RECLAMATION

Managing Water in the West

Assessment of Sockeye Salmon Production Potential in the Cle Elum River Basin

Storage Dam Fish Passage Study
Yakima Project, Washington

Technical Series No. PN-YDFP-008

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.

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Introduction

This technical report presents information regarding sockeye salmon *(Oncorhynchus nerka)* 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 watershed; 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 *(Salvelinus confluentus)* and Mid-Columbia River steelhead *(O. mykiss)*, 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), the 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.

Sockeye salmon in the Yakima and Upper Columbia River Basins

Four natural glacial lakes in the Yakima River Basin supported sockeye salmon *(Oncorhynchus nerka)* populations historically (Fulton 1970; Tuck 1995), but the salmon were extirpated in the early 1900s when timber crib dams were constructed at the outlets of the lakes. Cle Elum Lake was first dammed in 1906. Several decades later in 1933 the contemporary Cle Elum Dam was constructed to increase the lake's water storage capacity for irrigation (Haring 2001).

Currently there are three stocks or evolutionarily significant units (ESUs) of sockeye salmon in the interior Columbia River basin: Lake Wenatchee ESU (Washington), Okanogan River ESU (Washington), and the Snake River ESU (Idaho). The Snake River sockeye salmon ESU was federally listed under the ESA on November 20, 1991 (56 FR 58619). A subsequent final listing determination issued by NOAA Fisheries on June 28, 2005 (70 FR 37160) reconfirmed the endangered status of the Snake River sockeye salmon ESU, which primarily occurs in the upper Salmon River basin in Redfish Lake. The Lake Wenatchee and Okanogan River sockeye salmon ESUs in central Washington state were found to not be warranted for listing under the ESA, and are therefore potential source populations for

sockeye salmon reintroduction into Cle Elum Lake. Lake Wenatchee is smaller and shallower than Cle Elum Lake; both lakes are oligotrophic. Lake Wenatchee, however, does not undergo the annual water level fluctuations that occur in Cle Elum Lake as a result of seasonal water storage and release for irrigation and other purposes in the Yakima Basin. Lake Osoyoos on the Okanogan River extends into Canada and is shallower, warmer and meso- to eutrophic. Lake Osoyoos sockeye salmon smolts are generally greater than 100 mm in length, while Lake Wenatchee sockeye salmon smolts are generally less than 100 mm in length and are easily differentiated at downstream juvenile fish facilities. Fisheries co-managers are assessing the advantages and disadvantages of using either one or the other of these as donor stock for sockeye salmon reintroduction into Cle Elum Lake. Recent production estimates in Lake Wenatchee may provide some indication of sockeye salmon production potential in Cle Elum Lake.

Some aspects of sockeye salmon life history

Sockeye salmon spend from one to (occasionally) three growing seasons in freshwater and from one to four years in the ocean and return to spawn in their natal streams as 2- to 7-year-old adults (Foerster 1968). Unlike coho and Chinook salmon, juvenile sockeye salmon rear predominantly in lakes; fry migrate into lakes soon after emerging from the gravel.

Water temperature for upstream migration of adult sockeye salmon generally ranges from 7.2 to 15.5°C (Bell 1991). Spawning is reported to occur at various water temperature ranges: 3 to 7°C (Scott and Crossman 1973), 8 to 13°C (Shepherd et al. 1986 cited in Bjornn and Reiser 1991), 10.5 to 12.2°C (Bell 1991), and 10.6 to 12.2°C (Pauley et al. 1989). Incubation temperatures range from 4.4 to 13.3°C (Pauley et al. 1989). Bell (1991) reported preferred water temperature for sockeye salmon as ranging between 11.6 and 14.4°C, while Brett (1952) reported that a temperature range of 12 to 14°C is close to the optimum for maximum growth efficiency.

Reiser and Bjornn (1979 cited in Pauley et al. 1989) note that sockeye salmon require at least 5.0 mg/L dissolved oxygen (DO) for successful incubation. Foerster (1968) reported that sockeye salmon appear to tolerate DO levels lower than those tolerated by chum and pink salmon. Semko (1954 cited in Lorenz and Eiler 1989) reported that sockeye salmon can incubate at lower levels of DO than many other salmonids, but spawning adults avoided areas with intra-gravel DO levels below 3.0 mg/L (www.fisheries.ubc.ca/grad/abstracts/scopeab.pdf). Dissolved oxygen concentrations at or near saturation, generally around 8 to 9 mg/L, are required for best swimming performance and growth (Brett 1965). However, a substantial sockeye salmon population exists in eutrophic Lake Osoyoos on the Okanogan River in Washington and British Columbia that is warmer and presumably less well oxygenated than the typical oligotrophic lake habitat occupied by sockeye salmon.

Sockeye salmon spawn over a range of habitat types but in streams generally spawn at the downstream end of pools at the pool-riffle interface (www.fisheries.ubc.ca/grad/abstracts/scopeab.pdf). Sockeye salmon also spawn in inlets and outlets of lakes in water velocities of 0.3 to 0.91 m/sec (Bjornn and Reiser 1991), normally in riffles or where groundwater seepages occur, in minimum water depth of 0.15 m (Bjornn and Reiser 1991), but they prefer a depth of 0.3 to 0.5 m (Burgner 1991). Fukushima and Smoker (1998) reported that sockeye salmon utilized channel gradient lower than about 1.6 deg (≈ 2.8 percent). Sockeye salmon have been documented to spawn successfully over coarse sand substrate as well as over cobble too large to move and in which to construct a redd (Foerster 1968). Sockeye salmon also spawn in lakeshore locations at deeper depths where groundwater seepage occurs. Haring (2001) noted that historically sockeye salmon probably spawned both in Cle Elum Lake and its tributaries. Lake Wenatchee sockeye salmon, a potential donor stock for re-establishment of sockeye salmon in Cle Elum Lake, are tributary spawners (John Easterbrooks, WDFW, Yakima, WA, December 2004, pers. comm.; Mike Tonseth, WDFW, Wenatchee, WA, December 2004, pers. comm.).

Sockeye salmon fry in tributaries move downstream at a size of 25 to 31 mm soon after emerging from the gravel beginning about mid-April to juvenile rearing habitat in lakes (Pauley et al. 1989). Fry are relatively light-sensitive and generally move at night (Pauley et al. 1989), which is also a behavioral mechanism to avoid or reduce predation. Once in the lake, fry initially occupy shallow, littoral zone water, feeding on insects. As the juveniles grow, they move into deeper offshore water, feeding principally in the pelagic zone, generally in waters from 10 to 20 m deep (Foerster 1968, Burgner 1991). Rearing juvenile sockeye salmon are sight feeders and make diel vertical migrations from deep water around dusk to feed primarily on cladoceran and copepod zooplankters in the epilimnion, then descend at night, driven by concentrations of prey, optimal temperature for metabolism, and to avoid or reduce predation (Quinn 2005).

Methods

We used several methods to assess sockeye salmon production potential in the Cle Elum River basin. We estimated potential sockeye salmon smolt production from the amount of available spawning habitat in the Cle Elum, Waptus, and Cooper rivers based on results of several stream surveys conducted by the U.S. Forest Service. We primarily considered stream gradient, distance to impassable fish barriers, substrate composition, the size of riffles and pools and the areal extent of riffles with substrate in the appropriate size range. We considered the average size of sockeye salmon redds and area “recommended” per redd (Burner 1951), and estimated the number of redds that the area would support and 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, then incorporated an average fecundity of 2,700 eggs per female for sockeye salmon. We estimated the number of smolts that could be produced at several egg to smolt survival rates and the number of adults that would return at smolt to adult return (SAR) rates of from one to six percent.

Since juvenile sockeye salmon typically rear in lakes, we adapted several methods of estimating production reported by BioAnalysts (2000): number of smolts per lake surface area, lake euphotic volume, and number of spawners per lake hectare (ha). Where appropriate, we incorporated information from the September 2003 to October 2004 limnological study of Cle Elum Lake (Lieberman and Grabowski 2006). After estimating the number of smolts that could be produced by these methods, we estimated the number of adults that would return at smolt to adult return rates (SARs) of from one to six percent.

Available Spawning Habitat

Overview

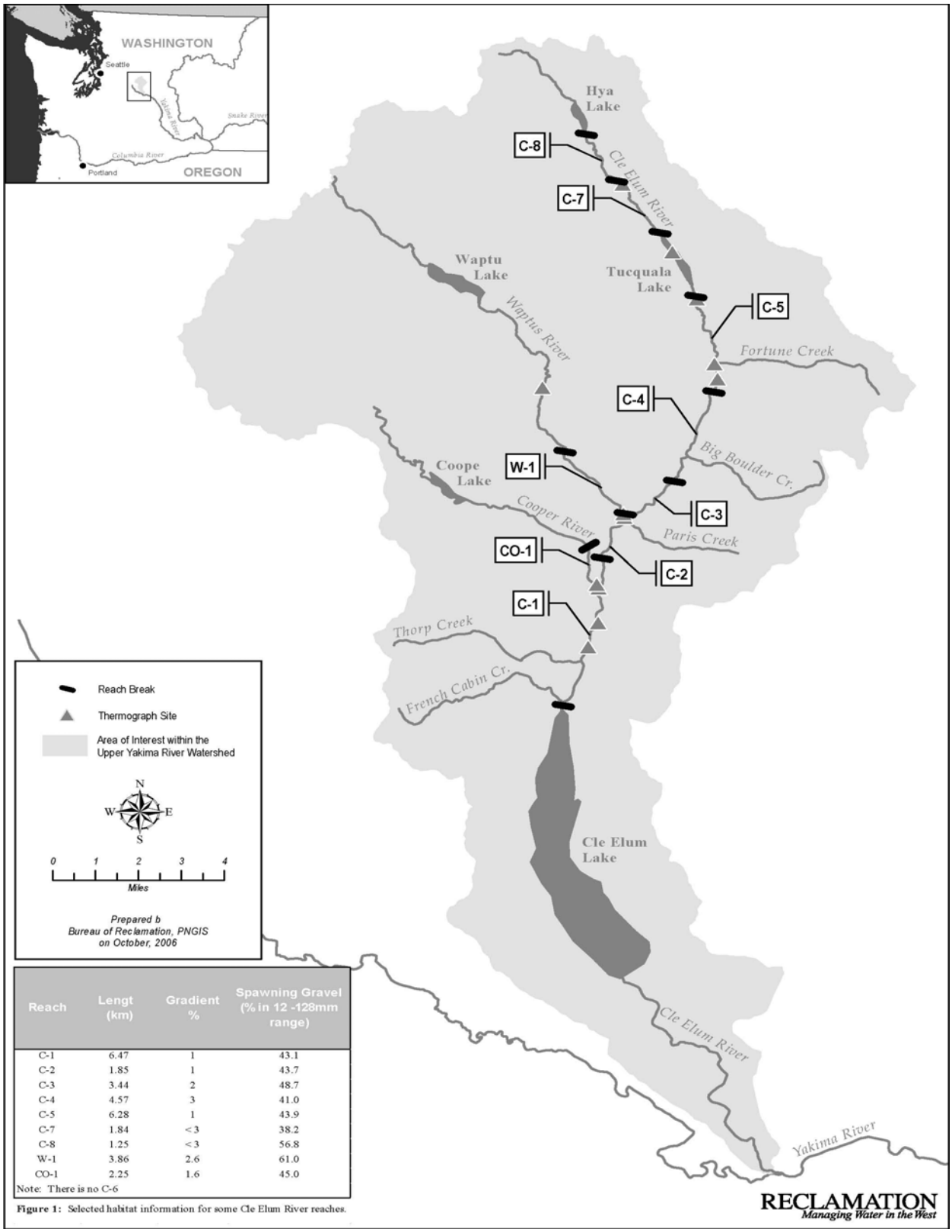
In general, sockeye salmon spawning substrate consists of small- to medium-size gravel with a limited amount of coarse sand, through which a good flow of water can be maintained (Foerster 1968). Sockeye salmon prefer spawning gravels ranging in size from 13 to 102 mm (Bjornn and Reiser 1991), and similar in size to that reported for coho salmon. Salmon reportedly can spawn in gravels 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 salmon; larger adult fish can move and therefore spawn in larger-sized gravel than smaller fish. Lorenz and Eiler (1989) reported that in the Taku River in Canada, mean composition of sockeye salmon redd substrate was 67.3 percent gravel measuring from 2 mm to 10 cm. Burner (1951) reported that in the Wenatchee River, sockeye salmon redd substrate consisted of 94 percent medium and small gravel, that is, gravel less than 15 cm in size. Sockeye salmon have been observed to spawn over large boulders (Foerster 1968) and in lakes to depths of 30 m in coarse granitic sand in areas of strong upwelling (Olsen 1968 cited in Burgner 1991).

Substrate suitability

Fisheries biologists from the Wenatchee National Forest, Cle Elum Ranger District (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, 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 in this assessment. Cooper River stream surveys were conducted in 1972 and 1989. The Cooper River has 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. Information such as stream substrate composition and physical attributes were gleaned from these stream survey reports and summarized. Information was not reported consistently in the various survey reports. 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, cobble, boulder, 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 1). Particle size categories are shown in Table 2. Substrate was qualitatively estimated and grouped in broad size categories for the Cooper River stream survey conducted in 1972. The size range of suitable spawning substrate for sockeye 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 2). Data from Wolman pebble counts collected at selected transects during the stream surveys allowed us to calculate the percent of the substrate in the size range 12 to 128 mm. This size range mostly bracketed the size range of suitable spawning substrate reported above.



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.

Table 1. Percent 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 1972, 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 (2-64 mm); Cobble (64-256 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.

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 12 to 128 mm size range. 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.

The Wenatchee National Forest Land and Resource Management Plan (WNF 1990) states that spawning gravel contain 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, and this is likely true for sockeye salmon as well. Samples with less than 12 percent fine sediment are

Table 2. Particle sizes of several gravel and cobble categories identified during surveys of the Cle Elum River and tributaries in 2003. Particle type and size categories highlighted in bold are considered suitable spawning substrates for sockeye 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.

considered GOOD, samples with 12 to 17 percent fine sediment are considered FAIR, and samples with greater than 17 percent fine sediment are consider POOR. Geometric mean diameter (D_g) 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.

Stream reaches on the Cle Elum, Waptus, and Cooper rivers were delineated by stream gradient. Only those reaches with moderate (<4 percent) to low gradients were included in the available spawning habitat approach. Based on average reach gradients, sockeye 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). One short area in reach C-4 has a gradient of 4.06 percent, but this short reach was not deemed to be a barrier to upstream adult migration and therefore was included in the analysis. Gradient in Cooper River reach CO-1 was two percent or less, and averaged 1.6 percent; reach CO-2 had areas with gradients up to 15 percent, as well as an impassable barrier at RM 3.2 (Cle Elum Ranger District 1989).

Redd size

Bocking and Gaboury (2003) reported that the minimum area required for a sockeye salmon redd is about 1.75 m^2; Burner (1951) reported that the average size of sockeye salmon redd is about the same. Foerster (1968) reported redd sizes of 1.67 m^2, 1.76 m^2, 1.5 m^2 and 2.0 m^2 for the White River, Okanogan River, Wenatchee River, and Little Wenatchee River, respectively. Under competitive conditions for space, a female averages a spawning territory of about 3.7 m^2; when competition for space is eliminated a female occupies an average area of 6.97 m^2 (http://fwie.fw.vt.edu/WWW/macsis/lists/M010588.htm). Salmon are also believed to require some additional defensible space larger than the redd itself to reproduce successfully. Burner (1951) recommended that the area for sockeye salmon spawning should be about 4 times the redd size, which based on 1.75 m^2 would be about 7.0 m^2.

Fecundity

Fecundity of adult sockeye salmon varies with size and age (Foerster 1968), and size of females and the number of years spent in the ocean (Burgner 1991). Larger fish have more eggs, but the increase in number of eggs is not linear with increase in weight (Foerster 1968). Fecundity of Lake Wenatchee sockeye salmon, a potential donor stock for Cle Elum Lake, averages from about 2,500 eggs per female (Mike Tonseth, WDFW, Wenatchee, WA, December 2004, pers. comm.), 2,700 eggs per female (Andrew Murdoch, WDFW, Wenatchee, WA, February 2005, pers. comm.), or 3,000 eggs per female (John Easterbrooks, WDFW, Yakima, WA, December 2004, pers. comm.). For this assessment, we used fecundity of 2,700.

Estimation of smolt production

We estimated the number of redds that the adjusted riffle area could potentially support and the number of spawning females that would be needed to fully utilize or seed the estimated area of suitable spawning habitat available. We estimated the number of smolts that would

be produced at egg to smolt survivals of 1, 2, and 5 percent. We then estimated the number of adults that would return at smolt to adult return (SAR) rates from 1 to 6 percent. SAR is smolt to adult return for smolts outmigrating from the Cle Elum Lake to adults returning to Cle Elum Lake. Using SARs eliminates the need to consider life stage-specific survival rates during outmigration, during time spent in the estuary and ocean, and during the adult upstream migration; and harvest in the ocean or the Columbia River.

We also considered some environmental constraints to sockeye salmon production in Cle Elum Lake, such as abundance of copepod and cladoceran prey, inter- and intra-specific competition (with resident kokanee), predation by other resident fish such as lake trout, and the seasonal water level fluctuations and temperature regime that could influence production.

Smolts per Lake Surface Area and Morphoedaphic Index

We assessed production potential of sockeye salmon smolts in Cle Elum Lake using a smolts per surface area and morphoedaphic index (MEI) method BioAnalysts (2000) used to estimate sockeye salmon yield for Lake Chelan, Washington. BioAnalysts (2000) used smolt production information from Lake Wenatchee from 1998 to 2000 (Murdoch 2000 cited in BioAnalysts 2000) and calculated the number of sockeye salmon smolts produced per hectare (ha). Since we use this approach and relevant information from lakes Chelan and Wenatchee, we provide some of this information in Table 3, as well as corresponding information from Cle Elum Lake.

Table 3. Some limnological characteristics of Cle Elum Lake, Lake Wenatchee, and Lake Chelan.

	Cle Elum Lake	Lake Wenatchee	Lake Chelan
Surface area	1,948.2 ha; 19.48 km^2; 4,812 ac	989 ha; 9.89 km^2 ; 2,442 ac	13,494 ha; 134.94 km^2; 33,316 ac
Mean/max depth, m	44.1/101.5 (144.6/333 ft)	46/73 (151/240 ft)	145/457 (475/1,499 ft)
Secchi depth, m	8.35 (6.9-10.2)	6.5 (6-7)	7-17, 6.8-14.6
Chlorophyll a, µg/L	0.43-1.9		0.3-1.6 µg/L
TP, mg/L, epilimnion	0.003-0.008	5.0 µg/L	ND-10 µg/L, 0.9-2.3 µg/L
OP, mg/L, epilimnion	0.001-0.007		
Specific cond., µS/cm	40.1-51.4, avg. = 45.2		31-70
TDS, mg/L (est.)	25.7-32.9, avg. = 28.9 [1]		40
MEI	0.66	0.17 - 0.51	0.08 [2], 0.28 [3]
Euphotic volume	438.3 at el. 2,240 ft 340.9 at el. 2,188.8 ft	173.6 at full pool	

1 Calculated from specific conductance times 0.64 (Davine Lieberman, USBR, Denver, February 2005, pers. comm.).
2 MEI value from BioAnalysts (2000), apparently based on maximum depth of 457 m.
3 MEI value calculated from TDS = 40 mg/L and mean depth of 145 m.

Murdoch (2000 cited in BioAnalysts 2000) reported 1,177,000 to 1,815,000 sockeye salmon smolts from Lake Wenatchee from 1998 to 2000. From this information, BioAnalysts (2000) calculated a range of from 1,190 to 1,835 smolts per ha, with a midpoint of about 1,500, based on Lake Wenatchee surface area of 989 ha. We used these values as well as an

arbitrary lower value of 500 smolts per ha to estimate smolt production; BioAnalysts (2000) used an additional lower value of 430 smolts per ha based on estimates of smolt production on a series of lakes with a MEI of less than 0.50. For Cle Elum Lake, we estimated smolt production at three lake elevations and their corresponding surface areas: full pool elevation of 2,240 ft and lake surface area of 1,948 ha, a median lake elevation of 2,188.8 ft for water years 1990 to 2004 with corresponding lake surface area of 1,515 ha, and the lowest water surface elevation of 2,139 ft encountered during the limnological study and a corresponding lake surface area of 1,009.5 ha.

The MEI is an estimator of lake productivity and is the ratio of total dissolved solids (TDS in mg/L) to mean depth in m, so that

$$\text{MEI} = \text{TDS mg/L} \div \text{mean depth in m}$$

For Cle Elum Lake, total dissolved solids were estimated from measures of specific conductance obtained during the September 2003 to October 2004 limnological study; TDS = 0.64 x specific conductance (Davine Lieberman, USBR, Denver, CO, February 2005, pers. comm.). Specific conductance in Cle Elum Lake at station CLE2 for all depths and sampling dates ranged from 40.1 to 51.4 µS/cm and averaged 45.2 µS/cm. The average specific conductance yielded an average TDS of 28.9 mg/L, ranging from 25.7 to 32.9 mg/L. Cle Elum Lake has a surface area of about 1,948 ha and a mean depth of 44.1 m (based on an estimated dead storage volume of 265,420 ac-ft (Haring 2001) plus the active storage volume of 436,950 ac-ft for a total volume of 702,370 ac-ft, resulting in a mean depth = volume ÷ surface area at elevation 2,240 ft. = 44.1 m.) For Cle Elum Lake, MEI was about 0.66 units, ranging from 0.58 to 0.75. For the median water surface elevation, mean depth was 39.5 m and MEI averaged 0.73, ranging from 0.65 to 0.83. BioAnalysts (2000) reported an MEI of 0.17 for Lake Wenatchee and 0.08 for Lake Chelan (this appears to be based on the maximum depth rather than on the mean depth), although Gustafson et al. (1997) reported an MEI of 0.51 for Lake Wenatchee. This discrepancy for Lake Wenatchee may be due to calculation of MEI based on data from different years or different times of the year. Since MEI is an index of production, the MEI of 0.73 for Cle Elum Lake at median elevation suggests that it is potentially more productive than Lake Wenatchee.

Euphotic Volume Method

Koenings and Burkett (1987) found a relationship between euphotic volume and total abundance of sockeye salmon smolts in some Alaskan lakes, although Hume et al. (1996) found that this relationship was inappropriate for British Columbia sockeye salmon lakes. However, this method was applied to Lake Chelan (BioAnalysts 2000), and we use it in this assessment.

The euphotic zone volume (EV) is calculated from the euphotic depth (ED), depth in m where light intensity falls to 1 percent of that at the surface and is the limit of photosynthesis and the surface area in km^2, so that

$$EV = ED\ (m) \times \text{surface area}\ (km^2)$$

and

$$ED = \text{Secchi depth}\ (m) \times 2.7$$

For Cle Elum Lake, the Secchi depth at the midlake site CLE2 averaged 8.35 m during the 2003 to 2004 period of the limnological study and ranged from 6.9 to 10.2 m, resulting in an average euphotic depth of 22.5 m (range 18.6 to 27.5 m). From this, we calculated EV units for full pool water surface elevation; to account for fluctuating water levels in Cle Elum Lake and the possible effects on lake productivity, we calculated EV units using average Secchi depth at the median lake elevation of 2,188.8 ft and the corresponding lake surface area of 1,514.9 ha for the 15-water-year period 1990 to 2004, and when Secchi depth was minimum and maximum; and at the lowest lake elevation encountered during the limnological study. For example, at full pool elevation of 2,240 ft, surface area of 19.48 km^2, and ED = 22.5 m, Cle Elum Lake had 438.3 EV units.

Lake Wenatchee Secchi depth ranged from 6 to 7 m, and BioAnalysts (2000) used a Secchi depth of 6.5 m to calculate an ED = 17.55 m, and from the Lake Wenatchee surface area of 9.89 km^2, an EV of 173.6 units. From this result, and an average smolt production of 1,481,000 (Murdoch 2000), BioAnalysts (2000) estimated 8,531 smolts per EV unit, which we use as a starting point to estimate smolt production potential for Cle Elum Lake. For the low and high estimates of smolts produced in Lake Wenatchee, 1,177,000 and 1,815,000, respectively, we calculated 6,780 and 10,455 smolts per EV unit. We used these estimates from Lake Wenatchee under the several scenarios described above to estimate sockeye salmon smolt production in the Cle Elum Lake.

Spawners per Lake Surface Area

Sockeye salmon smolt production has also been estimated from the number of adult spawners per lake surface area in ha (BioAnalysts 2000). Estimates of spawners per lake ha vary widely, and Burgner (1991) noted that average spawner densities per lake ha were generally less than 30 adults in Bristol Bay and Fraser River lake systems. We estimated smolt production for Cle Elum Lake using 10 and 30 spawners per ha, assuming 50 percent females, fecundity of 2,700 for Lake Wenatchee sockeye salmon (Andrew Murdoch, WDFW, Wenatchee, WA, February 14, 2005, pers. comm.) and egg to smolt survivals of 1, 2, and 5 percent. Chapman et al. (1995) reported that average egg to smolt survival for Lake Wenatchee sockeye salmon was estimated at 5.5 percent, ranging from 1.7 to 12.3 percent. Bocking and Gaboury (2003) assumed 5 percent egg to smolt survival in their euphotic volume method. Hyatt et al. (2005) reported wild sockeye salmon egg to smolt survival for Tatsamenie and Tahltan lakes in British Columbia as 5.8 and 3.6 percent, respectively. Egg to smolt survivals for sockeye salmon in the literature range from 0.005 to 17.4 percent (Chapman et al. 1995). The egg to smolt survivals used here represent values within the reported range.

We used three lake surface areas of 1,948 ha, 1,515 ha, and 1,009.5 ha corresponding to full lake elevation of 2,240 ft, median lake elevation of 2,188.8 ft for the 15-water-year period from 1990 to 2004, and the lowest lake elevation of 2,139 ft encountered during the 2003 to 2004 limnological study, respectively.

Related Study

Limnological Study of Cle Elum Lake

Since sockeye salmon juveniles rear in lakes, comprehensive limnological information was needed for Cle Elum Lake to assess production potential. Of particular interest was the trophic status of the lake and information about the seasonal abundance and distribution of zooplankton prey for juvenile sockeye salmon, and data on water temperature, dissolved oxygen, and nutrient levels. Staff from Reclamation's Technical Service Center in Denver conducted monthly limnological surveys at three stations on Cle Elum Lake, including the deepest point at mid-lake (station CLE2) from September 2003 to October 2005, except for the winter months, to obtain the desired information. Samples for nutrient analyses were collected in the inflow and outflow waters of the lake.

Water column profiles for water temperature, dissolved oxygen, specific conductance, and pH were recorded with a Hydrolab® multiparameter probe from surface to bottom at 1-m increments through the thermocline (if present), and thereafter at 5-m depth increments to the bottom. Secchi depth transparency was recorded using a 20-cm-diameter black and white round disk. Other parameters were generally sampled by depth strata of 0 to 10 m, 10 to 20 m, and 20 to 30 m and included chlorophyll *a* (chl *a*), an indicator of algal biomass; composite phytoplankton samples, to determine species composition and biovolume (μm^3/mL). Zooplankton samples were collected with a 30- (opening of net) by 120-cm (length) x 64-µm (mesh size) simple closing net from each of the three depth strata and identified to species (or genus in some cases). Discrete water samples for total phosphorus (TP), orthophosphorus (OP), dissolved nitrate and nitrite nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen (TKN), total organic carbon (TOC), and dissolved organic carbon (DOC) were collected with a Van Dorn water sampler at each station from 1 m below the surface and 0.5 m above the bottom. Plankton samples were analyzed by biologists at Reclamation's Technical Service Center in Denver, CO. Water samples were analyzed by Reclamation's Environmental Chemistry Laboratory, also in Denver. Additional details of sampling, preservation, and analytical methods will be provided in the final report of the limnological study (Lieberman and Grabowski 2006). In the assessment of sockeye salmon production potential, we used limnological information from the September 2003 to October 2004 period of the study.

Results

Available Spawning Habitat

We estimated that the seven reaches of the Cle Elum River upstream from the lake and the lowermost reaches of the Waptus and Cooper rivers upstream to impassable barriers had 159,160 m^2 of suitable spawning habitat, shown as adjusted riffle area in Table 4. Assuming that about 7 m^2 is required for a redd, this area would accommodate 22,737 redds and provide spawning habitat for 22,737 female sockeye salmon (Table 4). The nine reaches had average gradient less than 3 percent, although in a short section of reach C-4 gradient just exceeded four percent but was not considered to be a barrier to migration. The estimated total number of eggs expected to be produced are shown in Table 4. We estimated that 613,899, 1,227,798, and 3,069,495 sockeye salmon smolts could potentially be produced at 1, 2, and 5 percent egg to smolt survival rates, respectively (Table 4). We estimate that the mainstem Cle Elum, Waptus, and Cooper rivers have the potential to produce anywhere from 6,139 to 184,170 adult sockeye salmon assuming one to six percent SAR rates (Table 5). The higher estimates are probably optimistic. We assume that all suitable habitat in all reaches is fully utilized by 45,474 spawning sockeye salmon. To produce this number of returning adults would require a 2 percent egg to smolt survival and about a 3.7 percent SAR rate to obtain sufficient adults to seed the estimated spawning habitat. 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. Counts of adult sockeye salmon at Tumwater Dam on the Wenatchee River were 27,628, 5,040, and 30,142 in 2002, 2003, and 2004, respectively (Andrew Murdoch, WDFW, Wenatchee, WA, June 2, 2005, pers. comm.).

Smolts per Lake Surface Area and Morphoedaphic Index

At the midpoint value of 1,500 smolts per lake ha and surface area of 1,948 ha at full lake elevation 2,240 ft, we estimated that Cle Elum Lake could produce about 2,922,000 sockeye salmon smolts, ranging from 2,318,120 and 3,574,580, for the low and high smolt per ha estimates derived from Lake Wenatchee, respectively (Table 6). At the median surface area of 1515 ha, we estimated that between 1,802,731 and 2,779,842 smolts would be produced (Table 6). During the September 2003 to October 2004 limnological study, Cle Elum Lake depth was close to maximum at elevation 2,237 ft or only about one meter below full in June 2004. Water level dropped to elevation 2,139.25 ft. in September 2004. Surface area at elevation 2139.25 ft is 1,009.5 ha. Estimated smolt production at this lake surface area would be 1,514,250 smolts, ranging from 1,201,305 to 1,852,433 (Table 6).

BioAnalysts (2000) reported that some other sockeye salmon lakes with some limnological characteristics similar to Lake Wenatchee produced fewer numbers of smolts per ha. In their

estimate of potential smolt yield for Lake Chelan, they used a median of 430 smolts per ha from six lakes that had an MEI less than 0.5. We applied this approach to Cle Elum Lake but increased smolts per ha to 500 to account for the higher estimated MEI for Cle Elum Lake and estimated that about 974,000 sockeye salmon smolts would be produced at full pool, 757,450 at median lake surface area, and 504,750 at low lake elevation and corresponding surface area (Table 6).

Estimated number of returning adults at median and low lake elevations at SARs ranging from one to six percent are shown in Table 6.

Euphotic Volume

We estimated that at full pool, Cle Elum Lake could produce 3,739,137 smolts assuming an average of 8,531 smolts per EV unit, ranging from 2,971,674 to 4,582,427 sockeye salmon smolts for 6,780 and 10,455 smolts per EV unit, respectively (Table 7). At median water surface elevation and average Secchi depth, estimated production ranged from 2,310,624 to 3,563,064 smolts.

Estimates of potential smolt production at minimum and maximum Secchi depths and the corresponding water surface elevation, as well as at lowest reservoir water surface elevation encountered during the limnological study (in September 2004) and the corresponding Secchi depths, are also shown in Table 7. Estimated sockeye salmon smolt production is lowest at the low water surface elevation.

The estimated number of returning adults at SARs from one to six percent is based on estimated smolt production at median lake elevation and average Secchi depth.

Table 4. Estimated number of sockeye salmon smolts produced at one, two, and five percent egg to smolt survival rates, based on number of redds and adult female spawning sockeye salmon that the habitat is estimated to support.

Reach	Reach length, m	Total riffle length, m	Average gradient (range)	Total riffle area (m^2), calculated from USFS stream surveys	Percent suitable substrate, 12-128 mm, from pebble counts	Adjusted riffle area (m^2)	No. redds at 7 m^2 each	No. of potential female spawners required at one per 7 m^2	Estimated no. of eggs produced per reach if fecundity is 2,700 eggs per female	No. smolts at 1% egg to smolt	No. smolts at 2% egg to smolt	No. smolts at 5% egg to smolt
C-1	6,471.2	4,597.0	0.77 (0.12-1.44)	118,031	43.1	50,872	7,267	7,267	19,620,900	196,209	392,418	981,045
C-2	1,851.2	1,469.9	1.87	6,208	43.7	2,713	388	388	1,047,600	10,476	20,952	52,380
C-3	3,444.9	1,740.2	2.02 (0.05- 3.48)	30,123	48.7	14,670	2,096	2,096	5,659,200	56,592	113,184	282,960
C-4	4,571.7	2,893.2	2.73 (1.79-4.06)	42,783	41.0	17,540	2,506	2,506	6,766,200	67,662	135,324	338,310
C-5	6,278.0	4,931.0	0.99 (0.25-2.79)	55,221	43.9	24,242	3,463	3,463	9,350,100	93,501	187,002	467,505
C-7	1,842.2	578	<3	7,861	38.2	3,003	429	429	1,158,300	11,583	23,166	57,915
C-8	1,252.4	469	<3	7,041	56.8	3,999	571	571	1,541,700	15,417	30,834	77,085
W-1	3,799	2,780	2.6	45,751	61.0	27,908	3,987	3,987	10,764,900	107,649	215,298	538,245
CO-1	2,300	2,155	1.6	31,584	45.0	14,213	2,030	2,030	5,481,000	54,810	109,620	274,050
Total	26,416	13,480.3		298,117		159,160	22,737	22,737	61,389,900	**613,899**	**1,227,798**	**3,069,495**

Table 5. Number of returning adult sockeye salmon to the Cle Elum River at various SARs, at 1, 2, and 5 percent egg to smolt survival. Production potential for sockeye salmon in the Cle Elum, Waptus, and Cooper rivers considering the number of smolts that could be produced based on estimated extent of suitable spawing substrate.

	No. smolts at 1 % egg to smolt	No. smolts at 2 % egg to smolt	No. smolts at 5 % egg to smolt
	613,899	1,227,798	3,069,495
SAR	Estimated number of returning adults		
1 %	6,139	12,778	30,695
2 %	12,780	24,556	61,390
3 %	18,417	36,834	92,085
4 %	24,556	49,112	122,780
5 %	30,695	61,390	153,475
6 %	36,834	73,668	184,170

Table 6. Potential sockeye salmon smolt production using the lake surface area approach and estimated number of returning adults based on several estimates of smolts per lake surface area (ha) and several SARs.

	Smolts per lake surface area			MEI
Lake surface area (and elevation)	1,190 smolts/ha	1,500 smolts/ha	1,835 smolts/ha	500 smolts/ha
1948 ha (2,240 ft)	2,318,120	2,922,000	3,574,580	974,000
1514.9ha (2,188.8 ft)	1,802,731	2,272,350	2,779,842	757,450
1009.5 ha (2,139 ft)	1,201,305	1,514,250	1,852,433	504,750
SAR	Estimated number of returning adults at median lake elevation			
1%	18,027	22,724	27,798	7,575
2%	36,055	45,447	55,597	15,149
3%	54,082	68,171	83,395	22,724
4%	72,109	90,894	111,194	30,298
5%	90,137	113,618	138,992	37,873
6%	108,164	136,341	166,791	45,447
	Estimated number of returning adults at low lake elevation			
1%	12,013	15,142	18,524	5,048
2%	24,026	30,285	37,049	10,095
3%	36,039	45,428	55,573	15,143
4%	48,052	60,570	74,097	20,190
5%	60,065	75,713	92,622	25,238
6%	72,078	90,855	111,146	30,285

Table 7. Potential sockeye salmon smolt production in Cle Elum Lake using the euphotic volume approach at full pool and several lower water surface elevations.

				Estimated number of smolts produced at:		
Condition		ED, m	EV	6,780 smolts/EV	8,531 smolts/EV	10,455 smolts/EV
Avg. Secchi depth, full pool	Secchi = 8.35 m, elev. = 2,240 ft Area = 1,948 ha	22.5	438.3	2,971,674	3,739,137	4,582,427
Avg. Secchi depth, median elev.	Secchi = 8.35 m, elev. = 2,188.8 ft Area = 1,514.9 ha	22.5	340.9	2,310,624	2,907,365	3,563,064
May 13, 2004 minimum Secchi depth	Secchi = 6.9 m elev. = 2,216.04 ft Area = 1,741 ha	18.6	323.8	2,195,364	2,762,338	3,385,329
July 22, 2004 maximum Secchi depth	Secchi = 10.2 m elev. = 2,204.18 ft Area = 1,638 ha	27.5	450.5	3,054,390	3,843,216	4,709,978
Sept. 14, 2004 low pool elevation	Secchi = 7.0 m elev. = 2,139.25 ft Area = 1,009.5 ha	18.9	190.8	1,293,624	1,627,715	1,994,814
SAR				Estimated number of returning adults at median pool elevation and average Secchi depth		
1%				23,106	29,074	35,631
2%				46,212	58,147	71,261
3%				69,319	87,221	106,892
4%				92,425	116,295	142,523
5%				115,531	145,368	178,153
6%				138,637	174,442	213,784
				Estimated number of returning adults at low pool elevation and corresponding Secchi depth		
1%				12,936	16,277	19,948
2%				25,872	32,554	39,896
3%				38,809	48,831	59,844
4%				51,745	65,109	79,793
5%				64,681	81,386	99,741
6%				77,617	97,663	119,689

Spawners per Lake Surface Area

For Cle Elum Lake at full pool, assuming 10 spawners per ha, 50 percent females, and fecundity of 2,700, we estimate that about 9,740 females could potentially produce 26,298,000 eggs, or about 13,500 eggs per ha. With egg to smolt survival of 1, 2, and 5 percent, the Cle Elum River system could produce 262,980, 525,960, and 1,314,900 sockeye salmon smolts, respectively (Table 8). At median lake surface area, potential smolt production estimates range from 204,512 to 1,022,558.

At full pool, assuming 30 spawners per ha, 788,940, 1,577,880, and 3,944,700 smolts could potentially be produced at the three survival rates, respectively. At low water surface elevation and a lake surface area of 1009.5 ha, the estimate of smolt production is reduced to about 51.8 percent of that at full pool elevation (Table 8). If we assume 40 percent females in the spawning population as BioAnalysts did (2000), about 20 percent fewer smolts would be produced (Table 8). The estimated number of adults returning at SARs of from one to six percent is shown in Table 8.

Table 8. Potential production of sockeye salmon smolts using the number of spawners per lake surface area method at two spawner abundance levels, two proportions of females in the spawning population, and three egg to smolt survival rates. Estimated number of returning adults is based on smolt production at median and low water surface elevation and corresponding lake surface area.

Lake surface area	Smolt production at 1 % egg to smolt survival				Smolt production at 2 % egg to smolt survival				Smolt production at 5 % egg to smolt survival			
	10 spawners/ha at 50% fem	10 spawners/ha at 40% fem	30 spawners/ha 50% fem	30 spawners/ha 40% fem	10 spawners/ha 50% fem	10 spawners/ha 40% fem	30 spawners/ha 50% fem	30 spawners/ha 40% fem	10 spawners/ha 50% fem	10 spawners/ha 40% fem	30 spawners/ha 50% fem	30 spawners/ha 40% fem
1,948 ha	262,980	210,384	788,940	631,152	525,960	420,768	1,577,880	1,262,304	1,314,900	1,051,920	3,944,700	3,155,760
1,515 ha	204,512	163,609	613,534	490,828	409,023	327,218	1,227,069	981,655	1,022,558	818,046	3,067,673	2,454,138
1,009.5 ha	136,296	109,039	408,848	327,078	272,592	218,074	817,695	654,156	681,412	545,130	2,044,238	1,635,390
SAR	Estimated number of returning adults at median water surface elevation											
1%	2,045	1,636	6,135	4,908	4,090	3,272	12,271	9,817	10,226	8,180	30,677	24,541
2%	4,090	3,272	12,271	9,817	8,180	6,544	24,541	19,633	20,451	16,361	61,353	49,083
3%	6,135	4,908	18,406	14,725	12,271	9,817	36,812	29,450	30,677	24,541	92,030	73,624
4%	8,180	6,544	24,541	19,633	16,361	13,089	49,083	39,266	40,902	32,722	122,707	98,166
5%	10,226	8,180	30,677	24,541	20,451	16,361	61,353	49,083	51,128	40,902	153,384	122,707
6%	12,271	9,817	36,812	29,450	24,541	19,633	73,624	58,899	61,353	49,083	184,060	147,248
	Estimated number of returning adults at low water surface elevation											
1%	1,363	1,090	4,088	3,271	2,726	2,181	8,177	6,542	6,814	5,451	20,442	16,354
2%	2,796	2,181	8,177	6,542	5,452	4,361	16,354	13,083	13,628	10,903	40,884	32,708
3%	4,089	3,271	12,265	9,812	8,178	6,542	24,531	19,625	20,442	16,354	61,327	49,062
4%	5,452	4,362	16,354	13,083	10,904	8,723	32,708	26,166	27,256	21,805	81,770	65,416
5%	6,815	5,452	20,442	16,354	13,630	10,904	40,885	32,708	34,071	27,257	102,212	81,770
6%	8,178	6,542	24,531	19,625	16,356	13,084	49,062	39,249	40,885	32,708	122,654	98,123

Related Study

Limnological Study of Cle Elum Lake

Water temperature and dissolved oxygen – The information obtained during the limnological study of Cle Elum Lake was essential for considering the prospects of juvenile sockeye salmon survival in the lake. Cle Elum Lake strongly thermally stratifies during the summer, typical of temperate dimictic lakes. Surface water temperature at midlake station CLE2 warms from April through July, then begins decreasing in the fall. In June, water temperature ranged from 14.9°C at the surface to 12.9°C at 10 m, and ranged from 12.9 to 9.8°C in the 10 to 20 m depth stratum. Water temperature was 21.1°C in July at the surface, and 18.8°C at 10 m depth. In the 10 to 20 m depth strata, water temperature ranged from 18.8 to 13.3°C. By August the surface water temperature decreased slightly to 19.3°C and was 15.4°C at 10 meters depth. In the 10 to 20 m depth strata, water temperature ranged from 15.4 to 6.3°C. By September the surface water temperature had decreased to 13.8°C and 13.3°C at 10 m depth. In the 10 to 20 m depth stratum, temperature ranged from 13.5 to 5.8°C. Juvenile sockeye salmon rearing in lakes make diel vertical migrations to feed, metabolize and seek refuge from predators. The range of water temperatures documented during the limnological study should not impact diel migrations of juvenile sockeye salmon.

Dissolved oxygen was near or above saturation in the lake, and exhibited a slight retrograde profile during thermal stratification. DO was 8.4 mg/L at the surface in July and increased to 8.6 mg/L at 10 m, 9.4 mg/L at 20 m, and 10.6 mg/L at 30 m.

Secchi depth at midlake station CLE2 ranged from 6.9 to 10.2 m and averaged 8.35 m (Table 9).

Nutrients – Epilimnetic nitrate-nitrite nitrogen levels in Cle Elum Lake ranged from 0.003 to 0.048 mg/L and generally remained less than 0.030 mg/L once the lake stratified. Hypolimnetic nitrate-nitrite nitrogen levels ranged from 0.024 to 0.083. Epilimnetic total Kjeldahl nitrogen (TKN) levels were generally low, averaging 0.19 mg/L and ranging from 0.05 to 0.47 mg/L. Hypolimnetic (TKN) levels were also low, averaging 0.18 mg/L and ranging from 0.05 to 0.57 mg/L (Lieberman draft report 2006).

Epilimnetic orthophosphorus levels were low, averaging 0.0028 mg/L and ranging from 0.001 to 0.005 mg/L. Hypolimnetic orthophosphorus levels were also low, averaging 0.0027 mg/L and ranging from 0.001 to 0.005 mg/L. Nutrient concentrations in the inflow and outflow were lower than those at midlake station. Phosphorus levels in the sediments of Cle Elum Lake declined 19 percent after 1906, attributable in part to the elimination of marine-derived nutrients from returning adult salmon spawning in the Cle Elum Basin (Dey 2000).

Phytoplankton – Chlorophyll *a* in the composite samples, used as an indicator of phytoplankton abundance, ranged from 0.56 µg/L in August 2004 to 1.84 µg/L in September 2004 in the 0 to 10 m depth stratum, from 0.72 µg/L in April 2004 to 1.63 µg/L in September 2004 in the 10 to 20 m depth stratum, and from 0.35 µg/L in September 2003 to 1.39 µg/L in July 2004 in the 20 to 30 m depth stratum (Table 9). Higher concentrations of chl *a* occurred in the 10 to 20 m depth stratum in June, July, and August, coincident with strong thermal stratification. All chl *a* concentrations were low and indicative of oligotrophic conditions. Koenings and Kyle (1997) reported chl *a* for four oligotrophic Alaskan lakes ranging from 0.35 to 0.86 µg/L. Thirty-six species of phytoplankton were identified in Cle Elum Lake.

Zooplankton – Thirty-two species of zooplankton were collected from all stations in Cle Elum Lake. *Bosmina longirostris* and *Daphnia rosea* were the dominant cladocerans; *Acanthocyclops vernalis* and *Leptodiaptomus ashlandi* were the dominant copepods. Rotifers were abundant and seasonally comprised the major portion of the zooplankton. Maximum adult copepod density was about 12 individuals/L in May 2004 in the 0 to 10 m depth stratum; maximum cladoceran density was about 6.1 individuals/L in the 0 to 10 m depth stratum in August 2004. The combined densities of cladocerans and copepods, which together constitute the principal prey items for rearing juvenile sockeye salmon, were most abundant at about 13 individuals/L in 0 to 10 m depth stratum in May and 11 individuals/L in the 10 to 20 m depth stratum in April (Table 10, Figure 2).

Table 9. Secchi depth (m) and chlorophyll a concentrations (µg/L) at station CLE2 at the surface and in three depth strata from September 2003 to October 2004.

Date	Secchi depth, m	Chlorophyll *a*, µg/L			
		1 m	0-10 m	10-20 m	20-30 m
Sept. 17, 2003	7.0	0.51	0.67	1.15	0.35
Oct. 15, 2003	8.7	1.20	1.40	1.10	0.80
Apr. 17, 2004	8.2	0.53	0.69	0.72	0.67
May 13, 2004	6.9	1.23	1.23	1.17	0.77
June 16, 2004	9.1	0.43	0.72	0.91	0.80
July 22, 2004	10.2	0.51	1.04	1.55	1.39
Aug. 23, 2004	9.3	0.56	0.56	1.04	0.83
Sept. 14, 2004	7.0	1.90	1.84	1.63	0.99
Oct. 20, 2004	8.8	1.47	1.52	1.23	0.64

The water surface elevation during the September 2003 to October 2004 limnological survey varied from 2,139.25 feet on September 14, 2004 to 2,237 feet on June 16, 2004, as shown in Figure 3. More detailed analysis is provided in the report of the limnological study (Lieberman and Grabowski 2006).

Table 10. Total zooplankton and total cladocerans, copepods, nauplii, and rotifers at Cle Elum Lake midlake station CLE2, in three depth strata 0 to 10, 10 to 20 and 20 to 30 meters, September 2003 to October 2004. Data are in individuals per L.

Stratum / Date	Total cladocerans	Total copepods	Total cladocerans and copepods	Total nauplii	Total rotifers	Total zooplankton
0-10 m						
Sept. 19, 2003	0.76	1.01	1.77	2.8	44.77	49.34
Oct. 14, 2003	2.23	0.46	2.69	1.7	4.88	9.27
Apr. 17, 2004	0.52	4.84	5.36	0.88	0.08	6.32
May 13, 2004	0.71	12.12	12.83	6.32	1.63	20.78
June 16, 2004	0.74	3.64	4.38	3.27	4.54	12.2
July 21, 2004	0.95	0.33	1.29	0.19	11.55	13.03
Aug. 23, 2004	6.13	0.74	6.86	2.94	98.04	107.84
Sept. 14, 2004	5.29	0.96	6.25	3.85	128.81	138.91
Oct. 19, 2004	0.8	1.3	2.11	1.3	19.55	22.96
10-20 m						
Sept. 19, 2003	0.71	2.87	3.58	20.67	54.63	78.88
Oct. 14, 2003	0.64	1	1.64	13.72	13.47	28.83
Apr. 17, 2004	1.88	9.07	10.96	9.77	0.63	21.36
May 13, 2004	0.98	8.45	9.43	6.79	1.96	18.18
June 16, 2004	1.63	4.2	5.84	5.76	8.95	20.54
July 21, 2004	0.69	0.08	0.76	0.92	21.85	23.53
Aug. 23, 2004	0.69	2.78	3.47	2.08	85.7	91.25
Sept. 14, 2004	1.99	2.81	4.80	3.47	46.52	54.8
Oct. 19, 2004	0.77	2.31	3.08	8.76	12.71	24.55
20-30 m						
Sept. 19, 2003	0.1	3.47	3.56	13.93	25.07	42.56
Oct. 14, 2003	0.19	0.84	1.02	9.96	6.34	17.33
Apr. 17, 2004	0.09	5.91	6.00	13.35	0.9	20.25
May 13,2004	0.79	9.61	10.40	6.63	2.67	19.71
June 16, 2004	1.01	3.54	4.55	7.5	5.92	17.97
July 21, 2004	0.13	0.7	0.84	2.62	4.9	8.35
Aug. 23, 2004	0.38	1.97	2.35	3.67	3.72	9.75
Sept. 14, 2004	1.17	4.18	5.35	5.09	14.88	25.32
Oct. 19, 2004	0	1.92	1.92	6.27	6.94	15.13

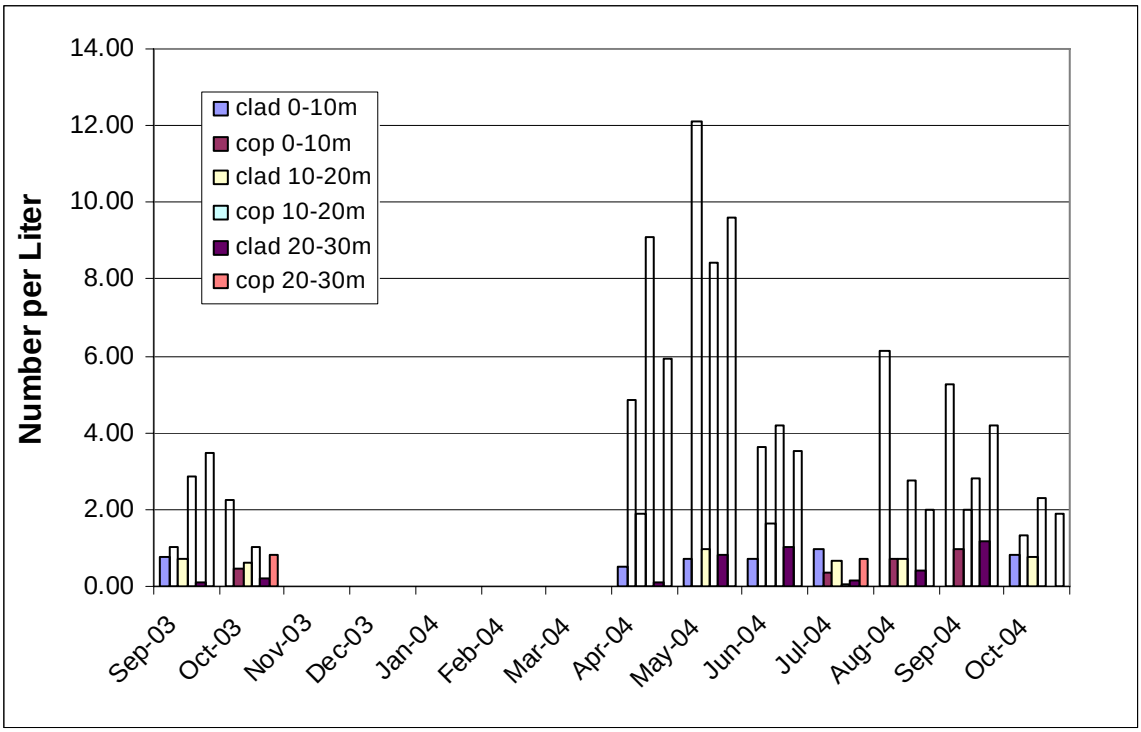


Figure 2. Seasonal abundance and distribution of cladoceran and copepod zooplankton in three depth strata at Cle Elum Lake station CLE2 from September 2003 to October 2004.

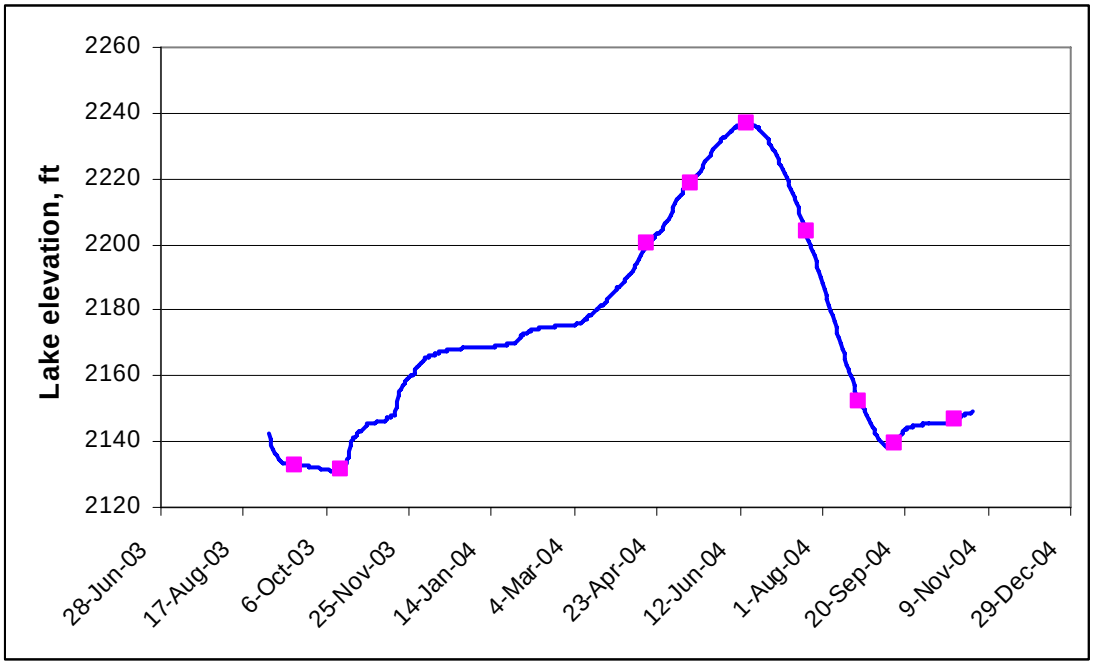


Figure 3. Cle Elum Lake water surface elevations and sampling dates during the September 2003 to October 2004 limnological study.

Discussion

The several methods we used to assess sockeye salmon smolt production in Cle Elum Lake produced a range of estimates. We estimated that the nine reaches of the Cle Elum River upstream from the reservoir and the Waptus and Cooper rivers up to impassable barriers had 159,160 m^2 of suitable spawning habitat for sockeye salmon that theoretically could provide area for 22,737 redds. However, microhabitat conditions may not be uniform or homogeneous across the entire estimated area of spawning habitat, and spawning sockeye salmon might select spawning areas based on some microhabitat conditions such as water flow and depth, gradient, groundwater influences, and other factors (Geist and Dauble 1998). We did not include water flow and depth along with estimation of areal extent of spawning gravel in our determination of suitable spawning habitat for sockeye salmon. These factors, including the preference for spawning salmon to select areas for redds at the downstream end of pools at the pool-riffle interface (www.fisheries.ubc.ca/grad/abstracts/scopeab.pdf) may concentrate spawning in more limited areas, which will not be known until a sufficient number of adult sockeye salmon returning to spawn in the Cle Elum River upstream from the reservoir are tagged and tracked to spawning areas, or the rivers are surveyed for redds and carcasses.

The estimated production of sockeye salmon smolts using the available spawning habitat approach corresponded closely with smolt production estimated from 30 spawners per lake ha at median lake elevation and surface area of 1,515 ha (Table 11). Since Cle Elum Lake level fluctuates seasonally and maximum and minimum water surface elevations vary annually, estimate of smolt production potential derived from a median water surface elevation is probably a more realistic estimate than that at full pool. With the available spawning habitat approach at two percent egg to smolt survival, smolt production is similar to that at the lower estimate of number of smolts per lake surface area and to the lake elevation for the euphotic volume approach.

Table 11. Summary of potential sockeye salmon smolt production using four approaches and a range of conditions.

Available spawning habitat	1% egg to smolt	2% egg to smolt	5% egg to smolt	
	613,899	1,227,798	3,069,495	
				MEI
Smolts per lake surface area	1,190 smolts/ha	1,500 smolts/ha	1,835 smolts/ha	500 smolts/ha
1948 ha (2,240 ft)	2,318,120	2,922,000	3,574,580	974,000
1515 ha (2,188.8 ft)	1,802,731	2,272,350	2,779,842	757,450
1009.5 ha (2,139 ft)	1,201,305	1,514,250	1,852,433	504,750
Euphotic Volume	6,780 smolts/EV	8,531 smolts/EV	10,455 smolts/EV	
Full pool, Secchi 8.35 m	2,971,674	3,739,137	4,582,427	
Avg. Secchi 8.35 m Med. lake elev.	2,310,624	2,907,365	3,563,064	
Max Secchi 10.2 m	3,054,390	3,843,216	4,709,978	
Min Secchi 6.9 m	2,195,364	2,762,338	3,385,329	
Secchi 7.0 m Low lake elev.	1,293,624	1,627,715	1,994,814	
Spawners per lake surface area		50% females, 1% egg-to-smolt	50% females, 2% egg-to-smolt	50% females, 5% egg-to-smolt
10 spawners/ha at 1,948 ha		262,980	525,960	1,314,900
at 1,515 ha		204,512	409,023	1,022,558
at 1,009.5 ha		136,296	272,592	681,412
30 spawners/ha at 1,948 ha		788,940	1,577,880	3,944,700
at 1,515 ha		613,534	1,227,069	3,067,673
at 1,009.5 ha		408,848	817,695	2,044,238

For the euphotic volume approach we used the range of number of smolts per EV unit, calculated by BioAnalysts (2000) for Lake Wenatchee, at several water surface elevations representing several different lake surface areas that resulted in a range of EV units in Cle Elum Lake. Koenings and Burkett (1987 cited in Hume et al. 1996) reported that adult sockeye salmon production in some Alaskan lakes was maximal with an average spawning density of 425 adults (or about 213 females, assuming an even sex ratio) per EV, which produced 23,000 smolts per EV unit. This represents about a 4 percent egg to smolt survival. This estimate was about 2.2 times greater than the high estimate of 10,455 smolts per EV for Lake Wenatchee used in this assessment. At the median Cle Elum Lake water surface elevation of 2,188.8 ft, lake surface area of about 1,515ha, and 340.9 EV units, and a 5 percent egg to smolt survival, 26,393 females would be required, and 52,786 adults, assuming 50 percent females in the spawning population. This is about 16 percent more than the number of adult female sockeye salmon we calculated would be needed to fully utilize the available spawning habitat in the Cle Elum basin upstream from the lake, and represents

about 77.4 females per EV unit. Sockeye salmon smolt production based on the 22,737 females (or 45,474 spawners) required to fully seed the estimated available spawning habitat could perhaps be considered the upper limit to the number of smolts that could ultimately be produced in Cle Elum Lake, that is to say, any level of sockeye salmon smolt production in Cle Elum Lake, regardless of the lake elevation and surface area as discussed above, is dependent on fry production upstream in the tributaries.

To produce about one million sockeye salmon smolts at two percent egg to smolt survival would require about 18,519 females with fecundity of 2,700, or a total of about 37,038 adult sockeye salmon. This would result in about 24.5 adults per lake ha at median pool elevation and lake surface area of about 1,514.9 ha. For comparison, about 30,000 adult sockeye salmon were counted at Tumwater Dam on the Wenatchee River in 2004. If these 30,000 fish reached Lake Wenatchee, it would result in about 30 spawners per lake ha.

Flagg et al. (2000) reported that the Cle Elum River and some of its tributaries contain substantial spawning habitat for anadromous salmonids, which could probably support "tens of thousands" of returning anadromous salmonids. Their estimates were based in large part on visual inspection of the tributary habitat. The historical level of sockeye salmon production in the original Cle Elum Lake is estimated to be 38.8 adults per ha, or about 31,125 fish. Using the median lake elevation of 2,188.8 ft and a surface area of 1,515 ha for contemporary Cle Elum Lake, we can expand this estimate to about 58,782 adults. This estimate may be optimistic. However, examining the range of returning adults within the estimated range of historic production of sockeye salmon in Cle Elum Lake, estimated from the number of smolts produced under the several methods, we see that at a two percent egg to smolt survival for available spawning habitat and three and four percent SARs, 36,834 and 49,112 adults would return (Table 5). For the smolts per lake surface area method using the median 1,500 smolts per ha, about 22,724 and 45,447 adults would return at one and two percent SAR, respectively (Table 6). For the euphotic volume method at median lake elevation and average secchi depth using the average smolts per EV, about 29,074 and 58,147 adults would return at one and two percent SAR, respectively (Table 7). For the number of spawners per lake surface area method and two percent egg to smolt survival and 30 spawner per lake surface area, about 36,812 and 49,083 adults would return at three and four percent SAR, respectively (Table 8). At five percent egg to smolt survival, this changes to about 30,677 and 61,353 adults at one and two percent SAR, respectively. These numbers show the variability in production that can occur in natural systems; they indicate that at egg to smolt survivals reported in the literature, and at SARs that could reasonably be expected to occur, about 30,000 to 50,000 adults could return when sockeye salmon become fully restored to the system.

Lakeshore spawning by sockeye salmon might have occurred historically prior to the construction of the timber crib dam in 1906 on Cle Elum Lake and its subsequent management to provide water for irrigation, with consequent water level fluctuations. Even

with lakeshore spawning possibly occurring at depths to 30 m (Chapman et al. 1995), it is unknown if the seasonally fluctuating water level in contemporary Cle Elum Lake would provide or maintain suitable lakeshore spawning habitat.

Regarding nutrient levels in Cle Elum Lake, an analysis of lake sediment core samples found that prior to 1906, there was an average of 19 percent more phosphorus in the sediments each year (Dey 2000). The timber crib dam eliminated anadromous salmonid access to the lake, and eliminated the annual infusion of marine-derived nutrients that likely contributed to a more productive system upstream from the lake and 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, one might expect a gradual increase in stream and lake nutrient levels and productivity from the infusion of marine-derived nutrients from fish carcasses.

Water temperature is an important environmental condition for upstream migration of adult sockeye salmon, and generally ranges from 7.2 to 15.5°C (Bell 1991). Migration can proceed at higher water temperatures, although Hyatt et al. (2003) reported that migration of adult Okanogan River sockeye salmon essentially stops when water temperature reaches 21°C. The fish can survive at temperatures a few degrees warmer, and will resume migrating when the water temperature decreases to below 21°C. Exposure to water temperatures higher than about 17°C can increase susceptibility to disease, impair maturation, reduce swimming performance, reduce viability of gametes, and reduce efficiency of energy use (Hyatt et al. 2003).

Daily average water temperatures in the lower Yakima River at Kiona (RM 29.0) exceed the 21°C threshold for delay of migration from about the third week in June until about the beginning of September; this time period varies from year to year. This is just about the time migrating adult sockeye salmon begin arriving at McNary Dam. Figure 4 shows the water temperature in the Yakima River at Kiona from June through the end of September for the years 2000 to 2004, and the count of sockeye salmon at McNary Dam for 2002, 2003, and 2004. The high water temperature in the Yakima River may impede entry of the fish into the river, except for the earlier returning adults. Later returning adults may delay migration, stray elsewhere or possibly hold in the Columbia River until water temperature decreases sufficiently for migration to resume.

The water temperature data collected in the Cle Elum River in 2003 suggested that spawning could occur after about mid September. Lukas (1999) reported that most mid-Columbia sockeye salmon spawn in October through November. Pauley et al. (1989) stated that the optimum temperature for sockeye salmon egg incubation was 4.4 to 13.3°C. Brett (1952) reported a temperature range for maximum growth efficiency in freshwater for sockeye salmon of 12 to 14°C, with a lower lethal of 1.7°C and upper lethal of 26.0 or 28.8°C, depending on acclimation temperature. Growth rate of juvenile sockeye salmon in the lake would be expected to increase with increasing water temperature up to some point, as has

been observed for sockeye salmon in Lake Osoyoos. Maximum surface water temperature measured during the limnological study was 21.1°C at station CLE2 in July 2004. Although the lake was strongly stratified at this time, water temperatures dropped below 14°C near the bottom of the 10 to 20 m depth stratum, so water temperatures within the preferred range would be available for rearing sockeye salmon.

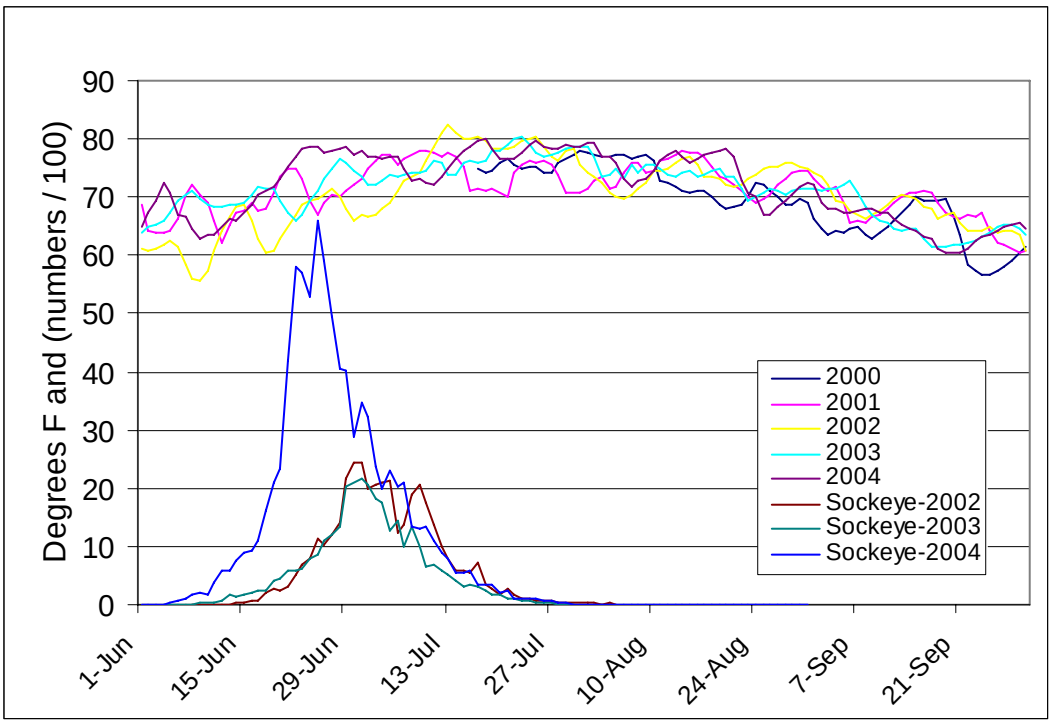


Figure 4. Daily average water temperature in the Yakima River at Kiona (2000 to 2004) and number of sockeye salmon counted at McNary Dam (2002 to 2004).

The availability of food for rearing juvenile sockeye salmon in Cle Elum Lake is an important consideration relative to potential production. Copepods and cladocerans are preferred prey. In most months, copepod abundance was much greater than cladoceran abundance. Cladoceran prey decreased in abundance with depth in July, although copepod prey increase slightly in the 20 to 30 m depth stratum. Total cladoceran and copepod abundance was greatest in April and May and decreased in June and July; abundance was lowest in July. So in July when water temperatures in the top 20 m of the lake are higher than the temperature for maximum growth efficiency for rearing sockeye salmon, and when they likely seek deeper depths with lower water temperatures, the availability of preferred prey is reduced. Copepod abundance always exceeded cladoceran abundance in the 0 to 10 and 10 to 20 m depth strata except for July 2004. Abundance of total copepods and cladocerans increased in August, then decreased in September and October. There was a shift to more

cladocerans than copepods in the 0 to 10 m depth stratum in September 2004, but cladoceran abundance declined rapidly in the lower depth strata (Table 10 and Figure 2). It is not known if this shift in cladoceran distribution is due to the low water level or is a life history characteristic.

Sockeye salmon production might be affected by predation in the lake and by interspecific competition from native resident and introduced fish, both salmonids and non-salmonids. Large lake trout are present in Cle Elum Lake although there is no estimate of their abundance (Matt Polecek, WDFW, pers. comm.). In addition, if reintroduction of other anadromous salmonids proceeds as planned by the fisheries co-managers, additional interspecific competition may occur. Long-term fisheries studies on Cle Elum Lake and its tributaries would increase understanding of predator-prey dynamics.

Mullan (1986) reported that 1,982 acres (802.1 ha) of sockeye salmon habitat was lost when passage into Cle Elum Lake was blocked in 1909. This is the surface area at about elevation 2,110 ft, which is the lower limit of storage capacity for the existing reservoir, and likely represents the elevation of original Cle Elum Lake. The original lake then had about 81 percent the surface area of Lake Wenatchee, which suggests that if production potential for the two lakes were about the same, historically Cle Elum Lake may have produced slightly fewer sockeye salmon than Lake Wenatchee. Current management of Cle Elum Lake for water storage and release with annual water level fluctuation might influence sockeye salmon production in the lake.

Some riverine and riparian habitat improvement work in the Cle Elum River basin would likely benefit anadromous salmonids. 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 banks. Through its Respect the River program, the Cle Elum Ranger District is working to secure funding to thoroughly survey 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.

Additional stream survey information from the Cle Elum River and tributaries is desirable to document in greater detail physical features of the habitat such as substrate size and distribution, flow, depth, and areas of upwelling and refine the estimate of suitable spawning habitat for sockeye salmon and other anadromous salmonids proposed for re-introduction.

Summary

Estimates of smolt production in Cle Elum Lake range from 136,296 (at low lake elevation and low egg to smolt survival) to 4,582,427 (at maximum Secchi depth and high smolts per EV), across a range of approaches and assumptions. The actual production would likely correspond to average egg to smolt survivals and conditions prevailing at median lake

elevations. The number of adults returning to the lake from this range of smolt production likewise varies widely. Since the Cle Elum River basin supported sockeye salmon historically, it is likely that over time anadromous salmonid populations could be re-established as fish passage facilities are installed at the dam. The lake is oligotrophic, similar to other lakes in the Pacific Northwest, Canada, and Alaska that support viable sockeye salmon populations. Preferred prey items for rearing juvenile sockeye salmon are present in the lake but are in low abundance. The historical level of sockeye salmon production in the original Cle Elum Lake is estimated to be 38.8 adults per ha, or about 31,125 fish (Yakama Nation et al. 1990). Based on a median lake elevation of 2,188.8 ft and a surface area of 1,515 ha, we can expand this estimate to about 58,782 adults, about 6,000 more than the number of adults estimated to produce the 10,455 smolts per EV. However, examining the estimated adult returns from the estimated number of smolts produced under a range of methods, we see that from about 23,000 to 60,000 adults could be produced assuming average survivals and a median lake elevation. Some environmental factors may affect potential production. Summertime average daily water temperatures greater than 21°C in the Yakima River might delay sockeye salmon entry into the Yakima River. Water temperatures begin to exceed 21°C in the lower Yakima River around the time of peak passage of migrating sockeye salmon in the Columbia River. Inter- and intraspecific predator-prey interactions may influence production. Based on the range of estimated smolt production under average conditions, we estimate that Cle Elum Lake could eventually produce sufficient smolts to yield an adult return of 30,000 to 50,000 sockeye salmon.

Acknowledgements

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