RECLAMATION
Managing Water in the West

Coho Salmon Production Potential in the Cle Elum River Basin

Storage Dam Fish Passage Study
Yakima Project, Washington

Technical Series No. PN-YDFP-007

U.S. Department of the Interior
Bureau of Reclamation
Pacific Northwest Region
Boise, Idaho

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U.S. Department of the Interior

Mission Statement

The mission of the Department of the Interior is to protect and provide access to our Nation’s natural and cultural heritage and honor our trust responsibilities to Indian tribes and our commitments to island communities.

U.S. Bureau of Reclamation

Mission Statement

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

This document should be cited as follows:

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Introduction

This technical report presents information regarding coho salmon production potential in the Cle Elum River basin above Cle Elum Dam. This information is a key component in determining estimates of biological and economic benefits attributable to proposed fish passage features at the dam.

Objectives

The Bureau of Reclamation (Reclamation) is leading a cooperative investigation with the Yakama Nation (YN), state and Federal agencies, and others, to study the feasibility of providing fish passage at the five large storage dams of the Yakima Project. These dams—Bumping Lake, Kachess, Keechelus, Cle Elum, and Tieton—were never equipped with fish passage facilities. Four of the five reservoirs were originally natural lakes and historically supported Native American fisheries for sockeye salmon and other anadromous and resident fish.

Implementation of passage features at the dams has the potential to reintroduce sockeye salmon to the Yakima River basin; increase populations of upper basin steelhead, coho salmon, and Chinook salmon; restore life history and genetic diversity of salmon; and reconnect isolated populations of bull trout. Two species in the basin, bull trout and Mid-Columbia River steelhead, are listed as threatened under the Endangered Species Act (ESA).

Project Purpose

Authority

Authority to undertake a feasibility study is contained in Public law No. 96-162, *Feasibility Study, Yakima River Basin Water Enhancement Project*, (Act of December 28, 1979, 93 Stat. 1241). The study area is in the Yakima River basin in south central Washington on the east side of the Cascade Range and includes most of Yakima, Kittitas, and Benton counties.

Core team

Reclamation is supported in this effort by a core team of biologists, engineers, and other specialists from Federal, state, and local entities. Partners include the YN, National Oceanic and Atmospheric Administration (NOAA Fisheries), U.S. Fish and Wildlife Service

(USFWS), Washington Department of Fish and Wildlife (WDFW), Washington Department of Ecology, Washington Department of Agriculture, and local irrigation districts.

Background

Reclamation's commitment to study the feasibility of fish passage at the five large storage dams of the Yakima Project is documented in agreements, permits, and litigation settlements associated with the Keechelus Dam Safety of Dams (SOD) construction. Early in 2001, many Yakima Basin interests viewed the proposed Keechelus SOD construction as an opportunity to add fish passage features at Keechelus Dam. Reclamation carefully considered this issue but determined that fish passage facilities could not be added to Keechelus Dam under existing SOD authority.

To respond to the stated fish passage concerns, Reclamation negotiated a "mitigation agreement" with WDFW and also agreed to certain conditions contained in the State of Washington Hydraulic Project Approval (HPA) permit for the Keechelus SOD modifications. These conditions included specific tasks and milestone dates regarding the feasibility study, and the installation of interim (temporary, experimental) fish passage features at the dams. Reclamation also agreed to seek funding and implement passage where determined to be feasible.

Phase I Assessment

Reclamation completed a *Phase I Assessment Report* in 2003 (Reclamation 2003). The Phase I assessment process examined a range of options and opportunities for providing fish passage and potentially reestablishing populations of anadromous salmonids in some tributaries of the five Yakima Project storage reservoirs. From this initial assessment, it appeared that some form of upstream and downstream passage for anadromous salmonids and bull trout connectivity would be technically possible at all the storage projects.

Change in Scope

Early in the study process it became apparent that programmed funding was not sufficient to evaluate all five storage dams in detail. For this reason, the scope of the study was reduced to reflect detailed evaluation of passage features only at Cle Elum and Bumping Lake dams. Successful implementation of fish passage at Cle Elum and Bumping Lake dams could eventually lead to future detailed study of the other three dams (Kachess, Keechelus, and Tieton). The intent, to the extent possible, is to meet all of the essential Keechelus Dam SOD requirements outlined in the Record of Decision, the HPA, and the Mitigation Agreement.

Feasibility Study

In fiscal year 2004, following completion of the *Phase I Assessment Report*, Reclamation began detailed studies to evaluate the feasibility of providing fish passage at Cle Elum and Bumping Lake dams. The Yakima River Basin fisheries co-managers (WDFW and YN) developed an *Anadromous Fish Reintroduction Plan* that outlines the sequence and timing for reintroducing anadromous salmonids above the reservoirs (Fast and Easterbrooks 2005). They proposed a phased approach starting with coho salmon (*Oncorhynchus kisutch*), followed by sockeye salmon (*O. nerka*), and eventually Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*). Reclamation's evaluation of production potential follows this phased approach. The following Technical Reports support Reclamation's estimates of coho and sockeye salmon production potential above Cle Elum and Bumping Lake dams.

- *Coho Salmon Production Potential in the Cle Elum River Basin, Storage Dam Fish Passage Study, Yakima Project, Washington, Technical Report Series No. PN-YDFP-007*, Bureau of Reclamation, Boise, Idaho, March 2007.

- *Assessment of Sockeye Salmon Production Potential in the Cle Elum River Basin, Storage Dam Fish Passage Study, Yakima Project, Washington, Technical Report Series No. PN-YDFP-008*, Bureau of Reclamation, Boise, Idaho, March 2007.

- *Coho Salmon Production Potential in the Bumping River Basin, Storage Dam Fish Passage Study, Yakima Project, Washington, Technical Report Series No. PN-YDFP-009*, Bureau of Reclamation, Boise, Idaho, March 2007.

- *Assessment of Sockeye Salmon Production Potential in the Bumping River Basin, Storage Dam Fish Passage Study, Yakima Project, Washington, Technical Report Series No. PN-YDFP-010*, Bureau of Reclamation, Boise, Idaho, March 2007.

Coho salmon in the Yakima River Basin

Coho salmon were native to the Yakima River basin (Wydoski and Whitney 2003). Tuck (1995) stated that coho salmon spawning was quite widespread in the Yakima River basin, including the Cle Elum River and its tributaries. Haring (2001) also noted that coho salmon were assumed to have used virtually every low-gradient stream in the Yakima Basin prior to extensive habitat alteration. Adult coho salmon passage data from Roza Dam for the period 1941 to 1968 indicated that the endemic Yakima River stock had early run timing (Haring 2001). Coho salmon were considered extirpated in the Yakima Basin in the 1970s, but a recent reintroduction program has shown some success. Starting in 1985, coho salmon smolts from the lower Columbia River were released below Wapato Dam to provide harvest opportunities. Some of the returning adults spawned naturally; adult progeny of these spawners began showing up at Roza Dam in 1997 and from 1997 to 2005 their numbers ranged from 1 in 2003 to 556 in 2001 (Table 1). Hatchery adult returns from 1999 to 2005 have ranged from none in 2003 to 65 in 2001 (YKFP 2005 http://www.ykfp.org/).

Table 1. Natural-origin (wild) and hatchery adult coho salmon counted at Roza Dam, 1997 to 2005.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005
Wild	3	7	22	143	556	43	1	33	28
Hatchery			5	5	65	4		3	3

Some Life History Requirements for Coho Salmon

Adult coho salmon generally migrate upstream at water temperatures ranging from 7.2°C to 15.6°C (Reiser and Bjornn 1979 cited in Laufle et al. 1986). Spawning normally occurs in riffles or where ground water seepages occur, in minimum water depth of 0.18 m, at water temperatures ranging from 4.4°C to 9.4°C, and velocities ranging from 0.3 to 0.91 m/sec (Thompson 1972). Davidson and Hutchinson (1938 cited in Sandercock 1991) stated that the optimum temperature for coho salmon egg incubation was 4°C to 11°C.

Coho salmon require dissolved oxygen concentrations at or near saturation, generally around 8 to 9 mg/L, for best swimming performance and growth; symptoms of DO deprivation begin to occur at about 6 mg/L, even though under certain circumstances salmonids can survive DO concentrations less than 5 mg/L (Bjornn and Reiser 1991). Bell (1991) reported preferred water temperatures for coho salmon as ranging between 11.6°C and 14.4°C, while Brett (1952) reported a temperature range of from 12°C to 14°C is close to the optimum for maximum growth efficiency.

Jones and Moore (1999) noted that juvenile coho salmon survive best in low gradient habitats (generally less than four percent), while Bradford et al. (1997) and Reeves et al. (1989) indicated that juvenile coho salmon use tributaries with a stream gradient less than three percent with complex and deep pools or beaver ponds, abundant large woody debris in the channel, and where the rearing reaches were less than 10 m wide and flowed through wide valleys. Optimum juvenile rearing habitat consists of a mixture of pools and riffles, with abundant instream and bank cover, with summertime water temperatures between 10° and 15°C (Reiser and Bjornn 1979 cited in Laufle et al. 1986). Young fish prefer low velocity areas but move to higher velocity areas as they grow (Lister and Genoe 1970 cited in Sandercock 1991).

Coho salmon generally spend one growing season in freshwater and two growing seasons (about 18 months) in the ocean before returning as 3-year-old adults (Hassler 1987) to spawn in their natal streams (Beamish et al. 2004).

Assessment of coho salmon production potential

In this paper we estimate the production potential for coho salmon in the Cle Elum River basin upstream from Cle Elum Lake. Production potential is the estimated number of salmon that might be produced from a population under a particular set of natural environmental circumstances (Oregon Coastal Salmon Restoration Initiative Conservation Plan 1997). The estimate of production potential for coho salmon described here is based on substantial stream survey information from the Wenatchee National Forest (WNF) Cle Elum Ranger District (CRD) staff biologists, literature values for redd size and fecundity, information from an existing coho salmon supplementation program in the Yakima Basin, and additional information on habitat characteristics and limiting factors from various sources. This estimate of coho salmon smolt production potential is the first part of a more comprehensive and longer-term effort that will eventually consider production potential for other anadromous salmonid species upstream from five Reclamation water storage projects in the upper Yakima River basin.

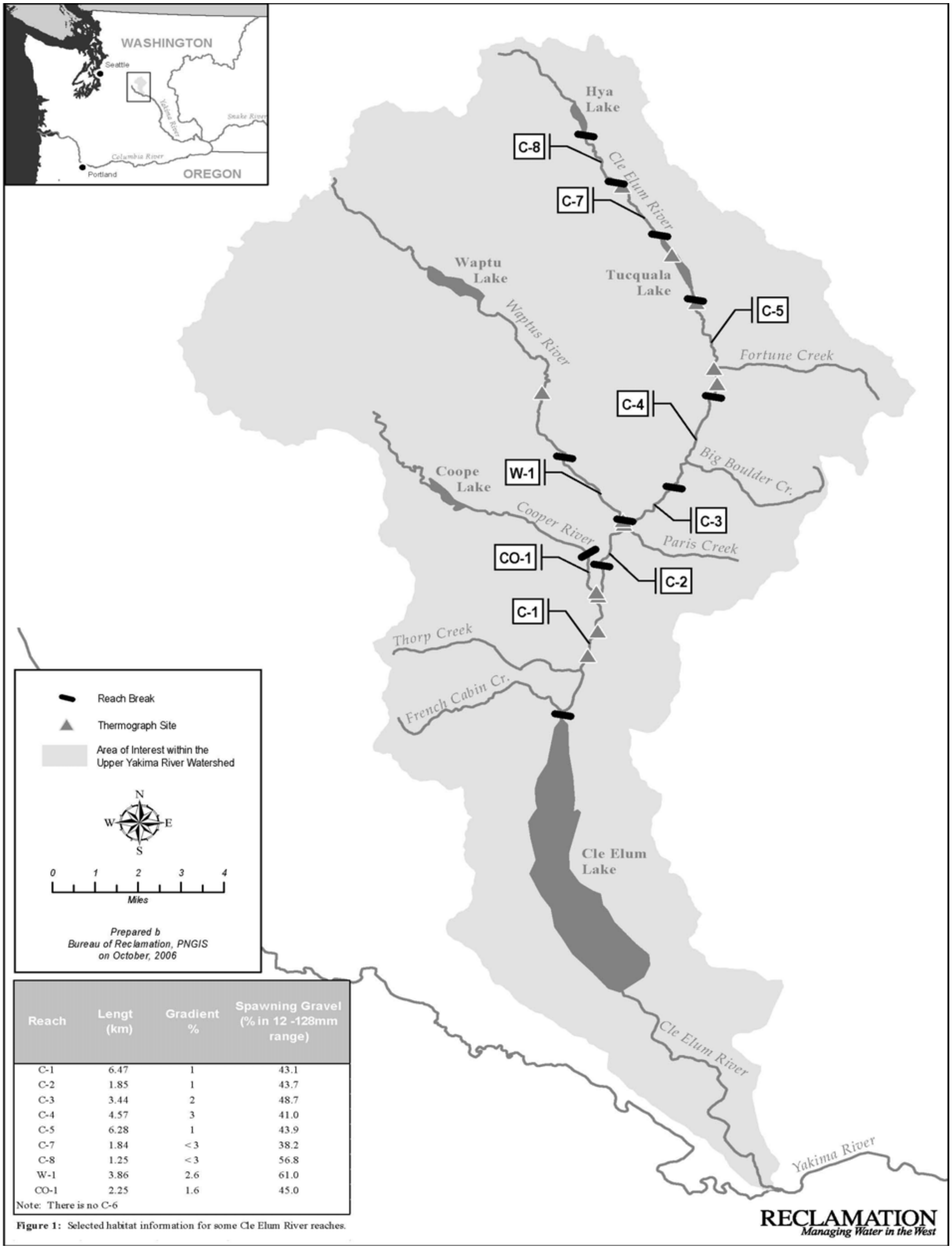
The study area for this assessment of coho salmon production potential is primarily the Cle Elum River upstream from Cle Elum Reservoir and the Waptus and Cooper rivers, which were identified by Reclamation (2003) as potentially providing about 31.8 km of new habitat for anadromous salmonids when upstream and downstream fish passage is re-established (Figure 1).

We used two approaches to estimate coho salmon production potential in the Cle Elum River, by estimating first available spawning habitat and second juvenile rearing/overwintering habitat that would be available in the newly assessable river reach. Suitable spawning habitat is primarily a function of suitable water velocity, depth, and substrate composition; spawning site selection by fish is complex and likely based on a range of environmental or microhabitat conditions such as depth, flow, and substrate size (Bjornn and Reiser 1991) that might differ for the same species in different streams (McHugh and Budy 2004). Rearing/overwintering habitat also includes cover for protection from predators and prey. The estimates of production for both approaches are limited by the quality and quantity of available data and by the several assumptions that results in a range of likely outcomes. These will be discussed in detail below.

Nickelson (1998) noted that overwintering pool habitat in coastal systems is important for juvenile coho salmon, and is the primary bottleneck to coho salmon smolt production, so this could also be a factor limiting coho salmon production in this interior system (Nickelson et al. 1992). Similarly, McMahon (1983), citing several authors, noted that the amount of suitable winter habitat may be a factor limiting coho salmon production. However, Baranski (1989) noted that available rearing habitat during the summer low flow period is a limiting factor in Puget Sound coho salmon production. As will be discussed below, low flow conditions in the Cle Elum River upstream from Cle Elum Lake occur in the late summer, during which time the several stream surveys were conducted; flows increased substantially in the fall and winter.

Nickelson (1998) developed a coho salmon production potential model for Oregon coastal rivers; however, coastal rivers are different in several respects from inland rivers such as the Cle Elum. Volume and timing of runoff differ between moister coastal climates and drier inland climates. Montgomery et al. (1999) reported that "[h]igh flows in rain-dominated watersheds generally occur in winter, whereas high flows in snowmelt-dominated watersheds generally occur in spring." Therefore, we used some aspects of Nickelson's (1998) model in this assessment with some caution. In addition, juvenile coho salmon have been documented to rear in lakes, although this is not their typical rearing strategy (Sandercock 1991). Juvenile coho salmon could potentially rear in Cle Elum Lake but we suspect would have limited success doing so, considering the oligotrophic nature of the lake (Lieberman and Grabowski 2006). However, there might be opportunities to enhance primary production in Cle Elum Lake through a limited and focused fertilization program to improve its productivity and thus rearing potential.

As mentioned above, we estimated the production potential for coho salmon in the upper Cle Elum River system by using both the spawning habitat availability and the juvenile rearing/overwintering habitat models. The methods used and the results obtained are described below. These results were compared with potential production assessments in other river systems, and a discussion is provided.



Reach	Lengt (km)	Gradient %	Spawning Gravel (% in 12 -128mm range)
C-1	6.47	1	43.1
C-2	1.85	1	43.7
C-3	3.44	2	48.7
C-4	4.57	3	41.0
C-5	6.28	1	43.9
C-7	1.84	<3	38.2
C-8	1.25	<3	56.8
W-1	3.86	2.6	61.0
CO-1	2.25	1.6	45.0

Note: There is no C-6

Figure 1: Selected habitat information for some Cle Elum River reaches.

Figure 1. The Cle Elum River basin in Washington showing reaches of the upper Cle Elum River and some tributaries considered in this assessment.

Methods

Available spawning habitat approach

Overview

We estimated the amount of available spawning habitat in the Cle Elum, Waptus, and Cooper rivers based on a suite of environmental parameters including stream gradient and the size range of substrate used by spawning coho salmon reported in the literature and the estimated areal extent of substrate in this size range in riffles determined from USFS stream surveys and subsequent analyses. We considered the average size of coho salmon redds and area “recommended” per redd (Burner 1951), then incorporated an average fecundity of 2,500 for coho salmon, estimates of life stage survivals from Nickelson (1998), Reeves et al. (1989), and others, and estimated the number of spawning females that would be needed to fully and uniformly utilize or seed the estimated amount of spawning habitat available based on substrate composition and stream gradient, without superimposition of redds. We estimated the number of smolts that could be produced and the number of adults that would return at several smolt to adult return (SAR) rates. SAR is smolt to adult return from smolt outmigration from the Cle Elum River to adult return to the Cle Elum River.

Substrate suitability

Coho salmon select spawning substrate ranging in size from a pea to an orange (OCSRI 1997); 13 to 102 mm (Reiser and Bjornn 1979 as cited in Laufle et al. 1986); 39 to 137 mm, averaging 94 mm (Briggs 1953 cited in Sandercock 1991); 9 to 100 mm, with less than 20 percent sand (Fleming and Gross 1989); 75 to 150 mm, with less than 20 percent embedded fine material. Salmon reportedly can spawn in substrate with a median diameter up to about 10 percent of their body length (Kondolf and Wolman 1993), which explains in part the size range of gravels used by spawning coho salmon; larger adult fish can move and therefore spawn in larger-sized substrate than smaller fish.

Staff biologists of the WNF CRD conducted late summer stream surveys in 1997 and 1999 in five reaches of the Cle Elum River totaling 22.5 km (14.05 miles) upstream from the reservoir to about Tucquala Lake following a modified Hankin and Reeves (1988) protocol. Three reaches of the Waptus River, a tributary of the Cle Elum River, totaling 9.6 km (6.0 miles) were surveyed in 1995. A natural impassable barrier exists at about Waptus rkm 3.86 (RM 2.4), so only this lower reach was considered. The Cooper River has an impassable falls about rkm 5.1 (3.2 miles) from its confluence with the Cle Elum River, but a series of high gradient areas in the lower part of reach 2, so only the 2.25 km (1.4 mile) lower-most reach was considered. Cooper River stream surveys were conducted in 1973 and 1989. Stream habitat information such as substrate composition and physical attributes were gleaned from these stream survey reports and summarized. Information was not reported consistently across all surveys. The Forest Service conducted additional sampling in the Cle Elum River and tributaries in 2003. An additional survey of 3.09 km of the Cle Elum River upstream from Tucquala Lake to Hyas Lake, although not Lake Tucquala itself, was conducted in late summer 2005.

The WNF CRD 1997 through 2005 stream surveys of the Cle Elum and Waptus rivers reported the percentage of sand, gravel, cobbles, boulders, and bedrock at numerous locations in riffles in each of the reaches indicated in Figure 1. From these data and some additional analyses reported in 1999, we summarized the percent composition of substrate type in riffles by reach (Table 2). Particle size categories are shown in Table 3. Substrate was qualitatively estimated and grouped in broad size categories for the Cooper River stream surveys conducted in 1972.

Table 2. Substrate composition in riffles in seven reaches of the Cle Elum River, one reach of the Waptus River, and one reach of the Cooper River surveyed by USFS WNF staff in 1973, 1989, 1995, 1997, 1999, and 2005.

Reach	Length, km		Sand[a]	Gravel	Cobble	Boulder	Bedrock
C-1 n = 63[b]	6.47	Avg. %	13.02	25.24	33.81	14.92	13.02
		Range	10-100	10-60	10-60	10-40	0-70
C-2 n = 14	1.85	Avg. %	5.0	17.79	25.36	23.93	33.93
		Range	0-10	5-25	15-35	5-60	0-70
C-3 n = 70	3.44	Avg. %	5.36	16.36	26.00	30.79	21.60
		Range	0-20	0-35	0-60	0-50	0-100
C-4 n = 85	4.57	Avg. %	5.0	13.24	24.82	23.24	34.47
		Range	0-25	5-25	5-50	0-60	0-100
C-5 n = 78	6.28	Avg. %	12.18	29.29	33.08	18.53	6.54
		Range	0-80	0-60	10-50	0-50	0-80
C-7 n = 7	1.84	Avg. %	11.43	18.57	42.86	25.71	1.43
		Range	0-30	10-30	40-50	10-40	0-10
C-8 n = 9	1.25	Avg. %	16.67	54.44	23.33	5.56	0
		Range	10-30	30-70	10-40	0-20	0
W-1	3.86	Avg. %	1	25	39	27	8
CO-1 n = 5	2.25	Avg. %		32[c]	28		
		Range		25-40	20-30		

Source: U.S. Forest Service stream inventories for the Cle Elum, Waptus, and Cooper rivers.

Note: Cle Elum River reaches are designated C-1 through C-8; reach C-6 is Tucquala Lake, which was not surveyed; Waptus River reaches were surveyed in 1995, and the lowermost 3.86-km reach is designated W-1; the Cooper River reach is designated CO-1.

[a] Substrate size range: Sand, silt and clay (< 2 mm); Gravel (2 to 64 mm); Cobble (64 to 256 mm); Boulder (256-4096 mm); Bedrock (> 4096 mm).

[b] n = number of sites sampled during the Forest Service stream survey.

[c] Stream survey reported substrate size categories for the Cooper River as 0.25-3 in., 3-6 in., not consistent with later stream surveys.

The size range of suitable spawning substrate for coho salmon based on the reported literature values would fall within the mid range of gravel up to the lower range of cobble, that is, medium through very coarse gravel and small cobble (Table 3). From stream pebble counts and sizes at selected transects we calculated the percent of the sample in the size range 12 to 128 mm. This size range mostly bracketed the size range of suitable spawning substrate reported above. We calculated the area of riffle habitat in each reach from the recorded length and width of riffles. We then adjusted the area of riffle habitat by the percentage of gravel/cobble within the suitable size range (12 to 128 mm) for coho salmon. The USFS reported only two habitat types, riffles and pools, in their early stream surveys. This somewhat coarse habitat delineation could likely overestimate the extent of riffles, since other habitat types such as runs and glides might have been present but not identified as such. The Cooper River stream surveys reported stream substrate in the 0.25 to 3 inch and 3 to 6 inch size classes.

Table 3. Particle sizes of several gravel and cobble categories identified during surveys of the Cle Elum River and tributaries. Particle type and size categories highlighted in bold are considered suitable spawning substrates for coho salmon based on values reported in the literature.

	Particle type	Size, mm
Sand		<2
Gravels	Very fine	2-4
	Fine	4-6
	Fine	6-8
	Medium	8-12
	Medium	**12-16**
	Coarse	**16-24**
	Coarse	**24-32**
	Very Coarse	**32-48**
	Very Coarse	**48-64**
Cobble	**Small**	**64-96**
	Small	**96-128**
	Large	128-192
	Large	192-256

Source: USFS, 2003

Note: The duplicate categories for several particle types were reported as such in the USFS stream survey data.

The Wenatchee National Forest Land and Resource Management Plan (WNF 1990) states that spawning gravel contains no more than 20 percent fine sediment (sediment less than 1.0

mm in size); excessive fine sediment results in embedded substrate conditions, and at high concentrations reduces the quality of salmonid spawning habitat.

Watershed Analysis ratings (Schuett-Hames et al. 1999) are based on the percent of a gravel sample that is less than 0.85 mm in diameter. Cederholm and Reid (1987) reported that coho salmon eggs and alevins are severely affected by particles smaller than 0.85 mm. Samples with less than 12 percent fine sediment are considered GOOD, samples with 12 to 17 percent fine sediment are considered FAIR, and samples with greater than 17 percent fine sediment are considered POOR. Geometric mean diameter (Dg) of spawning gravel is the most sensitive measure of salmonid survival to emergence, and percentage of particles less than 0.85 mm is the most sensitive indicator of changes to substrate induced by land management activities (Young et al. 1991). The percent sand in reaches C-1 through C-8 ranges from 5.0 to 16.7 (Table 2), and about one percent for the Waptus River, mostly within the "good" category for salmonid spawning habitat according to the criteria discussed above, except for C-8 with a "fair" rating at 16.7 percent sand. However, since the fair and good categories are based on particle size less than 1.0 mm, and the sand fraction includes particles larger than the limit of 1.0 mm, we assume that Reach C-1 is also probably "good." No sand is listed as a bottom type in Cooper River reach CO-1 (Hand 1973), so this stream reach would be included in the "good" category.

Coho salmon would likely be able to utilize the seven reaches of the Cle Elum River to Hyas Lake and the lower 3.86-km reach of the Waptus River that have reported average gradients ranging from 0.77 to 2.73 percent (U.S. Forest Service, unreported data, 2005) (Table 3). One short area in reach C-4 has a gradient of 4.06 percent that was not deemed to be an obstacle to upstream adult migration. Gradient in Cooper River reach CO-1 was two percent or less, and averaged 1.6 percent; reach CO-2 had gradients up to 15 percent, along with a 70 to 80 percent bedrock substrate up to an impassable barrier at RM 3.2 (Cle Elum Ranger District 1989).

Redd Size

To estimate the number of redds and therefore the number of spawning female fish that the available habitat could support, it was necessary to assign an average area required for a single spawning pair of salmon to construct and defend a redd. The average size of a coho salmon redd reported by various authors cited in Sandercock (1991) was about 1.5 m^2. Crone and Bond (1976 cited in Sandercock 1991) indicated the average area of gravel disturbed (presumably for a redd) was 2.6 m^2, while Burner (1951) noted an average redd size of 2.8 m^2. Nickelson (1998) estimated an average redd size of 3 m^2. Fleming and Gross (1989) reported an equation from Tautz (1977) for estimating redd size:

$$\text{Avg. redd size} = (FL/31)^2 * 2{,}358 \text{ cm}^2 * 4 * 0.7$$

Where FL is the average fork length (cm) of females in the population, 4 is the modal number of nests per redd, 0.7 adjusts for nest overlap, and 2,358 cm^2 is the area used by a 31-cm female during construction. We used the average fork length of 63.04 cm for 1,036 adult coho salmon measured by the Yakama Nation in 2003 at the collection facility at Roza Diversion Dam on the Yakima River (Joel Hubble, YN, 2004, pers. comm.). This yielded an average redd size of 2.7 m^2. Averaging the reported and calculated redd sizes yields a redd size of 2.5 m^2. Salmon are also believed to require some additional defensible space larger than the redd itself to reproduce successfully. Burner (1951) recommended that the area needed for spawning coho salmon should be about four times the redd size, which based on 2.5 m^2 would be about 10 m^2. In our estimate of production potential, we used 10 m^2 as the area needed for a single female coho salmon to spawn.

Fecundity

In order to estimate the number of juveniles that might be produced from the estimated number of spawning adults the available habitat would support, we needed an estimate of the average fecundity of female coho salmon. Fecundity of adult salmon varies with fish size and latitude (Wydoski and Whitney 2003, Nemeth et al. 2004). Salo and Bayliff (1958; cited in Sandercock 1991) developed a regression equation to predict the number of eggs produced per female based on standard length. Only fork length data were available for the 1,036 adult coho salmon returning to Roza Dam in 2003; however, the average fork length of 63.04 cm included both male and female salmon. Using this average in Salo and Bayliff's regression equation

$$y = -2596 + 84.53x$$

where y = number of eggs per female and x = standard length (cm)

we obtained an average fecundity of 2,733 eggs per female. Nickelson (1998) used a fecundity of 2,500 eggs per female in his coho salmon production model. Substituting 2,500 in Salo and Bayliff's (1958) equation produced a fish standard length of 60.3 cm, which was probably close to the average standard length of the coho salmon measured in 2003 since standard length is less than fork length. Thus, we felt justified in using Nickelson's fecundity of 2,500 eggs per female in this potential production assessment.

The steps we took to assess the production potential for coho salmon in the Cle Elum River above Cle Elum Dam included calculating the areal extent of riffles from WNF CRD stream surveys, estimating the percent of substrate in the size range reported to be suitable for coho salmon spawning, adjusting the amount of riffle habitat by that percentage, incorporating information about redd size, calculating the number of spawning female coho salmon needed to fully utilize the habitat, then incorporating average fecundity to calculate the number of eggs those females could produce, and for egg to smolt survival of 1.5 percent, estimating the number of smolts that could be produced. Egg to smolt survival of 1.5 percent was selected based on a range of estimates from literature. Neave and Wickett (1953 cited in Sandercock 1991) reported egg to smolt survival for British Columbia coho salmon as 1 to 2 percent, Reeves et al. (1989) listed an egg to smolt survival of 0.02 (2 percent), Nickelson (1998) used egg to smolt survival of about 0.3 percent in his model, and Anderson and Hetrick (2003) estimated egg to smolt survival of 2.1 and 1.7 percent in Kametolook and Clear Creek, Alaska, respectively.

From the number of coho salmon smolts estimated that could be produced, we estimated the number of adults returning at SARs from one to six percent. This range of SARs was selected to bracket annual variability expected to occur, those observed both historically and recently, and the interim objective of the NPCC's 2003 Mainstem Amendment of achieving SARs in the two to six percent range (average four percent) for Snake River and upper Columbia River salmon and steelhead (NPCC 2003). Using SARs from the Cle Elum River back to the Cle Elum River eliminates the need to consider life stage-specific survival during outmigration, residence time in the estuary and ocean and during the adult upstream migration, and harvest in the ocean or the Columbia River.

Juvenile rearing/overwintering habitat approach

Overview

Juvenile coho salmon exhibit considerable plasticity in behavior and use of habitat (Sandercock 1991). During early rearing they utilize riffles and pools in streams, but as water temperatures decrease they move to tributaries, side channels, or deeper pools with some structure for overwintering. In some cases they move considerable distances both upstream and downstream from summertime rearing areas to overwintering habitat (Sandercock 1991). Low summertime river flows and overwintering habitat conditions may be factors limiting coho salmon production. Both of these time periods have been noted as constituting production bottlenecks (Nickelson 1998, Baranski 1989).

Estimation of pool habitat

We used stream survey data for the Cle Elum, Waptus, and Cooper rivers collected by the WNF CRD in late summer during low flow to estimate the number and area of pool habitat conditions in seven low gradient reaches of the Cle Elum River and the lowermost reaches of the Waptus and Cooper rivers up to impassable barriers. This would be a minimum estimate of overwintering habitat, since as noted above; juvenile coho salmon also use tributaries and side channels as well as deep pools for overwintering. Reeves et al. (1989) stated that stream habitat surveys should be done during the low-flow period in late summer or early fall and another in late winter or early spring during nonflood flows to accurately portray habitat conditions and availability; however, only data from late summer stream surveys were available. However, Cle Elum River flows increased during the fall and winter as discussed in detail below and likely provide some unquantifiable increase in overwintering habitat by reestablishing side channels and deeper pools.

We calculated the area of pools in all the reaches of the Cle Elum River and the lower reaches of the Waptus and Cooper rivers from the dimensions of the pools reported in the several stream surveys. We estimated the average size of pools per reach. We recognize that the number and size of pools and side channels could change with the nearly eight-fold increase in flows that occurs from late summer to early winter discussed below. Limited information was available about the substrate and amount of cover in the form of large woody debris or other material present in the pools. Some of the larger pools in the Cle Elum River would not be expected to provide homogeneous or uniformly suitable rearing/overwintering habitat conditions; coho salmon often concentrate around the edges and near structure in large pools, and intraspecific competition could force smaller fish to less suitable habitat (Sandercock 1991).

From the area of pools in the river reaches, we calculated the number of juveniles that could be expected to survive to the following spring to outmigrate as smolts. We calculated these using three values to show a range of possible outcomes: 0.25 and 0.5 overwintering juveniles per m^2 (Pete Bisson, USFS, Olympia, WA, March 2004, pers. comm.), and one overwintering juvenile per m^2 (Keeley et al. 1996). We estimated the number of smolts per 100 m^2 of pool habitat that could be produced within each reach. From the number of fish expected to survive the winter, we calculated number of fish per km for the total length of the upper Cle Elum River and tributaries to compare with published values. To compare potential production based on total area of habitat in the reaches, we summed riffle and pool area and calculated number of smolts per 100 m^2 of reach.

We estimated the number of returning adults based on SARs from one to six percent, using the low end of the range of 0.25 overwintering juvenile coho salmon per m^2 (Pete Bisson, USFS, Olympia, Washington, pers. comm.). We calculated the number of adult fish per km and compared these to numbers reported in the literature.

To understand better the annual hydrologic conditions in the upper Cle Elum River, we examined the calculated daily average Cle Elum River flows for the 20-year period, 1985 to 2004. Following annual low late summer flows, there was a substantial increase in flow and periodic freshets from early October through late November, with flows decreasing later in December but remaining greater than the late summer low flows (Figure 2). The about four- to eight-fold increase in flow from early October to late November with subsequent decrease likely alters conditions in the river substantially, may redistribute juvenile fish, and may improve or expand overwintering habitat for juvenile coho salmon, although quantitative stream survey information for this time period is not available. Since information is lacking to describe quantitatively habitat conditions during the fall and winter, this assessment of potential production may underestimate the extent of coho salmon overwintering habitat, since it relies on an estimate of pool habitat available based on the late summer stream conditions. Without additional late wintertime stream surveys, we do not know to what extent the increased flow during the fall and winter would change habitat conditions and availability for juvenile coho salmon.

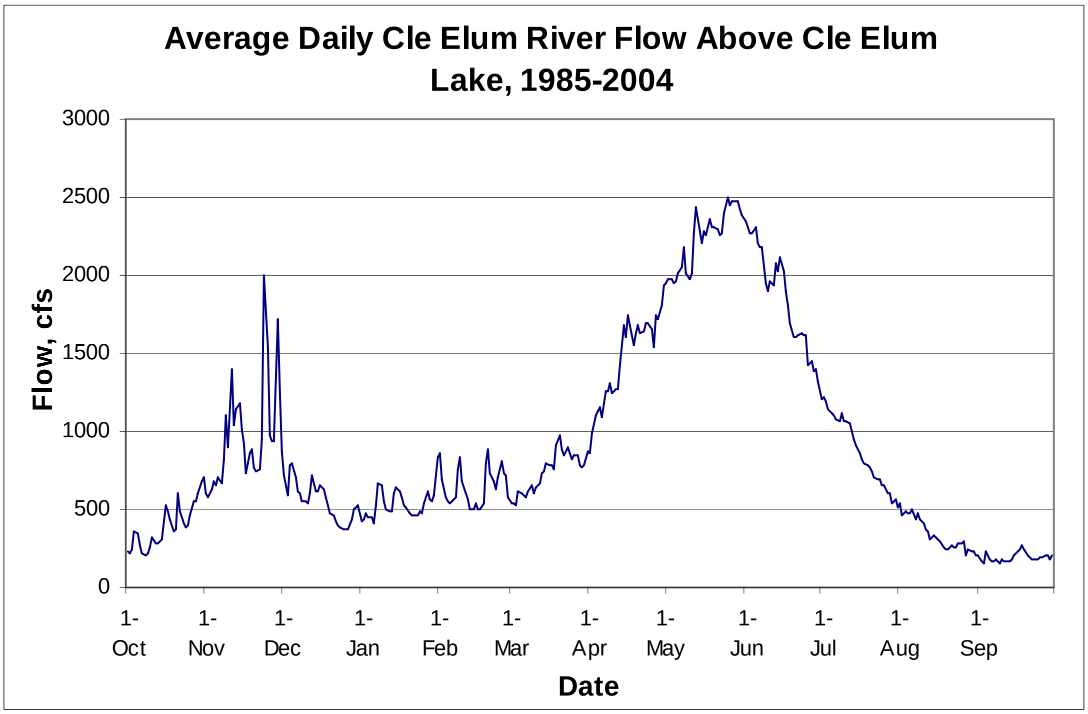


Figure 2. Average daily Cle Elum River flow above Cle Elum Lake for the period 1985 to 2004.

Related Investigations

Additional information was required to complement the stream survey information to evaluate the ability of the upper Cle Elum River basin to support re-introduced anadromous salmonids. Water temperature data were needed to determine if summertime water temperature might limit coho salmon production. A survey to assess the abundance and distribution of benthic macroinvertebrates that would constitute one food source for rearing juvenile coho salmon, and an estimate of the nutrient concentration that influences primary production were deemed necessary and appropriate. These related investigations are described briefly below.

Upper Cle Elum River Water Temperature

The U.S. Forest Service recorded water temperature using thermographs at nine locations in the Cle Elum River from RM 17.5 to RM 32.5 from July 17 to October 4, 2004 and at several locations in 2005. Several were placed upstream from Tucquala Lake. Only three recording thermographs were retrieved in 2005; the others were lost due to unknown circumstances.

Upper Cle Elum River Benthic Macroinvertebrate Survey

A benthic macroinvertebrate survey of the upper Cle Elum, Waptus, and Cooper rivers was conducted in September 2003 and March and September 2004 to assess benthic macroinvertebrate species composition and standing crop in the Cle Elum watershed above Cle Elum Lake. Sampling focused on riffle/run types of lotic habitat; however, a small number of instream pools were also sampled. A kick method was used, along with a Surber sample at a subset of the sampling sites. Surber samples (0.09 m^2) were used to relate kick-net dry weight biomass to g/m^2 using the regression equation:

$$\text{grams dry weight of invertebrates/m}^2 = 0.0569 + 1.3551 \text{ x grams of invertebrates/kick-net}$$

($R^2 = 0.8433$, $P = 0.0005$, $n = 9$). Drift samples were also collected, as were samples for coarse particulate organic matter (CPOM) and periphyton. Macroinvertebrate taxa richness and abundance and dry weight biomass were determined. Results were compared to water quality biological criteria developed by the Washington State Department of Ecology (Merritt et al. 1999). Functional feeding groups were assigned based on the primary feeding mechanism of the group, with categories defined as predators, scrapers, shredders, collector-filterers, and collector-gatherers. Standing crop categories promulgated by Mangum (1989) were used to relate biomass data collected in this survey to fish production. Complete details of the survey are reported by Nelson (2005).

Nutrient Concentrations in the Cle Elum River upstream from Cle Elum Lake

Water samples were collected to determine nutrient concentration in the Cle Elum River upstream from the lake concurrent with a limnological study conducted on Cle Elum Lake that took place monthly from September 2003 to October 2005, except during the winter. Nutrient concentration analyses were conducted in the Water Quality Laboratory at Reclamation's Technical Service Center, Denver, Colorado. A report is in preparation (Lieberman 2006).

This study and the benthic macroinvertebrate survey were conducted by biologists from Reclamation's Technical Service Center in Denver.

Preliminary Test of the Interim Downstream Passage Facility

Although not a component of a salmonid potential production assessment, it is interesting to note that the performance of the interim downstream passage facility that Reclamation constructed on Cle Elum Dam in spring 2005 was evaluated and the PIT-tag detectors were calibrated. The planned test for 2005 was to release 10,000 PIT-tagged coho salmon smolts from net pens near Cle Elum Dam and evaluate the use of the downstream passage facility. This evaluation could not be conducted as planned in 2005 since the water level in the lake did not reach the spillway due to the ongoing drought and low runoff. Some late season rains did provide a limited amount of flow to conduct the calibration tests of the interim downstream passage facility. The fisheries co-managers released small test groups of PIT-tagged coho salmon smolts directly into the passage facility. The planned large-scale test with about 10,000 PIT-tagged coho salmon was conducted in 2006. Six hundred and seventeen PIT-tagged coho salmon were detected passing through the juvenile downstream passage facility.

Results

Available spawning habitat approach

Cle Elum River reaches C-1 and C-2 have a little over 43 percent substrate in the suitable spawning size range, 12 to 128 mm, reach C-3 has about 48.7 percent, reach C-4 has about 41 percent, and reach C-5 has about 43.9 percent suitable substrate in this range. Interestingly, reaches C-7 and C-8 between Tucquala Lake and Hyas Lake had the lowest and highest percent suitable substrate, 38.2 and 56.8 percent, respectively. Estimated percent substrate composition for reach W-1 of the Waptus River from the 1995 survey at rkm 1.22 and rkm 3.74 averaged about 61.0 percent gravels in the size range 12 to 128 mm (Table 4). Cooper River reach CO-1 had an estimated 60 percent substrate in the 6.4 to 152 mm range (the earlier stream surveys for the Cooper River grouped substrate into larger size categories than the later stream surveys for the Cle Elum and Waptus rivers). Based on discussions with WNF fisheries biologists, who noted that substrate in the Cooper River was in the high end of the 6.4 to 152 mm range, we reduced the percentage of suitable substrate to 45 percent. We estimated that the seven reaches of the Cle Elum River upstream from the reservoir to Hyas Lake and the lowermost reach of the Waptus and Cooper rivers, upstream to impassable barriers, with an average gradient less than 3 percent had 159,160 m^2 of suitable spawning substrate that could accommodate 15,916 female coho salmon (Table 4). From the estimated 2,500 eggs per female and a 1.5 percent egg to smolt survival, 596,817 smolts could potentially be produced (Table 4). This assumes that all suitable spawning habitat in all reaches of the Cle Elum, Waptus, and Cooper rivers is fully and uniformly utilized by spawning coho salmon.

SAR by reach for one to six percent, based on 1.5 percent egg to smolt survival, are shown in Table 5. For comparison, the Yakima Coho Master Plan (Yakama Nation 2003) reported SARs in 2001 for hatchery and wild adult coho salmon as 1.8 percent and 3.8 percent, respectively, and in 2002, 0.04 percent and 0.87 percent, respectively.

Juvenile rearing/overwintering habitat approach

We estimated that 123,267 m^2 of pool habitat was present in the seven reaches of the upper Cle Elum River, the 3.8 km reach of the Waptus River, and the 2.3 km lower reach of the Cooper River during the late summer low flow period (Table 6). The number and average size of pools in the several reaches are shown in Table 6. If these pools were used as overwintering habitat by juvenile coho salmon, at densities ranging from 0.25 to one juvenile per m^2, we estimated that from 30,818 to 123,267 smolts could be produced in the Cle Elum River and some tributaries upstream from the reservoir (Table 6). At 0.25 smolt per m^2, the number of fish per linear meter of stream was 0.97, a little less than the average of 1.12 coho salmon smolts per linear meter of stream, ranging from 0.26 to 2.24, reported by Baranski (1989) for coho salmon in 10 Puget Sound streams. The calculated number of smolts per 100 m^2 of combined riffle and pool habitat within each reach is shown in Table 7; these were at the lower end of the range of values reported in the literature. Based on 0.25 smolt per m^2, 309, 617, 926, 1,233, 1,545, and 1,851 adult coho salmon would be expected to return at from one to six percent SARs, respectively (Table 6).

Table 4. Production potential for coho salmon in the Cle Elum, Waptus, and Cooper rivers considering the number of smolts that could be produced based on estimated extent of suitable spawning substrate.

Reach	Reach length, m	Average gradient, (range)	Total pool length, m	Total riffle length, m	Total riffle area (m^2), calculated from USFS stream surveys	Percent suitable substrate, 12-128 mm, from pebble counts	Adjusted riffle area (m^2)	Potential no. of redds at 10 m^2 each	No. of females required at one per 10 m^2	Estimated no. of eggs produced per reach with fecundity of 2,500	No. smolts at 1.5% egg to smolt
C-1	6,471.2	0.77 (0.12-1.44)	1,874.2	4,597.0	118,031	43.1	50,872	5,087	5,087	12,717,500	190,763
C-2	1,851.2	1.87	381.3	1,469.9	6,208	43.7	2,713	271	271	677,500	10,165
C-3	3,444.9	2.02 (0.05- 3.48)	1,704.7	1,740.2	30,123	48.7	14,670	1,467	1,467	3,667,500	55,013
C-4	4,571.7	2.73 (1.79-4.06)	1,678.5	2,893.2	42,783	41.0	17,540	1,754	1,754	4,385,000	65,775
C-5	6,278.0	0.99 (0.25-2.79)	1,347.0	4,931.0	55,221	43.9	24,242	2,424	2,424	6,060,000	90,900
C-7	1,842.2	<3	253.3	578	7,861	38.2	3,003	300	300	750,000	11,250
C-8	1,252.4	<3	766.0	469	7,041	56.8	3,999	400	400	1,000,000	15,000
W-1	3,799	2.6	1,019	2,780	45,751	61.0	27,908	2,791	2,791	6,977,500	104,663
CO-1	2,300	1.6	226	2,155	31,584	45.0	14,213	1,421	1,421	3,552,500	53,288
Total	31,811		9,024	19,458	313,019		159,160	15,916	15,916	39,787,500	596,817

Note: Percent suitable gravels for Cooper River reach CO-1 was reduced from the 60 percent to 45 percent after discussion with the forest fisheries biologist to adjust for the wider range of substrate size groups used in the early stream survey.

Table 5. Estimated number of returning adult coho salmon in reaches of the Cle Elum, Waptus, and Cooper rivers based on available spawning habitat and a 1.5 percent egg to smolt survival and SARs of one to six percent.

		SAR					
Reach	No. of smolts	1 %	2 %	3 %	4 %	5%	6 %
C-1	190,763	1,908	3,815	5,723	7,631	9,538	11,446
C-2	10,165	102	203	305	407	508	610
C-3	55,013	550	1,100	1,650	2,201	2,751	3,301
C-4	65,775	658	1,316	1,973	2,631	3,289	3,947
C-5	90,900	909	1,818	2,727	3,636	4,545	5,454
C-7	11,250	113	225	338	450	563	675
C-8	15,000	150	300	450	600	750	900
W-1	104,663	1,047	2,093	3,140	4,187	5,233	6,280
CO-1	53,288	533	1.066	1,599	2,132	2,664	3,197
Total	596,817	5,970	10,871	17,905	23,875	29,841	35,810
Fish/km		188	342	563	751	938	1,126

Note: SARs are based on 1.5 percent egg to smolt survival, and refers to adult coho salmon returning to the Cle Elum River.

Table 6. Potential production of coho salmon smolts and number of returning adult coho salmon based on overwintering pool habitat in the seven reaches of the Cle Elum River and the lowermost reach of the Waptus and Cooper rivers. Number of returning adults is based on 0.25 smolts per m^2 of pool habitat and SARs from one to six percent.

Reach	No. pools	Avg. size of pools, m^2	Pool area, m^2	Estimated no. of smolts at 0.25 per m^2 of pool habitat	Estimated no. of smolts at 0.5 per m^2 of pool habitat	Estimated no. of smolts at 1 per m^2 of pool habitat	SAR					
							1 %	2 %	3 %	4 %	5%	6%
C-1	23	1,284	29,530	7,383	14,765	29,530	74	148	222	295	369	443
C-2	7	801	5,605	1,401	2,803	5,605	14	28	42	56	70	84
C-3	43	605	26,014	6,504	13,007	26,014	65	130	195	260	325	390
C-4	40	506	20,228	5,057	10,114	20,228	51	101	152	202	253	303
C-5	31	393	12,174	3,044	6,087	12,174	30	61	91	122	152	183
C-7	13	241	3,131	783	1,566	3,131	8	16	24	32	40	48
C-8	11	904	9,939	2,485	4,970	9,939	25	50	75	100	125	150
W-1	15	973	14,601	3,650	7,301	14,601	37	73	110	146	183	219
CO-1	8	256	2,045	511	1,023	2,045	5	10	15	20	26	31
Total	191		123,267	30,818	61,636	123,267	309	617	926	1,233	1,543	1,851
Fish/km *							10	19	29	39	49	58

Note: SAR based on smolt to adult return from upper Cle Elum River back to Cle Elum River spawning sites.
* Based on sum of reach lengths from Table 4 = 31.8 km.

Table 7. Potential production of smolts per 100 m^2 in several reaches of the Cle Elum, Waptus, and Cooper rivers, based on 0.25 juveniles per m^2 rearing/overwintering in pool habitat, and total area of habitat in the reaches.

	Reach									
	C-1	C-2	C-3	C-4	C-5	C-7	C-8	W-1	CO-1	Total
Total reach area, riffles + pools, m^2	147,561	11,813	56,137	63,011	67,395	10,992	16,980	60,352	33,629	467,870
Total smolts	7,383	1,401	6,504	5,057	3,044	783	2,485	3,650	511	30,818
Smolts per 100 m^2 of total reach area	5	12	12	8	5	7	15	6	2	7

Related Investigations

River Water Temperature

Average, minimum, and maximum water temperatures recorded at four locations in the Cle Elum River from July to October 2004 are shown in Figures 3 to 6. At these and several other locations sampled, maximum water temperature exceeded the state water temperature standard of 16.1°C for some time during the summer (Table 8). Maximum water temperature downstream from Scatter Creek exceeded 21.1°C in August and most likely reflects the warming of shallow Tucquala Lake. Further downstream maximum water temperatures approached but did not exceed 21.1°C. Average water temperatures generally exceeded the 15°C upper optimum range for rearing juvenile coho salmon from about mid July to the third week in August, and slightly later at the Scatter Creek location. Maximum water temperature generally drops below 15°C by about the end of August. A few areas of groundwater upwelling have been identified by USFS biologists, but the flow from these, even though they may have a localized cooling effect on the river, are apparently insufficient to offset the apparent larger effect of warm water from Tucquala Lake. Water temperatures were 11.3°C and 11.5°C in C-2 and C-3, respectively, during the benthic macroinvertebrate sampling in September 2003.

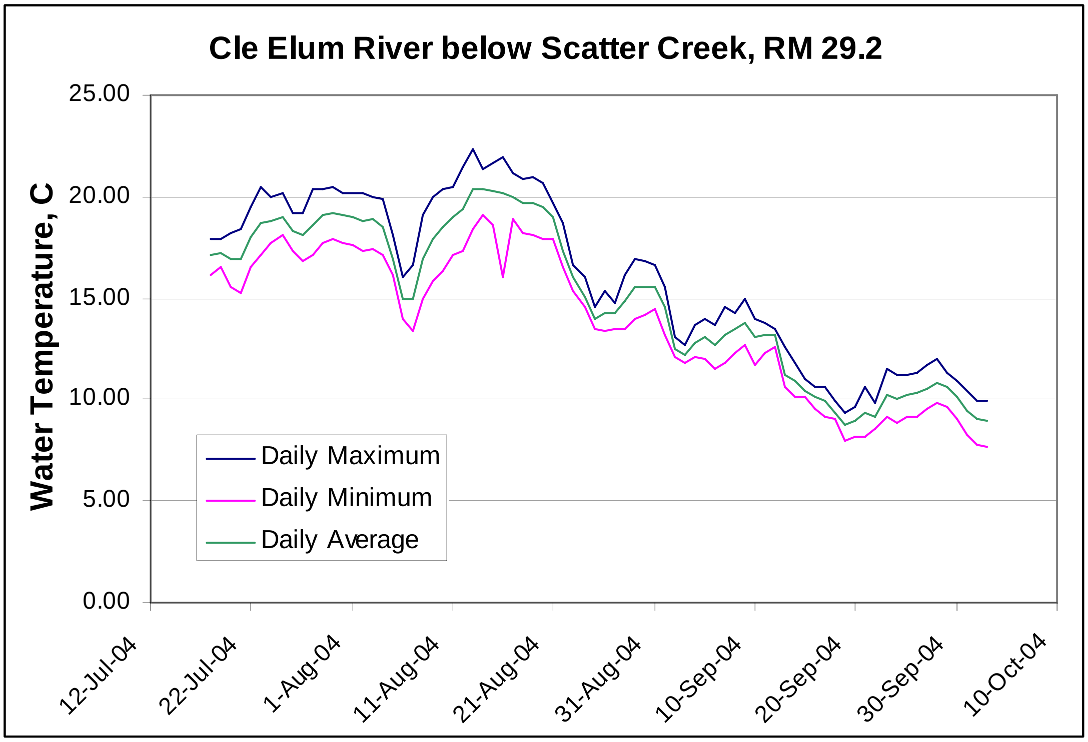


Figure 3. Water temperatures on the Cle Elum River downstream from Scatter Creek from July to October 2004.

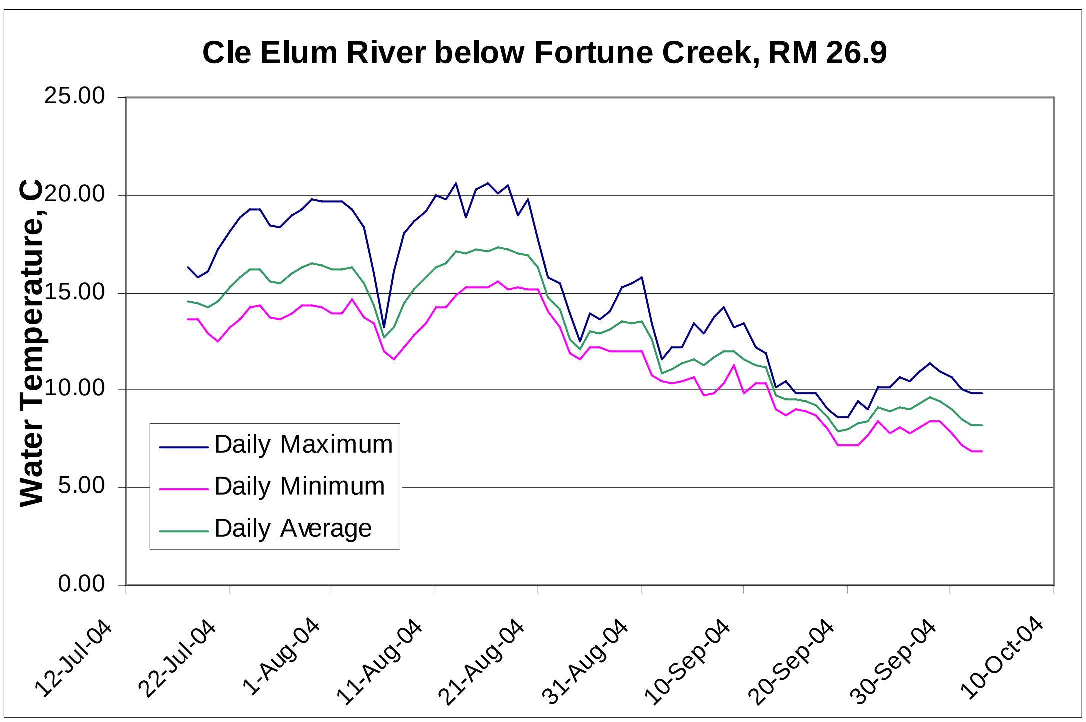


Figure 4. Water temperatures on the Cle Elum River downstream from Fortune Creek from July to October 2004.

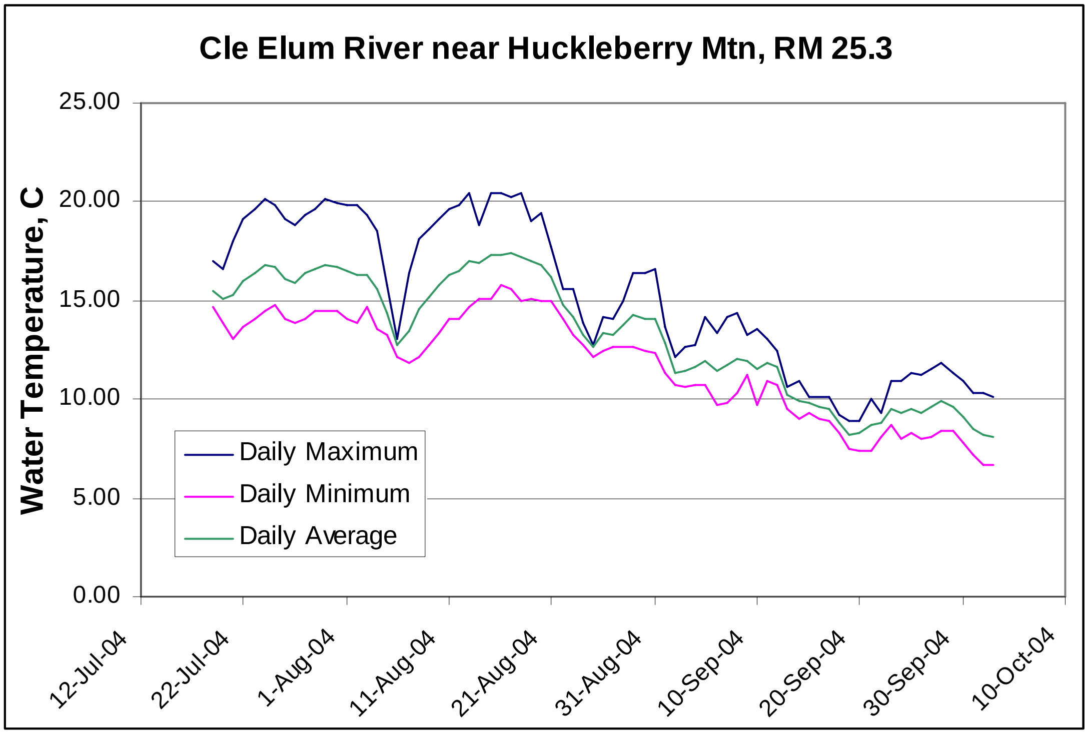


Figure 5. Water temperatures on the Cle Elum River near Huckleberry Mountain from July to October 2004.

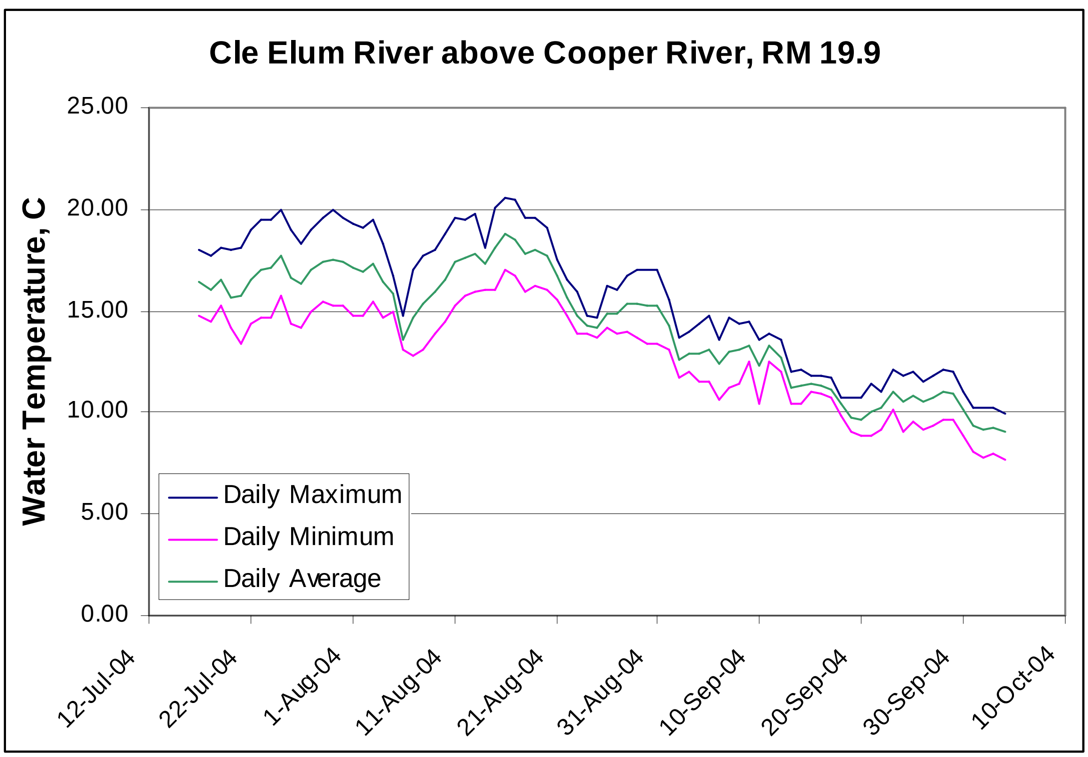


Figure 6. Water temperatures on the Cle Elum River upstream from the Cooper River from July to October 2004.

Benthic Macroinvertebrate Survey

Benthic macroinvertebrate dry weight biomass in the Cle Elum River upstream from the reservoir varied seasonally at sites but was generally low and ranged from 0.0590 g/m^2 in W-1 in September 2004 to 0.5417 g/m^2 in C-4 in March 2004 (Table 9, summarized from Nelson 2005). Averaged across the duration of the study, the lowest dry weight biomass of 0.0758 g/m^2 occurred in W-1 while the highest dry weight biomass of 0.3839 occurred in C-4, followed by 0.3656 in C-7. These sites would be described by Mangum's (1989) criteria for standing crop as poor. Mean dry weight values in March/April were 0.2960 ± 0.1728 g/m^2, while in September 2003 values were 0.2371 ± 0.1854 g/m^2 and in September 2004 values were 0.1260 ± 0.0493 g/m^2.

Drift net sampling (n = 5) in the Cle Elum River reach C-2, C-3, and C-5 indicated that there were few organisms in the drift during sampling in March and September 2004. Values were 0.2836 ± 0.1644 individual organisms/m^3 and 0.0000698 ± 0.0000426 g/m^3 (dry weight). Diptera (33.8 percent) and Ephemeroptera (26.5 percent) made up most of the drift organisms, with the rest made up of Plecoptera (19.1 percent), Coleoptera (16.2 percent), and Trichoptera (4.4 percent).

Organic Material

CPOM biomass (dry weight) was significantly correlated with macroinvertebrate biomass (r = 0.4406, p = 0.0072) and baetid abundance (r = 0.3780, p = 0.0230). Periphyton biomass (ash-free-dry-mass) was negatively correlated with scraper abundance (r = -0.3366, p = 0.0447).

Table 8. Water temperature for several locations in the Cle Elum River from July to October 2004.

Site	River Mile	Recording dates	Maximum Temperature °C	Days Exceeding 16.1°C	Max 7-day Average Maximum Temperature	Days Where 7-day Average Exceeded 14.4°C
Cle Elum River at Deception Pass	32.53	7/18/04 - 10/3/04	21.40	38	20.65	43
Cle Elum River above Lake Tucquala	30.10	7/18/04 - 10/3/04	20.65	38	20.21	43
Cle Elum River at Scatter Creek	29.20	7/18/04 - 10/3/04	22.32	40	21.54	44
Cle Elum River below Fortune Creek	26.90	7/18/04 - 10/3/04	20.61	30	20.10	36
Cle Elum River at South End of Goat Mountain	26.10	7/19/04 - 10/3/04	20.46	34	19.86	42
Cle Elum River at Huckleberry Mt. Spawning Area	25.30	7/19/04 - 10/3/04	20.44	35	20.09	40
Cle Elum River at Salmon la Sac	19.90	7/17/04 - 10/4/04	20.59	41	19.76	46
Cle Elum River above French Cabin Creek	17.50	7/13/04 - 10/4/04	20.61	41	19.82	45
Source: U.S. Forest Service, Wenatchee National Forest, Cle Elum Ranger District, 2005						

Nutrient Concentrations in the Cle Elum River upstream from Cle Elum Lake

Concentrations of total phosphorus and total nitrogen in the Cle Elum River upstream from the reservoir averaged 0.004 mg/L (range 0.003 – 0.005 mg/L) and 0.176 mg/L (range 0.061 – 0.494 mg/L), respectively, for the study period September 2003 to October 2005 (Lieberman and Grabowski 2006).

Preliminary Test of the Interim Downstream Passage Facility

The large-scale test of the interim juvenile downstream bypass facility with about 10,000 PIT-tagged coho salmon was conducted in 2006. Six hundred and seventeen PIT-tagged coho salmon were detected passing through the downstream bypass facility.

Table 9. Macroinvertebrate dry weight biomass (g/m^2), CPOM (g), and periphyton (g/m^2) in several reaches of the Cle Elum and Waptus rivers.

Site	CPOM, [a] g	Periphyton, g/m^2	Macroinvertebrates dry weight biomass (g/m^2) [b]				Potential for supporting fishery [c]
			Sept 2003	Mar 2004	Sept 2004	Average	
C-1	3.49 (0.62)	5.9 (0.7)	0.1162 (0.2015)	0.2574 (0.1975)	0.1241 (0.2012)	0.1659	Poor
C-2	10.70 (2.86)	3.8 (1.8)	0.5161 (0.1972)	0.4299 (0.1963)	0.1373 (0.2007)	0.3611	Poor
C-3	4.00 (1.11)	4.0 (1.1)	0.2036 (0.1987)	0.1178 (0.2014)	0.0834 (0.2028)	0.1349	Poor
C-4	16.59 (7.11)	3.5 (0.6)	0.4149 (0.1962)	0.5417 (0.1976)	0.1951 (0.1989)	0.3839	Poor
C-5	9.06 (8.01)	8.8 (3.7)	0.1070 (0.2018)	0.3253 (0.1966)	0.1569 (0.2001)	0.1964	Poor
C-7	6.41 (3.63)	14.9 (1.8)	0.4271 (0.1963)		0.3040 (0.1968)	0.3656	Poor
C-8	2.80 (1.12)	9.3 (1.6)	0.4330 (0.1963)		0.1642 (0.1998)	0.2986	Poor
W-1	1.19 (0.50)	2.5 (0.2)	0.0648 (0.2035)	0.1037 (0.2019)	0.0590 (0.2038)	0.0758	Poor
CO-1	33.53	3.2	0.1714 (0.1996)			0.1714	Poor
Avg.			0.2727	0.2960	0.1260	0.2393	

[a] Coarse particulate organic material in kick sample; macroinvertebrate food source.

[b] Based on the regression derived from Surber samples: grams of invertebrates/m^2 = 0.0569 + 1.3551 x grams of invertebrates/kick-net. Standard error of predicted values in parentheses.

[c] Standing crop (g/m^2) categories are: poor = 0.0 to 0.5; fair = 0.6 to 1.5; good = 1.6 to 4.0; and excellent = 4.1 to 12.0 (Mangum 1989).

Discussion

The seven reaches of the Cle Elum River upstream from the reservoir and the Waptus and Cooper rivers, up to impassable barriers or high gradient reaches, had an estimated 159,160 m^2 of suitable spawning substrate for coho salmon that we estimate could produce 596,817 smolts, if the habitat were fully utilized by 15,916 adult pairs. However, spawning fish may select spawning areas based on some suite of microhabitat conditions such as water flow and depth, temperature, groundwater influences, and other factors that will not become apparent until a sufficient number of tagged adult coho salmon return to spawn in the Cle Elum River and are tracked to spawning areas, or the rivers are surveyed for redds and carcasses, so this estimate is probably optimistic.

For juvenile rearing/overwintering habitat, we conservatively estimated that the Cle Elum, Waptus, and Cooper rivers could produce about 30,818 coho salmon smolts at 0.25 smolts/m^2, or about 7 smolts per 100 m^2 of total reach area, ranging from 2 to 15 for the several reaches (Table 7). The low estimate of 2 is for the Cooper River that has only 8 pools that represent about 6.1 percent of stream reach area; however, it does have several side channels that were not considered in the assessment. Reaches C-2 and C-3 have about an equally high potential for smolt production, although they are relatively short reaches. Reach C-8 has a high calculated potential for smolt production, but based on some limited information that indicated high summertime water temperatures, we suspect that actual production in this reach would be lower. Increasing summertime water temperatures may force fish to disperse downstream. Chapman (1965 cited in Sandercock 1991) reported a production of 18 to 67 smolts per 100 m^2 over a 4-year period in three Oregon coastal streams. Tripp and McCart (1983 cited in Sandercock 1991) reported production of 8.4 to 8.5 smolts per 100 m^2, while Armstrong and Argue (1977 cited in Sandercock 1991) reported 125 to 141 smolts per 100 m^2 in side channels of the Cowichan River in British Columbia. The Cowichan River appeared to have an abundant insect fauna, implying a greater food base for rearing coho salmon. Baranski (1989) reported that the number of coho salmon smolts captured in 10 Puget Sound streams over a 10-year period averaged 18 coho salmon smolts per 100 m^2, ranging from 8 to 26. Overall estimates for coho salmon smolt production in the Cle Elum River basin are low compared to reported estimates. The recent benthic macroinvertebrate study (Nelson 2005) revealed that the benthic fauna was sparse in the upper Cle Elum River, perhaps due to the low productivity of this high elevation watershed that has been deprived of marine-derived nutrients for a century, and rated “poor” on Mangum’s (1989) scale. Nelson (2005) also noted that there appears to be a lack of CPOM retention.

Bradford et al. (1997) reported that stream length was useful in predicting mean smolt abundance, and that streams between 48 to 50 °N latitude were most productive, with those between 46 to 48 °N latitude somewhat less so. Cle Elum Lake is about 47.245 °N latitude.

Bradford et al. (1997) related loge mean coho salmon smolt abundance to loge stream length (km) in the equation:

$$Y = 6.90 + 0.97X$$

With Y = loge mean coho salmon smolt abundance and X = loge stream length (km). From this equation we calculate that the 31.8 km of the Cle Elum River and its tributaries could produce 28,443 coho salmon smolts, about eight percent less than the 30,818 smolts we estimated could be produced assuming 0.25 smolts per m^2 of overwintering habitat.

Bradford et al. (2000) analyzed 14 datasets and reported that about 19 spawning females per km, ranging from 4 to 44, were needed for full smolt recruitment. This was at low spawner abundance. Based on the juvenile rearing/overwintering approach discussed here, this would require about a four percent SAR based on the number of smolts produced at 0.25 smolts/m^2. Beidler et al. (1980 cited in Nickelson et al. 1992) noted that at least 25 spawners were needed to seed juvenile rearing habitat in some Oregon coastal streams. Our assessment of production potential indicates 29 adult fish per km at 0.25 smolts per m^2 of rearing/overwintering pool habitat and a 3 percent SAR (Table 6). Estimated adult returns for one to three percent SAR are in the range reported by Bradford et al. (2000). Shaul and Van Alen (2001) reported low average spawner and smolt densities of 5 to 6 females per km and 213 to 420 per km, respectively, in interior Taku River tributaries compared to coastal streams. They suggest that low coho salmon densities may be characteristic of interior habitats, perhaps similar to the Cle Elum River basin. The 5 to 6 females per km Shaul and Van Alen (2001) reported compares closely with the low estimate of 10 adults per km for 0.25 smolts per m^2 of rearing/overwintering pool habitat and the number of returning adults at one percent SAR estimated here.

Environmental factors will influence coho salmon production; Baranski (1989) observed significant variability in coho salmon smolt production among years in Puget Sound streams. One factor relative to juvenile coho salmon rearing successfully in the Cle Elum River and its tributaries is the available prey base. Streams vary in productivity and the rates of primary and secondary production determine in large part the amount of food available for fish (Bjornn and Reiser 1991). The Cle Elum River upstream from the reservoir is relatively unproductive, as indicated by the 2003 and 2004 macroinvertebrate study (Nelson 2005). These data substantiate the statement in the 1972 stream survey of the Cooper River that the fish food supply was relatively poor (Hand 1973). Mangum (1989) stated that invertebrate biomass levels below 0.5 g/m^2 resulted in poor fisheries; only reach C-2 in September 2003 and C-4 in March 2004 barely exceeded 0.5 g/m^2 dry weight biomass (Table 9). Weng et al. (2001) found that juvenile salmonids experienced higher growth rates when streams were enriched to the point where benthic invertebrate biomass was in the range of 0.6 to 0.8 g/m^2, while Hetrick et al. (1998) found that salmon streams contained 0.5 to 1.0 g/m^2 of invertebrate biomass. The limited amount of benthic macroinvertebrate prey available for rearing juvenile coho salmon will likely affect survival and growth. Competition for limited food resources would likely occur with resident fish and other species of reintroduced anadromous salmonids. The wider sites associated with the Cle Elum River were numerically dominated by collector-filterer functional feeding groups of macroinvertebrates and included organisms such as *Hydropsyche*. Collector-filterers have anatomical structures (setae or fans) or secretions that sieve particulate matter from suspension. An abundance of collector-filterers (Cle Elum lotic sites) suggests high-flow, low-retention habitats (Wallace and Webster 1996).

Even though Reach C-2 and C-3 are relatively short in length compared to other reaches, they are estimated to be the most potentially productive for coho salmon. Reaches C-2 and C-3 each had about equal proportions of riffle and pool habitat (Tables 4 and 6). McMahon (1983) reported that a pool to riffle ratio of 1:1 provides optimum food and cover conditions for coho salmon parr. Nelson's (2005) benthic macroinvertebrate study found that Reach C-4 averaged the highest dry weight biomass per m^2 than any other Cle Elum River reach; reach C-3 had the lowest, but upstream reach C-4 might produce substantial macroinvertebrate drift important to rearing coho salmon in reach C-3. McMahon (1983) reported that benthic invertebrate production seemed to be greater in rubble, followed by bedrock, gravel, and sand. Reach C-2 had 49.29 percent cobble and boulder substrate combined (there was no separate "rubble" substrate category), 33.93 percent bedrock, 17.79 percent gravel, and only 5.0 percent sand (Table 2). Reach C-3 had 56.79 percent cobble and boulder substrate combined 21.60 percent bedrock, 16.36 percent gravel and 5.36 percent sand. Reach C-4 had 48.06 percent cobble and boulder substrate combined 34.47 percent bedrock, 13.24 percent gravel, and 5.0 percent sand. Reach C-1, by contrast, had less percent cobble-boulder and bedrock, and just over 38 percent combined gravel and sand, almost two times the amount in reaches C-2 and C-3. The low benthic macroinvertebrate production in C-3 seems inconsistent with McMahon's (1983) finding.

The concentration of nutrients in Cle Elum River was lower than those in oligotrophic Cle Elum Lake and consistent with the low macroinvertebrate production discussed above. An analysis of Cle Elum Lake sediments found that before 1906, there was an average of 19 percent more phosphorus deposited in the lake sediments each year (Dey 2000). In 1906 a timber crib dam was constructed on the outlet of Cle Elum Lake; this dam eliminated anadromous salmonid access to the lake, and eliminated the annual infusion of marine-derived nutrients that apparently contributed to a more productive system upstream from the lake and presumably in the lake itself. When passage for adult anadromous salmonids is re-established at Cle Elum Dam, and the number of returning adult salmonids increases over time from the initial reintroductions, we would expect an increase in stream and lake nutrient levels and productivity, if the carcasses are retained in the stream. It is not possible at this time to estimate the expected increase in stream or lake productivity from the infusion of marine-derived nutrients from returning spawning adults, or prespawning mortality.

If excess fry are produced in a fully seeded system, some fry may be forced downstream away from the spawning and early rearing area due to territorial behavior of the fish (Ruggles 1966 cited in Sandercock 1991), crowding, or changing environmental conditions. This movement would redistribute rearing juvenile coho salmon into areas of the river where habitat might be less suitable. Conversely, habitat away from spawning and early rearing habitat may be more structurally complex and support a larger or more diverse and abundant food base (Sandercock 1991). As noted above, coho salmon are relatively resilient.

The water temperature data collected on the Cle Elum River in 2004 by the U.S. Forest Service suggested that maximum summertime water temperatures sometimes exceed the preferred range for rearing coho salmon, but did not approach the lethal temperature. These data indicate that the Cle Elum River is a relatively warm river system. Tucquala and Hyas lakes likely contribute to the warm water temperatures in the Cle Elum River. Tucquala Lake is shallow and warms appreciably. This warm water flowing downstream contributes to increased river water temperature. A few locations of groundwater upwelling have been identified, but the flow from these, even though they may have a localized cooling effect on the river, is apparently insufficient to offset the larger effect of warm water from Tucquala Lake.

Coho salmon production potential could be affected by interspecific competition from native resident fish, both salmonids and nonsalmonids. Large lake trout have been reported in Cle Elum Lake (Matt Polacek, WDFW, Ellensburg, WA, pers. comm.); they could prey upon juvenile coho salmon migrating through the lake during their outmigration from the Cle Elum River. In addition, if reintroduction of other anadromous salmonids proceeds as planned by the fisheries co-managers, additional interspecific competition may occur. Lake and river investigations to elucidate predator-prey relationships may be needed to provide fisheries co-managers with sufficient information to implement changes in sport fishing regulations, if necessary. The carrying capacity of the river and tributaries could change annually to some degree due to fluctuating environmental and atmospheric conditions that influence the timing and extent of runoff and the effects on the riverine habitat, as well as biological production.

The USFS is implementing a riparian restoration program to improve habitat in the Cle Elum River basin. Currently, dispersed camping along the Cle Elum River is compacting soil, removing riparian vegetation, and eroding the bank. Through its Respect the River program, the Cle Elum Ranger District is working to secure funding to survey thoroughly and map the existing use pattern in the basin, plan for a sustainable distribution of recreational opportunities across the landscape, and perform on-the-ground restoration and redesign work. If this program is successful, habitat in the river should benefit.

Summary

The two approaches used here yielded two different estimates of coho salmon potential production in the upper Cle Elum River and tributaries. We submit that the estimate from the juvenile rearing/overwintering approach is probably more consistent with estimates of coho salmon production reported in the literature for other systems in the U.S. and Canada, and may be conservative since our estimates of habitat availability were based on late summer low flow conditions.

The number of juvenile coho salmon estimated from the rearing/overwintering habitat approach is comparable to and falls within the range of values reported in the literature for number of smolts per 100 m^2 stream habitat, estimates based on stream length and latitude, and reported estimates of the number of spawning female fish per km needed for full smolt recruitment. We feel that the estimate of production potential presented here is reasonable and conservative, considering that the estimates were based on low streamflow conditions from stream surveys conducted in late summer, and the potential increase in habitat availability with increased fall and winter flows. This assessment of potential production indicates that a self-sustaining coho salmon population in the Cle Elum River would require an average 1.5 percent egg to smolt survival coupled with about a 5.5 percent smolt to adult return. To illustrate this numerically, a return of 1,540 adult coho salmon with equal sex ratio would result in 770 females producing an estimated 1,925,000 eggs. A 1.5 percent egg to smolt survival would produce 28,875 outmigrants, and with a 5.5 percent SAR, 1,588 adults would be expected to return. The Yakima Coho Master Plan (Yakama Nation 2003) reported SARs up to 3.8 percent for wild coho salmon in 2001, but only 0.87 percent in 2002. Four percent SAR is the average interim SAR objective (ranging from two to six percent) in the NPCC mainstem amendment for Snake River and upper Columbia River salmon and steelhead (NPCC 2003). A 5.5 percent SAR is optimistic, but if egg to smolt survival is greater than the average 1.5 percent used here, a lower SAR would result in a similar number of returning adults. An EDT model for the upper Yakima Basin predicted a total spawner escapement of 486 adults for current conditions with SAR of 1.5 to 1.8 percent, and 88,945 spawners for historic conditions with SAR of 6.3 to 6.9 percent.

A return of 1,588 adult coho salmon to the upper Cle Elum River would not seem unreasonable, since recent returns to the Yakima River counted at Prosser Dam were as high as 6,138 adults in 2000, but dropped substantially to 818 in 2002 (Yakama Nation 2003). However, the low abundance of macroinvertebrate prey and warm summertime water temperatures, among other environmental factors, will limit coho salmon production in the Cle Elum River, at least until stream and lake productivity increases due to the infusion of marine-derived nutrients and any necessary habitat improvements are implemented. The two reaches of the Cle Elum River upstream from Tucquala Lake would provide suitable spawning habitat and would likely produce coho salmon, but the warm water temperatures in the summer will likely displace young coho salmon downstream for rearing.

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