring chinook run to the Columbia River of 500,000 fish, the second largest run since 1938, when Bonneville Dam counts began.[5] Tribal gillnet fisheries in Zone 6 are likely to harvest an additional 8 to 10%.

Current restrictions also require sport anglers between the Rocky Point/Tongue Point line in the estuary upstream to the I-5 bridge to maintain caught fish that have intact adipose fins in the water as they remove the hook. Commercial fishers must use a combination of tangle net (4.25 inch mesh) and large mesh sizes (9-9.75 inches), not longer than 150 fathoms. Recovery boxes on board must be used for any wild fish captured, and on-board observers determine the number of wild fish caught and released.

ESA-listed upriver stocks, including those in the upper Columbia, prevent directed fisheries, even though substantial numbers of hatchery-produced spring chinook could be taken. Upriver summer steelhead may not be harvested in the commercial fishery of zones 1-5.

A set-gillnet fishery for spring chinook and steelhead, classed as “ceremonial and subsistence” is prosecuted by Indians in Zone 6. Steelhead captured by Indians in Zone 6 can be sold or used as “ceremonial and subsistence” harvest. Mean catch rates in the last half of the 1990s equaled about 10%.

Fishing in the future

Schaller et al. (1999) estimated spawner numbers required for full seeding of spawning areas used by wild Columbia River spring chinook salmon as 4,808 for the Wenatchee River, 496 for the Entiat River, and 1,379 fish for the Methow River, a total of 6,683. Other estimates have placed the spawner requirement higher.

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[5] The counting stations at Bonneville Dam permit managers to estimate upriver run size by adding known fish harvests downstream from the dam.

Mainstem multipurpose dam projects in the Columbia River kill upper Columbia River spring chinook and steelhead smolts at cumulative rates that may approach 45-50%.[6] Adult interdam loss at 4% per project accumulates to 25% (Wenatchee River fish), and more for fish destined for tributaries upstream from Rocky Reach and Wells dams.[7] Under these pressures from dam-related mortality, wild fish cannot sustain a directed fishery prosecuted with gillnets, and their escapements, even at full seeding, are insufficient to return one progeny spawner for each parent spawner.

Four solutions are theoretically feasible. The first, the approach now employed, is to severely restrict harvest, and to supplement wild fish with hatchery programs aimed at maintaining and fostering genetic adaptiveness peculiar to each upper Columbia River spawning/rearing area. The long-term utility and appropriateness of this approach has yet to be demonstrated.

A second approach is to shift mainstem fisheries to live-catch methods that permit identification and release of wild fish unharmed (NRC 1996). Although live-catch systems would permit substantially greater harvest of hatchery fish, political resistance to this option is strong. Tribal interests regard such proposals as interference with treaty rights.

The third is to confine fisheries aimed at hatchery fish to terminal areas (e.g., Icicle Creek spring chinook, supported by Leavenworth National Fish Hatchery and by some natural spawners not listed under the ESA, are harvestable in Icicle Creek downstream from the hatchery). Fish quality for spring chinook destined to spawn in terminal areas of the upper Columbia River declines as fish progress upstream. Quality in the terminal areas cannot compete with quality of pen-reared, or ocean- or estuary-caught salmon. Pen-reared salmon have made up over 50% of marketed salmon in recent years.

The fourth is to stop all fishing other than terminal harvests. NRC (1996) discussed this option, but noted that it is fraught with treaty and international political and legal issues.

Effects of fishing on population characteristics

High fishing rates in the 1800s virtually extirpated some late-spring and summer stocks of chinook salmon. Past effects of fishing on now-listed spring chinook and steelhead of the upper Columbia River are unknown. Attempts to sustain fishing by use of hatchery fish influenced genetic composition of at least summer steelhead, as progeny of adults trapped at Priest Rapids and Wells dams were, for several generations, liberated as smolts in the major tributaries of the upper Columbia River without regard to fostering local adaptations. NRC (1996) noted: “The continual erosion of the locally adapted groups

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[6] These estimated per-project mortalities for spring chinook and steelhead produced in the upper Columbia area are based in large measure on estimates of per-project losses at dam projects in the lower Snake River, and on fragmentary data in the Columbia River. The cumulative loss estimate derives primarily from PIT tag detections of Snake River salmon and steelhead at projects as far downstream as McNary Dam. Actual per-project and cumulative mortality rates for upper Columbia spring chinook and steelhead may differ.

[7] Chapman et al. (1994 and 1995) discussed the several uncertainties associated with estimates of interdam conversion rates.

that are the basis of salmon reproduction constitutes the pivotal threat to salmon conservation today."

Nelson and Soule′ (1987) and Thorpe (1993) reviewed effects of fishing on genetic makeup of salmon populations. Intense fishing probably altered genetics of pink salmon in the north Pacific, for example, with the result that adult size declined. Historically, intense gillnetting in the Columbia River may have increased the proportion of smaller fish in escapements, with potential increases in jack fractions and reduced fecundity of females. Three-ocean spring chinook adults may have been selected against at earlier high fishing rates. At current low fishing rates, genetic selection against large spring chinook and steelhead by gillnets likely does not occur (Chapman et al. 1995).

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3.5.2 MOST IMPORTANT FACTORS FOR DECLINE

A number of key documents and reports have addressed factors affecting the decline of wild spring chinook and steelhead in the upper Columbia. Often the assessments take the form of limiting factor analyses and are reported as such. There is not always clear agreement regarding the importance of various factors. Here we summarize and compare some of the central findings and conclusions offered in a number of key reports.

Chapman et al. (1995) reviewed the status of the spring chinook salmon ESU of the upper Columbia Basin, including populations in the Wenatchee, Entiat, Methow, and Okanogan rivers. Their key findings and conclusions regarding factors affecting the decline of these wild populations are:

- The extensive development of mainstem dams and upstream storage reservoirs reduced productivity by 43% from the 1950s through the 1980s.
- Spawning and rearing habitat has not suffered functional degradation in most areas. However, water withdrawal for irrigation is a serious concern in several key tributaries, particularly in the Methow River Basin.
- There is no evidence to indicate that inter-specific competition from exotic or native fish species reduced the productivity of this ESU.
- Inriver harvest rates have been minimal since 1974, but in decades before that, harvest rates ranged from 40-85%. Marine harvest impacts are low, less that 1% for the years 1978-1993.

Their report emphasized hydro-passage effects as the primary factor limiting the productivity of this ESU. Risks associated with hatchery programs, and modest degradation in tributary habitat conditions were discussed, but they were not identified as critical factors responsible for the decline in the ESU. Inriver harvest pressures were substantial before 1974, but subsequent to that year harvest rates have been minimal or negligible with the imposition of harvest restrictions.

Chapman et al. (1994) wrote a similar status report for steelhead populations comprising the listed upper Columbia ESU. In their assessment the following factors were identified as the chief causes of the decline of wild steelhead.

- Overfishing prior to the 1950s.
- Elimination of access to productive habitat above Grand Coulee Dam with dam emplacement.
- Mainstem dams have been the major cause for the depressed runs in recent decades.

Additionally, they suspect two other human activities probably contributed to the decline of wild steelhead:

- Hatchery practices that mixed fish from a variety of sources to seed tributaries.
- Mortality (direct and incidental) associated with sport fishing for hatchery-released and resident trout.

They did not identify tributary habitat conditions as being important factors in the population decline. In fact they characterize most spawning and rearing areas as being in fair to good condition. However, they noted that irrigation withdrawals in late summer in the Methow, Wenatchee, and Okanogan rivers posed a risk.

Mullan et al. (1992) focused on conditions and processes (including both hatchery influences and habitat factors) within three major watersheds, the Wenatchee, Entiat, and Methow rivers. In general they concluded that the carrying capacity of those rivers is similar to what it was historically. On page 28 they conclude that natural production of chinook salmon and steelhead smolts now may be similar to historical production. Overall human activities have not badly degraded the tributary habitat, although some localized problem areas were identified. Even so, they note that coho are now extinct in this area. Furthermore, they point to mainstem dams and reservoirs as critical factors impacting stocks emanating from this basin, noting that 62-71% of smolts die while passing through the hydrosystem.

More recently a series of draft subbasin summaries have been published that address limiting factors in the subbasins of the upper Columbia. Electronic copies of these are on the NPCC website. The summaries are supported by a series of limiting factor analyses that were conducted for individual subbasins. Their characterization of tributary habitat conditions as limiting factors contrast with the portrayal by Mullan et al. (1992) and Chapman et al. (1994, 1995). In general, the limiting factors analyses describe a network of tributaries that has been degraded by assorted human activities, and ecological processes have been compromised. The implication being that some of these areas may well be important in limiting the productivity of anadromous fish in the basin. However, to date no quantitatively structured analysis of limiting factors has been reported in the documents discussed here. Such analyses are being considered or planned using EDT or QHA. Until those analyses are published these qualitative assessments will have to suffice

Wenatchee Subbasin

The limiting factors analysis for the Wenatchee River (Andonaegui 2001) focused on assessing conditions and processes within the subbasin. The report identifies a number of habitat conditions that compromise ecological function, particularly the reduction in both habitat complexity and connectivity within portions of the subbasin. This view generally contrasts with the characterization offered by Mullan et al. (1992) and Chapman et al. (1995) for the same subbasin. However, the recent limiting factors analyses delve into more detail for individual stream systems, and probably reflect current conditions in localized areas.

Human activities within the Wenatchee Subbasin have impaired ecosystem function by exacerbating natural conditions that already limit productivity. The net effect has been a reduction in habitat quality and quantity. These anthropogenic effects have been concentrated in the lower reaches of tributaries of the Wenatchee River, primarily in the lower portion of the subbasin. Deleterious activities include road building, destruction of riparian habitat associated with agriculture and residential development, water diversions, reduced large woody debris (LWD) recruitment, berm construction, and stream channelization. Many of these actions have resulted in a reduction in floodplain connectivity. Additionally, the reduction of spawning and rearing habitat in the mainstem Wenatchee River also limits fish production, particularly below the town of Leavenworth.

Access to some tributary habitat is also problematic in some locales and has been identified as an important limiting factor in those areas. For example, human-made fish passage barriers on Icicle Creek prevent access to a Wenatchee subbasin watershed that is mostly in a highly functional condition. Also, Harza and BioAnalysts (2003) identified a number of locations where fish passage barriers are problematic and limit access to productive habitat. Re-establishing connectivity and ecosystem function within such watersheds such as Nason Creek, Icicle Creek, and Peshastin Creek is important to salmon recovery within the subbasin.

Columbia Upper Middle Subbasin

The subbasin summary referred to as the "Columbia Upper Middle" focuses on the mainstem Columbia River hydrosystem from Chief Joseph Dam to Wanapum Dam (Peven 2002). It also includes a few minor tributaries like Moses Coulee and Foster Creek. The summary readily acknowledges that a formal limiting factors analysis has not been completed for this subbasin, but it identifies potential factors that are likely limiting. These include:

- Passage-related survival of smolts and adult salmonids migrating through the hydrosystem.
- Impacts on water quality and quantity associated with agricultural and urban/residential development.
- Predation on juvenile salmonids by native and exotic species of fish and birds.

Entiat Subbasin

Andonaegui (1999) authored the limiting factors analysis for the Entiat Subbasin. That report primarily addresses limiting factors within the confines of the watershed. The report indicates human-induced habitat perturbations limit the productivity of anadromous salmonids. The document is detailed in identifying specific ecological conditions and processes that have been compromised.

The reduction in over-winter habitat, reduced complexity, and reduced connectivity associated with diking and channelization are chief concerns in the Entiat Subbasin. A significant flood occurred in 1948, which triggered the initiation of a USCOE flood control project. River channelization and the construction of dikes on the lower river reduced connectivity to the floodplain. These activities have resulted in:

- Blocking access to or eliminating over-wintering habitats such as sloughs and side channels, constricted the channel.

- Increased flow velocity and scour during flood events.
- Reducing subsurface flows.
- Reducing stream complexity (straightened channels and eliminated pools).
- Diminished streamside shade and large woody debris inriver.

Other factors also contributed to the simplification of fish habitat, including moderate to heavy sheep grazing in the uplands, removal of beaver with associated impacts on water storage capacity, and altered flow regimes. Timber harvest, fire suppression, and the conversion of floodplains to crops, pasture, roads, and urban uses have also contributed to losses in important salmonid rearing habitat through compacted soils, simplification and destruction of vegetative communities, accelerated sediment and water delivery to stream channels, and increases in the frequency, intensity, and duration of flood and mass wasting events.

The negative effects associated with these anthropogenic actions are compounded by the backdrop of naturally occurring seasonal low flow periods. Low flows in late summer and fall are a normal offshoot of the natural hydrology and geography of the subbasin.

In a number of locations, improperly designed water diversions and dams, and unscreened or inadequately screened surface water diversions (pumps and ditches) also pose a direct threat to salmonids. The 1997 Yakima Screen Shop survey of irrigation structures in the Entiat Valley identified two out of six ditch diversions and eight of 45 pump diversions that were inadequately screened.

In contrast with Mullan et al. (1992), the assessment of Andonaegui (1999) indicates that the production potential of anadromous fish in this watershed has been substantively reduced by human activity and restoration actions are warranted.

Methow Subbasin

The most recent subbasin summary of the Methow Subbasin (Foster 2002) echoes concerns voiced by Mullan et al. (1992) and Chapman et al. (1994, 1995), regarding the hydrosystem as an important agent of decline. Their discussion points to high smolt and adult passage mortality through nine dams as the primary anthropogenic agent affecting salmonid resources outside the subbasin. However, they recognize that oceanic conditions have a pronounced effect on salmon abundance. Beyond these factors they suggest that the lack of coordinated resources to monitor populations and environmental conditions is an important factor contributing to decline.

Within the subbasin the limiting factors analysis of Andonaegui (2000) describes the watershed as a compromised ecosystem that contributes to poor salmonid productivity as a consequence of habitat fragmentation and degraded habitat quality. The analysis points to a variety of conditions that limit salmonid productivity, including:

- Degradation and reduction in riparian habitat.
- Loss of connectivity.
- Floodplain alterations.

- Passage barriers, both natural and man-made (Gower and Espie 1999).
- Water extractions exacerbate natural low water conditions during the summer, and contribute to seasonal high water temperatures.
- Sedimentation.
- Limited nutrients associated with low spawner abundance.

Okanogan Subbasin

The salmon and steelhead habitat limiting factors assessment for the Okanogan watershed (Entrix & Golder 2002) is the most extensive subbasin evaluation published thus far. This assessment emphasizes that ongoing hatchery programs have not been able to reestablish salmon and steelhead populations to self-sustaining levels. This failure can be attributed to a number of factors including, passage problems and mortality associated with nine hydroelectric facilities on the mainstem Columbia River, unfavorable ocean conditions, harvest pressures, and degradation of ecological processes and habitat within the Okanogan watershed. Importantly, the climatic conditions of the Okanogan naturally restrict habitat use due to thermal and flow barriers that can affect the overall production in the watershed.

These natural environmental conditions limit natural production of salmonids in the Okanogan watershed. In particular, low stream flows in the summer and winter, and high ambient summer temperatures restrict or limit access to habitats. Also, extreme winter conditions can reduce fish growth and activity. In years when moisture availability is limited, dewatered reaches are not uncommon. These conditions restrict salmonid access to habitat, dewater redds, and may strand juveniles, resulting in direct mortality to salmonids.

In some portions of the Okanogan watershed, human activities have perturbed the landscape and exacerbated the degradation of the already naturally limiting habitat. These human activities have primarily occurred in the lower gradient, lower reaches of the tributaries. These impacts are mostly the result of past timber harvest operations, road building and placement, and grazing.

Synthesis

Collectively, these assessments point to two primary classes of factors associated with anthropogenic activities that have caused the decline and continue to constrain both wild spring chinook and steelhead production in the Columbia Cascade Province. These principal factors are hydropower development on the mainstem Columbia and degradation of ecological function in important areas within these subbasins. Although we caution that rigorous quantitative evaluations have yet to be completed. Nevertheless, in order to realize a timely recovery of these ESUs, it appears the prudent strategy is to move forward improving conditions in both sectors simultaneously. Improving access to and condition of spawning and rearing habitat, while fish passage improvements advance, will ensure that the tributaries can offer full advantage to the expected increased escapement associated with implementing the fish passage programs. To move forward on either front alone, or delay efforts in one sector, may constrain the rate of recovery, or even prevent it. Implementing improvements in hydro and habitat in tandem should maximize productivity by compounding survival improvements across several life stages in lock-step. We think this interaction will maximize the potential for a swifter recovery of these ESUs.

Survival during estuarine and marine residence is recognized as a dominant factor influencing overall returns of adult salmonids. In recent years stocks in the Northwest have benefited from favorable ocean conditions. But climate-driven marine conditions are cyclic, and periods of poorer marine survival are inevitable in the future. During periods of poor ocean survival, the performance of freshwater life stages takes on increased importance in sustaining robust and resilient populations. Thus, improvements in tributary habitat and hydrosystem passage can increase survival during these critical life stages, and will serve to offset looming periods of poor marine survival.

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