Enumeration of Salmonids in the Okanogan Basin Using Underwater Video in 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 2008 are presented based on video data collected 1 January through 31 December. Steelhead passage data at Zosel Dam were acquired in 2008 but the results of that component of the video project are discussed in a separate document (Arterburn and Miller 2009). 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, 17 adult spring Chinook salmon and 267 adult summer/fall Chinook salmon were estimated to pass in 2008. Summer/Fall Chinook peaked in daily passage on 5 and 8 October when 28 fish passed the dam. Hourly passage estimates of summer/fall Chinook salmon counts for 2008 at Zosel Dam revealed a slight diel pattern as passage events tended to remain low from 1900 hours to 0600 hours relative to other hours of the day. Summer/fall Chinook salmon showed a slight preference for passing the dam through the west bank video chutes. Summer/Fall Chinook passage at Wells Dam in 2008 totaled 25,023 fish, approximately 84% of the 10-year average.

A total of 81,260 adult sockeye salmon were estimated passing through Zosel Dam in 2008. After an initial detection in February, the sockeye run arrived at Zosel Dam on 26 June. An initial primary mode of passage occurred from 3 through 16 July when 72% of the total sockeye run passed the dam. Smaller pulses of passage occurred from 16 July through 9 August when 25% of the run was observed to pass the dam. Sockeye passage peaked on 11 July with 11,371 fish. Hourly passage estimates of sockeye salmon counts for 2008 at the dam did not show the strong diel pattern with increased passage during nighttime hours relative to daytime hours observed in 2006 and 2007. Sockeye showed a strong preference for passing Zosel Dam on the east bank (73%) relative to the west bank (27%). Sockeye passage at Wells Dam in 2008 was 165,334 fish (approximately 448% of the 10-year average).

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 of naturally produced summer steelhead in the Okanogan River basin to be 104 wild 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. In 2008, between 1.341 and 1,436 summer steelhead returned to the Okanogan River, and of those between 213 and 266 were likely of natural origin (Arterburn and Miller 2009).

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 (Johnson et al. 2008).

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). The second year of the video project occurred in 2007 and the results of that study are discussed in Johnson et al. (2008).

Objectives

The primary objectives of the 2008 OBMEP video project were to:

1. Install, operate and evaluate a video system at Zosel Dam to enumerate salmonid species; and;
2. Enumerate the number of anadromous fish passing this point, and collect additional data related to origin, species, run timing, and passage patterns.

This report documents the results from operations conducted in 2008 that provides species-specific abundance estimates of anadromous fish using an automated method. Steelhead passage data at Zosel Dam were acquired in 2008 but the results of that component of the video project are not presented here and are discussed in a separate document (Arterburn and Miller 2009).

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.

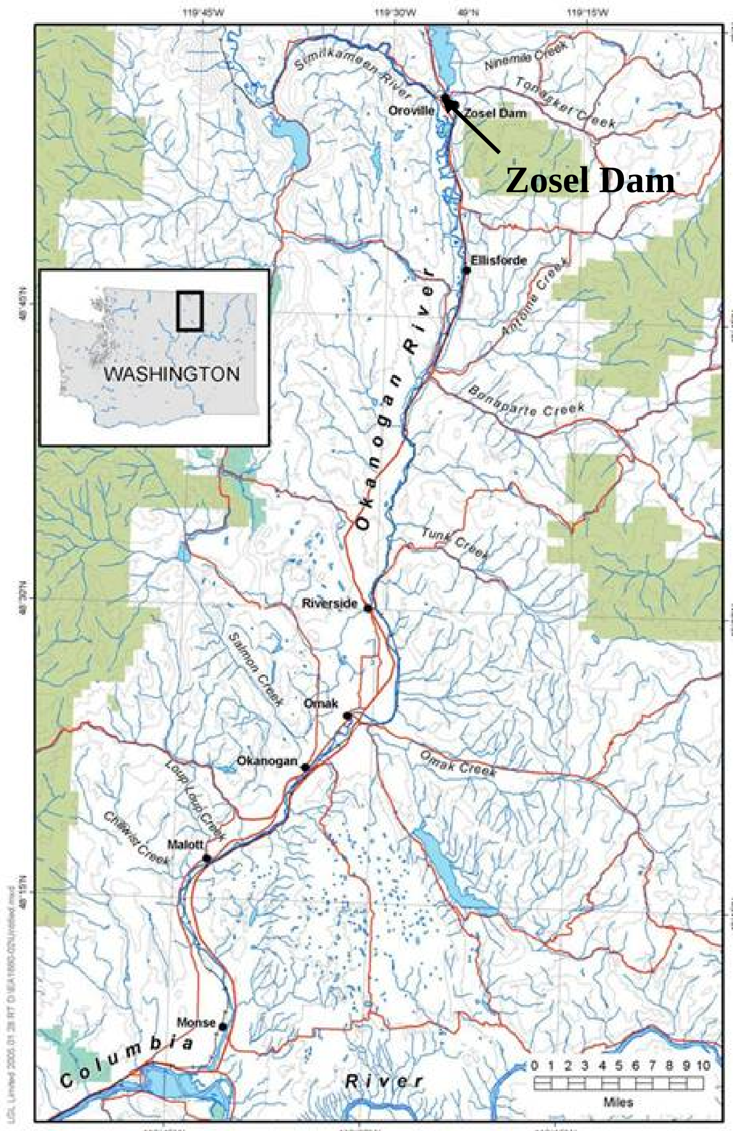


Figure 1. Map of the Okanogan River Basin. A video monitoring system is deployed at Zosel Dam to enumerate adult salmonid passage.

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-fourth 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 2008. 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. 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. Downstream fish passage events were subtracted from 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.

Numbers of fish that passed during periods in which the video recording system was non-functional were estimated using interpolation. Average daily passage was calculated based on numbers passed during the three days prior to and three days following the missing data period. This average was applied to each full day of lost data. Passage estimates for days in which some hours of data were collected were based on the average daily passage multiplied by the proportion of hours not sampled. For example, if 12 hours of data were collected in a day then the estimated number of missed fish for that day was calculated by multiplying the average daily passage for the time period by 0.5.

Total enumeration estimates include estimated fallback numbers for Chinook and sockeye salmon. For Chinook salmon an estimated fallback proportion of 14% (Bjornn et al. 2000b) was used for both spring and summer/fall run fish. For sockeye salmon, an estimated fallback proportion of 5% was applied (Bjornn et al. 2000b).

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 peak flows (> 2,000 cfs) occurring on 24 May and 13 June and sustained period of low flows (< 370 cfs) in March, and mid-July through mid-August (Figure 5). Mean daily water temperature at the USGS gauging station in Oroville, WA peaked at 26.2°C on 18 August then gradually declined through the rest of the passage season. Mean daily water temperature exceeded 24°C on several days in July (8-10, 16-28) and August (6-7, 14-19).

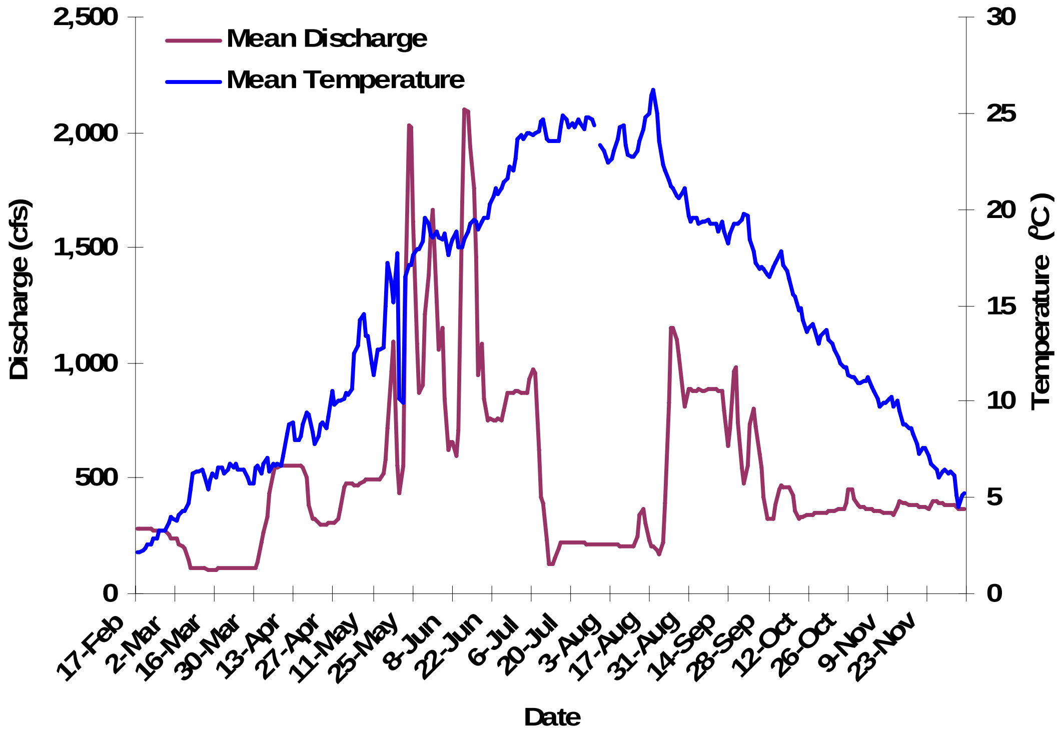


Figure 5. Daily mean temperature and discharge for the Okanogan River below Zosel Dam through the period in which salmon were detected with the video system (17 February through 6 December 2008). Data courtesy of USGS gauge at Oroville, WA. http://waterdata.usgs.gov/wa/nwis

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 2008 period in which salmon were detected at Zosel Dam, at least one spillway gate was opened greater than 12" for a limited number of days (a single gate was open for 14 days and two gates were open greater than 12" on three 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.

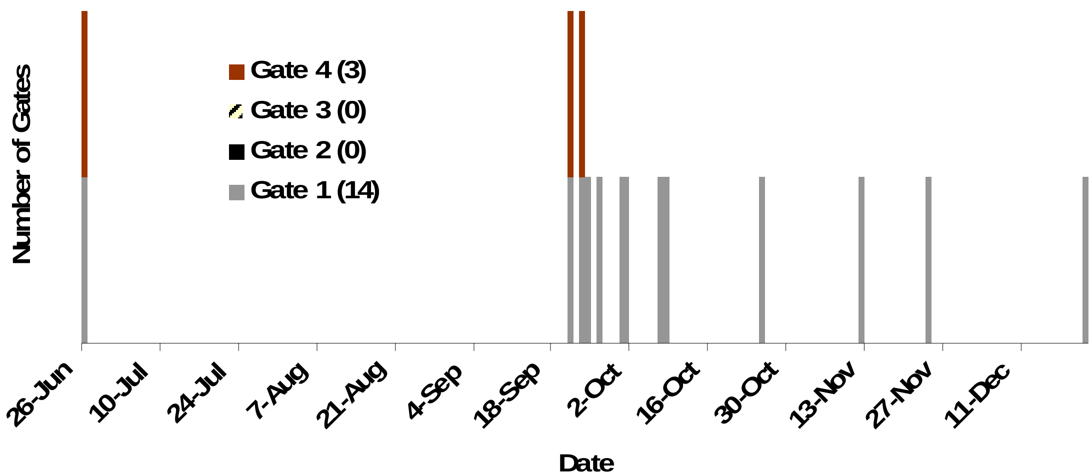


Figure 6. Dates in which individual spillway gates at Zosel Dam were opened more than 12 inches for the time period of 26 June through 22 December 2008 (time period in which Chinook and sockeye were observed passing Zosel). Numbers in parentheses indicate the number of days in which the gates were opened greater than 12".

Downtime and Missing Data

There were several instances during the sampling period in which passage data were not collected (Table 1). A total of 342 hours of video data were lost due to corrupt or unformatted hard drives, or unsuccessful swapping of the DVR.

Table 1. List of time periods in which data collection was interrupted at Zosel Dam in 2008.

Time Period	Cameras Affected	Total Hours Affected	Problem
15 May 12:00 to 20 May 12:00	All	120	Corrupt Hard Drive
17 July 00:00 to 18 July 19:00	All	42	Corrupt Hard Drive
9 Aug 10:00 to 12 Aug 12:00	All	74	Unsuccessful DVR Swap
31 Aug 00:00 to 4 Sep 10:00	All	106	Unformatted Hard Drive

Chinook Salmon

A total of 284 adult Chinook salmon were estimated to pass upstream through Zosel Dam in 2008 (Table 2). Spring Chinook salmon were estimated at 17 fish and summer/fall Chinook salmon were estimated at 267 fish (all Chinook that passed prior to 25 July were classified as spring run and all Chinook that passed after 24 July were classified as summer/fall run). Enumeration estimates account for the number of estimated fish missed during video system downtime and estimated fallback based on literature values (Bjornn et al. 2000b). About 33 percent of all Chinook were observed to be marked with adipose fin clips.

Table 2. Total number of adult Chinook and sockeye salmon and bull trout observed based on video counts at Zosel Dam in 2008. Numbers of observed marked and unmarked fish are listed by species. Missed fish were estimated during video system downtime using interpolation. Fallback numbers were estimated from Bjornn et al. (2000b).

	Chinook		Sockeye	Bull Trout
	Spring	Summer/Fall		
Unmarked	13	211	77,533	1
Adipose Clip	4	90	0	0
Unknown	1	9	0	0
Count Subtotal	**18**	**310**	**77,533**	**1**
Est. Missed	2	0	8,004	0
Est. Fallback	(3)	(43)	(4,277)	(0)
Est. Grand Total	**17**	**267**	**81,260**	**1**

Numbers in parentheses ( ) were subtracted from the running total

Summer/Fall Chinook showed a slight preference for the west bank array in 2008 (Table 3), a result not seen in previous years (Figure 7). Almost 80% of Spring Chinook were observed to pass through the east bank array in 2008. Within the chutes, total Chinook passage was recorded exclusively by the deeper cameras in 2008. Similarly, 100% of Chinook detections were observed with deeper cameras in 2006 (Johnson et al. 2007) and 99.6% with deeper cameras in 2007 (Johnson et al. 2008).

Table 3. Total number and proportion of adult summer/fall Chinook and Sockeye salmon observed by bank location based on video counts at Zosel Dam in 2008.

Summer/Fall Chinook		Sockeye	
Count	Percent	Count	Percent
147	47.4	56,800	73.3
163	52.6	20,733	26.7

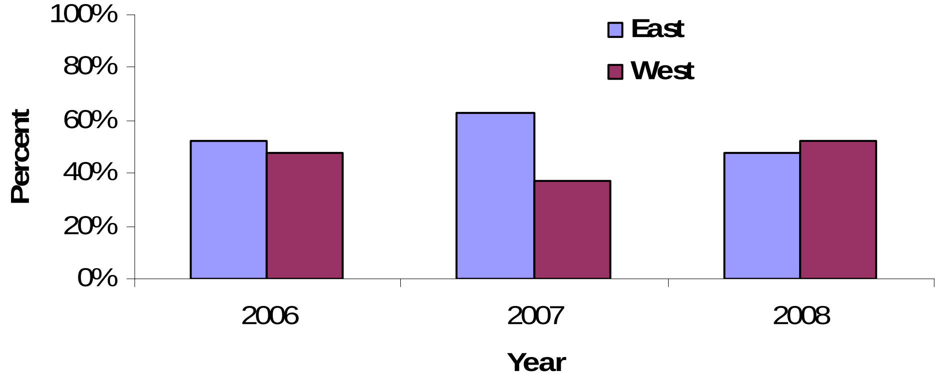


Figure 7. Chinook salmon passage location at Zosel Dam for 2006 through 2008. 2006 data from Johnson et al. (2007) and 2007 data from Johnson et al. (2008).

In 2008, Spring Chinook salmon were initially observed on 30 June (Figure 8) Summer/Fall Chinook salmon were initially observed on 4 August and the last fish was detected on 21 November (Figure 8). The primary mode of passage occurred 4 October through 16 October when almost 69% of the total run passed the dam. Summer/fall Chinook passage peaked with 28 fish observed on both 5 and 8 October.

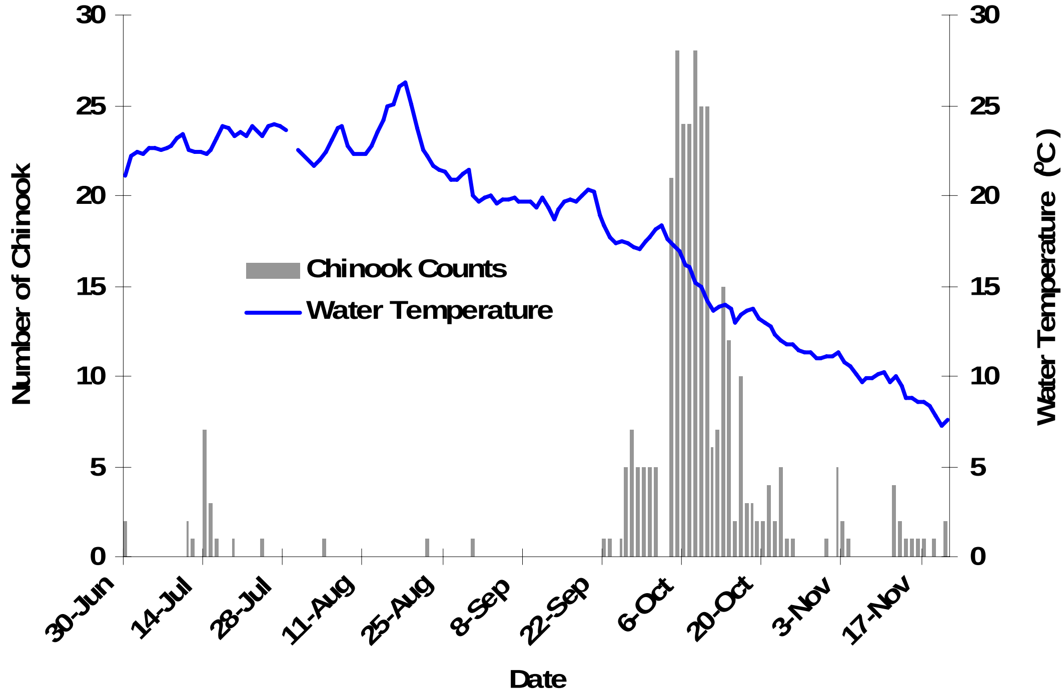


Figure 8. Adult Chinook salmon run timing based on video counts at Zosel Dam from 30 June through 21 November, 2008. Fish passing prior to 25 July were classified as spring run and fish passing after 24 July were classified as summer/fall run. Mean daily water temperature from the USGS gauge at Oroville, WA is also shown.

Hourly passage counts of summer/fall Chinook salmon indicate a slight diel pattern. Summer/fall Chinook passage remained generally low from 1900 to 0600 hours relative to other hours of the day (Figure 9, Table 4). Hourly passage peaked during 0800, and 1600 hours. A two-sample *t* test (Zar 1984) of the hypothesis that the mean number of summer/fall Chinook passing in 2008 during light hours (0700 through 1700) was equal to the mean number of summer/fall 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 summer/fall Chinook passage during day and night hours. The pattern of generally higher counts during the day than at night seen in 2008 was also observed in previous years (Figure 9).

Table 4. Total counts and percent frequency values for hourly data of summer/fall Chinook and sockeye salmon passage based on video counts at Zosel Dam in 2008.

	Summmer/Fall Chinook		Sockeye	
Hour	Count	Percent	Count	Percent
6	6	1.9%	4,437	5.7%
7	14	4.5%	3,523	4.5%
8	25	8.1%	3,604	4.6%
9	16	5.2%	3,906	5.0%
10	23	7.4%	4,366	5.6%
11	18	5.8%	6,586	8.5%
12	16	5.2%	5,082	6.6%
13	24	7.7%	3,510	4.5%
14	24	7.7%	2,717	3.5%
15	20	6.5%	1,464	1.9%
16	25	8.1%	1,119	1.4%
17	10	3.2%	1,074	1.4%
18	10	3.2%	960	1.2%
19	5	1.6%	737	1.0%
20	5	1.6%	577	0.7%
21	6	1.9%	950	1.2%
22	4	1.3%	1,481	1.9%
23	5	1.6%	3,174	4.1%
0	13	4.2%	3,444	4.4%
1	5	1.6%	3,864	5.0%
2	10	3.2%	4,065	5.2%
3	13	4.2%	3,635	4.7%
4	7	2.3%	6,297	8.1%
5	6	1.9%	6,961	9.0%

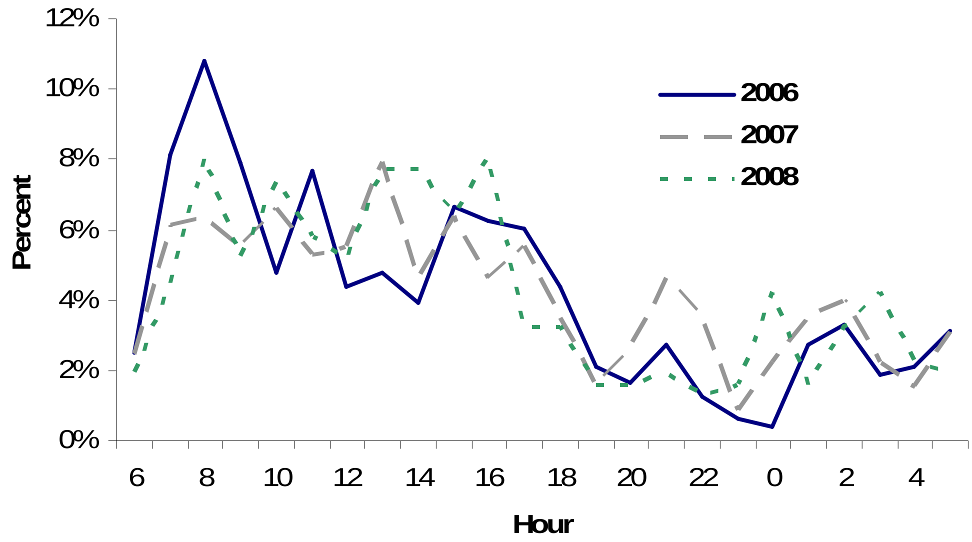


Figure 9. Hourly passage of Chinook salmon at Zosel Dam in 2006 through 2008. 2006 data from Johnson et al. (2007) and 2007 data from Johnson et al. (2008).

Sockeye Salmon

A total of 81,260 adult sockeye salmon were estimated to pass upstream through Zosel Dam in 2008; all observed fish with adipose fins (Table 2). Enumeration estimates account for the number of estimated fish missed during video system downtime and estimated fallback based on literature values (Bjornn et al. 2000b). Sockeye showed a strong preference for passing the dam on the east bank as 73% of all sockeye passage events occurred there (Table 3), a result consistent across the last three years (Figure 10). Deeper deployed cameras detected 99.97% of all sockeye passage events in 2008, which compares well with deeper camera detections of 99.8% in 2006 (Johnson et al. 2007) and 2007 (Johnson et al. 2008).

Figure 10. Sockeye salmon passage location at Zosel Dam for 2006 through 2008. 2006 data from Johnson et al. (2007) and 2007 data from Johnson et al. (2008).

Sockeye salmon were first detected at Zosel Dam on 17 February and last observed on 6 December (Figure 11). After the initial detection in February, the sockeye run arrived at Zosel Dam on 26 June. An initial primary mode of passage occurred from 3 through 16 July when 72% of the total sockeye run passed the dam. Smaller pulses of passage occurred from 16 July through 9 August when 25% of the run was observed to pass the dam. Sockeye passage peaked on 11 July with 11,371 fish.

Hourly passage counts of sockeye salmon at Zosel Dam in 2008 indicate increased passage in early and late morning periods relative to other hours of the day (Table 4, Figure 12). A two-sample *t* test of the hypothesis that the mean number of sockeye passing in 2008 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) could not be rejected indicating no significant difference in sockeye passage during night and day periods. Passage peaked during the 0500 hour, and a secondary peak was observed at 1100; passage was lowest during 1900 and 2000 hours. The hourly pattern of passage observed in 2008 is inconsistent with the trend of increased passage during nighttime hours relative to day time hours observed in 2006 and 2007 (Figure 12).

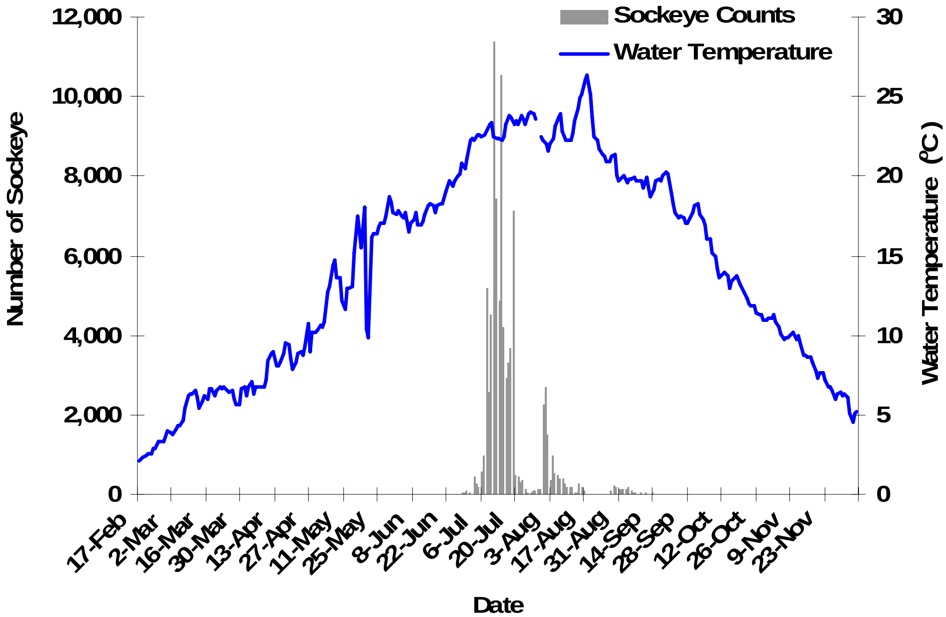


Figure 11. Adult sockeye salmon run timing based on video counts at Zosel Dam from 17 February to 6 December, 2008. Mean daily water temperature from the USGS gauge at Oroville, WA is also shown.

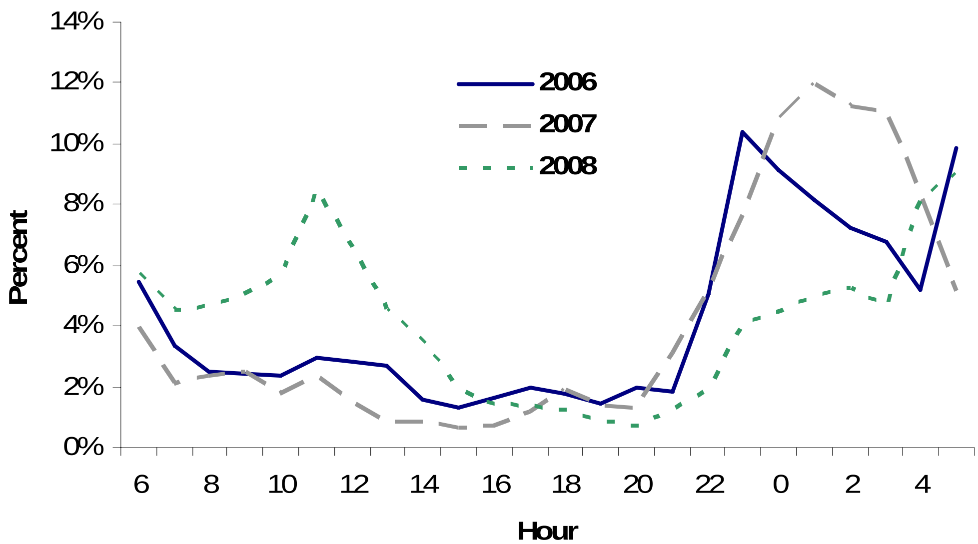


Figure 12. Hourly passage of Sockeye salmon at Zosel Dam in 2006 through 2008. 2006 data from Johnson et al. (2007) and 2007 data from Johnson et al. (2008).

Temperature Effects on Fish Passage

Water temperatures did not appear to negatively impact Chinook passage at Zosel Dam in 2008 as mean daily temperatures ranged between 13 and 17°C during the period of highest passage (Figure 8). Sockeye passage was likely impacted by excessive water temperatures in 2008 as water temperature exceeded 24°C on 23 days during the passage season (Figure 11). The relationship between mean hourly sockeye passage and temperature for the 4 July through 1 August period in which 90% of sockeye passage occurred indicates an inverse trend between temperature and passage (Figure 13).

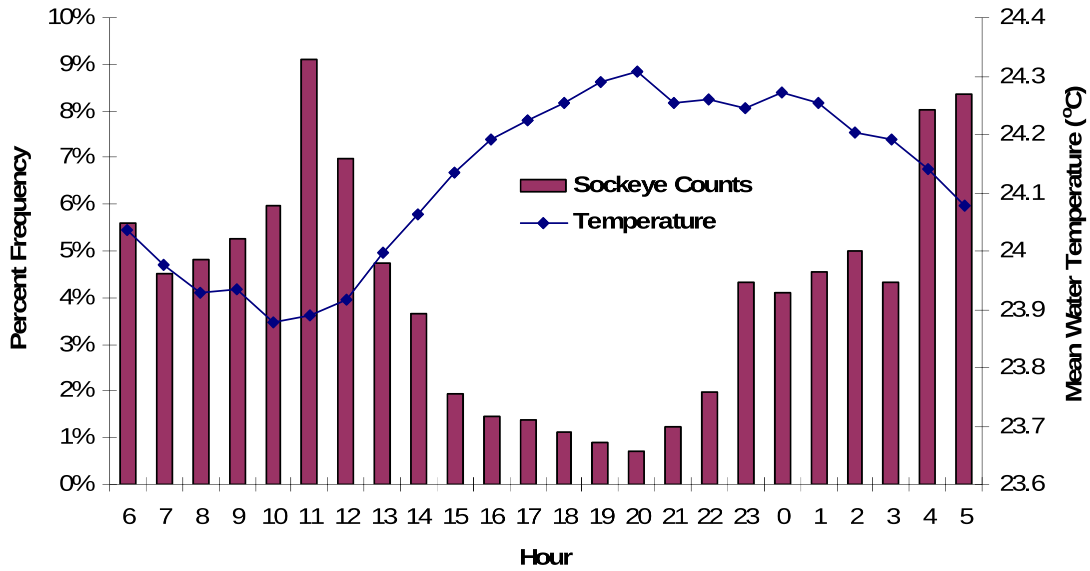


Figure 13. Percent frequency distribution of hourly adult sockeye salmon passage based on video counts at Zosel Dam and mean water temperature in 2008. Data reflect the period 4 July through 1 August.

Non-Target Fish

A total of 21 non-target fish species were observed with the video monitoring system at Zosel Dam in 2008, slightly more species than were seen in 2007 (Table 5). Largemouth bass were the most abundant non-target fish followed by bridgelip suckers and northern pikeminnow in 2008. With the exception of sockeye salmon smolts, largemouth bass was the most abundant non-target species observed in 2007. Similar numbers of steelhead, mountain whitefish, common carp, bluegill, largemouth bass and white crappie were seen in 2007 and 2008. The most disparate counts between species across years were for sockeye salmon smolts (2,931 in 2007 and four in 2008) and bridgelip sucker (one in 2007 and 1,209 in 2008).

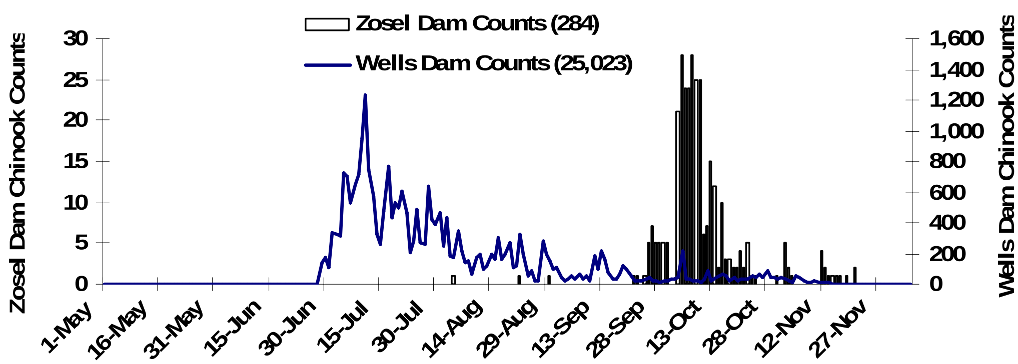
Table 5. List and count of all non-target fish observed at Zosel Dam in 2007 and 2008.

Common Name	2007	2008
Chinook Salmon (jack)	12	2
Chinook Salmon (smolt)	6	17
Steelhead	181	201
Rainbow Trout	86	14
Cutthroat Trout	0	1
Sockeye Salmon (smolt)	2,931	4
Unknown Adult Salmon	13	9
Brook Trout	4	2
Bull Trout	1	1
Mountain Whitefish	19	16
Yellow Perch	1	7
Brown Bullhead	6	45
Yellow Bullhead	0	20
Unknown Catfish	2	0
Common Carp	741	978
Chiselmouth	58	421
Northern Pikeminnow	596	1,091
Peamouth	157	27
Bluegill	249	344
Largemouth Bass	1,277	1,361
Smallmouth Bass	18	168
White Crappie	8	11
Black Crappie	0	2
Bridgelip Sucker	1	1,209
Largescale Sucker	0	4
Unknown Suckers	799	0
Three-spine Stickleback	0	1

DISCUSSION

Run Timing and Relative Abundance

Comparing the 2008 Zosel Dam passage data with the adult counts at Wells Dam (Fish Passage Center 2009) allows for better understanding of spawner distribution and run timing dynamics in the Upper Columbia and Okanogan River basins. Run timing patterns of 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 (22 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. Relative abundance of Chinook salmon at Zosel Dam in 2008 comprised 1.1% of the total number observed at Wells Dam, a lower proportion than was observed in 2006 (1.7%) (Johnson et al. 2007) and in 2007 (2.7%) (Johnson et al. 2008). Less than 20 Chinook salmon were observed on spawning grounds in Canadian waters in 2008 (Carla Davis, Okanagan Nation Alliance Fisheries Department, pers. comm.).



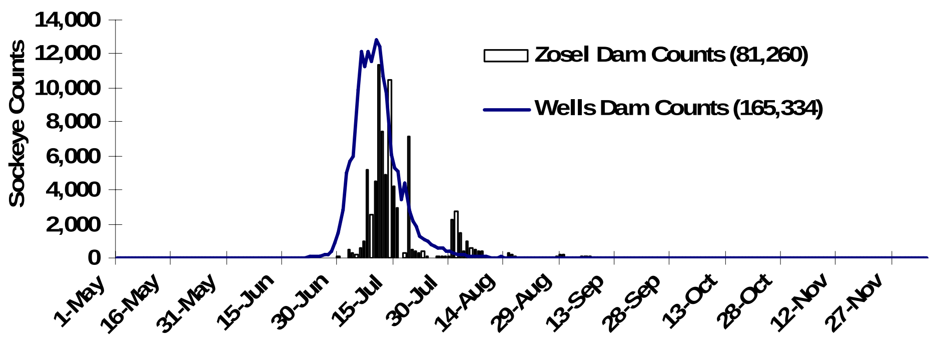


Figure 14. Run timing of Chinook and sockeye salmon at Zosel Dam on the Okanogan River and Wells Dam on the Columbia River in 2008. Total count estimates at Zosel Dam include estimates for missed fish during video system downtime and fallback. Note that the Chinook counts for Zosel and Wells Dams have different Y-axes. Wells Dam data from Fish Passage Center Website: http://www.fpc.org/.

Sockeye salmon run timing at Zosel Dam showed two pulses of fish: an initial primary one beginning in the beginning part of July followed by a smaller one in early August (Figure 11). Sockeye passage at Wells Dam was characterized by a bell-shaped run timing pattern centered the second week in July (Figure 14). Peak daily sockeye counts at Zosel Dam did not exceed those observed at Wells Dam, a result contrary to what was observed in 2006 and 2007. A 4-day shift in run timing from Wells to Zosel Dam (10 to 14 July reflects the time period in which 50% of the run had passed the respective dams) occurred. This result indicates major delays in sockeye migration between Wells and Zosel dams did not occur in 2008. Zosel Dam sockeye counts comprised 49% of the total number observed at Wells Dam, a smaller proportion than what was seen in 2006 (87%) and in 2007 (80%). The relative abundance estimate for sockeye passing Zosel Dam compares favorably with the peak live plus dead estimate of 72,598 spawning sockeye based on spawning ground surveys in the Upper Okanagan River in 2008 (Shala Lawrence, Okanagan Nation Alliance Fisheries Department, pers. comm.).

Diel Passage

Patterns of hourly passage at Zosel Dam differed between Chinook and sockeye salmon in 2008. Chinook passage showed a slight but not significant increase in daytime hours relative to nighttime hours in 2008 and in each of the last two years (Figure 9). Sockeye passage did not show the strong pattern of increased passage at night relative to during the day that was observed in each of the last two years (Figures 12 and 13). The increase in sockeye passage during daytime hours relative to previous years may be related to the timing of the sockeye run through Zosel Dam. A majority of the run (98%) passed the dam prior to the occurrence of peak water temperatures in mid August (Figure 11). Mean hourly passage showed an inverse relationship with mean hourly temperature in 2008 (Figure 13), whereas in previous years, highest hourly passage occurred during hours of decreasing water temperature (Johnson et al. 2007; 2008).

Hydroacoustic sampling conducted at Zosel Dam in 1991 indicated that sockeye passage was dissimilar to what was observed in 2008 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 2008 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 2008. 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

In 2008, negative impacts of water temperature on fish passage were not observed as demonstrated by the lack of large delay between the sockeye passage at Wells and Zosel dams (Figure 14). Only four days separated the timing in which 50% of the run had had passed the respective dams, and peak daily water temperatures occurred after 98% of the sockeye had passed the dam (Figure 11). Mean daily water temperatures were generally cooler when fish were passing Zosel in 2008 as compared with 2007 (Figure 15), when excessive water temperatures likely contributed to delays in migration. This delay in migration in some years 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).

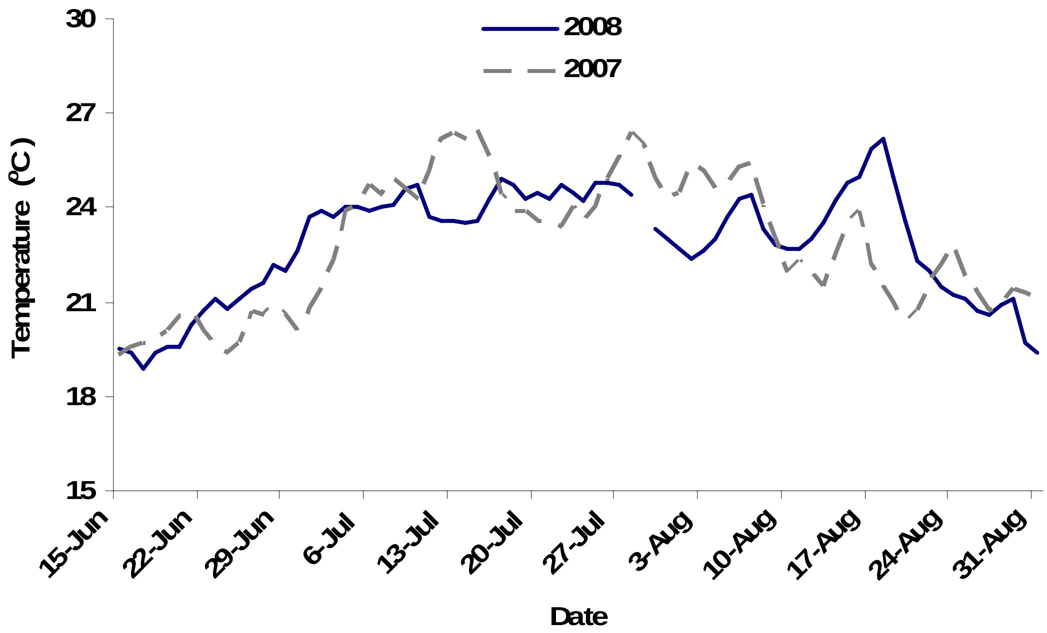


Figure 15. Mean daily water temperature from 15 June through 31 August for 2007 and 2008. Water temperature data from the USGS gauge at Oroville, WA.

Lateral and Vertical Passage Distributions

Sockeye salmon passage was skewed toward the east bank which indicates a preference for passing on the east side of the dam (Table 3). This result is consistent with what was observed in 2006 (Johnson et al. 2007) and in 2007 (Johnson et al. 2008). 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 or sockeye salmon in 2008 since the days in which the gates were open greater than 12” were limited during the period in which the majority of fish passage occurred (Figures 6, 8 and 12).

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; 2008). 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 2008 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). Because no recent monitoring had occurred, 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 occurred over the last several years 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 in 2008.

Non-target Species

Video counts of non-target fish in 2008 were similar to counts of some species and very different for other species as compared with counts in 2007 (Table 5). Differences in counts across years do not necessarily reflect differences in abundance in resident species. Movement direction is not noted for resident species observations, so it is assumed that many of the counts likely reflect the same individuals moving upstream and downstream through the video chutes. Large differences in counts across years (e.g., bridgelip sucker with one observation in 2007 and 1,209 in 2008) likely suggest an improvement in species identification from 2007 to 2008. In 2007, 799 observations were made of an unidentified sucker species. Based on 2008 counts, these fish were probably bridgelip suckers.

RECOMMENDATIONS

Based on the ongoing efforts and results from this video-based study and the ones conducted in previous years (Johnson et al. 2007; 2008), 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 and few adult salmonids are present anyway.

Accounting for Downstream Fish Passage

Downstream fish passage events in the video chutes at Zosel Dam have not been reported to date. Instead, downstream migrating fish detections were accounted for by modifying the total hourly count for each species before entry into the database. In future monitoring of salmonid passage at Zosel Dam, all instances of downstream movement through the video chutes should be recorded and hourly upstream estimates of fish passage. These data will allow for the assessment of potential trends in downstream movement that would lead to a better understanding of fish passage dynamics at Zosel Dam.

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. To account for fallback of salmonids at Zosel Dam with respect to total enumeration estimates, literature values of proportional fallback for salmonid species at other Columbia River dams (e.g., Bjornn et al. 2000b) will be applied to total upstream video counts in future monitoring studies.

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 2008. 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 in Johnson et al. (2008) 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. The effects of high water temperatures on fish passage in 2008 did not occur given the relatively moderate water temperatures observed. Nonetheless, 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 when high water temperatures negatively impact fish passage 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.

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