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Evaluate Factors Limiting Columbia River Gorge Chum Salmon Populations

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Prepared By:

Jeffrey Johnson
Jennifer Poirier
Tim Whitesel

U.S. Fish and Wildlife Service
Columbia River Fish Program Office
Habitat and Population Assessment Team
1211 S.E. Cardinal Court, Suite 100
Vancouver, Washington 98683 USA

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Abstract

Adult and juvenile chum salmon and spawning habitat were monitored November 2005 through May 2006 to evaluate potential factors affecting chum salmon production in Hardy Creek and Hamilton Springs. Adult spawning ground surveys were conducted November 2005 through January 2006. Total adult chum carcasses sampled for biological information was 66 in Hardy Creek and 81 in Hamilton Springs.

Adult abundance estimates were calculated using the area-under-the-curve method assuming a 10-day residence time and 100% visibility. Population estimates in Hardy Creek and Hamilton Springs were 98 and 157 respectively. A second estimate of adult abundance was calculated using a carcass mark recovery method. Estimated abundance in Hardy Creek based on recovery of marked chum salmon carcasses was 73, with a 95% confidence interval of 70-76 fish. Estimated abundance in Hamilton springs was 84, with a 95% confidence interval of 83-82 fish. We are uncertain which method produced more accurate estimates. Age structure of fish in both streams was dominated by age 4 individuals (>70%).

First capture of Juvenile chum salmon in emigration traps occurred 9 February and 15 February in Hardy Creek and Hamilton Springs, respectively. Estimates of abundance (95% confidence interval) for juvenile chum salmon were 101,849 (90,700-117,259) for Hardy Creek and 103,979 (69,639-134,059) for Hamilton Springs.

Juvenile chum salmon were collected from two emergence traps in Hardy Creek and three traps in Hamilton Springs. Temperature units (TUs °C)

accumulated when 50% of all fish were captured was estimated for the traps (828-1195 TUs).

Introduction

In the Pacific Northwest, chum salmon (*Oncorhynchus keta*) abundance is severely depressed over much of its historical range. Although there are no historic run-size data for chum salmon in the Columbia River basin, maximum historical commercial fishery landings were reported to be as high as 425,000 fish in 1942 (Washington Department of Fish and Wildlife (WDFW), and Oregon Department of Fish and Wildlife (ODFW) 2000). Harvest declined to about 10,000 fish annually during the mid 1950s (WDFW, and ODFW 2000). On 24 May 1999, NOAA-Fisheries (formally the National Marine Fisheries Service (NMFS)) listed the Columbia River chum salmon Evolutionary Significant Unit as threatened under the Endangered Species Act (NMFS 1999).

Historically, Columbia River chum salmon spawned as far upstream as the Walla Walla and Umatilla River drainages (Nehlsen et al. 1991). Currently, natural spawning of wild fish appears to be primarily limited to tributaries and some mainstem areas downstream of Bonneville Dam. Although spawning has been documented in many lower Columbia River tributaries, substantial numbers of chum salmon regularly spawn in three general areas. The Grays River drainage (RKm 34), a lower Columbia River tributary, Woods Landing/Rivershore (RKm 182) a mainstem area just upstream of the I-205 bridge, and finally Hardy Creek, Hamilton

Creek, and the Columbia River side channel adjacent to Pierce and Ives islands (RKm 231). Hardy Creek and Hamilton Springs harbor the most upstream population of chum salmon at RKm 229-231 approximately 3km downstream of Bonneville Dam.

The United States Fish and Wildlife Service (USFWS), Columbia River Fisheries Program Office (CRFPO), has monitored adult and juvenile chum salmon in Hardy Creek since 1997. In 1999, Bonneville Power Administration provided funding to the CRFPO to monitor chum salmon in Hardy Creek and Hamilton Springs. Adult chum salmon in these streams have been monitored during the fall by operating adult weirs, conducting spawning ground surveys, and investigating fish movement using radio telemetry. Juvenile chum salmon have been monitored during the spring by operating fyke nets to trap emigrating fish.

The goal of this ongoing project is to monitor Columbia River gorge chum salmon populations throughout their freshwater life history to develop a better understanding of population staus and factors that may limit chum salmon production primarily in Hardy Creek and Hamilton Springs. We propose three objectives to address this goal: 1. Estimate abundance of adult and juvenile chum salmon in Hardy Creek and Hamilton Springs, 2. Determine trend in abundance in Hardy Creek and Hamilton Springs, 3. Describe behavioral and biological characteristics of spawning adult and juvenile chum salmon and calculate adult-to-fry ratio in Hardy Creek and Hamilton Springs, 4. Examine habitat features associated with redds in Hardy Creek and Hamilton Springs, and investigate relations among juvenile survival, emergence time, and habitat features.

Study Area

Hardy Creek

Hardy Creek is a 6 km long tributary of the Columbia River located downstream of Bonneville Dam at Rkm 229. A majority of the Hardy Creek watershed is public land (primarily Washington State Parks) with a small private holding bordering State Route 14. The lower 2 km of the stream is located on Pierce National Wildlife Refuge. Chum salmon access to Hardy Creek (Figure 1) is restricted to the lower portion of the stream because a railroad culvert forms an impassable barrier approximately 2.1 km upstream from the mouth. In addition, habitat upstream of the culvert is inadequate for spawning due to steep gradient (2-10%) and unsuitable substrate composition. The lower Hardy Creek channel was re-routed in the early 1900s and dredged creating a relatively straight, entrenched channel. Every 2-5 years, Hardy Creek experiences high water runoff and, in addition, detrimental backwater effects from the Columbia River periodically deposits fine sediments on available spawning habitat in lower Hardy Creek (USFWS unpubl. data). The lower 2.1 km of Hardy Creek was monitored during this project.

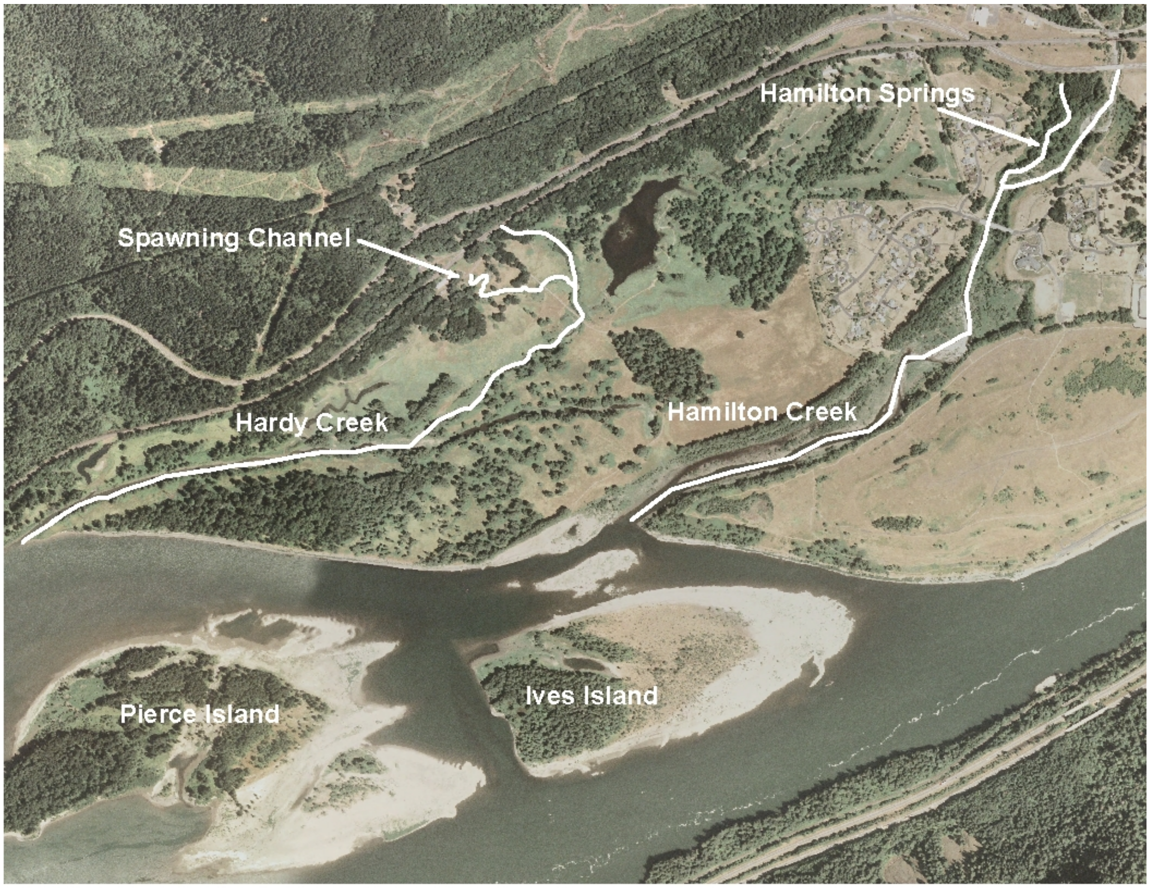

Figure 1. Area map of Hardy and Hamilton Creeks, and Pierce and Ives islands.

In 1996, the USFWS undertook emergency habitat restoration actions to mitigate for flooding that degraded essentially all spawning habitat available to chum salmon in Hardy Creek. The flood scoured redds and deposited sediments that likely suffocated embryos. The USFWS stabilized eroding banks, restored riparian vegetation, and exposed previously buried spawning areas along a 0.64 km reach (UFFWS unpublished). Chum salmon have been successfully spawning in the lower section of Hardy Creek since these actions were taken.

During August-September 2000, the CRFPO constructed an artificial spawning channel adjacent to Hardy Creek. The intent of the channel was to improve chum salmon production by increasing existing spawning habitat and providing habitat that was not as susceptible to flooding from Columbia River backwater and high flow events. Because water is supplied to the channel by diverting a portion of the surface flow in Hardy Creek, its operation is limited to normal and/or high water years.

Hamilton Creek and Hamilton Springs

Hamilton Springs is a 530 m long artificial spawning channel originally constructed in the early 1960s adjacent to Hamilton Creek (a tributary of the Columbia River located downstream of Bonneville Dam at Rkm 231) in the town of North Bonneville (Figure 1). Natural springs provide water to Hamilton Springs, which typically flows during fall through late spring and are dry during summer and early fall. The majority of chum salmon spawning in the Hamilton Creek drainage use Hamilton Springs. The USFWS monitored chum salmon only in Hamilton Springs for this project.

Methods

Spawning ground surveys

Spawning ground surveys were conducted in Hardy Creek beginning on 3 November 2005. Surveys were performed two times per week for a six week period (7 November through 16 December 2005), and one time per week for a three week period (3 November, 22 December and 27 December 2005). Partial surveys were conducted during a two week period in early January (3 January through 13 January 2006), due to Columbia River backwater making the lowest two reaches of Hardy Creek inaccessible. Spawning ground surveys concluded on 13 January 2006. Spawning ground surveys were conducted in Hamilton Springs beginning on 3 November 2005. Surveys were performed two times per week for an eight week period (7 November through 16 December 2005, and 27 December through 5 January 2006), and one time per week for a two week period (3 November and 22 December 2005). Spawning ground surveys concluded on 5 January 2006. Surveyors walked the stream along bank margins enumerating live chum salmon, carcasses, and documented areas of spawning activity. Care was taken to avoid walking in the stream channel so as not to disturb spawning activity. All observed chum salmon carcasses were enumerated and inspected for tags or marks. Biological information collected from each new (previously unsampled) carcass included sex, fork length, postorbital-hypural length, percentage spawned, and scales for age analysis. New carcasses were marked with a single uniquely identifiable plastic tag (varying in color, shape, and number) under each operculum, and placed back into the stream channel for a carcass tag mark-recapture study. Previously sampled chum carcasses were inspected for tags and condition. Carcasses in good condition (i.e., surveyor still able to positively identify species) were sampled for carcass tag information and returned to the creek in the same location they were found. Chum carcasses in poor condition (i.e., carcass very decomposed) were sampled for carcass tag information, and the tags and tail of the carcass removed to prevent surveyors from sampling the fish again during subsequent surveys.

The physical location of a carcass in or along the stream channel may affect a surveyor’s ability to recover the carcass, ultimately influencing abundance estimates. To investigate how or if initial carcass location potentially biases carcass recovery, a sub-sample of new chum carcasses (one in five) were biologically sampled, marked with a uniquely identifiable habitat study tag (individually numbered pink Peterson disk tags), and placed in one of four randomly selected habitat types. The four possible habitat types included: north channel, south channel, mid-channel, and pool. When a previously sampled habitat study carcass was found, carcass tag information was recorded (including current location of carcass), and the carcass was returned to the creek in the same location it was found. Surveyors continued to recover and record information from habitat study carcasses until the carcass was too decomposed to identify at which time both tags and the tail of the carcass was removed to prevent the fish from being sampled again during later surveys.

Daily totals of live chum salmon enumerated during spawning ground surveys were used to estimate total adult abundance using trapezoidal approximation of the area-under-the-curve method (Hilborn et al. 1999). The number of live chum salmon observed during each survey date was used to calculate “fish-days”, and divided by stream residence time to estimate abundance. Residence time was assumed to be 10 days (see Ames 1982). A second estimate of adult abundance was calculated using the Jolly-Seber model based on mark-recapture of chum salmon carcasses, wherein recovery of marked carcasses were considered losses upon recapture. Analyses of mark-recapture data were performed using POPAN-6 (Arnason et al. 1998) following the approach by Rawding and Hillson (2003).

Redd characterization

Chum salmon spawning grounds were monitored one or two times per week November-December 2005 to identify chum salmon redds. One or two surveyors stood along bank margins and observed groups of live chum salmon to record spawning activity. Time of observation ranged from 5 to 30 minutes depending on digging activity. A redd was designated definite if a female was observed actively digging a nest. A redd was designated possible if a female was near a fresh dig (within approximately 3 meters), but not actively digging. The date and location of all definite and possible chum salmon redds were recorded and geo-referenced.

Chum salmon spawning habitat was characterized in Hardy Creek and Hamilton Springs in December 2005. Redd measurements were collected at identified (definite and possible) redd locations in Hamilton Springs and Hardy Creek. Measurements included water depth at the upstream edge of the redd's depression, bottom (at substrate) and mean water column velocities at the upstream edge of the depression, total redd length from upstream edge of depression to downstream edge of tail spill, maximum redd width, water temperature in degrees Celsius taken directly over the birm, and dominant and sub-dominant substrate type. Surveyors visually inspected the surface of the redd and assigned dominant and sub-dominant substrate type based on six Wentworth substrate size classifications.

Comparable habitat measurements such as depth, bottom and mean water column velocities, and substrate classification were also recorded at randomly selected locations lacking redds (i.e., non-use points). Non-use sites were selected using random number table. The table was comprised of two columns of randomly generated numbers (0-9). A single surveyor stood on the left bank margin nearest to a known use site (i.e., redd). The first column number determined whether the surveyor moved upstream or downstream. The second column number indicated the number of paces to walk in the channel. If the surveyor ended in a location that was not within the wetted channel, or in a known spawning area, the surveyor returned to the beginning position on the bank and new set of random numbers was selected from the table.

Surveyors also collected stream subtrate for composition analysis at use (i.e., sites identified as definite or possible redds) and randomly selected non-use locations in Hardy Creek and Hamilton Springs. Samples of surface and subsurface substrate layers were collected using a McNeil gravel core sampler. The McNeil sampler consists of a 15x10-cm cylinder and an attached basin that is used to trap sediments and suspended fines within a wetted stream channel. Sampling methodology followed that set forth by the Resource Information Standards Committee (1997).The McNeil sampler was inserted into the substrate approximately 15 cm. All material inside the cylinder was removed by hand and placed in the larger basin. Suspended fines were collected by inserting the plunger into the bottom of the cylinder to create a seal. The sampler was then lifted from the streambed with the gravel and water retained inside and emptied into a bucket. Wet samples were allowed to settle for 24 hours before decanting the overlying water. Substrate samples were dryed, sorted and weighed. Substrate processing methodology followed that described in ASTM D422-63 (2002) Standard Test Method for Particle-Size Analysis of Soils. Substrate samples were sorted using brass W.S. Tyler sample sieves with mesh of 38.1mm, 2mm, and 125μm. Samples collected from known use locations were also sorted through two additional sieves (4mm and 1mm). The volume of material collected by each sieve was weighed according to sieve mesh size and the percent composition of each particle size range was calculated.

Measurement of environmental variables

Stream discharge and intergravel conditions were recorded November 2005 through May 2006 to monitor environmental conditions in each stream throughout the season. Stream discharge was monitored one time per week at three locations in Hardy Creek and at a single location in Hamilton Springs. A minimum of 20 cross-sectional depth and flow measurements were taken using a top-setting rod and Marsh-McBirny flow meter to calculate total stream discharge. Piezometers and temperature loggers were installed on both streams to characterize intergravel water conditions relative to surface water. Four piezometers were installed on 2 November in Hardy Creek at locations encompassing the reaches used by spawning chum salmon. Two piezometers were installed on 2 November in Hamilton Springs, one at the upper and another near the lower portion of the channel. Subsurface water samples were drawn from the piezometers one time per week 8 November through 13 April. Temperature, dissolved oxygen, and conductivity of the samples were compared to that of surface water in the streams adjacent to the piezometers. A single temperature logger was attached to each piezometer immediately above the substrate. Each logger was programmed to record water temperature every 4 hours from November 8 until May 13 in Hamilton springs and June 28 in Hardy Creek.

Juveniles

Juvenile fyke nets and traps were installed on Hardy Creek and Hamilton Springs on 8 February 2006 to capture emigrating juvenile chum salmon. The fyke net in Hamilton springs was anchored to the stream bottom with leads to the stream margins, while the fyke net in Hardy Creek was mounted on a floating platform. The live boxes for the traps were inspected daily. Captured fish were identified by species, enumerated, examined for external marks and released downstream below the trap.

To estimate the abundance of juvenile chum salmon emigrating from each stream, up to 200 chum salmon were externally marked each week, to estimate weekly trapping efficiency. The fish were marked with Bismark brown. Prior to marking, the fish were individually anaesthetized in a 0.3 g/l solution of MS-222, and fork length was measured. Once recovered, the chum salmon were immersed in a 0.1g/l solution of Bismark brown for 30 minutes. Immediately following the 30 minute marking period, all marked fish were released at a designated site upstream of the trap. Fish marked in Hamilton Springs were released at the top of the spawning channel approximately 250 m upstream of the trap. Fish marked in Hardy Creek were released approximately 700 m upstream of the trap. Weekly trapping efficiency was estimated as the proportion of marked fish subsequently recaptured during a seven-day marking period. The total number of unmarked, newly marked, and mark recaptured chum salmon within marking periods were compiled and analyzed using a Stratified Population Analysis System (SPAS) (Arnason et al. 1996) program to produce an abundance estimate and associated measures of confidence for each stream.

Intergravel conditions and juvenile emergence

Juvenile emergence traps were installed beginning 1 December on three chum salmon redds in Hamilton Springs, and on two chum salmon redds in Hardy Creek. Live boxes on each emergence trap were inspected daily beginning 8 February on both creeks. All captured fish were identified by species, enumerated, and released downstream of the emergence trap. Crews were unable to access Hardy Creek emergence traps after 5 April due to deep water resulting from Columbia River backwater. Live boxes were forcibly removed to allow any remaining juvenile chum salmon a means of escape. As a result of this premature removal, Hardy Creek juvenile emergence results are presented through the last day of functional operation (i.e., 5 April).

A piezometer was installed adjacent to each emergence trap at estimated embryo pocket depth (approx. 30 cm), to investigate the relationship between emergence timing and environmental conditions. Water temperature, dissolved oxygen, and conductivity of the water samples drawn from each piezometer were measured using a YSI meter. Water temperature was logged every 4 hours. A single temperature logger was attached to each piezometer and inserted into the substrate at estimated embryo pocket depth to monitor temperature during incubation and emergence so that accumulated temperature units (i.e., the sum of mean daily water temperature above 0°C) could be estimated. Temperature units began accumulating on the date of embryo deposition recorded by surveyors during spawning ground observations.

Results

Spawning Ground Surveys

Seventeen spawning ground surveys were conducted between 3 November and 13 January. Chum salmon were first observed in Hardy Creek on 3 November (Figure 2). Peak counts of 52 live chum salmon occurred on 2 December. Live chum salmon were last observed 3 January 2006. Chum salmon were first observed in Hamilton Springs on 7 November (Figure 3). Peak counts of 90 live chum salmon occurred on 23 November. Live chum salmon were last observed 30 December.

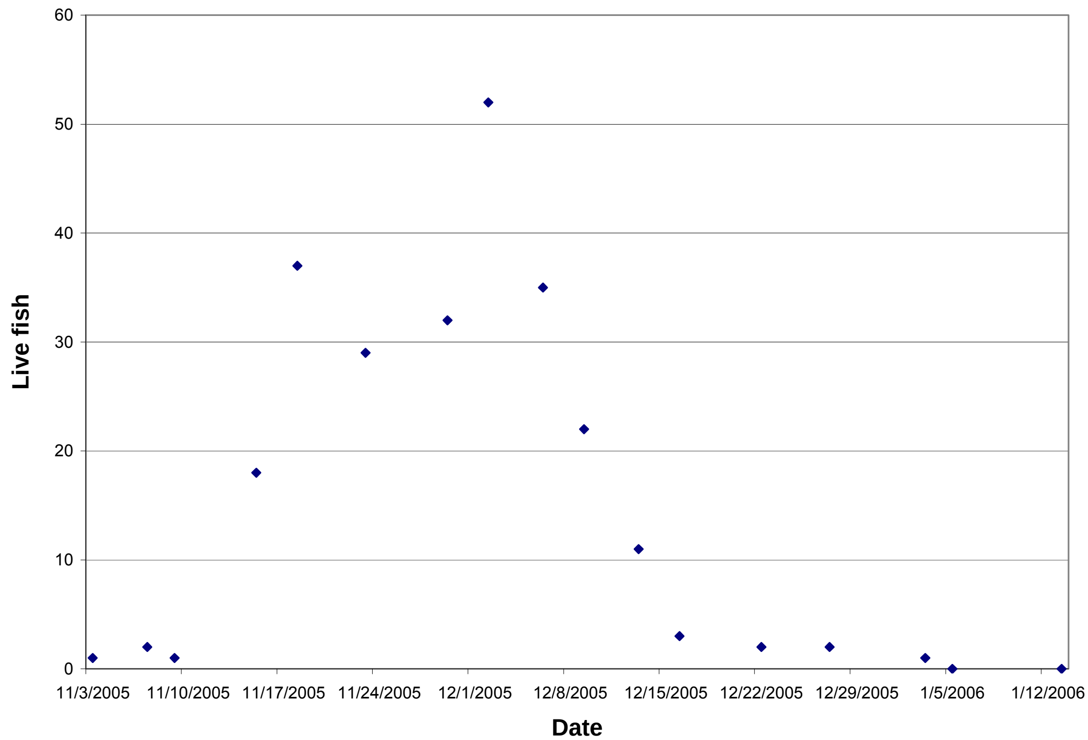

Figure 2. Number of live chum salmon observed at Hardy Creek during 3 November 2005 through 13 January 2006.

Sixty-six chum salmon carcasses were sampled in Hardy Creek during surveys. Surveyors located an additional 3 chum salmon carcasses but were unable to collect biological information because of the advanced state of decomposition. Of the 66 chum salmon carcasses sampled for biological information, 50% (33 fish) were males while 50% (33 fish) were females. Ages were determined for 64 individuals, and ranged from ages 3 through 5 (Table 1). Seventy percent of male chum salmon and 77% of female chum salmon were age 4 individuals. Estimated abundance of adult chum salmon in Hardy Creek was 98 individuals, calculated by the area-under-the-curve method assuming 10-day residence time and 100%

detection. Of the 66 tags placed on chum carcasses, 89% (59 tags) were subsequently recovered. Estimated abundance based on recovery of marked chum salmon carcasses was 73, with a 95% confidence interval of 70-76 individuals.

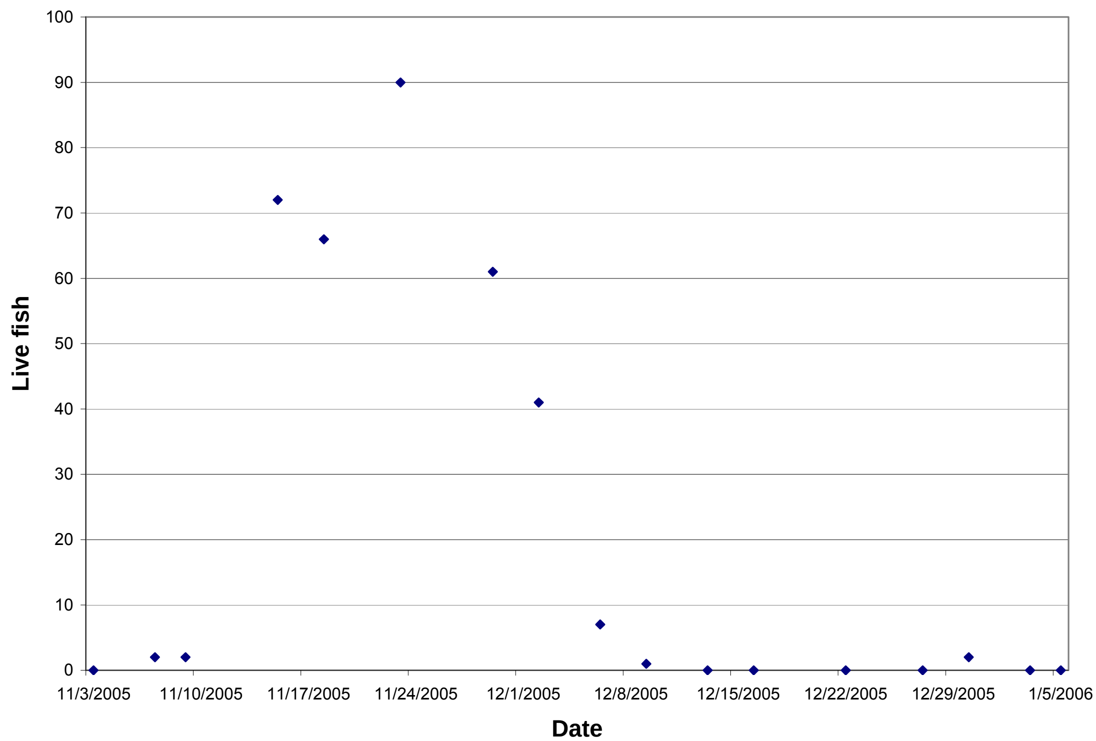

Figure 3. Number of live chum salmon observed at Hamilton Springs during 3 November 2005 through 5 January 2006.

Eighty-one chum salmon carcasses were sampled in Hamilton Springs during spawning ground surveys. Surveyors located an additional 2 chum salmon carcasses but were unable to collect biological information because of the advanced state of decomposition. Of the 81 chum salmon carcasses sampled for biological information, 58% (47 fish) were males while 42% (34 fish) were females. Ages were determined for 80 individuals and ranged from ages 3 through 5 (Table 1). Seventy-eight percent of male chum salmon and 71% of female chum salmon were age 4 individuals.

Table1. Number, mean fork length, and postorbital-hypural length by age and sex of chum salmon carcasses in Hardy Creek and Hamilton Springs 2005, 2006. Standard deviation is presented in parentheses.

Age	Number		Fork Length (mm)		Postorbital-hypural Length (mm)	
	Male	Female	Male	Female	Male	Female
			Hardy Creek			
3	9	6	720.3 (21.3)	658.2 (47.2)	572.4 (32.8)	541.7 (32.6)
4	23	24	791.9 (48.4)	725.3 (31.1)	619.9 (39.7)	600.3 (31.2)
5	1	1	772	760	585	627
			Hamilton Springs			
3	10	8	743.4 (56.5)	656.1 (24.3)	547.6 (37.4)	533.1 (27.3)
4	36	24	802.4 (41.5)	716.3 (44.5)	606.9 (36.8)	584.0 (44.2)
5	0	2	--	742.0 (60.8)	--	592.5 (10.6)

Estimated abundance of adult chum salmon in Hamilton Springs was 157 individuals, calculated by the area-under-the-curve method assuming 10-day residence time and 100% detection. Of the 81 tags placed on chum carcasses, 98% (79 tags) were subsequently recovered. Estimated abundance based on recovery of marked chum salmon carcasses was 84, with a 95% confidence interval of 83-85 individuals.

Carcass recovery

Twelve habitat study tags were placed on chum salmon carcasses in Hardy Creek. Of the 12 tags, 67% were recovered a minimum of one time during subsequent surveys. Habitat study carcasses were recovered one to six times during the season (average three recoveries), and carcass stream life ranged from three to 25 days (average 15 days). Fifty-six percent of recovered carcasses were found in a different stream channel location from their original placement after tagging. Four of the 12 carcasses were never recovered. Two carcasses were originally placed along the south channel in sample reach four (middle Hardy Creek), one carcass was placed mid-channel in sample reach three (upper Hardy Creek), and one carcass was placed in a pool in sample reach five (lower Hardy Creek).

Sixteen habitat study tags were placed on chum salmon carcasses in Hamilton Springs. Of the 16 tags, 100% were recovered at least one time during a subsequent survey. Carcasses were recovered one to five times during the season (average three recoveries), and carcass stream life ranged from seven to 20 days (average 13 days). Ninteen percent of recovered carcasses were found in a different stream channel location from their original placement after tagging.

Redd characterization

A total of eight definite and six possible chum salmon redds were identified during spawning ground surveys in Hardy Creek. Surveyors were unable to collect redd measurements from the majority of redd locations in Hardy Creek due to high water levels from Columbia River backwater. Redd measurements were collected from one definite and two possible chum salmon redds. The most frequent dominant substrate type in use locations was gravel (100% of the sites), and sub-dominant substrate type was fines (67% of the sites). In three non-use locations, the most frequent dominant substrate type was sand/silt (67% of the sites), and subdominant substrate type was gravel (67% of sample sites) (Table 2). Average (SD) bottom and mean column velocities in use locations were 1.57 (0.40) and 3.02 (0.97) ft/s, respectively, and bottom and mean column velocities in non-use locations were 0.31 (0.41) and 0.89 (1.03) ft/s, respectively. Average water depth at use locations was 1.47 (0.40) ft, and average depth at non-use locations was 1.4 (0.56) ft.

A total of 13 definite and eight possible chum salmon redds were identified during spawning ground surveys in Hamilton Springs. The most frequent dominant substrate type was gravel (86% of the sites), and sub-dominant substrate type was small cobble (67% of the sites). In 21 randomly selected non-use locations, the most frequent dominant substrate type was sand/silt (57% of the sites), and subdominant substrate type was gravel (38% of the sites) (Table 3). Average bottom and mean column velocities in use locations were 0.33 (0.35) and 0.70 (0.53) ft/s, respectively, while bottom and mean column velocities in non-use locations were 0.23 (0.46) and 0.48 (0.65) ft/s, respectively. Average water depth at use locations was 1.50 (0.40) ft, and average depth at non-use locations was 1.37 (0.47) ft.

Table 2. Percentage of locations in each substrate class for dominant and sub-dominant substrates at redds (use areas) and randomly selected sites (non-use areas) in Hardy Creek, 2006 (n = 3).

Substrate Type	**Use Areas**		**Non-use Areas**	
	Dominant Substrate	Sub-dominant Substrate	Dominant Substrate	Sub-dominant Substrate
Sand/Silt (≤4 mm)	0%	67%	67%	0%
Gravel (> 4-75 mm)	100%	0%	33%	67%
Small Cobble (>75-150 mm)	0%	33%	0%	33%
Large Cobble (>150-300 mm)	0%	0%	0%	0%
Boulder (>300 mm)	0%	0%	0%	0%

Seven use and 12 known non-use sites were selected for substrate size analysis in Hardy Creek. Samples extracted from non-use locations were composed of 9-72% sand/fines (average 28%), 27-64% gravel (average 53%), and 0-43% cobble (average 19%). Samples taken from known use locations were composed of 8-25% sand/fines (average 14%), 45-82% gravel (average 62%), and 7-46% cobble (average 24%) (Figure 4). Non-use substrate has a significantly higher proportion of sand/fines than that of redds (P=0.031, Mann-Whitney Rank Sum Test). Proportions of gravel and cobble were not significantly different between redds and non-use areas.

Table 3. Percentage of locations in each substrate class for dominant and sub-dominant substrates at redds (use areas) and randomly selected sites (non-use areas) in Hamilton Springs, 2006 (n = 21).

Substrate Type	Use Areas		Non-use Areas	
	Dominar Substrat	Sub-dominant Substrate	Dominant Substrate	Sub-dominant Substrate
Sand/Silt (≤4 mm)	5%	19%	57%	29%
Gravel (> 4-75 mm)	86%	9%	24%	38%
Small Cobble (>75-150 mm)	9%	67%	19%	19%
Large Cobble (>150-300 mm)	0%	0%	0%	0%
Boulder (>300 mm)	0%	5%	0%	14%

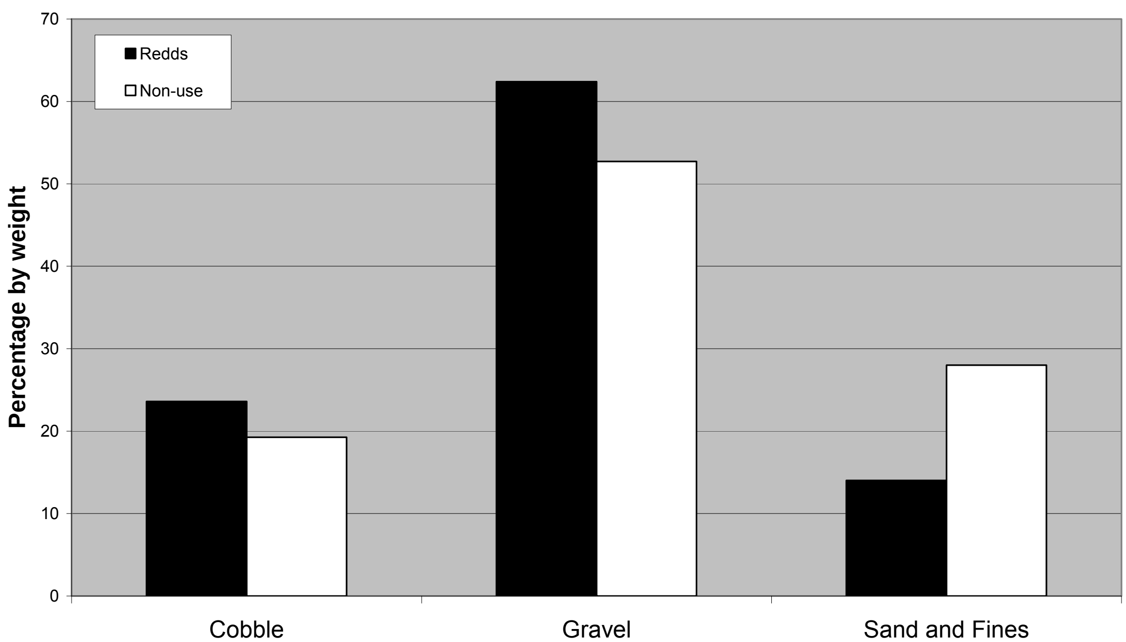

Figure 4. Hardy Creek average percent of substrate categories (by weight) in use and non-use locations, 2006.

Thirteen use and 13 non-use sites were selected for substrate size distribution analysis in Hamilton Springs. In general, samples collected from non-use areas were composed of 0-90% sand/fines (average 18%), 8-100% gravel (average 77%), and 0-24% cobble (average 5%). Substrate samples collected from known use locations were composed of 0-18% sand/fines (average 6%), 67-99% gravel (average 83%), and 0-28% cobble (average 11%) (Figure 5).). Non-use substrate had a significantly higher proportion of sand/fines than that of use areas (P=0.021, Mann-Whitney Rank Sum Test). Proportions of gravel and cobble were not significantly different between redds and non-use areas.

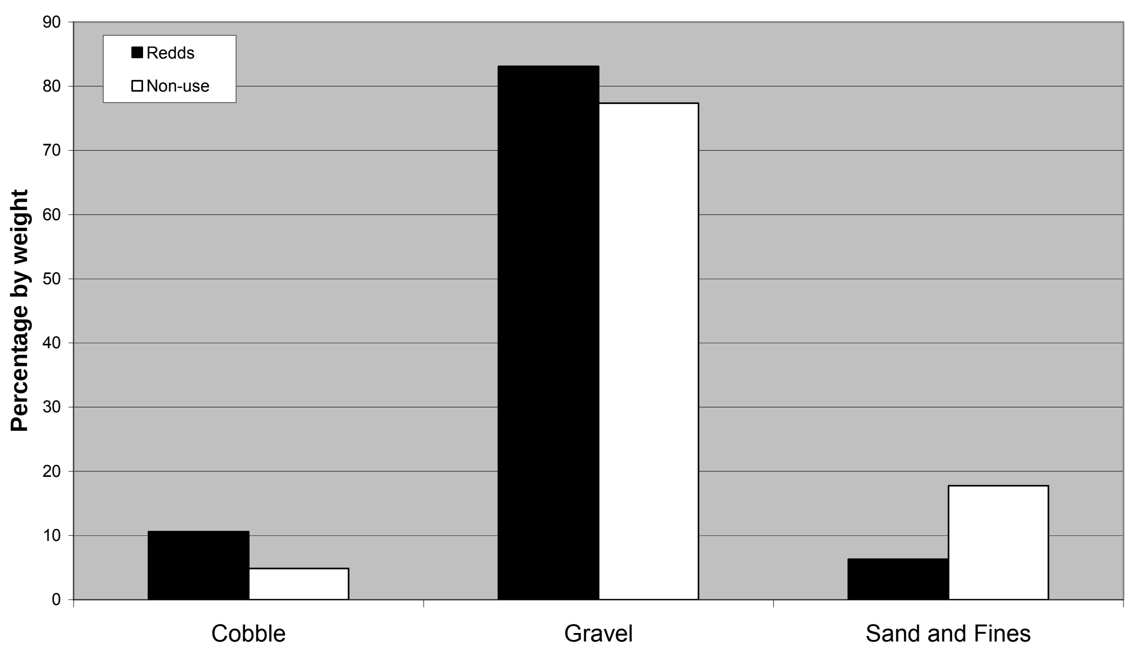

Figure 5. Hamilton Springs average percent of substrate categories (by weight) in use and non-use locations, 2006.

Measurement of environmental variables

Peak stream flow (127.3 cfs) was recorded in middle Hardy Creek on 17 January (Figure 6). Stream discharge in upper Hardy Creek ranged from 6.6 to 56.3 cfs. Stream discharge in middle Hardy creek ranged from 3.4 to 127.3 cfs, and discharge in lower Hardy Creek ranged from 8.8 to 71.4 cfs. High water velocities and Columbia River backwater events prevented surveyors from measuring discharge in upper Hardy Creek on five occasions, middle Hardy Creek on one occasion, and lower Hardy Creek on 14 occasions. Stream discharge in Hamilton Springs ranged from 3.6 to 15.6 cfs (Figure 6).

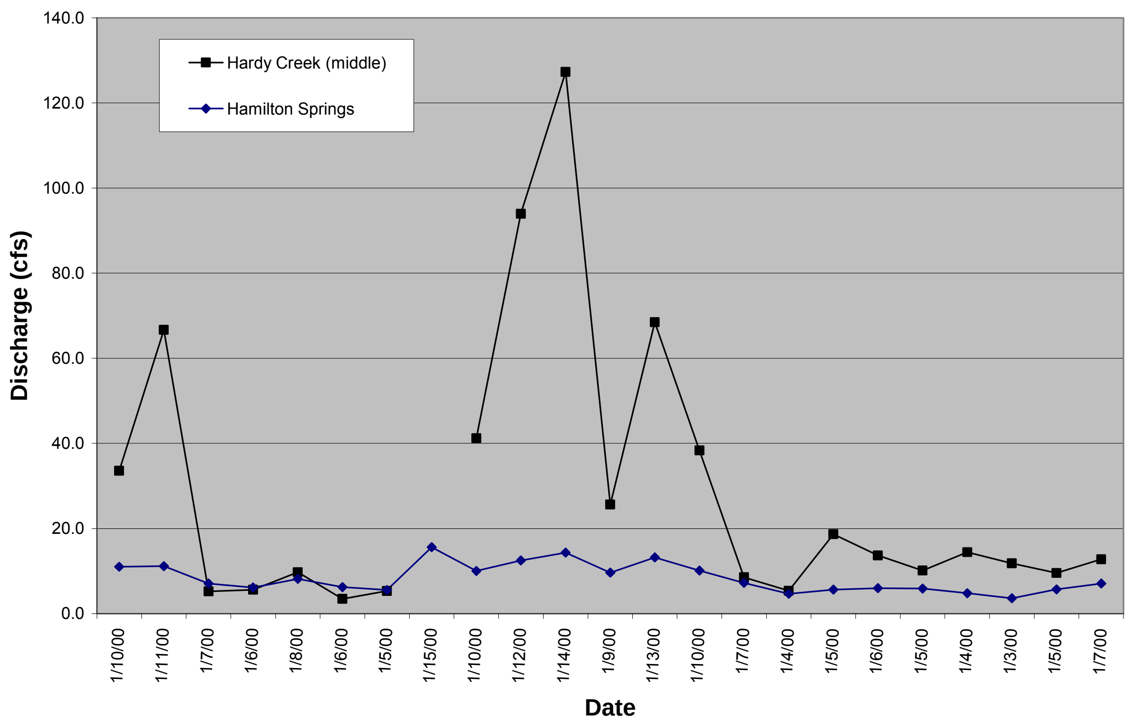

Figure 6. Stream discharge by date in Hardy Creek and Hamilton Springs, 2005-2006.

Overall, temperature and conductivity were higher and dissolved oxygen was lower in intergravel water samples collected from piezometers compared to surface water samples in both Hardy Creek and Hamilton Springs. Differences in temperature between subsurface and surface water samples ranged from -4.7 to 5.0°C in Hardy Creek and -1.6 to 2.2°C in Hamilton Springs. Differences in conductivity between subsurface and surface water samples ranged from -1.4 to 242.2 µS/cm in Hardy Creek, and -0.3 to 20.0 µS/cm in Hamilton Springs. Surface dissolved oxygen levels ranged from 9.2 to 11.2 mg/l in Hardy Creek and 6.4 to 10.1 mg/l in Hamilton Springs. Subsurface dissolved oxygen levels ranged from 1.1 to 12.2 mg/l in Hardy Creek and 4.0 to 9.6 mg/l in Hamilton Springs.

Juveniles

The floating fyke net was operated during 9 February through 29 April 2006 in Hardy Creek (Table 4). Thirty-two juvenile chum salmon were captured during the first marking period of operation. Zero juvenile chum were captured during the final marking period. A total of 6,591 juvenile chum salmon were captured throughout the season. Peak capture (2,281 juveniles) occurred from 26 February through 4 March. Fifty percent of all the juveniles had been captured by 5 March (Figure 7). Water temperature, recorded approximately at the mid-reach of spawning habitat, ranged from 0.8 to 12.7 °C with an average temperature of 7.3 °C (Figure 8). Estimated abundance of juvenile chum salmon passing the trap was 101,849 (Darroch estimator, Arnason et al. 1996), with a 95% confidence interval of 69,639-134,059 individuals. Mean fork length of fish 40.1 ± 1.6 mm.

Table 4. Trap efficiency, juvenile chum salmon captured, and mean fork length of marked fish by marking period for Hardy Creek, 2006. Standard deviation is presented in parentheses.

Marking Period	Dates	Marked	Recaptured	Unmarked Captured	Trap Efficiency (%)	Mean Fork Length (mm)
1	2/5-2/11	0	0	32	--	39.0 (0.7)
2	2/12-2/18	0	0	145	--	39.6 (1.3)
3	2/19-2/25	200	55	578	27.5	40.9 (1.0)
4	2/26-3/4	200	10	2081	5.0	40.4 (1.8)
5	3/5-3/11	200	12	1142	6.0	39.1 (1.9)
6	3/12-3/18	180	12	660	6.7	40.2 (1.6)
7	3/19-3/25	199	13	651	6.5	39.9 (1.1)
8	3/26-4/1	49	2	194	4.1	40.9 (1.3)
9	4/2-4/8	54	0	19	--	41.0 (1.3)
10	4/9-4/15	0	0	4	--	--
11	4/16-4/22	0	0	3	--	--
12	4/23-4/29	0	0	0	--	--

The stationary fyke net was operated during 9 February through 13 May 2005 in Hamilton Springs (Table 4). The first juvenile chum salmon was captured 15 February. The final juvenile chum salmon was captured on 5 May. A total of 23,584 juvenile chum salmon were captured throughout the season. Peak capture (5740 juveniles) occurred during 5-11 March. Fifty percent of all the juveniles had been captured by 12 March (Figure 7). Water temperature, recorded approximately mid-reach of spawning habitat, ranged from 5.4 to 7.5 °C with an average temperature of 6.2 °C (Figure 8). Estimated abundance of juvenile chum salmon passing the trap was 103,979 (Darroch estimator, Arnason et al. 1996), with a 95% confidence interval of 90,700-117,259 individuals. Mean fork length of fish was 38.9 ± 1.9 mm.

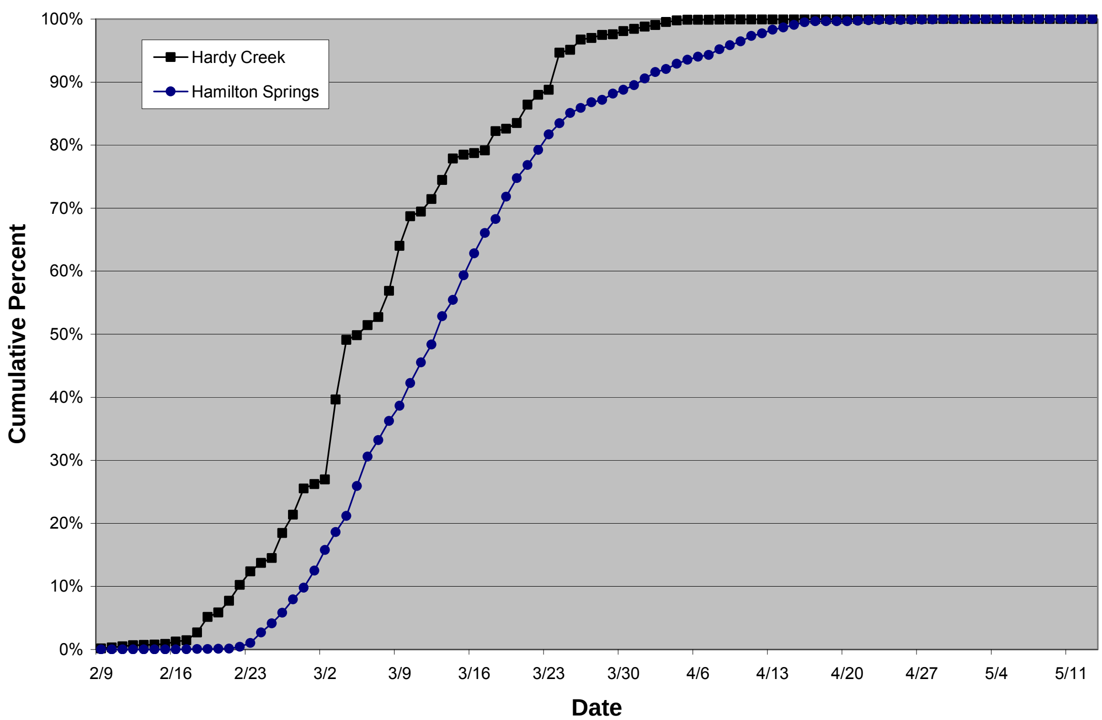

Figure 7. Cumulative percent of juvenile chum salmon captured at Hardy Creek and Hamilton Springs by date, 2006.

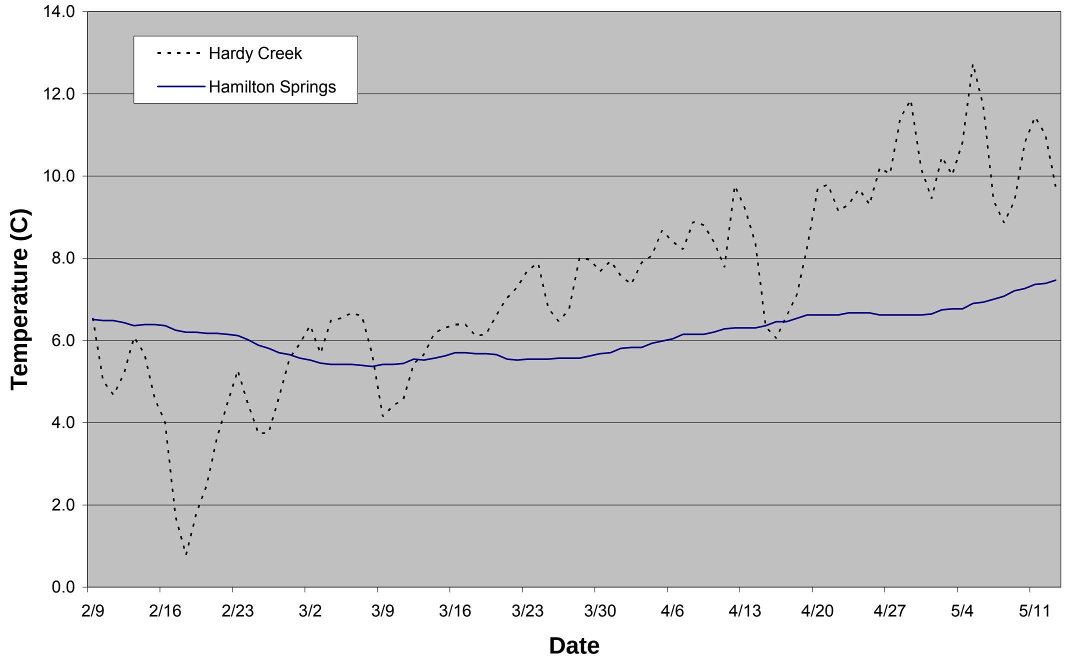

Figure 8. Mean daily water temperatures during juvenile trapping in Hardy Creek and Hamilton Springs by date, 2006.

Juvenile chum mortality associated with trapping was very low in Hardy Creek (17) and Hamilton Springs (52) this season. The majority of mortalities were due to predatory fish species (i.e., sculpin (*Cottidae spp.*)) and debris in the live box.

Intergravel conditions and juvenile emergence

Juvenile emergence traps were installed on two definite chum salmon redds in Hardy Creek on 7 December. Subsurface water samples were collected weekly from each piezometer beginning 14 December through 14 March. Overall, temperature and conductivity were higher and dissolved oxygen was lower in the

Table 5. Trap efficiency, juvenile chum salmon captured, and mean fork length of marked fish by marking period for Hamilton Springs, 2006. Standard deviation is presented in parentheses.

Marking Period	Dates	Marked	Recaptured	Unmarked Captured	Trap Efficiency (%)	Mean Fork Length (mm)
1	2/5-2/11	0	0	0	--	--
2	2/12-2/18	0	0	12	--	--
3	2/19-2/25	0	0	958	--	37.7 (1.6)
4	2/26-3/4	200	59	3828	29.5	38.5 (1.7)
5	3/5-3/11	200	33	5540	16.5	39.1 (1.2)
6	3/12-3/18	200	49	5160	24.5	39.4 (1.6)
7	3/19-3/25	200	49	3770	24.5	39.6 (1.4)
8	3/26-4/1	201	36	1088	17.9	39.4 (1.6)
9	4/2-4/8	200	37	899	18.5	37.7 (1.6)
10	4/9-4/15	200	42	711	21.0	38.8 (2.8)
11	4/16-4/22	0	0	169	--	38.9 (2.4)
12	4/23-4/29	0	0	37	--	--
13	4/30-5/6	0	0	11	--	--
14	5/7-5/13	0	0	0	--	--

water samples collected from the piezometers compared to the ambient samples from the stream. Differences in temperature between subsurface and surface water samples ranged from 1.8 to 5.7°C. Average surface dissolved oxygen was 10.1 mg/l

(0.3) in trap one, and 10.0 mg/l (0.4) in trap two. Average subsurface dissolved oxygen was 7.6 mg/l (0.7) in trap one, and 7.4 mg/l (0.5) in trap two.

Juvenile chum salmon were first captured in trap one on 21 February. A total of 913 juvenile chum salmon were collected through 5 April (Table 6). By 5 March, over half of the total fish collected in the trap had been captured. Accumulated temperature units when 50% of all fish were captured was 828 TUs based on a temperature logger located above the substrate on the piezometer adjacent to the emergence trap (Figure 9).

Juvenile chum salmon were first captured in trap two on 24 February. A total of 146 juvenile chum salmon were collected through 5 April (Table 6). By 30 March, over half of the total fish collected in the emergence trap had been captured. Accumulated temperature units when 50% of all fish were captured was 1138 TUs based on a temperature logger located above the substrate on the piezometer adjacent to the emergence trap (Figure 10).

Juvenile emergence traps were installed on 3 definite chum salmon redds in Hamilton Springs. Trap one and two were installed 1 December, and trap three was installed 7 December. Subsurface water samples were collected weekly from each piezometer beginning 5 December through 7 March. Overall, temperature and conductivity were higher and dissolved oxygen was lower in the water samples collected from the piezometers compared to the ambient samples from the stream. Differences in temperature between subsurface and surface water samples were minimal ranging from -1.1 to 2.7°C. Average surface dissolved oxygen was 8.8 mg/l (0.4) in emergence trap one, 8.9 mg/l (0.4) in emergence trap two, and 9.2 mg/l (0.4) in emergence trap three. Average subsurface dissolved oxygen was 7.2 mg/l (0.6) in emergence trap one, 6.2 mg/l (0.6) in emergence trap two, and 7.1 mg/l (0.5) in emergence trap three.

Table 6. Dates of events, total chum salmon collected, and accumulated temperature units (°C) at 50% emergence of juveniles for emergence traps in Hardy (HC) Creek and Hamilton Springs (HS) 2005, 2006.

Trap ID	Redd identified	First juvenile observed	50% emergence date	Total juveniles observed	Accumulated TU's at 50% observed
HC 1	11/18/2005	2/21/2006	3/5/2006	913	828
HC 2	11/16/2005	2/24/2006	3/30/2006	146	1138
HS 1	11/28/2005	3/10/2006	3/21/2006	601	1195
HS 2	11/20/2005	3/2/2006	3/7/2006	1334	1098
HS 3	11/16/2005	3/11/2006	3/22/2006	228	1189

*Unable to check Hardy Creek emergence traps after 04/05/2006 due to high water levels

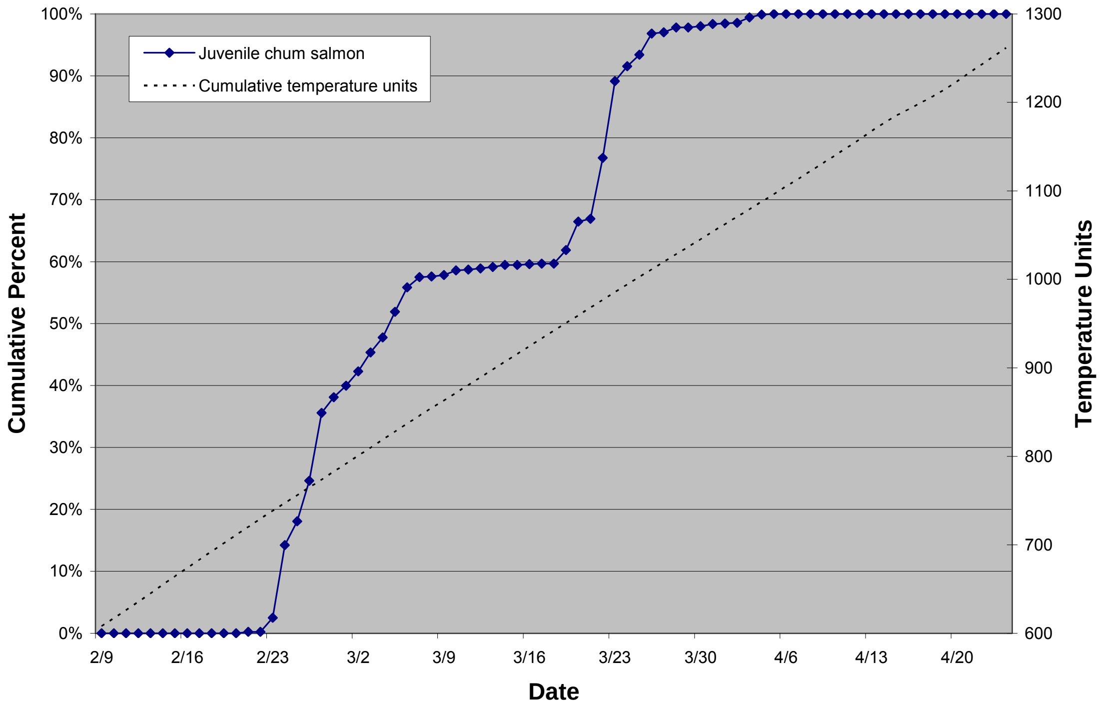

Figure 9. Cumulative percent of juvenile chum salmon captured and accumulated temperature units (°C) by date in Hardy Creek emergence trap one, 2006.

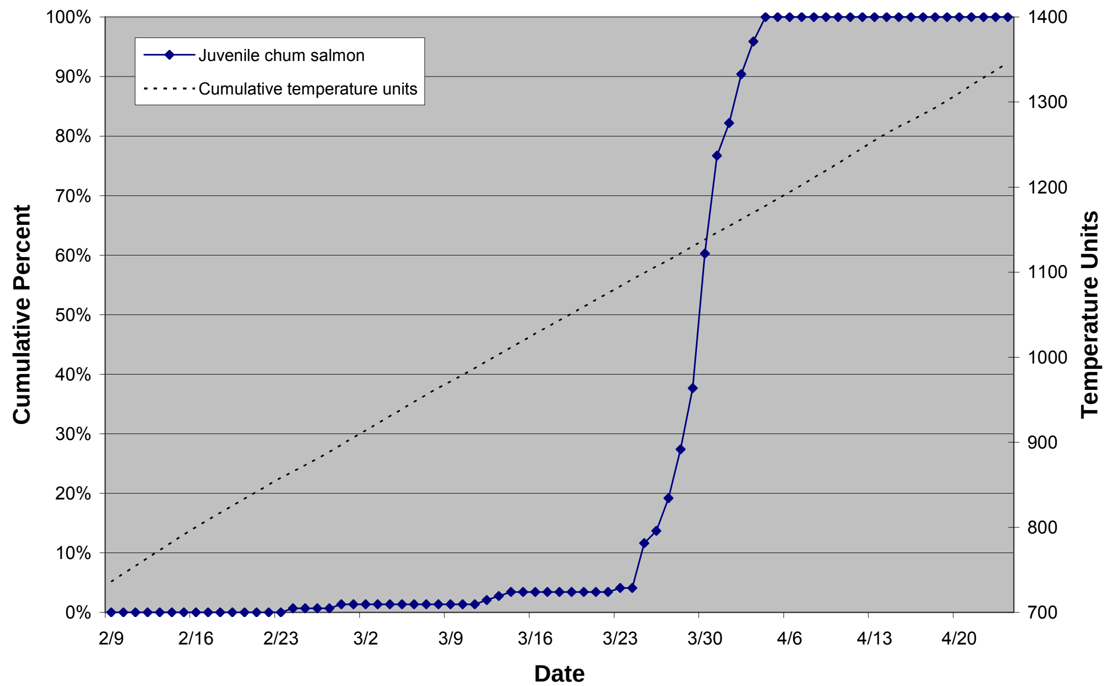

Figure 10. Cumulative percent of juvenile chum salmon captured and accumulated temperature units (°C) by date in Hardy Creek emergence trap two, 2006.

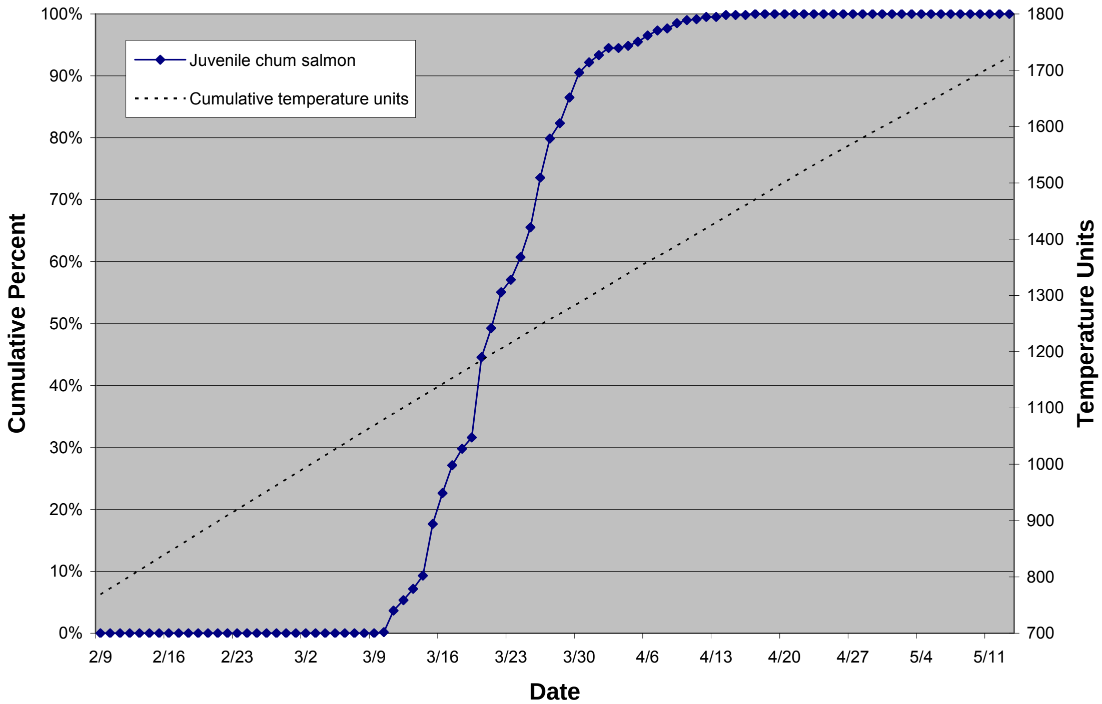

Figure 11. Cumulative percent of juvenile chum salmon collected and accumulated temperature units (°C) by date in Hamilton Springs emergence trap one, 2006.

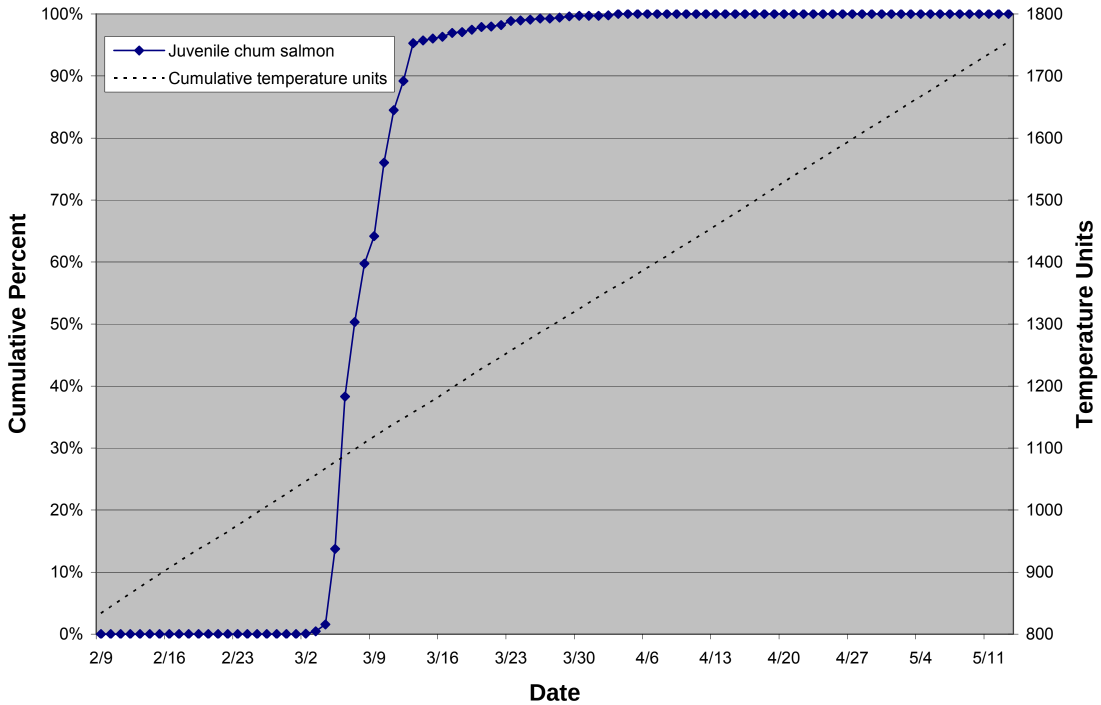

Figure 12. Cumulative percent of juvenile chum salmon collected and accumulated temperature units (°C) by date in Hamilton Springs emergence trap two, 2006.

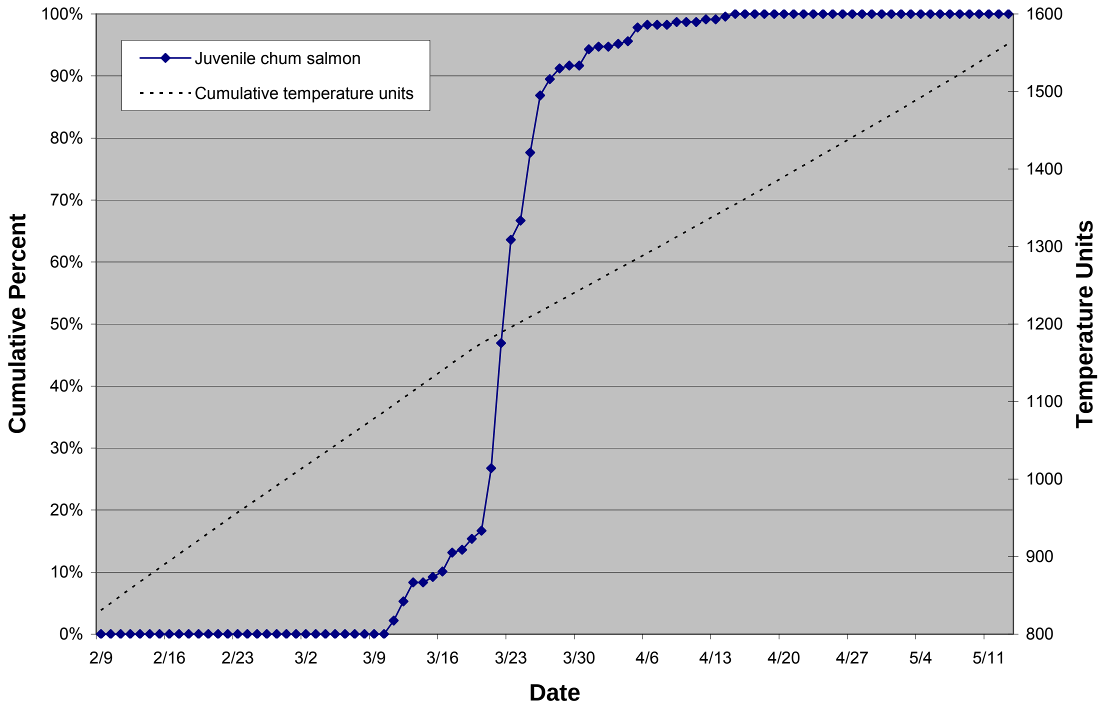

Figure 13. Cumulative percent of juvenile chum salmon collected and accumulated temperature units (°C) by date in Hamilton Springs emergence trap three, 2006.

Discussion

Total adult Chum salmon estimates for the 2005 spawning year (255) were the lowest total since 2000 when an estimated 194 adults returned to Hardy Creek and Hamilton Springs. Juvenile production resulting from fall 2000 adults (spring 2001 juveniles) was the lowest recorded during this studies tenure (1997-2006). Age 4 adults normally dominate the spawning class (Hoffman 2001, Uusitilo 2003, Lohr 2004, Lohr 2005 and Poirier 2005). Age structure of 2005 adults follow this trend and was composed heavily of age four fish (74%) which would have resulted from the low production spring 2001 juvenile year.

First live adult observed and peak live count timing in both Hardy Creek and Hamilton springs was the earliest or matched the earliest date of the previous 4 years (Uusitilo 2003, Lohr 2004, Lohr 2005 and Poirier 2005). Since adult chum migration is associated to water temperature, Columbia River water likely was optimal temperature earlier in 2005 than in previous years. Another possible reason could be tributary water level or Columbia River elevation allowing earlier access into Hardy Creek and Hamilton Springs. Further evaluation is necessary to determine causation.

Area-under-the-curve methodology for estimating adult escapement requires estimates of stream residence time and observer's ability to see fish. Adult escapement estimates presented here were calculated assuming a 10-day stream residence time and 100% visibility. Actual stream residence is difficult to determine accurately. Mark recapture studies are required for this and must be designed to determine when individuals enter the survey area and when individuals stop being available for live counts (die or leave the area). Such studies that have been conducted result in estimates of 6 to 17 days stream residence (Rawding and Hillson 2003, Hoffman et.al. 2001). Our assumption of 10 days stream residence falls within these estimates but may add error to our adult escapement estimate.

Juvenile abundance estimate for Hardy Creek (101,849) is within the range of the previous 5 years (range 11,586 – 450,195, see Hoffman 2001, Uusitilo 2003, Lohr 2004, Lohr 2005 and Poirier 2005) and is the third highest among those years.

Juvenile abundance estimate for Hamilton Springs (103,979) is the lowest since 2001 when 84,520 juveniles were produced (five year range 84,520 – 561,462, see Hoffman 2001, Uusitilo 2003, Lohr 2004, Lohr 2005 and Poirier 2005). Hamilton Springs has shown a consistent reduction in production since 2002 that follows a trend of reduced adult spawners. Hardy Creek has witnessed this same trend of reduced production following lower adult spawners though not as consistent. Further analysis of this trend is necessary to determine population growth rates of each tributary.

Two methods were used to characterize substrate composition. Both characterized redd substrate consistently at both Hardy Creek and Hamilton springs. Non-use areas were characterized differently by the two methods. Visual inspection of surface composition resulted in characterization as sand and silt dominated at both Hardy Creek and Hamilton Springs whereas sieve analysis showed composition to be dominated by gravel. In both analyses, sand and silt were more pronounced in non-use areas when compared to redds.

On average, Hardy creek substrate contains more fines than does Hamilton Springs. This is true for both redds and non-use areas. Average fines in Hardy creek redds (14%) approached the level of non-use areas in Hamilton springs (18%). This higher level of fines in Hardy Creek is of concern as presence of fines may reduce egg to fry survival (Phillips et al. 1975; Harshbarger and Porter 1982; Hausle and Coble 1976)

Post-spawning substrate characterization may not lend evidence to what habitat parameters spawning adult chum select for redds. The process of digging suspends and displaces substrate material. Hydraulic forces then size fractionate substrate components causing finer material (silt, sand) to move further downstream than more coarse material (gravel, cobble). Later analysis of redd substrate composition may therefore be measuring the result of spawning activity rather than substrate preference.

Hardy creek is subject to seasonal high-flow events. When these events occur while adult chum salmon are present, displacement of spawning activity is likely. In addition, scouring of redds is a potential result. Hamilton Springs is not subject to similar high-flow events and as such experiences much lower potential for redd scouring or behavioral effects related to flow. Therefore, during years when high precipitation events occur, it can be expected that production from Hardy Creek will be negatively effected to a higher degree than Hamilton Springs.

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