Enumeration of Salmonids in the Okanogan Basin Using Underwater Video

COLVILLE TRIBES/AF-2008-04 **September 2008**

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BPA Project # 200302200

Performance Period: 01 January 2007– 31 December 2007

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Prepared for:

U.S. Department of Energy

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September 2008

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ABSTRACT

The Confederated Tribes of the Colville Reservation (Colville Tribes) are collecting baseline data on adult salmonid populations and threats to their habitat throughout the Okanogan River Basin through the Okanogan Basin Monitoring and Evaluation Program (OBMEP). Adult Chinook and sockeye salmon passage counts for 2007 are presented with a temperature relationship discussion and the development of a hypothesis to explain sockeye mortality above Zosel Dam. Steelhead passage data at Zosel Dam were acquired in 2007 but the results of that component of the video project are discussed in a separate document (Arterburn et al. 2007). Fish passage data for anadromous salmonids passing Zosel Dam were collected between 01 January and 31 December 2007. Data collection was suspended between 18 June and 16 July for retrofit and repairs to video chutes. A complete description of the apparatus and methodology can be found in *Fish Enumeration Using Underwater Video Imagery - Operational Protocol* (Nass 2007). Adult counts from all years of operation are posted to the Columbia River DART website: http://www.cbr.washington.edu/dart/adult.html

At Zosel Dam, 455 adult summer/fall Chinook salmon were observed with peak daily passage occurring on 6 October when 28 fish passed the dam. Hourly passage estimates of Chinook salmon counts for 2007 at Zosel Dam revealed a slight diel pattern as Chinook passage events tended to remain low from 1900 hours to 0600 hours relative to other hours of the day. Chinook salmon showed a preference for passing the dam through the video chutes on the east bank (63%) relative to the west bank (37%). Chinook passage at Wells Dam in 2007 totaled 16,918 fish, approximately 52% of the 10-year average.

A total of 17,709 adult sockeye salmon were counted passing through the Zosel Dam video chutes in 2007. An initial mode of passage occurred from 16 July through 1 August when 20% of the total sockeye run passed the dam. A larger bimodal pulse of passage occurred from 14 to 29 August when 75% of the run was observed to pass the dam. During this period, sockeye passage peaked on 17 August with 1,899 fish (10.7% of the total run). Hourly passage estimates of sockeye salmon counts for 2007 at the dam showed a strong diel pattern with increased passage during nighttime hours relative to daytime hours. Sockeye showed a strong preference for passing Zosel Dam on the east bank (80%) relative to the west bank (20%). Sockeye passage at Wells Dam in 2007 was 22,273 fishes (approximately 60% of the 10-year average).

Apparent effects of water temperature on fish passage were observed at Zosel Dam in 2007. Sockeye were observed to pass Zosel Dam during periods in which temperatures exceeded what prior investigators defined as thresholds that when met would result in the ceasing of upriver migration. Hyatt et al. (2003) defined a set of temperature mediated 'decision rules' governing sockeye migration, and determined that adult migration stops as water temperatures exceed 21°C and then restart when temperatures decrease and fall below 21°C. Results from 2007 are in sharp contrast to the governing rules of Hyatt et al. (2003) as 66% of the sockeye run passed the dam during days when mean daily temperatures were $\geq$ 22°C, with some passing when temperatures exceeded 26°C.

The large disparity between sockeye counts at Zosel Dam (17,709) and estimates of spawners in Osoyoos Lake (8,283) in 2007, coupled with historical disparities between Wells Dam counts and spawner estimates in some years, suggests a link between high water temperatures and adult sockeye mortality. Although it is unknown to what duration sockeye are exposed to lethal water temperatures during years in which exceedingly high water temperatures occur, the exposure is

likely of long enough duration to induce mortality above Zosel Dam. This may be especially the case in the shallow southern basin of Osoyoos Lake where sockeye cannot find refuge from lethal water temperatures. In the northern basin of Osoyoos Lake, fish mortality also likely occurs as a result of the temperature-oxygen "squeeze" conditions in late summer that are characterized by high water temperature in the surface layers and low dissolved oxygen in the bottom layers.

INTRODUCTION

Salmon recovery in the Pacific Northwest region has become a focal point within the Columbia River Basin. The Colville Tribes are actively participating in a recovery program for salmonids in the Okanogan River Basin which include recent inventories of habitat condition, water quality, and barriers to migration. Currently, there is population information available for spawning fish within the United States portion of the basin (Hillman 2006; Arterburn et al. 2007). However, data are lacking regarding spawner abundance for all anadromous fish (except sockeye) within the Canadian portion of the basin.

Okanogan River steelhead, (*Oncorhynchus mykiss),* were listed as *endangered* under the U.S. Endangered Species Act (NOAA 1997). The combined five-year escapement average for the Methow and Okanogan rivers from 1989 to 1993 was estimated at approximately 2,400 fish; 450 of which were from natural production. From 1997 to 2006, NOAA (2008) estimated the mean abundance to be 104 fish. Arterburn et al. (2007) summarized steelhead data from 2005 through 2007 and estimated overall escapement to range from 779 to 1,492 fish with natural production ranging from 127 to 185 fish.

Summer/Fall Chinook salmon (*O. tshawytscha*) spawn in the Okanogan River Basin but currently are not listed as either threatened or endangered (NOAA 2008). As of 1998, these fish were classified as having a population of approximately 1,500 with the population increasing at 1%-5% per year (NOAA 1998). The Washington Department of Fish and Wildlife (WDFW) salmonid stock inventory program classified summer Chinook as having a "healthy" status with an average run of 4,346 for 12 years of data (http://wdfw.wa.gov/fish/sasi). The majority of this stock spawns in the Similkameen River below the migration barrier at Enloe Dam. Spring Chinook salmon are listed as *endangered* in the Upper Columbia Evolutionary Significant Unit (ESU) Historically, this run ranged up into the Okanogan River (NOAA 2008) but are now considered to be extirpated from the basin.

Sockeye salmon (*O. nerka*) in the Okanogan River ESU are not listed under the ESA; however the status of Okanogan sockeye salmon is rated as chronically "depressed" by the WDFW (http://wdfw.wa.gov/fish/sasi). This stock is of mutual concern to the United States and Canada as the Okanogan sockeye population is one of only two remaining populations in the Columbia River Basin. The annual escapement of sockeye salmon spawners has varied between a low of 1,600 in 1994, to a high of 60,000 in 2000, and has a 16-year mean of 25,000 (http://wdfw.wa.gov/fish/sasi, as based on counts at Wells Dam). Fisheries and Oceans Canada recommends an escapement of 59,000 for propagation of a healthy population (http://wdfw.wa.gov/fish/sasi).

Chapman et al. (1995) summarized available data on sockeye and illustrated a noticeable discrepancy in counts between returning adult sockeye crossing Wells Dam and the number estimated in spawning areas in Canada. Several hypotheses have been proposed for this discrepancy:

1. Substantial mortality of Okanogan sockeye salmon between Wells Dam and upriver spawning grounds;
2. Considerable error in spawning ground counts based upon visual observations; and
3. Undiscovered spawning areas existing above Wells Dam.

Improved counts of sockeye salmon at Zosel Dam will help answer key questions regarding adult sockeye salmon spawner abundance and the disparity between Wells Dam counts and escapement estimates (Table 1).

Table 1. Adult sockeye counts at Wells Dam and raw escapement estimates from Canadian waters from 1967 to 2007. Wells Dam data from Fish Passage Center Website: http://www.fpc.org/. See Stockwell and Hyatt (2003) for original data sources for escapement estimates through 2000. Estimates from 2001 through 2007 from M. Stockwell, DFO (pers. comm.) to R. Klinge, Douglas County PUD.

Year	Wells Dam Counts	Highest Daily Spawner Counts (Index Streams)	(Channel Section)	Est. Spawner Counts (Index + Channel)	Spawners as % of Wells Counts
2007	22,273	8,210	73	8,283	37.2%
2006	22,075	17,616	470	18,086	81.9%
2005	55,559	23,565	596	24,161	43.5%
2004	78,053	21,049	259	21,308	27.3%
2003	28,977	10,234	156	10,390	35.9%
2002	10,586	2,355	434	2,789	26.3%
2001	74,490	23,433	not surveyed	23,433	31.5%
2000	59,944	26,095	634	26,729	44.6%
1999	12,228	2,874	564	3,438	28.1%
1998	4,669	567	29	596	12.8%
1997	25,754	7,175	335	7,510	29.2%
1996	17,701	9,572	not surveyed	9,572	54.1%
1995	4,893	1,960	200	2,160	44.1%
1994	1,666	73	25	98	5.9%
1993	27,849	not surveyed			
1992	41,951	26,630	3,617	30,247	72.1%
1991	27,490	7,165	375	7,540	27.4%
1990	7,972	1,456	42	1,498	18.8%
1989	15,976	10,200	219	10,419	65.2%
1988	33,978	18,961	1,010	19,971	58.8%
1987	40,109	12,190	not surveyed	12,190	30.4%
1986	34,788	9,056	1,150	10,206	29.3%
1985	52,989	19,552	790	20,342	38.4%
1984	81,054	34,021	1,210	35,231	43.5%
1983	27,925	3,430		3,430	12.3%
1982	19,005	not surveyed			
1981	28,234	not surveyed			
1980	26,573	not surveyed			
1979	26,655	844		844	3.2%
1978	7,458	421	128	549	7.4%
1977	21,973	2,994	861	3,855	17.5%
1976	27,619	8,552	not surveyed	8,552	31.0%
1975	22,286	6,684	1,032	7,716	34.6%
1974	16,716	3,072	2,630	5,702	34.1%
1973	37,178	6,328	2,485	8,813	23.7%
1972	33,398	9,441	3,642	13,083	39.2%
1971	48,172	21,767	3,761	25,528	53.0%
1970	50,667	not surveyed			
1969	17,352	not surveyed			
1968	81,530	4,190	not surveyed	4,190	5.1%
1967	113,232	17,200	not surveyed	17,200	15.2%

The Biological Opinion (BiOp) released in 2008 by NOAA's National Marine Fisheries Service (NMFS) addressed the operation of the federal Columbia River power system. The BiOp defined criteria for acceptable fish population levels to ensure the survival of critical fish stocks. One indicator to ensure survival was the number of naturally spawning adult salmon returning to spawning areas. Therefore, accurate determination of adult salmon spawner abundance is of critical importance to fisheries managers (Faurot and Kucera 2002).

Visually monitoring fish passage at dam fish ladders provides excellent opportunities for enumerating adult fish migrating upstream to spawning areas. However, observer counts based on specimen identification at viewing windows should not be treated as absolute estimates because they are not repeatable and cannot be reviewed for accuracy (Hatch et al. 1994a). Due to these limitations, it was necessary to improve methods for monitoring fish passage.

Fish enumeration programs throughout the Columbia River Basin have shifted to using time-lapse and motion detection video monitoring equipment due to its wide ranging applications (Irvine et al. 1991; Hatch et al. 1994b; Hiebert et al. 2000; Otis and Dickson 2001; Faurot and Kucera 2002; Anderson et al. 2004; Hetrick et al. 2004). Unlike mark/recapture studies, underwater video sampling requires no handling of fish and is a passive, non-invasive process that can potentially operate continuously throughout the year. Digital video images can be reviewed numerous times without degradation, are easily archived, are defensible, and can reduce possible study impacts to the species being observed (Edwards 2005). Images captured with video technology provide a permanent record of fish passage events to obtain accurate specimen and population abundance estimates. Video also permits uninterrupted monitoring of fish passage events allowing for assessment of diurnal movement patterns. Coupled with fish guidance structures, underwater video can be deployed at virtually any location provided there is adequate flow and good visibility. Compared with on-site counting, video monitoring can reduce data gathering costs by approximately 80% while simultaneously increasing data collected by 33% (Hatch et al. 1994a). Unlike other sampling methods such as hydroacoustics and DIDSON systems which require verification of species composition, underwater video provides a way to efficiently collect data describing not only species and natal origin, but in some cases the sex of individual fish.

Zosel Dam has long been considered a desirable location for monitoring adult salmonids by local fisheries managers. Resource managers believed that a counting station placed on the Okanogan River would improve assessments of target salmonid populations entering Canada and better inform future fisheries decision-making. Efforts to count fish at Zosel Dam began with a hydroacoustic study in 1991, but this effort was abandoned due to the difficulty in interpreting the data with any level of certainty (Anglea and Johnson 1991). In 1991 and 1992, Super VHS video equipment was used to estimate sockeye salmon escapement at Zosel Dam (Hatch et al. 1992).

These two years of video estimation of sockeye salmon escapement concluded that:

1. Using underwater video for estimating fish passage was feasible at Zosel Dam;
2. Fish passage only occurred at temperatures below 73°F (23°C); and
3. Most fish passage occurred during overnight hours.

The Colville Tribes recognized the importance of estimating escapement for all anadromous fish species migrating into Canada and solicited funding from the Northwest Power and Conservation

Council (NPCC) for project #29008; a video-based, fish counting station at Zosel Dam. The Columbia River Basin Fish & Wildlife Authority (CBFWA) rated this project as a high priority in the 2003-2005 Fish and Wildlife program work plan. Although video enumeration would provide an assessment for the effectiveness of Bonneville Power Authority (BPA) funded projects and other salmon recovery efforts underway in the Okanogan sub basin, funding was not allocated (CBFWA 2002).

However, in 2005, as part of the Okanogan Basin Monitoring and Evaluation Program (OBMEP) to promote the recovery of Pacific salmon and steelhead populations, the Colville Tribes received funding and initiated a project titled "*Design and construction of video detection systems in the Okanogan River Basin to enumerate adult salmon and steelhead*" (hereafter called the OBMEP video project) to provide census counts at strategic locations throughout the Okanogan River Basin. The target species of the OBMEP video project include anadromous forms of *Salmonidae* that have known production in the basin, including summer steelhead, sockeye salmon, and Chinook salmon.

The goal of the OBMEP video project was determining basin- and tributary-specific spawner distributions and evaluating the status and trends of natural salmonid species production in the basin. Target locations were chosen by weighing information regarding current and historic salmonid use, contemporary discharge levels and forecasts, in-stream hydraulic conditions, and access. This project was executed after an initial feasibility assessment exploring the use of video detection systems for enumerating fish passage at potential sites in the Okanogan Basin (Nass and Bocking 2005). The first year implementation of the OBMEP video project occurred in 2006 and the results of that study are discussed in Johnson et al. (2007).

Objectives

The primary objectives of the 2007 OBMEP video project were to:

1. Install, operate and evaluate a video system at Zosel Dam to enumerate salmonid species;
2. Determine relative abundance of spawners passing this point, and describe run timing and hourly passage patterns; and
3. Begin developing hypotheses to explain differences between Wells Dam adult passage counts and spawning ground survey counts for sockeye salmon that spawn in Canada.

This report documents the results from operations conducted in 2007 that provides species-specific abundance estimates of anadromous fish using an automated method. Steelhead passage data at Zosel Dam were acquired in 2007 but the results of that component of the video project are not presented here and are instead discussed in a separate document (Arterburn et al. 2007).

METHODS

Study Area

The U.S. portion of the Okanogan River is a 74 mile, low gradient waterbody draining a series of natural lakes located in Canada. The Okanogan River flows south through Oroville, Washington, and joins the Columbia River above Wells Dam near Brewster, Washington (Figure 1). Beginning at the outlet of Okanagan Lake in Canada, river discharges are regulated in order to maintain lake heights and supply irrigation water. The elevation of Lake Osoyoos, a transboundary waterbody, is controlled at the outlet by Zosel Dam, located approximately 4 miles south of the US/Canada border.

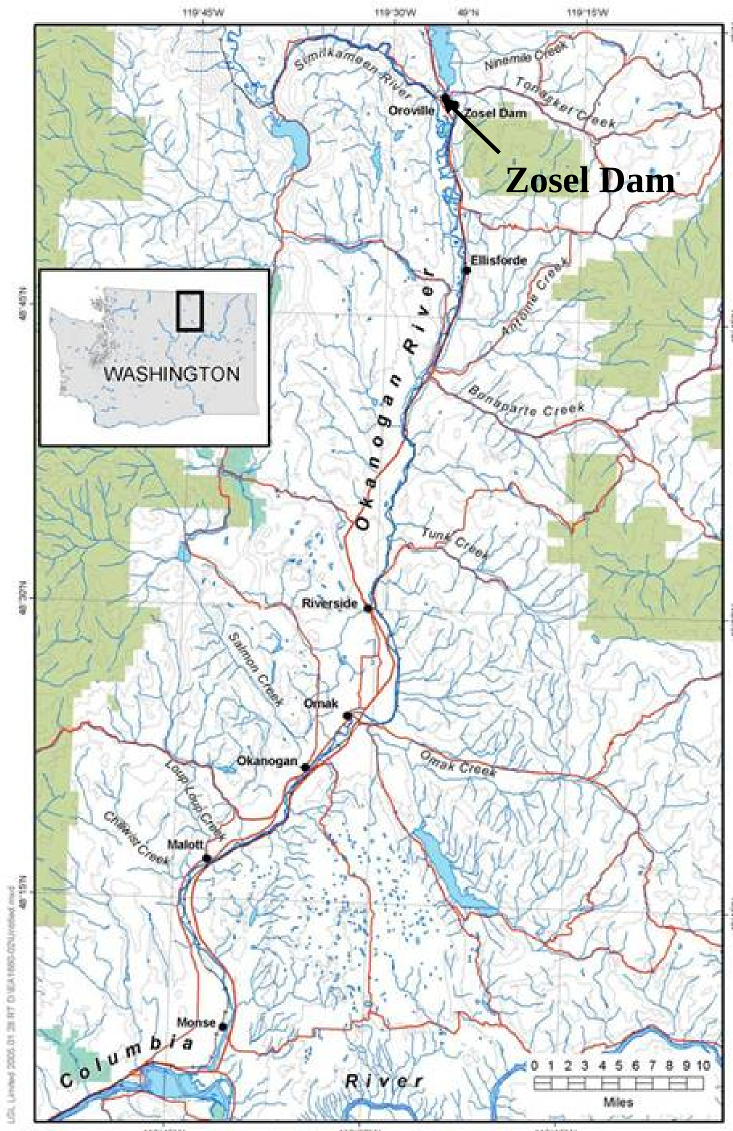

Figure 1. Map of the Okanogan River Basin. A video monitoring system is deployed at Zosel Dam to enumerate adult salmonid passage.

Zosel Dam Site

Zosel Dam (Figure 2) is located at the extreme southern end of Lake Osoyoos and is of prime importance to agricultural interests in the Osoyoos, British Columbia (BC) and Oroville, Washington areas. The lake further serves as a recreational resource and domestic water supply. Zosel Dam has four spillway gates and two pool and weir type adult fish ladders. Zosel Dam is a water control structure and does not have power generation facilities. Construction of the current facility was completed in 1987.

Figure 2. Aerial photograph of Zosel Dam taken in 2008.

Roughly one-third of the habitat currently accessible to anadromous fish in the Okanogan River Basin is found above Zosel Dam. Lake Osoyoos provides an area for suspended sediment to precipitate before reaching the dam. The flashiness and high turbidity that is characteristic of the lower Okanogan River during the spring freshet can be attributed to the snowmelt-driven Similkameen River which enters the Okanogan River a short distance below Zosel Dam.

Zosel Dam is owned by the Washington State Department of Ecology and operated by the Oroville-Tonasket Irrigation District (OTID) under orders established by the International Joint Commission (IJC). The IJC resolves disputes between the U.S. and Canada under the *1909 Boundary Waters Treaty*. The International Osoyoos Lake Board of Control, consisting of representatives from the BC Ministry of Water, Land and Air Protection, Environment Canada, the Washington Water Science Center, Land & Water BC Inc. and the US Army Corps of Engineers, was established by the IJC to supervise the operation of Zosel Dam in compliance with the IJC's Order of Approval. During normal years the lake elevation is held between a maximum elevation of 911.5 feet and a minimum elevation of 909.0 feet. However, during drought years water may be stored to lake elevations up to 913.0 feet. Zosel Dam effectively controls the elevation of Osoyoos Lake except during periods of very high snowmelt runoff when natural conditions force the lake above the 913.0 foot level. Lake heights are managed primarily to protect recreational properties, irrigation withdrawals and domestic water uses.

Video Chutes

The fish ladder exits provide an excellent location for video enumeration stations on the main stem Okanogan River. The Zosel Dam video chutes utilize pre-existing fish guidance structures as they sit at the top of permanent fish ladders and are essentially an extension of the fish ladder. The fish ladder exits are approximately 24” wide and 78” high, and have a combined flow of approximately 45 cfs at normal operating reservoir elevation (Tom Scott, OTID Secretary/Manager pers. comm.). Achieving quality imagery is partially dependent upon the clarity of the water. Under ideal conditions, camera-to-fish distances of 36” are feasible, but the distance decreases substantially under suboptimal water clarity; the frequency of high turbidity conditions requires guiding the fish to within 18” of the camera. Therefore, narrow chutes (e.g., 12”) are essential for relatively high turbidity conditions.

A basic video chute consists of three components: fish passage chute, viewing window, and camera housing. The Zosel Dam system uses eight underwater cameras placed in the two separate counting arrays. Both the west and east bank arrays were installed and functional by 1 January 2007. The west bank array was comprised of two separate chutes (Figure 3) and the east bank array was made up of four separate chutes (Figure 4). Cameras 1-4 were located in the west bank unit with cameras 1 and 2 monitoring the top chute and cameras 3 and 4 monitoring the bottom chute (Figure 3). Cameras 5-8 were installed in each of the four chutes that make up the east bank array and are numbered bottom to top.

Figure 3. Photographs of Zosel Dam west bank video chute array prior to (left) and during deployment.

Figure 4. Photographs of Zosel Dam east bank video chute array prior to (left) and during deployment.

Details related to system function and operations can be found in Nass (2007) and Johnson et al. (2007) on the OBMEP web site: http://nrd.colvilletribes.com/obmep/Reports.htm.

Monitoring and Maintenance

Maintaining the video arrays is an ongoing and important component of the video monitoring project. Maintenance visits to Zosel Dam generally occur every three to four days but are seasonally dependant. The units have operated without cleaning for as long as an entire week, while during other times of the year circumstances required daily cleaning. See Nass (2007) for operational protocols for use with the video systems.

Regular operations and servicing consists of:

1. Daily checks of the Zosel Dam cameras from the office via internet for monitoring system status and image clarity;
2. Frequent chute cleaning to reduce non-target motion triggers resulting from accumulated debris and macrophytes;
3. Frequent removal and cleaning of viewing windows;
4. Cleaning of camera lenses;
5. Monitoring of disk usage and status of underwater lights; and
6. Switching out hard drives when full or when review of previously collected data is complete.

Data Collection, Processing and Analysis

Data are collected on all salmonids passing through the counting chambers across the entire passage season. Therefore, technicians are trained to distinguish characteristics of target species following *Inland Fishes of Washington* (Wydoski and Whitney 2003). Fish counts are grouped into one hour increments. Fish passage events whereby adult salmonids were noted swimming downstream were accounted for by modifying the total hourly net upstream count for each species before entry into the database. All motion clips of Chinook and steelhead were archived by the reviewer. The archive clips were then reviewed by a tribal biologist for quality assurance and quality control of the data. All motion clips collected during the majority of the sockeye run were archived on a dedicated hard drive for future reference.

All data were collected following OBMEP protocols (Nass 2007). Past reports and representative photographs are available for viewing by all interested parties on the following web page: http://nrd.colvilletribes.com/obmep/Reports.htm.

RESULTS

Physical Variables

The Okanogan River hydrograph reflects a highly managed discharge pattern. Changes in outflows at Zosel Dam are abrupt and flattened when compared to a more natural system. The pattern of mean daily discharge at Zosel Dam throughout the study period was characterized by primary peak flows (> 600 cfs) occurring in mid to late September (Figure 5). Mean daily water temperature at the USGS gauging station in Oroville, WA peaked at of 26.4°C on 28 July then gradually declined through the rest of the passage season.

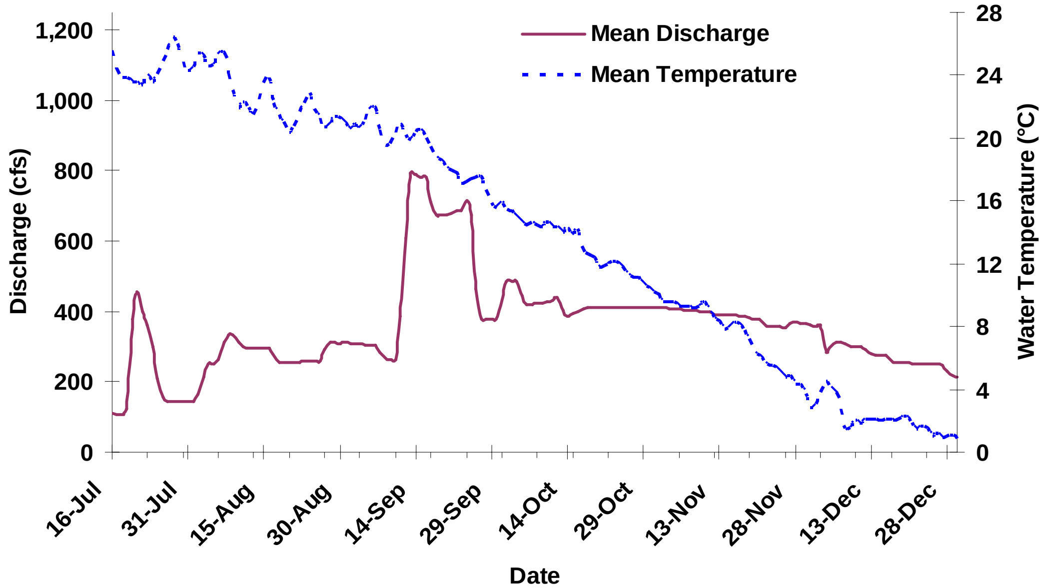

Figure 5. Daily mean temperature and discharge for the Okanogan River below Zosel Dam through the period in which salmon were detected with the video system (16 July through 30 December 2007). Data courtesy of USGS gauge at Oroville, WA. http://waterdata.usgs.gov/wa/nwis

Spillway Operations

In response to the varying water discharge from Canada, Zosel Dam spillway gates were raised and lowered to achieve the target lake levels set forth in the IJC lake level agreement. Throughout the 2007 period in which salmon were detected at Zosel Dam, at least one spillway gate was opened greater than 12" on 30 days (about 18% of the time) and two gates were open greater than 12" on five days (Figure 6). The pattern of spillway operations at Zosel Dam throughout the sampling season controlled the pattern of mean daily discharge observed at the USGS gauging station in Oroville.

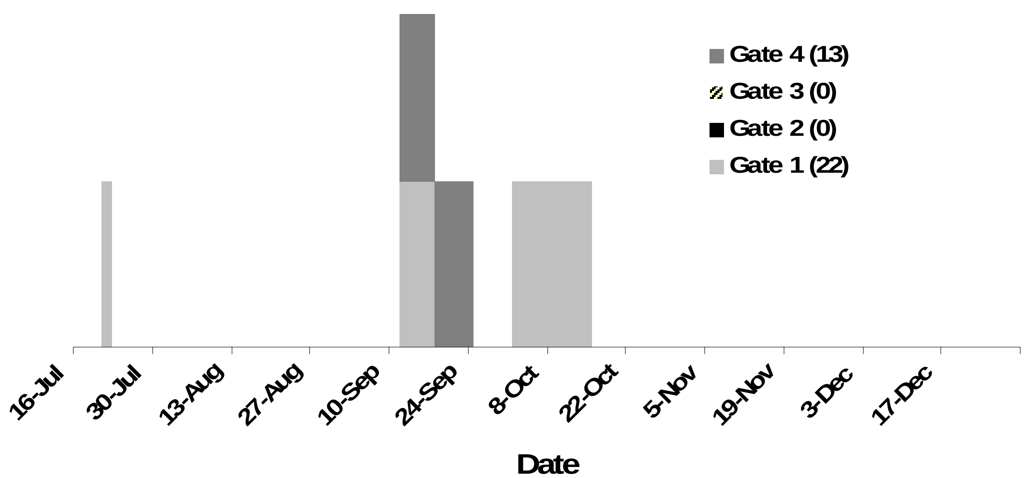

Figure 6. Dates in which individual spillway gates at Zosel Dam were opened more than 12 inches for the time period of 16 July through 30 December 2007. Numbers in parentheses indicate the number of days in which the gates were opened greater than 12".

Downtime and Missing Data

Monitoring was suspended between 18 June and 16 July for retrofit and repair. This time period was chosen for scheduled maintenance as it corresponded with a period of zero fish movement during the 2006 sampling year (Johnson et al. 2007). In addition, there were several instances during the sampling period in which passage data were not collected (Table 2).

Table 2. List of time periods in which data collection was interrupted at Zosel Dam in 2007.

Time Period	Cameras Affected	Total Hours Affected	Problem
16 Aug 11:00 to 14:00	All	3	Failure to reset hard drive at dam; formatted disk online from office
16 Aug 21:00 to 17 Aug 13:00	6	16	Equipment malfunction: water intrusion into underwater cable connection
14 Sep 13:00 to 17 Sep 07:00	All	56	No data recorded as DVR was not set to record after service visit
04 Dec 13:00 to 11 Dec 12:00	All	167	All data lost because hard drive was not changed before disk was reformatted
13 Dec 09:00 to 17 Dec 08:00	All	95	No data recorded as DVR was not set to record after service visit

Summer/Fall Chinook Salmon

A total of 455 adult Chinook salmon (Chinook count results reported here all refer to summer/fall Chinook salmon) were counted migrating upstream past Zosel Dam in 2007 (Table 3). Forty percent of the Chinook were observed to be marked with adipose fin clips.

Table 3. Total number of adult Chinook and sockeye salmon and bull trout observed based on video counts at Zosel Dam in 2007. Numbers of observed marked and unmarked fish are listed by species.

	Chinook	Sockeye	Bull Trout
Unmarked	270	16,727	1
Adipose Clip	182	982	0
Unknown	3	0	0
Total	455	17,709	1

Summer/Fall Chinook preferred the east bank array compared to the west bank (Table 4). Within the chutes, Chinook passage was recorded primarily by the deeper cameras. Shallow cameras recorded less than 1% of all Chinook counted.

Table 4. Total number and proportion of adult salmonids observed by bank location based on video counts at Zosel Dam in 2007.

	Chinook		Sockeye	
Location	Count	Percent	Count	Percent
East Bank	287	63.1%	14,206	80.2%
West Bank	168	36.9%	3,503	19.8%

In 2007, Summer/Fall Chinook salmon were initially observed on 22 July and the last fish was detected on 20 November (Figure 7). The primary mode of passage occurred 29 September through 23 October when almost 68% of the total run passed the dam. Chinook passage peaked on 6 October with 28 fish observed.

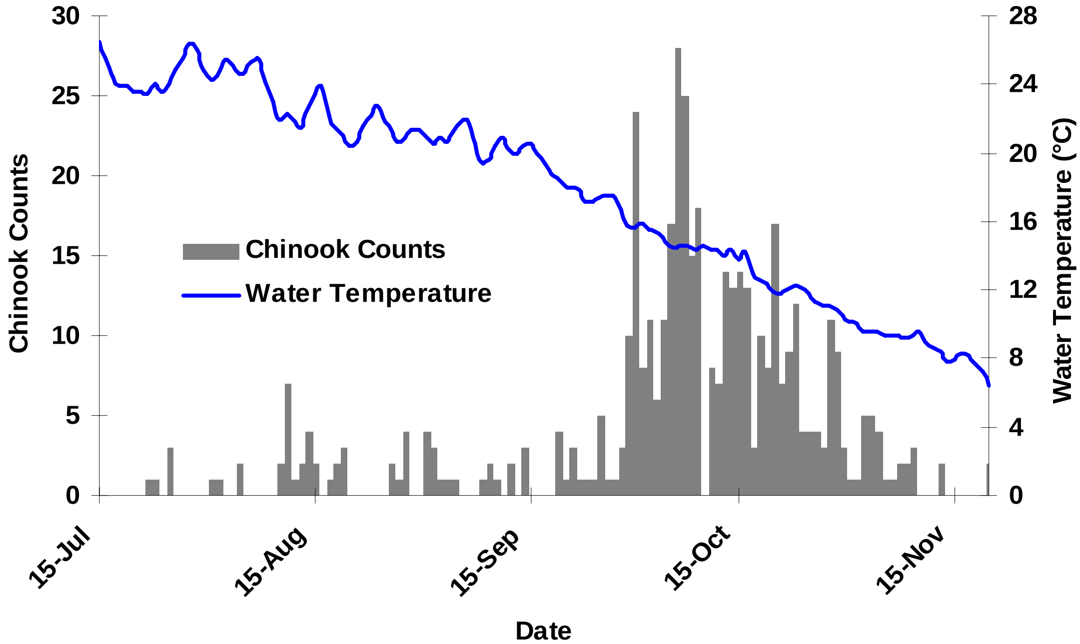

Figure 7. Adult Chinook salmon run timing based on video counts at Zosel Dam from 15 July through 20 November, 2007. Mean daily water temperature from the USGS gauge at Oroville, WA is also shown.

Hourly passage counts of Chinook salmon indicate a very slight diel pattern. Chinook passage remained generally low from 1900 to 0600 hours relative to other hours of the day (Figure 8, Table 5). Hourly passage peaked during 1300 hour. A two-sample *t* test (Zar 1984) of the hypothesis that the mean number of Chinook passing from 10 August to 6 November (95% of the run) during light hours (0700 through 1700) was equal to the mean number of Chinook passing during dark hours (2200 through 0500) in the same time period could not be rejected, indicating that there was no significant differences for Chinook passage during day and night hours.

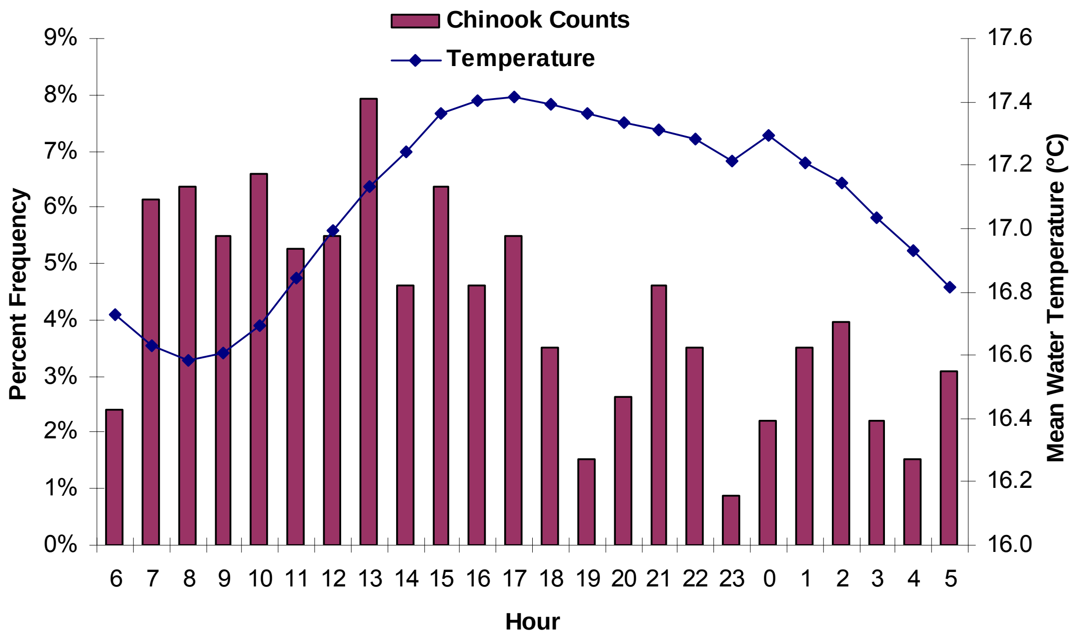

Figure 8. Percent frequency distribution of hourly adult Chinook salmon passage based on video counts at Zosel Dam and mean water temperature in 2007. Temperature data from period in which the central 95% of the run passed the dam (10 August through 6 November).

Table 5. Total counts and percent frequency values for hourly data of adult salmonid passage based on video counts at Zosel Dam in 2007.

	Chinook		Sockeye	
Hour	Count	Percent	Count	Percent
6	11	2.4%	701	4.0%
7	28	6.2%	374	2.1%
8	29	6.4%	415	2.3%
9	25	5.5%	446	2.5%
10	30	6.6%	311	1.8%
11	24	5.3%	415	2.3%
12	25	5.5%	268	1.5%
13	36	7.9%	150	0.8%
14	21	4.6%	148	0.8%
15	29	6.4%	119	0.7%
16	21	4.6%	127	0.7%
17	25	5.5%	214	1.2%
18	16	3.5%	334	1.9%
19	7	1.5%	239	1.3%
20	12	2.6%	237	1.3%
21	21	4.6%	547	3.1%
22	16	3.5%	918	5.2%
23	4	0.9%	1,367	7.7%
0	10	2.2%	1,911	10.8%
1	16	3.5%	2,121	12.0%
2	18	4.0%	1,991	11.2%
3	10	2.2%	1,959	11.1%
4	7	1.5%	1,486	8.4%
5	14	3.1%	911	5.1%

Sockeye Salmon

A total of 17,709 adult sockeye salmon were observed passing through the video chutes at Zosel Dam in 2007 (Table 3). Less than 6% of all sockeye were observed to have adipose fin clips. Sockeye showed a very strong preference for passing the dam on the east bank as 80% of all sockeye passage events occurred there (Table 4). Deeper deployed cameras detected 99.8% of all sockeye passage events.

Sockeye salmon were first detected at Zosel Dam on 16 July and last observed on 30 December (Figure 9). An initial mode of passage occurred from 16 July through 1 August when 20% of the total sockeye run passed the dam. A larger bimodal pulse of passage occurred from 14 to 29 August when 75% of the run was observed to pass the dam. During this period, sockeye passage peaked on 17 August with 1,899 fish. After 29 August, daily sockeye passage never exceeded 50 fish.

Hourly passage counts of sockeye salmon at Zosel Dam in 2007 indicate a strong diel pattern with increased passage during nighttime hours relative to daytime hours (Table 5, Figure 10). About 61% of all sockeye passed during the hours of 2300 through 0400. A two-sample *t* test of the hypothesis that the mean number of sockeye passing from 15 July to 30 August (95% of the run) during light hours (0700 through 2000) was greater than or equal to the mean number of sockeye passing during dark hours in the same time period (2200 through 0500) was rejected ($0.0025 < P < 0.005$), indicating that sockeye passage was significantly greater during the night than during the day. Passage peaked during the 0100 hour and was lowest during the early afternoon hours. The peak hourly count occurred at 0000 hour on 17 August with 337 fish.

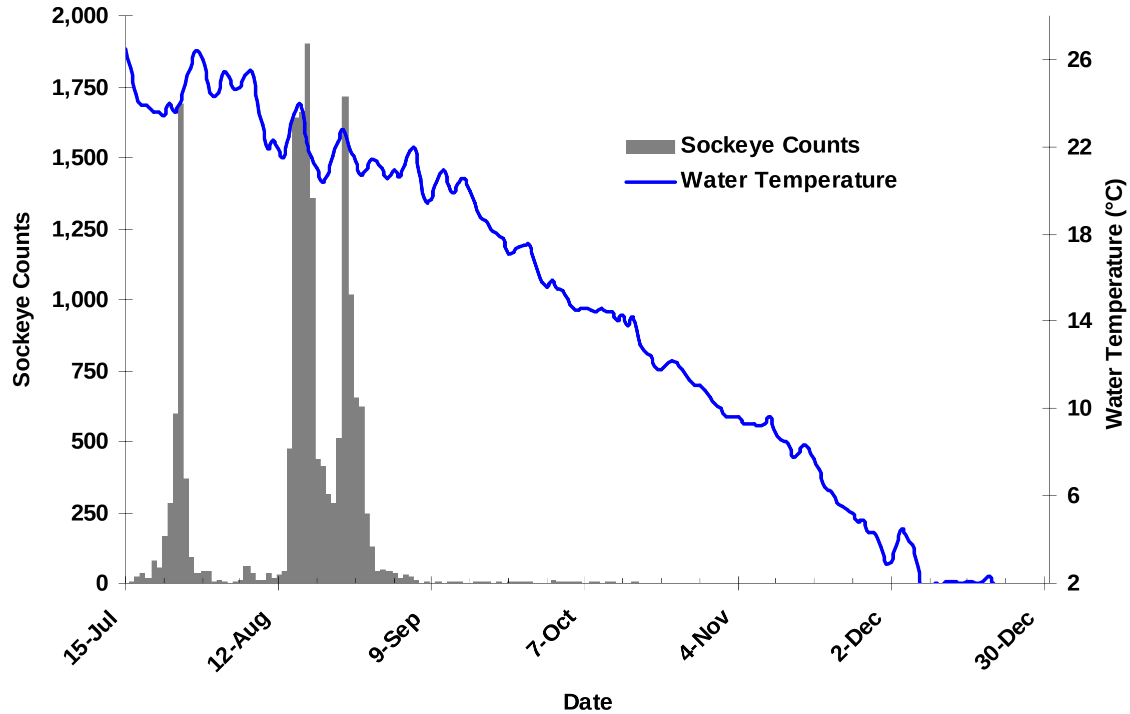

Figure 9. Adult sockeye salmon run timing based on video counts at Zosel Dam from 15 July to 31 December, 2007. Mean daily water temperature from the USGS gauge at Oroville, WA is also shown.

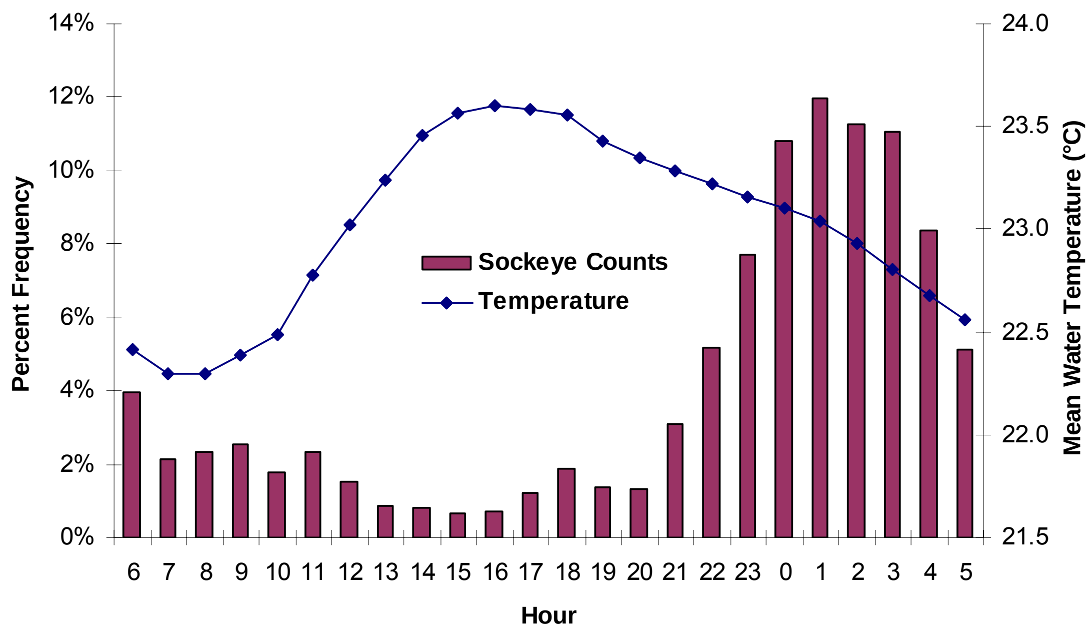

Figure 10. Percent frequency distribution of hourly adult sockeye salmon passage based on video counts at Zosel Dam and mean water temperature in 2007. Temperature data from the period in which 95% of the run passed the dam (15 July through 30 August).

Temperature and Flow Effects on Fish Passage

There were apparent effects of water temperature on Chinook and sockeye passage at Zosel Dam in 2007. Chinook and sockeye passage did not commence until mean daily water temperatures began to drop after the mid-July peak in water temperature (Figures 7 and 9). A total of 17 Chinook and over 11,600 sockeye passed Zosel Dam during days in which mean water temperature exceeded 22.0^{o}C (Table 6). There were 32 days in which mean water temperature was greater than or equal to 22^{o}C, a period that yielded the highest daily passage rate for sockeye and 66% of the run (Table 7). Sockeye counts within the 13 to 19 August time period indicated that passage primarily occurred when hourly temperatures decreased (Figure 11).

Hourly passage patterns of Chinook relative to mean hourly water temperature indicated that generally more fish passed during hours with lower temperatures (Figure 8). For sockeye, hours with higher temperatures yielded fewer fish and hours of increased passage occurred when temperatures decreased after sunset (Figure 10).

Table 6. Chinook and sockeye counts during days in which mean water temperature exceeded 22.0^{o}C. Daily minimum and maximum temperatures are also listed. Water temperature data from the USGS gauge at Oroville, WA.

	Temperature			Counts			Temperature			Counts	
Date	Min.	Mean	Max	Sockeye	Chinook	Date	Min.	Mean	Max	Sockeye	Chinook
16-Jul	24.3	25.6	27.6	5	0	1-Aug	22.6	24.5	25.6	13	1
17-Jul	22.9	24.4	26.4	23	0	2-Aug	23.8	25.4	26.1	4	0
18-Jul	23.2	23.9	25.2	38	0	3-Aug	24.1	25.2	25.3	1	0
19-Jul	22.9	23.9	24.9	19	0	4-Aug	23.3	24.6	24.8	9	2
20-Jul	23.2	23.6	24.1	80	0	5-Aug	23.1	24.7	24.8	14	0
21-Jul	22.8	23.6	24.4	54	0	6-Aug	23.8	25.3	25.2	59	0
22-Jul	22.8	23.4	24.1	168	1	7-Aug	24.4	25.4	25.6	40	0
23-Jul	22.7	24.0	25.3	282	1	8-Aug	23.2	24.1	24.6	11	0
24-Jul	22.6	23.6	24.8	598	0	9-Aug	22.3	23.0	24.0	15	0
25-Jul	23.0	24.0	24.9	1,691	3	11-Aug	21.5	22.3	22.8	17	7
26-Jul	23.7	24.9	26.0	371	0	14-Aug	21.6	22.5	23.4	474	4
27-Jul	24.2	25.6	26.8	91	0	15-Aug	22.7	23.5	24.2	1,645	2
28-Jul	25.1	26.4	27.4	37	0	16-Aug	23.2	23.9	24.4	1,660	0
29-Jul	24.8	26.0	27.1	45	0	17-Aug	21.1	22.2	23.8	1,899	1
30-Jul	23.6	24.9	25.8	42	0	23-Aug	21.4	22.2	23.0	511	0
31-Jul	23.1	24.3	24.9	9	1	24-Aug	22.1	22.8	23.6	1,713	0

Table 7. Chinook and sockeye counts, rates of passage, and number of days in which mean water temperature exceeded incremental temperature values. Table was constructed using a truncated data set consisting of the time period 16 July through 15 November. Water temperature data from the USGS gauge at Oroville, WA.

Daily Mean Water Temp. Value (°C) USGS Oroville	Number of Days with Temps at or above Temp. Value	Number of Sockeye Passing Zosel	Rate of Passage (Sockeye/Day)	Number of Chinook Passing Zosel	Rate of Passage (Chinook/Day)
≥ 27	0	0	0.0	0	0.0
≥ 26	2	82	41.0	0	0.0
≥ 25	8	282	35.3	0	0.0
≥ 24	18	2,746	152.6	8	0.4
≥ 23	27	7,023	260.1	11	0.4
≥ 22	32	11,637	363.7	23	0.7
≥ 21	46	15,797	343.4	40	0.9
≥ 20	60	17,520	292.0	56	0.9
≥ 19	64	17,545	274.1	59	0.9
≥ 18	68	17,565	258.3	67	1.0
≥ 17	74	17,593	237.7	77	1.0
≥ 16	75	17,596	234.6	80	1.1
≥ 15	81	17,629	217.6	150	1.9
≥ 14	92	17,673	192.1	308	3.3
≥ 13	93	17,675	190.1	323	3.5
≥ 12	99	17,686	178.6	369	3.7
≥ 11	105	17,696	168.5	415	4.0
≥ 10	109	17,699	162.4	429	3.9
≥ 9	118	17,704	150.0	452	3.8
≥ 8	121	17,704	146.3	454	3.8
≥ 7	123	17,705	143.9		

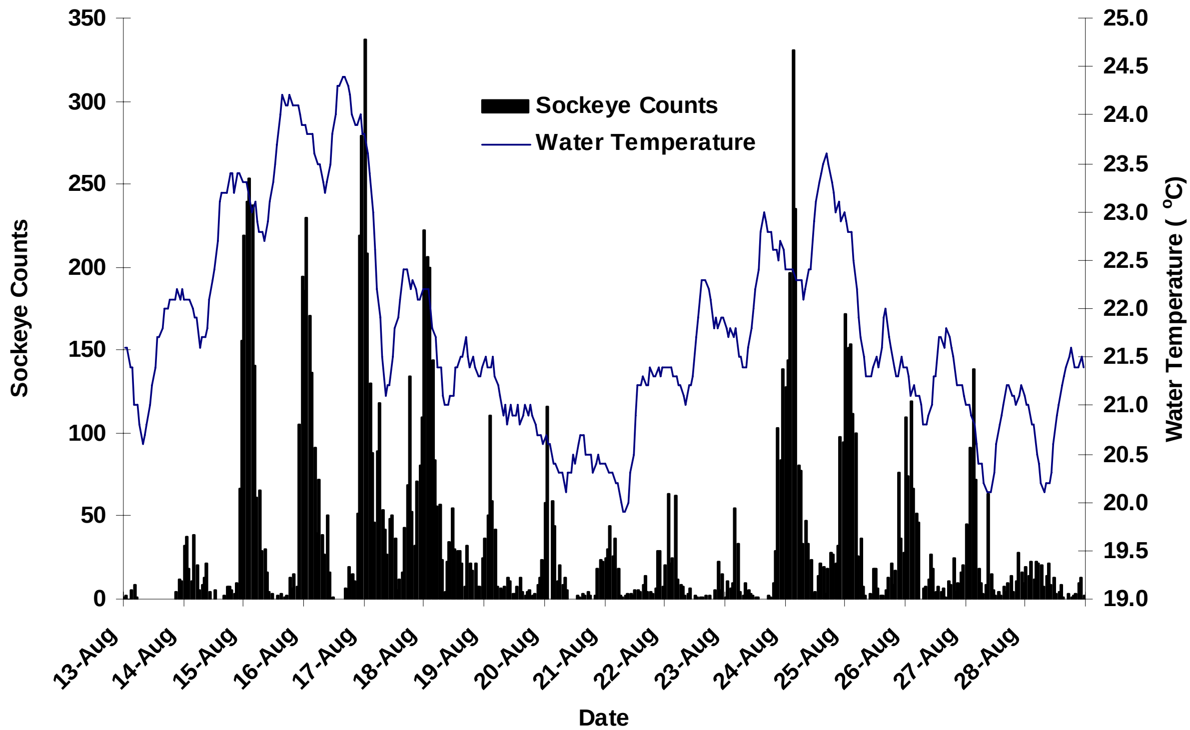

Figure 11. Hourly adult sockeye passage for the 16-day period of 13 to 29 August 2007 plotted with hourly temperature (on the half-hour) from USGS gauging station at Oroville, WA.

Passage of Chinook and sockeye salmon showed little effect from discharge across the sampling season. Sporadic counts of Chinook occurred from late July through late September during discharge that ranged from 108 to 793 cfs (Figure 12). The majority of fish passed in October and November when discharge was characterized with a moderate range of flows (380 to 486 cfs). The initial mode of sockeye passage coincided with a spike in discharge in the latter part of July but the majority of passage occurred in the latter half of August during a moderate range of discharge (245 to 311 cfs). Regression techniques to assess the relationship between daily fish counts and mean daily discharge revealed a lack of a linear relationship with discharge for both Chinook and sockeye passage (Figure 13).

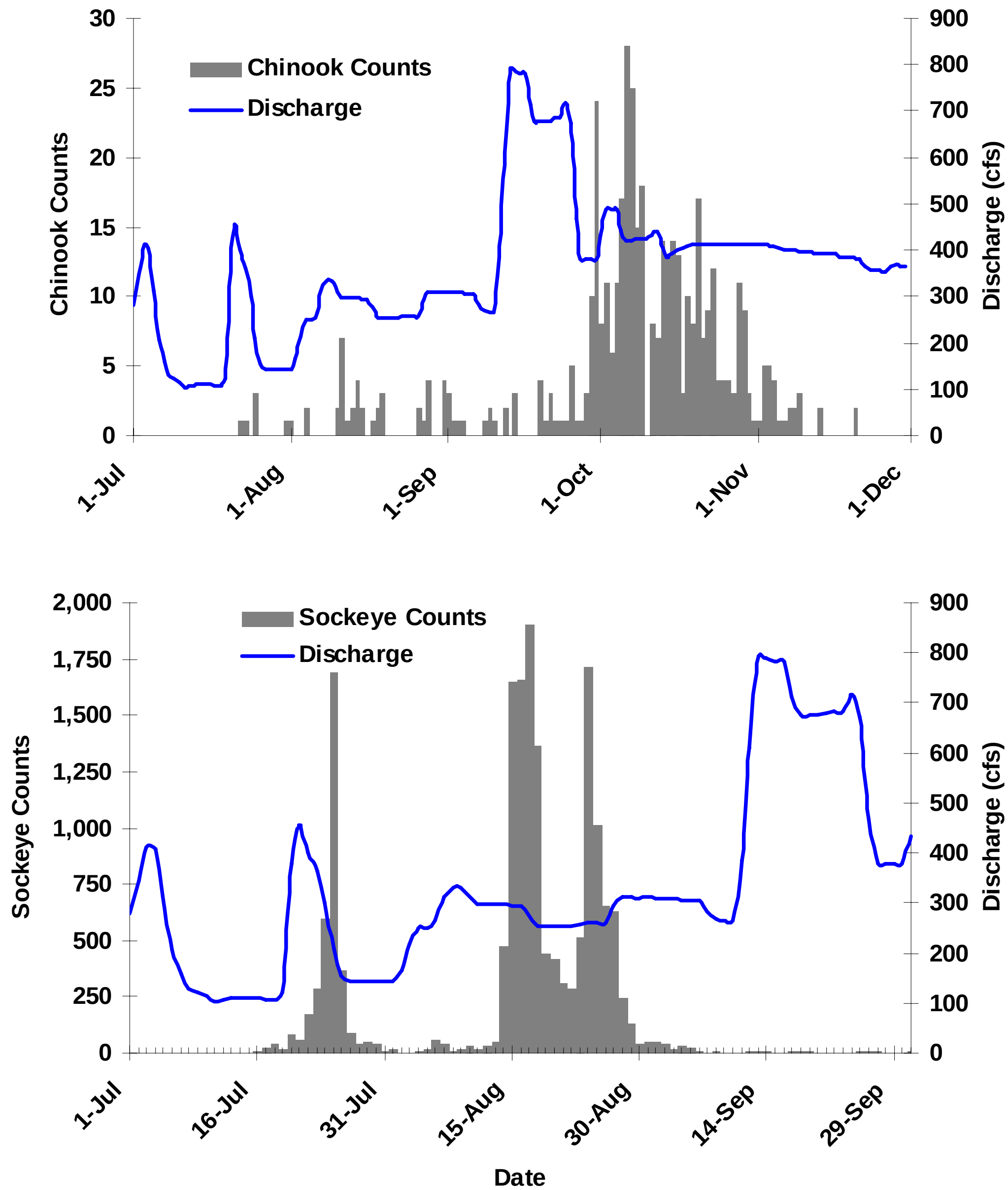

Figure 12. Chinook and sockeye run timing and mean daily discharge during periods of high relative fish counts in 2007.

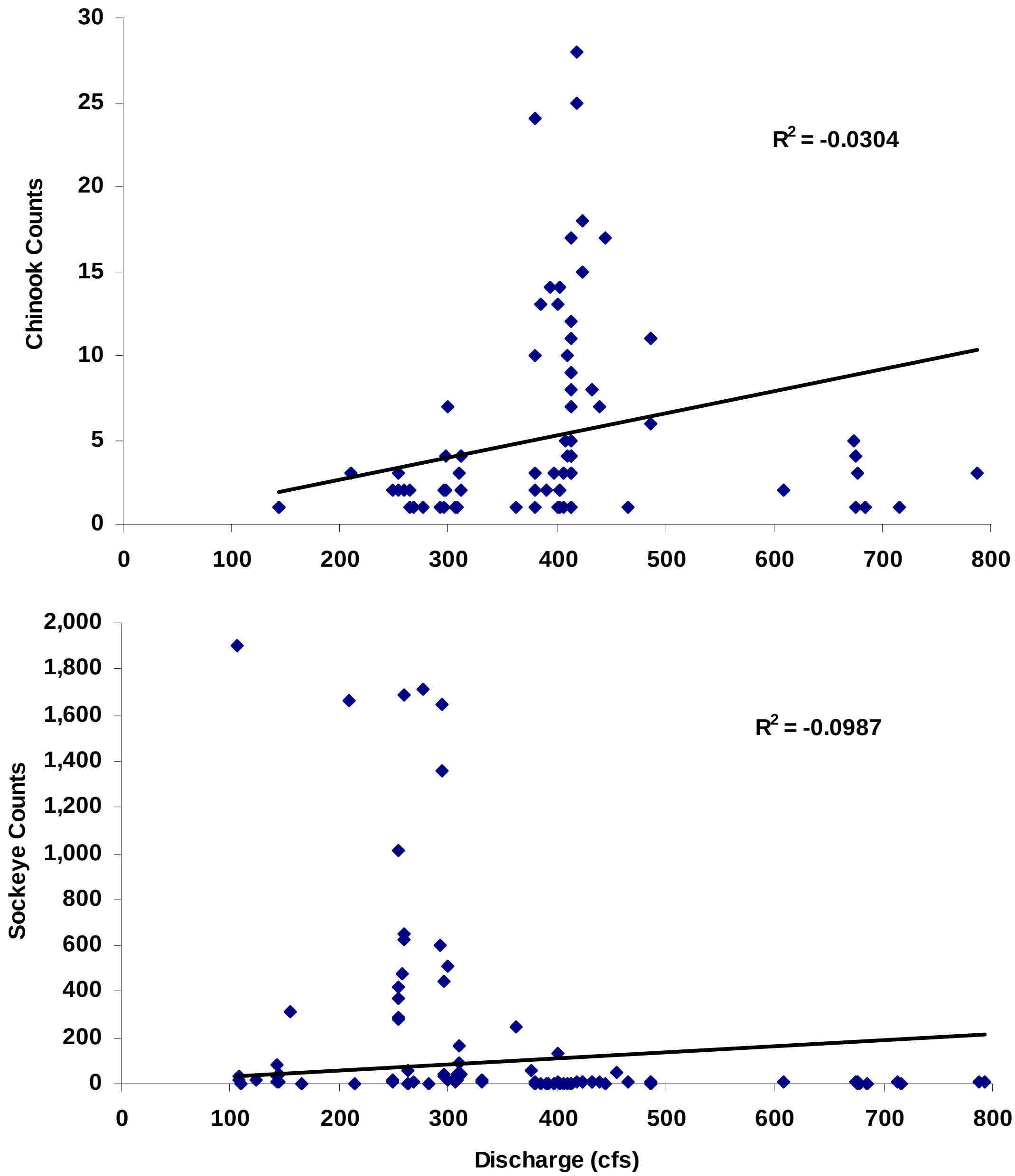

Figure 13. Relationship between Chinook and sockeye counts and mean daily discharge at Zosel Dam in 2007.

Downstream Fish Passage

Downstream passage events for Chinook and sockeye salmon occurred during 2007 but the frequency of occurrence of these events is uncertain. Downstream migrating fish detections were accounted for by modifying the total hourly count for each species before entry into the database and fallback of fish through the Zosel Dam flow gates is not monitored. As a result, specific instances of downstream movement were not recorded.

Non-Target Fish

A total of sixteen non-target fish species were observed with the video monitoring system at Zosel Dam in 2007 (Table). Of particular interest was the bull trout detected on 10 November at 1900 hours. The bull trout identification, based on a still video image, was confirmed by the following regional biologists: S. Deeds (USFWS), J. De La Vergne (USFWS), J. Dupont (Idaho Fish & Game), B. Le (Douglas County PUD), and N. Wells (USFS).

Table 8. List and count of all non-target fish observed at Zosel Dam in 2007.

Common Name	Scientific Name	Family	Count
Chinook Salmon (jack)	*Oncorhynchus tshawytscha*	Salmonidae	12
Steelhead	*Oncorhynchus mykiss*	Salmonidae	181
Rainbow Trout	*Oncorhynchus mykiss*	Salmonidae	86
Sockeye Salmon (smolt)	*Oncorhynchus nerka*	Salmonidae	2,931
Brook Trout	*Salvelinus fontinalis*	Salmonidae	4
Bull Trout	*Salvelinus confluentus*	Salmonidae	1
Mountain Whitefish	*Prosopium williamsoni*	Salmonidae	19
Unknown Salmonid		Salmonidae	13
Yellow Perch	*Perca flavescens*	Percidae	1
Brown Bullhead	*Ameiurus nebulosus*	Ictaluridae	6
Unknown Ictalurid		Ictaluridae	2
Common Carp	*Cyprinus carpio*	Cyprinidae	741
Chiselmouth	*Acrocheilus alutaceus*	Cyprinidae	58
Northern Pikeminnow	*Ptychocheilus oregonensis*	Cyprinidae	596
Peamouth	*Mylocheilus caurinus*	Cyprinidae	157
Unknown Cyprinid		Cyprinidae	1
Bluegill	*Lepomis macrochirus*	Centrarchidae	249
Largemouth Bass	*Micropterus salmoides*	Centrarchidae	1,277
Smallmouth Bass	*Micropterus dolomieu*	Centrarchidae	18
White Crappie	*Pomoxis annularis*	Centrarchidae	8
Unknown Centrarchid		Centrarchidae	1
Bridgelip Sucker	*Catostomus columbianus*	Catostomidae	1
Unknown Catostomid		Catostomidae	799

DISCUSSION

Run Timing and Relative Abundance

It is instructive to compare the 2007 Zosel Dam passage data with the adult counts at Wells Dam (Fish Passage Center 2008) to better understand spawner distribution and run timing dynamics in the Upper Columbia and Okanogan River basins. Run timing patterns of Summer/Fall Chinook salmon were similar between Wells and Zosel dams (Figure 14). The similarity in run timing pattern and the apparent shift in run timing from Wells Dam to Zosel Dam (21 July to 8 October reflects the time period in which 50% of the run had passed each respective dam) demonstrates that migration delays occur after Chinook pass Wells Dam but before they pass Zosel Dam. Chinook were first detected at Zosel Dam 80 days after being initially observed at Wells Dam, but this may be a conservative estimate of the migration timing between dams given that the Wells data set begins on 1 May and some Chinook may have shown up there prior to that date. Additionally, some fish may have arrived prior to the onset of video sampling (16 July). Relative abundance of Chinook salmon at Zosel Dam in 2007 comprised 2.7% of the total number observed at Wells Dam, a higher proportion than was observed in 2006 (1.7%) (Johnson et al. 2007). Less than 50 Chinook salmon have been observed on spawning grounds in Canadian waters in 2007 (Shala Lawrence, Okanagan Nation Alliance, pers. comm.).

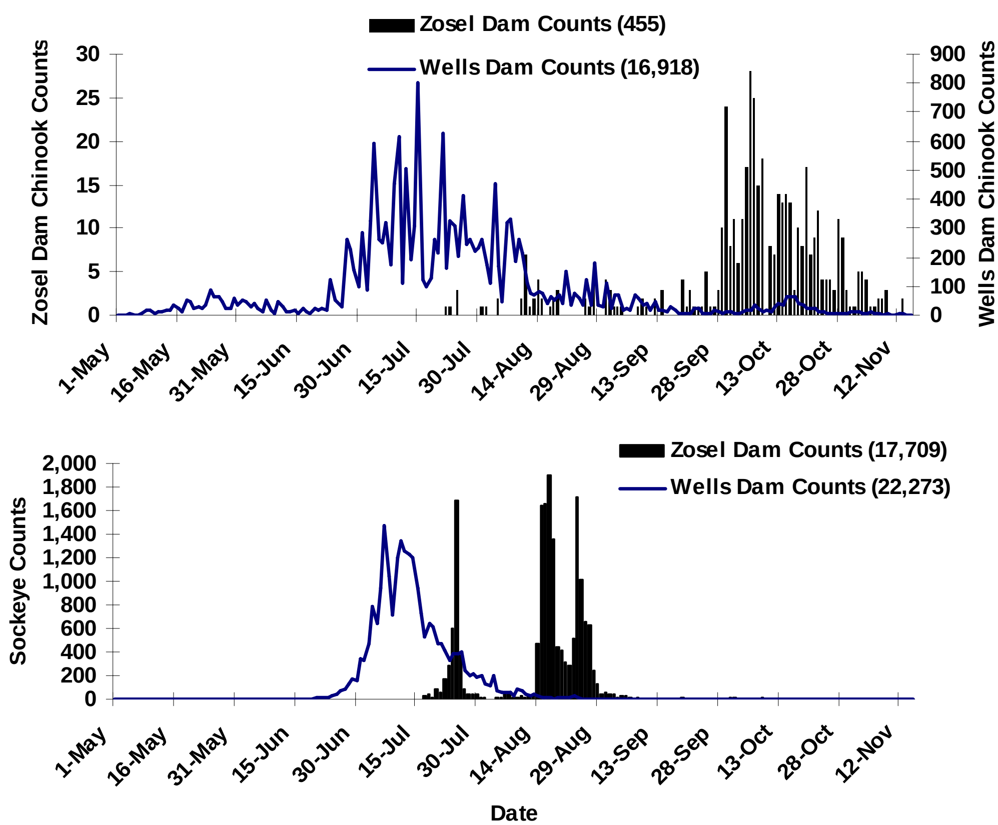

Figure 14. Run timing of summer Chinook and sockeye salmon at Zosel Dam on the Okanogan River and Wells Dam on the Columbia River in 2007. Note that the Chinook counts for Zosel and Wells Dams have different Y-axes. Wells Dam data from Fish Passage Center Website: http://www.fpc.org/. Note that Wells Dam counts are reported on the FPC website for the period 1 May through 15 November.

Sockeye salmon run timing at Zosel Dam showed three pulses of fish: an initial one beginning in the latter part of July followed by a larger bimodal group during the last half of August (Figure 9). Sockeye passage at Wells Dam was characterized by a bell-shaped run timing pattern centered in mid July (Figure 14). Peak daily sockeye counts at Zosel Dam exceeded those observed at Wells Dam, as was reported in 2006 (Johnson et al. 2007). A 37-day shift in run timing from Wells to Zosel Dam (12 July to 17 August reflects the time period in which 50% of the run had passed the respective dams) occurred. This result, coupled with the dissimilar run timing patterns, indicates that sockeye exhibit staging behavior prior to passing through Zosel Dam en route to their spawning grounds. This delay in migration is likely the result of the presence of a temporal thermal barrier at the confluence of the Columbia and Okanogan rivers (Duree 1991; Hatch et al. 1992; Alexander et al. 1998). In 2007, Zosel Dam sockeye counts comprised 79.5% of the total number of sockeye observed at Wells Dam, a decrease from the 87.2% observed in 2006 (Johnson et al. 2007).

The relative abundance estimate for sockeye passing Zosel Dam does not compare favorably with the preliminary estimate of 8,283 spawning sockeye based on spawning ground surveys in the Upper Okanagan River in 2007 (Ryan Benson, Biologist, Okanagan Nation Alliance Fisheries Department, pers. comm.). It is unknown why the preliminary spawner estimate is so low relative to the Zosel count (17,709) and the Wells count (22,273). For the 2006 passage year, the spawner estimate (20,819) compared favorably with the Zosel and Wells counts (19,245 and 22,075), respectively (Johnson et al. 2007).

Diel Passage

Patterns of hourly passage at Zosel Dam differed between Chinook and sockeye salmon in 2007. Chinook passage showed a slight but not significant increase in daytime hours relative to nighttime hours (Figure 8) whereas sockeye passage indicated a very strong and significant pattern of increased passage at night relative to during the day (Figure 10). Results from the 2005-2006 video enumeration study showed these similar trends with Chinook passage higher during the day than at night (more so than in 2007) and sockeye passage much higher during the nighttime than during the day (Johnson et al. 2007).

Hydroacoustic sampling conducted at Zosel Dam in 1991 indicated that sockeye passage was dissimilar to what was observed in 2005-2007 as sockeye were reported to pass most frequently during the 1900 and 0600 hours, with lows during the mid-morning hours (Anglea and Johnson 1991). Hatch et al. (1992) reported an even more pronounced nighttime trend in sockeye passage at Zosel Dam in 1992 then was observed in 2005-2007 as nighttime (2000 to 0600 hours) passage accounted for 93% of total passage. Also contrary to the results reported here, Hatch et al. (1994b) observed that nighttime passage of sockeye at Tumwater Dam on the Wenatchee River accounted for only 6.7% of total passage. In the Tumwater Dam passage study, Hatch et al. (1994b) reported that nighttime passage for Chinook accounted for 13.6% of total passage, an estimate lower than what are reported for Zosel Dam in 2005 and 2006 (Johnson et al. 2007) and in 2007. In a video sampling study at Prosser Dam on the Yakima River, Hiebert et al. (2000) found that peak Chinook passage occurred during the 1000 to 1200 hour time period, a result similar to what is reported here.

Temperature Effects

Similar to what was reported for the 2006 passage year (Johnson et al. 2007), sockeye passage data from 2007 indicates that the temperature threshold limits for sockeye migration reported in past studies are likely underestimated. Hourly sockeye passage totals plotted along with hourly water temperature (taken on the ½ hour) clearly shows that fish are passing in considerable numbers above 21°C and some still pass when temperatures exceed 23°C (Tables 6 and 7, Figure 11).

Prior investigators have reported that salmonid passage at Zosel Dam was regulated in part by water temperature, and that sockeye passage only occurred when water temperatures did not exceed 23^{o}C (Hatch et al. 1992). Alexander et al. (1998) illustrated using radio-telemetry that Chinook and sockeye destined for spawning in the Okanogan River demonstrated migration timing patterns that were inextricably linked with the temperature of the river. The 2007 results support the temperature / fish passage relationship as well: fish passage through Zosel Dam did not commence until mean daily water temperatures began to drop after the 15 July peak in water temperature (Figures 7 and 9). A subsequent decrease in water temperature resulted in a sharp increase in sockeye passage.

In work assessing climate variation and climate change effects on migration of Okanagan River sockeye salmon, Hyatt et al. (2003) identified a set of 'decision rules' governing fish behavior for modeling how water temperature mediates delays in up-river migration. The rules were developed based on historical data (Major and Mighell 1967) suggesting that annual variations in temperature differences between the Columbia and Okanogan rivers produced long delays of adult sockeye entry from Wells Pool into the Okanagan River in some years but not others, depending upon whether sockeye were exposed to temperatures exceeding 21°C near the river mouth. This trend was also supported by more recent investigations (Hatch et al. 1992; Sullivan and Dawson 1994; Alexander et al. 1998). The 'decision rules' developed by Hyatt et al. (2003) characterized sockeye migrations as ceasing when water temperatures increase and exceed 21°C and then restart when temperatures decrease and fall below 21°C.

Results from the 2007 passage study at Zosel Dam contrast sharply with assertions by Hyatt et al. (2003) regarding the 'decision rules' governing sockeye migration behaviors relative to Okanogan River water temperatures. Mean daily water temperatures $\geq$ 21°C did not result in delays in migration through Zosel Dam, as sockeye were observed to pass when mean daily temperatures climbed as high as 26°C (Table 6). Over 11,600 sockeye passed during the 32 days in which mean temperatures were $\geq$ 22°C (Table 7), accounting for 66% of the total run in 2007. Sockeye were observed to primarily pass during the cooler, nighttime hours (Figures 10 and 11). However, during days in which mean temperatures were $\geq$ 22°C, minimum temperatures never fell below 21°C (Table 6).

The temperature / migration behavioral rules for sockeye of Hyatt et al. (2003) may be relevant for entrance into the Okanogan River from the Columbia River, but this represents only a portion of the temperature-mediated migration issue. The rules are clearly not consistent with passage through Zosel Dam. If the rules are 'repeatable' as suggested by these authors, why then would the rules apply at certain locations and not others along the sockeye migration corridor? If sockeye were to delay their migration up into the Okanogan River due to a temperature threshold, then continue migrating once temperatures fall below the threshold, one would expect additional delays if sockeye were to encounter the threshold again further upstream near Zosel

Dam. However, as demonstrated by the sockeye passage / temperature relationship in 2007, this was not the case and as a result calls into question the validity of 21°C water temperature as a threshold that dictates sockeye migration behavior.

The results from 2007 indicate that sockeye migrate past Zosel Dam during periods in which water temperatures reach and exceed lethal levels (>24°C, Servizi and Jensen 1977). Although it is unknown to what duration sockeye are exposed to lethal water temperatures, it is likely that during years in which exceedingly high water temperatures occur, the exposure is of long enough duration to induce mortality above Zosel Dam and in the shallow southern basin of Osoyoos Lake. Sockeye may then be exposed to lethal water temperatures in the southern basin for prolonged time periods without access to a depth refuge with cooler water. As a result, sockeye may perish before they reach the deeper, cooler water of the northern basin. Once sockeye reach the northern basin however, mortality may occur there as well as a result of the high surface layer temperatures and anoxic conditions in the cooler bottom layers (Rae 2005). Occurrence of sockeye mortality upstream of Zosel Dam prior to arrival on their spawning grounds in 2007 may explain the disparate estimates of Dam counts (17,709) and spawner estimates (8,283). Differences between historic yearly sockeye counts at Wells Dam and counts from the spawning grounds (Table 1) may be attributed to lethal-temperature induced mortality occurring in the south basin of Osoyoos Lake. Further hypothesis development is warranted in order to gain insight into the sockeye mortality / water temperature relationship.

Discharge Effects

Discharge had little apparent effect on adult salmonid passage in 2007, a similar result to what was observed in 2005 and 2006 (Johnson et al. 2007), although the initial mode in sockeye passage coincided with a spike and subsequent reduction in discharge (Figure 12). Plotting daily fish counts with mean daily discharge showed a lack of a linear relationship for both Chinook and sockeye (Figure 13), suggesting further that fall flows do not influence fish passage at Zosel Dam.

Lateral and Vertical Passage Distributions

Chinook, and to a larger degree sockeye salmon passage was skewed toward the east bank (63 and 80%, respectively) which indicates a preference for passing on the east side of the dam (Table 4). These results were similar but more pronounced than what was observed in 2005 and 2006 (Johnson et al. 2007).

It is not clear what factors contributed to such a skewed distribution of passage towards the east bank. It may be that fish are distributed along or near the east bank of the river downstream of the dam due to favorable velocity or flow conditions, and that migrants simply pass up through the dam on the east side because they are already distributed to do so. Environmental conditions may then influence lateral passage fate without regard to operating conditions at the dam. Lateral passage fate could be assessed to determine whether downstream flow conditions or chute preference influence migrant passage by releasing groups of radio-tagged fish from both shorelines downstream several miles from the dam. Antennae and receivers located along the river could be used to detect if and when fish change their distributions; if distributions did not change significantly, then it would be reasonable to assume that flow conditions are the prime factors driving passage fate. If distributions showed significant change, especially in the vicinity of the dam, then it would be assumed that operational conditions drive passage fate.

Spill gate opening did not appear to influence lateral passage distributions for Chinook salmon in 2007 although the days in which the gates were open greater than 12" were limited during the period the majority of Chinook were observed (Figures 6 and 7). Based on fish that passed on days in which no gates were open at least 12", 58.5% (out of a total of 258 fish) preferred the east bank. A total of 181 fish passed when just Gate 1 (closest to the west bank) was open and of those fish 70% passed on the east bank. These results suggest preferential passage of Chinook along the east side of Zosel Dam.

Lateral passage of sockeye did not appear to be influenced by spill gate opening, but as with Chinook, few fish passed (1.5% of the total) during days in which spill gates were open greater than 12" (Figures 6 and 9). Of the 203 fish that passed during days when only Gate 1 was open at least 12", 73% were still observed with the east bank cameras. This result contrasts with what Anglea and Johnson (1991) reported regarding sockeye salmon showing an 80% preference for the west bank ladder, which they attributed to an influence of attraction flows set up by the exclusive use of Gate 1 during their study. Hatch et al. (1992) found no sockeye preference for either ladder with approximately the same volume of water passing through gates 1 and 4 (nearest gate to the east bank ladder).

The video monitoring results were also informative regarding vertical distribution of passage since the video chutes are vertically compartmentalized. Passage data strongly indicated that when flow conditions resulted in all levels of the chutes being watered up, the majority of Chinook and sockeye passed the monitoring stations through the deepest portions of the chutes, a similar result to what was observed in previous years (Johnson et al. 2007). The shallow-deployed cameras observed 0.4% and 0.2% in 2007 and 0.0% and 0.3% in 2006 (Johnson et al. 2007) of the Chinook and sockeye migrations, respectively. Given the very low proportions of migrants observed with the shallow-deployed cameras, efficiency of the video enumeration program can be increased by removing those cameras and thereby decreasing the amount of labor necessary for video review. In future years, overall video count estimates based only on deeper-deployed cameras could be increased by a very small factor to account for fish that would be observed with the shallow cameras if they were deployed and their data reviewed. A substantial program cost savings in terms of labor would be incurred if this efficiency measure was implemented.

Spillway Passage

Video monitoring arrays at Zosel Dam sampled only the primary passage routes (the pool and weir type fish ladders) in 2007 and in previous years. However, upstream passage by salmon through open spill gates has been documented at Zosel Dam (Major and Mighell 1967; Anglea and Johnson 1991; Hatch et al. 1992). Therefore, an attempt was made to monitor passage through this route using high intensity lights and color cameras on the tailrace side of Gate 1 in 2006. A single spill bay stop log was fitted with cameras and lights and lowered onto the spill apron. This technique was not successful due to the low contrast background, the variable effects of sunlight, and entrained air at the gate edge that made image recognition virtually impossible. As a result, the extent to which upstream or downstream passage occurred through the spill gates in 2005 through 2007 is unknown. Since spill gates were typically not open more than 12" through the period in which Chinook and sockeye were passing Zosel Dam, it is likely that few, if any fish of these species passed through the spillway on their way upstream.

RECOMMENDATIONS

Based on the ongoing efforts and results from this video-based study and the ones conducted in previous years (Johnson et al. 2007), we offer the following recommendations to further enhance the effectiveness and reliability of continued assessment of timing and abundance of adult salmonids in the Okanogan River Basin. Following these recommendations will further refine efforts in determining basin and tributary-specific spawner distributions, and evaluating the status and trends of natural salmonid production in the Basin.

Optimize Spillway Operation Protocol

Previous investigators determined that with spillway gate openings less than or equal to 12", anadromous fish passage up through the spillway gates at Zosel Dam was minimal. Gate openings larger than 12" facilitate passage through the spillway (Hatch et al. 1992). If spillway passage cannot be monitored, then stock abundance estimates for anadromous fish based on video sampling are not census counts but instead are less accurate, relative abundance estimates. Although the frequency of spill gate opening greater than or equal to 12" were fairly low during the passage season, some fish may have escaped detection by passing up through this route. It is important then to minimize spillway passage in order to increase the value and utility of the video counts. To do so, a spillway operation protocol should be put in place and implemented by the dam operators during the fish passage season. As increased discharge warrants the use of spill, the protocol should consist of only opening individual gates a maximum of 10" until all gates are open by that height. This approach would spill the same volume of water as opening a single gate 40" but would minimize unmonitored spillway fish passage compared to the latter approach. It is recognized that during the spring freshet period, the recommended protocol is not usually practical due to the high discharge requirements.

Assess Spillway Passage and Fallback

Fallback of adult salmonids occurs to varying degrees across years and locations in the Columbia River system. For example, during the period 1996 through 1998 at The Dalles Dam, fallback rates as high as 12%, 4% and 10% were estimated for summer Chinook, sockeye and steelhead, respectively (Bjornn et al. 2000a). For the same period at John Day Dam, fallback rates as high as 14%, 5%, and 6% were estimated for summer Chinook, sockeye and steelhead, respectively (Bjornn et al. 2000b). Fallback rates at Zosel Dam are unknown. More complete abundance estimates of salmonid stocks passing Zosel Dam could be obtained if spillway passage and adult fallback were to be monitored and assessed.

Spillway passage and fallback monitoring could be accomplished through use of PIT tags or radio telemetry methods. These techniques may be limited by small sample sizes since the assessments would based only on the number of tagged individuals. Another method would be to deploy a DIDSON in the forebay and aim it across the spillbay openings. Directional information is readily apparent with DIDSON imaging, so estimating spill passage and fallback would not be difficult. Also, sample size would be increased substantially over other methods discussed since DIDSON will sample all fish that pass though its field-of-view, not just tagged individuals. Where there are clear size differences among the salmonid species, species identification can be obtained with DIDSON. Salmonids would likely be discernible from other resident species, and during the majority of the steelhead run, species identification would be apparent since the Chinook and sockeye will not be migrating during that time period. When the Chinook and sockeye are running together, the DIDSON counts could be apportioned by date based on the video monitoring counts from the ladders. A short-term feasibility study to determine the efficacy of monitoring spillway passage and fallback with a DIDSON at Zosel Dam in future years would be a reasonable step towards gaining a more complete understanding of the abundance of salmonid stocks in the Okanogan River Basin.

Monitor Tributary Sites

Monitoring key tributaries in the Okanogan River Basin would broaden the knowledge base regarding the population status and distribution of tributary-specific steelhead stocks. Efforts in 2006 demonstrated the feasibility of monitoring steelhead passage in Bonaparte Creek using a video system (Johnson et al. 2007), but tributary sites were not monitored in 2007. In order to develop a better understanding of the abundance and production of those steelhead stocks, future monitoring efforts should include the following priority list of tributaries for steelhead passage using video monitoring systems: Salmon, Ninemile, Antoine, and Loup Loup creeks. In addition to adult steelhead abundance information, tributary video systems might also be used to provide relative abundance estimates for juvenile steelhead.

Assess Temperature Mortality Relationship for Sockeye

As discussed above, the disparity between sockeye counts at Zosel Dam and the number of estimated spawners may be explained by mortality that occurs as a consequence of sockeye exposure to lethal water temperatures upstream of the dam. To better understand the temperature mortality relationship it is important to continue assessing the factors that contribute to the relationship. Therefore we recommend additional analyses in future years and a review and synthesis of sockeye passage at Zosel Dam relative to water temperature patterns at Zosel as well as at the mouth of the Okanogan River.

To investigate the occurrence of mortality events and assess the relative magnitude of occurrence, it is essential to estimate the level of sockeye prespawn mortality in the southern basin of Osoyoos Lake. We recommend the use of periodic snorkel and SCUBA surveys throughout the mid July to early September time period to estimate the number of dead sockeye in the lake. Overall yearly mortality estimates could then be analyzed relative to Zosel counts, spawner estimates and water temperatures to better understand the dynamics of sockeye migration mortality.

ACKNOWLEDGEMENTS

Thanks go to Tom Scott and the entire Oroville/Tonasket Irrigation District for their cooperation in site access and gate height adjustments; to Keith Kistler, Edward Berrigan, Tim Erb, Jr., Rich Tonasket, Jordan Leskinen, Fred Jordan, Nicole Peone, Tony Moore, Tatum Gunn, Oly Zacherle, Esteban Cruz, Nick Erb and T.J. Whistling Elk for diligent efforts in maintaining the video units regardless of weather condition and extreme circumstance; Bryan Nass of LGL for ongoing operational consultation; Rick Klinge of Douglas County PUD, Ryan Benson and Shala Lawrence of Okanagan Nation Alliance, and Margot Stockwell of DFO for their efforts in providing sockeye spawner estimates; North Valley Internet (NVI) for providing internet service; Susannah Iltis from the Columbia Basin Research Center at the School of Aquatic and Fishery Sciences, University of Washington, for timely posting fish counts to the Data Access in Real Time (DART) website.

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