Puntledge River Radio Telemetry Study on Summer Chinook Migration in the Upper Watershed 2009

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Prepared for:

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EXECUTIVE SUMMARY

In 2005, BC Hydro initiated the Puntledge River Water Use Plan (PUN WUP). One of the key recommendations was the release of 5 pulse flows in Reach C during the months of July and August to improve summer chinook and steelhead migration. In 2007 a WUP radio telemetry study was initiated to assess the benefits of these pulse flows on chinook migration as per the WUP Monitoring Program. This monitoring program, which extends over three years, is being conducted by a team of DFO staff, private consultants, and the Fish Ecology and Conservation Physiology Laboratory at Carleton University. A concurrent study, funded by BC Hydro's Bridge Coastal Fish and Wildlife Restoration Program (BCRP), focuses on the behaviour of chinook migration during and after pulse flows and on spawning behaviour which extends into late October. The main objective of this concurrent telemetry study, which is the focus of this report, is to document summer-run chinook holding, migration behaviour and spawning success. Results from both studies are being used to develop a long-term strategy to rebuild the Puntledge Summer-run chinook stock to historical escapement levels.

The BCRP radio telemetry study tracked the movement of radio-tagged adult summer chinook in Reach C, and specifically at two known choke points - Stotan and Nib Falls, and in Reach B (headpond reach). Chinook were tagged using two types of radio transmitters as follows: a total of eight electromyogram (EMG) tagged fish were released in the river at the Lower Puntledge Hatchery on June 11 and 16; twenty-nine conventional radio-tagged fish were released on 6 dates between June 6 and 26. These fish were tracked in Reach C and Reach B using fixed stations and mobile receivers. An additional 10 conventionally tagged chinook were tagged and released directly into Comox Lake on June 26. Manual tracking was conducted twice/day from June to early August, and then from 1-3 times/week until the end of spawning. Manual tracking was also conducted on October 23, 2009 in the upper watershed (Cruickshank and Upper Puntledge rivers). During the migration period when tagged fish were present in the river, one 48-hr kayak pulse flow and five 48-hour migration pulse flows were released between June 6 and August 5. Although tagging was conducted in June 2009 to avoid elevated summer temperatures, the river was warmer earlier, and temperatures during the tagging period were equivalent to those in July, in previous years.

In 2009, the fate of EMG tagged fish differed from conventional tagged fish. A quarter of EMG releases failed to progress upstream from the site of release after tagging versus 14% of conventional tags. Only 1 out of 6 EMG chinook that reached Stotan Falls managed to migrate upstream to Nib Falls, a success rate of only 17%. This same fish failed to progress further above Nib Falls. In contrast, conventionally tagged fish had a 90% success rate of migrating above Stotan Falls and 89% success at Nib Falls. Overall, 16 out of 29 (i.e. 55%) conventionally tagged releases migrated to or upstream of the Upper Hatchery.

The Stotan and Nib Falls areas are known to be difficult for chinook passage. On average, between 2003 and 2009, 19% of radio-tagged chinook that reached Stotan and 18% that reached Nibs failed to migrate beyond these locations. Overall, migration success has been highly variable at both sites. Both the level of difficulty and the point of most difficultly changed year-to-year. The parameters that drive this variability are likely obscured by subtle interactions among a number of variables which include river discharge, temperature, light conditions, human disturbance levels and physiological condition of the fish. A more focused effort providing larger datasets with inherently greater power will be required to address this topic in any further studies. In contrast, river snorkel and video camera counts on summer chinook arriving in the river prior to the first week of July show that chinook migration success to the diversion dam appears to be higher than fish arriving in the river later in the summer. Similar to 2008, the success rate was above 90%.

Nine conventionally tagged chinook successfully reached the headpond and of these, 5 migrated into Comox Lake. Combined with the 10 fish that were released directly into Comox Lake, all but 2 chinook that held in the lake returned to the headpond during the spawning period. Temperature data recovered from 5 thermal loggers from chinook that held in the lake during peak summer temperatures indicates a general preference for these fish to hold at temperatures within a range of between 10 ^{o}C and 15 ^{o}C.

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1 INTRODUCTION

The migration of adult summer-run chinook salmon in the Puntledge River was first assessed using radio telemetry in 2002, during the Puntledge Water Use Planning process (PUN WUP). The study examined the migratory response of radio-tagged summer chinook to an experimental pulse flow in Reach C (Komori Wong Environmental and Bigsby 2003). Discharge in Reach C was ramped up from 5.7 m^3/s (200 cfs) to 17.5 m^3/s (610 cfs) between 29 Jul and 2 Aug at a rate of ~ 2.9 m^3/s (100 cfs) every 24 hours. The first year of telemetry results suggested that the pulse flow stimulated migration. Subsequently, the WUP Technical and Consultative Committee (CC) recommended 5 pulse flow releases in the months of July and August for summer run chinook salmon and summer run steelhead trout migration as outlined in the CC report (BC Hydro 2003). As per the recommendations of the PUN WUP CC, several operational changes to BC Hydro’s Puntledge Facilities require monitoring to ensure that anticipated benefits are properly documented and that the recommended operational constraints are followed. A WUP study to assess the benefits pulse flows have on the migration of summer chinook and steelhead during July and August was initiated in 2007. This three year study is being conducted by a team of DFO staff, private consultants, and the Fish Ecology and Conservation Physiology Laboratory at Carleton University.

A complimentary study, funded by BC Hydro’s Bridge Coastal Fish and Wildlife Restoration Program (BCRP), also focuses on the migration behaviour of chinook during pulse flows as well as behaviour post-pulse flows, and during the spawning season until late October. The main objective of this concurrent study, which is the focus of this report, is to document the migration behaviour, success and survival to the completion of spawning of summer chinook salmon. Results from both studies will potentially be used to develop a long-term strategy to rebuild the Puntledge summer-run chinook stock to historical escapement levels. This report summarizes results from 2009 and an overall review of the 3 year results.

1.1 Background

Hydroelectric generation on the Puntledge River dating back to 1912, and, more specifically, following expansion of the facilities in the 1950s, changed river discharges in Reach C from a more natural flow regime to a constant regulated flow throughout most of the year (BC Hydro 2003). A decrease in both the average flow and in the variability of flow below the diversion dam, as well as an increase in the rate of flow changes during the summer period has affected the ability of summer chinook to migrate though Reach C, and ascend Stotan and Nib Falls. A historic review of activities on the Puntledge River found that remedial work on these falls began in 1923 and continued sporadically until 1977 (Bengeyfield and McLaren 1994). The intention of the work was to improve access for summer chinook. These works inadvertently benefited other species previously not capable of ascending these falls. Radio-telemetry studies conducted in the last 5 years indicate that as many as 30% of the tagged fish fail to migrate above both Stotan Falls and, Nib Falls, (Taylor and Guimond 2006). In addition to Stotan and Nib Falls, the diversion dam and impoundment dam further delay migration and limit the number of summer chinook salmon successfully migrating into Comox Lake and the upper watershed.

In 1955, during the first year of operation of the expanded hydro facility, adult summer-run chinook salmon were delayed at the tailrace pool of the powerhouse, a phenomenon not previously recorded during the four decades of operation of the facility by Canadian Collieries (Hourston, 1962). The higher flows through the penstock (1000 m^3/s versus 300 m^3/s prior to expansion), combined with cooler temperatures from the powerhouse and lower flows in the mainstem “diversion” reach (Reach C) inadvertently attracted adult salmon to the tailrace pool. Chinooks attracted to the tailrace would suffer from exhaustion or serious injury and often died before spawning. Other fish delayed in the tailrace pool became susceptible to poaching and predation. Those fish that managed to reach the spawning grounds were often observed with injuries and covered in fungus. The degree to which the Powerhouse tailrace pool currently delays summer chinook migration in Reach C remains unclear.

The rebuilding of the summer chinook escapement to a pre-hydro expansion level of 3000 has not yet been achieved despite 50 years of efforts. A loss of spring freshet flows, lack of suitable spawning habitat, and either reduced or delayed access to Comox Lake are key Hydro facility ‘footprint impacts’ that have yet to be fully addressed. An on-going enhancement program and several successful habitat rehabilitation projects have been implemented to address these impacts. However, it is clear that unimpeded access to historical holding and spawning areas (i.e. Comox Lake and headpond, respectively) is essential to the success of summer chinook recovery.

Although significant improvements have been made at the Hydro Diversion and Impoundment Dam fishways, there may always remain a measurable impact on fish migration that can not be fully compensated. The telemetry study will potentially identify other access problems in the river that can be remedied to compensate for Hydro footprint impacts. For instance, improvements at Stotan and Nibs Falls might partially compensate for delayed access past the Hydro dams and Powerhouse tailrace. It is expected that improving spring and early summer adult access into Comox Lake which provides cooler holding temperatures will result in increased survival and spawning success, and therefore result in higher productivity of the stock.

1.2 Goals and Objectives

The objectives of the BCRP radio telemetry study on summer chinook migration in the Puntledge River watershed are threefold as follows:

1) Monitor the movement of adult summer chinook past Stotan and Nib Falls in Reach C. These two obstacles have been identified in past radio telemetry studies as having significant influence on the success of Puntledge summer chinook reaching the upper river (Taylor and Guimond 2006).
2) Track the movement of radio-tagged summer chinook in the headpond reach, into Comox Lake and in Comox Lake tributaries. This will provide information on whether adult chinook are able to access Comox Lake through the sluice gates when lake level and discharge conditions are favourable, determine if early summer-run chinook adult migrants hold in the cooler depths of Comox Lake during the summer and if the spawners use lake tributaries or spawn below the Comox Dam.
3) A release of a group of up to 10 radio-tagged adult summer chinook into Comox Lake will provide a means of assessing survival of adults holding in the Lake and allow field staff to observe the physical condition of spawners after holding all summer in the lake. It is anticipated that additional fish tagged in the lower river will successfully migrate into the Lake and provide additional information on lake holding survival.

2 STUDY AREA

The Puntledge River radio telemetry study on summer chinook migration tracked the movement of radio-tagged chinook in 3 key reaches as follows:

i. Between the diversion dam and the Powerhouse (Reach C) and at two known areas of difficult migration in the reach – Stotan and Nib Falls (Figure 1);

ii. Reach B also known as the headpond reach between B.C. Hydro’s diversion dam and the Comox Lake impoundment dam (Comox dam);

iii. and in Comox Lake tributaries, specifically the Cruickshank and Upper Puntledge Rivers (Figure 1 inset).

The Puntledge River Watershed encompasses a 600 km^2 area west of the city of Courtenay (Figure 1). The lower Puntledge River flows from Comox Lake in a north-easterly direction for 14 km where it joins with the Tsolum River. From this point downstream, the river is called the Courtenay River, which flows for another 2 km into the Strait of Georgia. The Lower Puntledge River is divided into 3 distinct reaches. Reach B, also known as the headpond, is located between the Comox impoundment dam and the diversion dam, approximately 3.7 km downstream. This is a low gradient reach (<0.01%) characterized by deep, slow moving water which is a result of backflooding from the diversion dam. The average channel width is about 60 m and ranges between 35 and 105 m (Bengeyfield and McLaren 1994). The substrate composition in this reach ranges from mud to large gravel and cobble with a small percentage of boulder. Discharge through the reach is controlled by BC Hydro which normally operates at a target discharge of 33 m^3/s in order to maintain a power output of 24 MW and provide a minimum instream flow of 5.7 m^3/s below the diversion dam. Reach C extends downstream of the diversion dam for 6.5 km to the Powerhouse. It is higher gradient and dominated by smooth bedrock with sections of cobbles and boulders. Two major waterfalls (Nib Falls and Stotan Falls) are located in this reach.

The Cruickshank and Upper Puntledge Rivers are the largest of the Comox Lake tributaries. The Cruickshank River (drainage area = 213 km^2) is a snow-fed system of moderate to high gradient with approximately 30 km of accessible habitat for salmon and trout. The mainstem contains large areas of spawning gravel, particularly in the lower to middle reaches. The Upper Puntledge River (drainage = 92 km^2) is warmer and lower gradient with several small lakes (Willemar and Forbush).

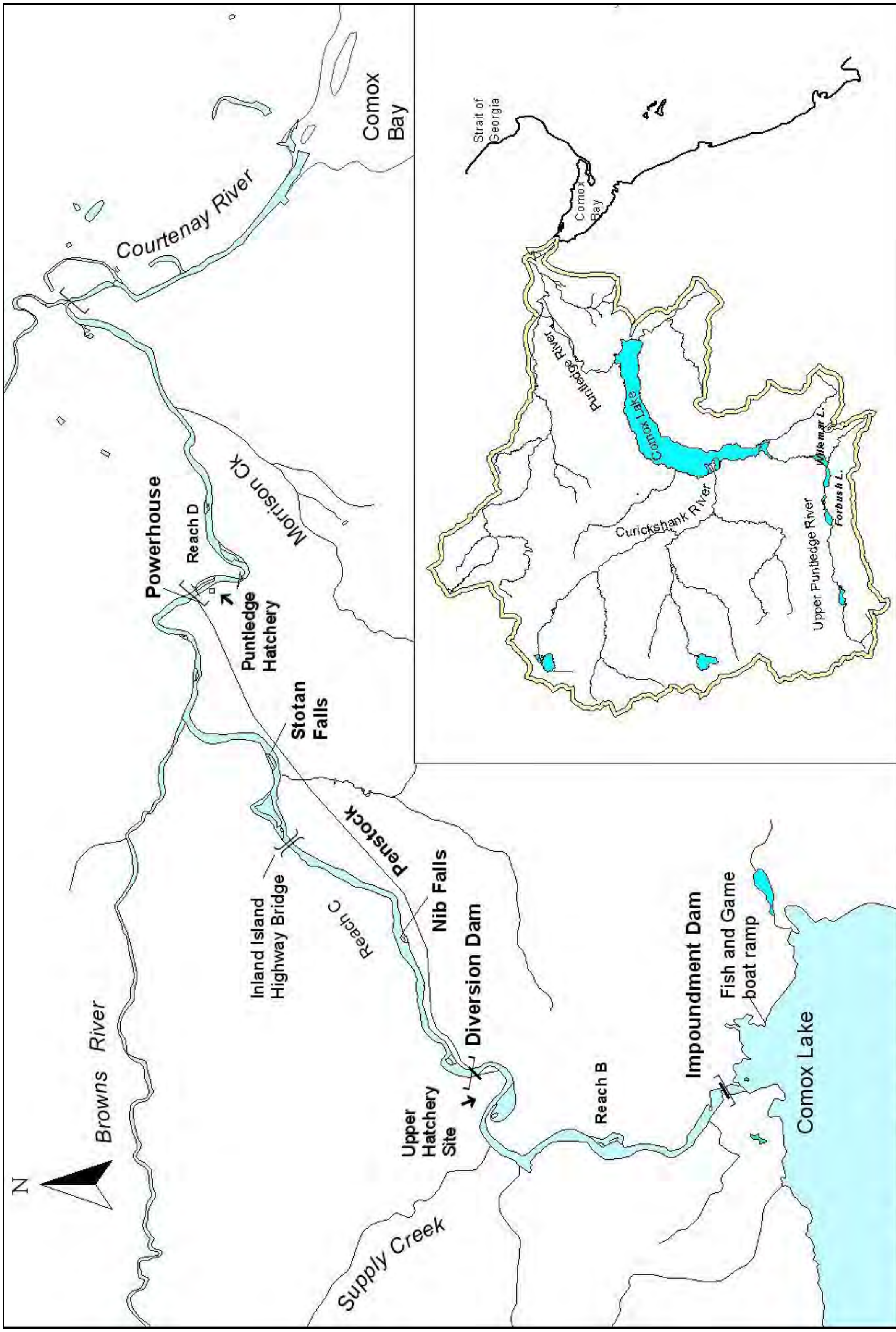

Figure 1. Puntledge River showing major features and areas monitored during the 2007 telemetry study, including Reach C, B and Comox Lake tributaries (inset map).

3 METHODS

3.1 Tagging

Summer chinook arriving at the lower Puntledge hatchery were diverted at the lower barrier fence into hatchery raceways commencing June 1, 2009. Between June 2 and June 26, a total of thirty-nine summer chinook were fitted with conventional coded radio transmitters (model MCTF-3A, Lotek Wireless Inc., Ontario). On the last day of tagging, ten of these conventionally tagged chinook were transported and released in Comox Lake (Table 1). On June 11 and June 16, five and three chinook respectively were fitted with coded electromyogram (EMG) transmitters (model CEMG2-R16-25, Lotek Wireless Inc.). These devices provide fine-scale information on fish activity, energetics, and behaviour (Hasler et al. 2008). Fish were netted from the hatchery raceway and transferred to a water-filled sampling trough that was continually supplied with freshwater. For fish requiring EMG tags, fish were anaesthetized in clove oil (40 ppm) and then transferred to a surgical table continuously supplied with a maintenance dose of anaesthetic (30 ppm). EMG transmitters were surgically inserted as per the methods described in Hasler et al. (2010). For fish requiring conventional tags, transmitters, coated with vegetable oil, were inserted orally into the stomach of each fish using a hollow plastic tube applicator.

Table 1. Summary of radio-tag application for the 2009 WUP and BCRP chinook migration studies.

Tagging Date	Conv	EMG	Reach C Total	Lake Total
2-Jun	6	0	6	0
11-Jun	5	5	10	0
16-Jun	3	3	6	0
18-Jun	4	0	4	0
22-Jun	4	0	4	0
26-Jun	17	0	7	10
TOTAL	**39**	**8**	**37**	**10**

Total length and sex of tagged fish was recorded (TL = 646 ± 56 mm), and all fish were non-invasively biopsied (prior to transmitter insertion). Due to the low numbers of summer chinook and the need to ensure adequate numbers of fish for hatchery production, transmitters were applied to male fish only, since they typically arrive at the hatchery in higher proportion than females. A blood sample (1.5 ml) was collected via caudal puncture from each tagged fish, as well as a small gill biopsy (3 mm off the tips of 5 to 8 filaments; Hasler et al. 2008). A non-invasive fat probe was used to assess energy density (Hasler et al. 2008). All physiological samples were processed and stored in liquid nitrogen until analysis by the University of Carleton team. In addition, all fish carrying radio transmitters (conventional and EMG) had a thermal logger (iButton DS1921Z, Integrated Products Inc., California) attached to the transmitter to allow reconstruction of the migration history of each fish (i.e., determining if they migrated into Comox Lake).

Fish destined for release into the Puntledge River were transported to a recovery pen located beside the barrier fence at the lower hatchery fishway. After a brief (2 hour) recovery period in the fishway holding pen, the pen was opened to the river so that tagged chinook could swim out volitionally. Fish destined for release into Comox Lake were placed in a transport tank after tagging, and transported directly to Comox Lake on the same day. The fish were released into the lake adjacent the Courtenay and District Fish and Game Clubhouse, 850 metres from the impoundment dam (Figure 1).

3.2 Tracking

The location (i.e. river kilometre chainage) of tagged fish was tracked and recorded using a portable Lotek SRX 400A and/or SRX 600 Telemetry Receiver. During each mobile tracking session, technicians travelled along the river and attempted to locate all tagged fish in Reach C and Reach B. In addition, continuous tracking using fixed telemetry stations (Lotek SRX 600 receivers) each with three directional antennae covered a large area upstream and downstream of Stotan and Nib Falls (Hasler et al. 2010). One station was located on a bluff upstream of the powerhouse, one at Stotan Falls, and a third just upstream of mid Nib Falls. The fixed stations operated from June to early August and provided more detailed information on timing of arrival and frequency and timing of attempts to move past these locations.

In Reach C, tracking was conducted manually twice/day from June to early August, and then from 1-3 times/week until the end of spawning (end of October).

Recovery of transmitters continued sporadically until December when conditions permitted. In Reach B, tracking was less frequent, but usually occurred on a weekly basis from early August until the end of October. Tracking in the upper watershed (Cruickshank and Upper Puntledge rivers) was conducted on October 23, 2009 to attempt to locate chinook that may have entered the lake from Reach B, and those remaining lake-released chinook that had not returned to Reach B to spawn.

Snorkel surveys (and associated costs) were completed under the WUP Steelhead Production monitoring program.[1] The distribution and relative abundance of tagged and untagged fish was documented during snorkel counts. This information was used to support results from the telemetry study and also provided immediate information on numbers of fish congregating below the fish ladders before and immediately following pulse flows. Snorkel counts were conducted July 7, 10, August 4 and 7.

3.3 Communications

A Communications Plan conducted by staff of Comox Valley Project Watershed Society informed the public about the Puntledge River Summer Chinook Radio Telemetry Study through notices in local newspapers, and an article in the *Watershed News* (Appendix C). More detailed reporting of the Community Outreach Program associated with this and three other BCRP projects in the Puntledge River watershed is summarized in a separate report (CVPWS 2010).

4 RESULTS AND DISCUSSION

4.1 Stream Discharge

Mean hourly discharge data for the Puntledge River Reach C and D was obtained from BC Hydro Power Records for Gauge 6 below the diversion dam (WSC Gauge No. 08HB084) and Gauge 8 below the Powerhouse (WSC Gauge No. 08HB006; Figure 2). Kayak pulse flows were released on June 6-7, and five weekly 48 hour migration pulse flows were released between July 8 and August 5, 2009 (Figure 2). The kayak pulse flow

[1] Snorkel counts for the steelhead stock assessment under the WUP Steelhead Production monitoring program, were being conducted at the same time as the summer pulse flows, therefore costs for snorkel counts were covered under the Steelhead Production monitoring program and data was provided to the Telemetry study crew.

reached a maximum discharge of 126 m^3/s in Reach C whereas the migration pulse flows were on average between 12-14 m^3/s in Reach C as outlined in the PUN WUP. In addition to these flows, discharge in Reaches C and D was increased on May 30-31 in order to facilitate the outmigration of chinook smolts released from both the upper and lower Puntledge hatchery sites.

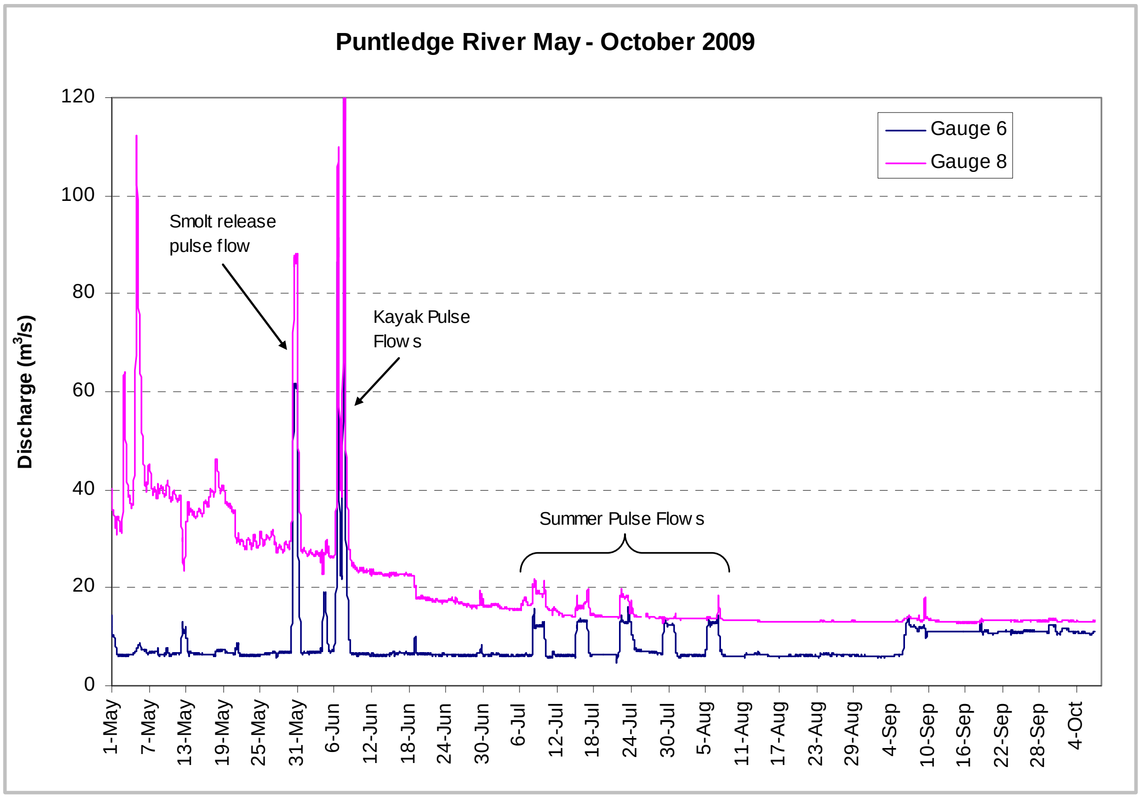

Figure 2. Hourly discharge for the Puntledge River at Gauge 6 below the diversion dam (WSC Gauge No. 08HB084) and Gauge 8 below the Powerhouse (WSC Gauge No. 08HB006). Pulse flows are indicated.

4.2 Temperature

In 2009, a modification to the WUP Migration Study Terms of Reference was approved, allowing for the tagging of early summer chinook migrants (fish that arrive at the barrier fence by late May/early June). It was recommended that tagging of an early group of summer chinook would provide an excellent opportunity to compare physiological condition, migration behaviour, fate and thermal biology compared to the later fish at warmer temperatures. It was also expected that surgical and handling stress on the early fish would be lower earlier in the season. The 2009 mean daily river temperature for the study period, recorded from the lower hatchery barrier fence temperature logger is illustrated in Figure 3 along with river temperature from the previous 2 years of telemetry studies. Overall 2009 was a much warmer year than 2007 and 2008, with temperatures reaching critical threshold levels for handling chinook earlier than in the previous 2 years. If the commencement of the 2009 telemetry study had not been advanced, it likely would not have proceeded at all due to the warm temperatures. Hasler et al. (2009) recommended that EMG tagging should only occur at temperatures between 14 and 16ºC.

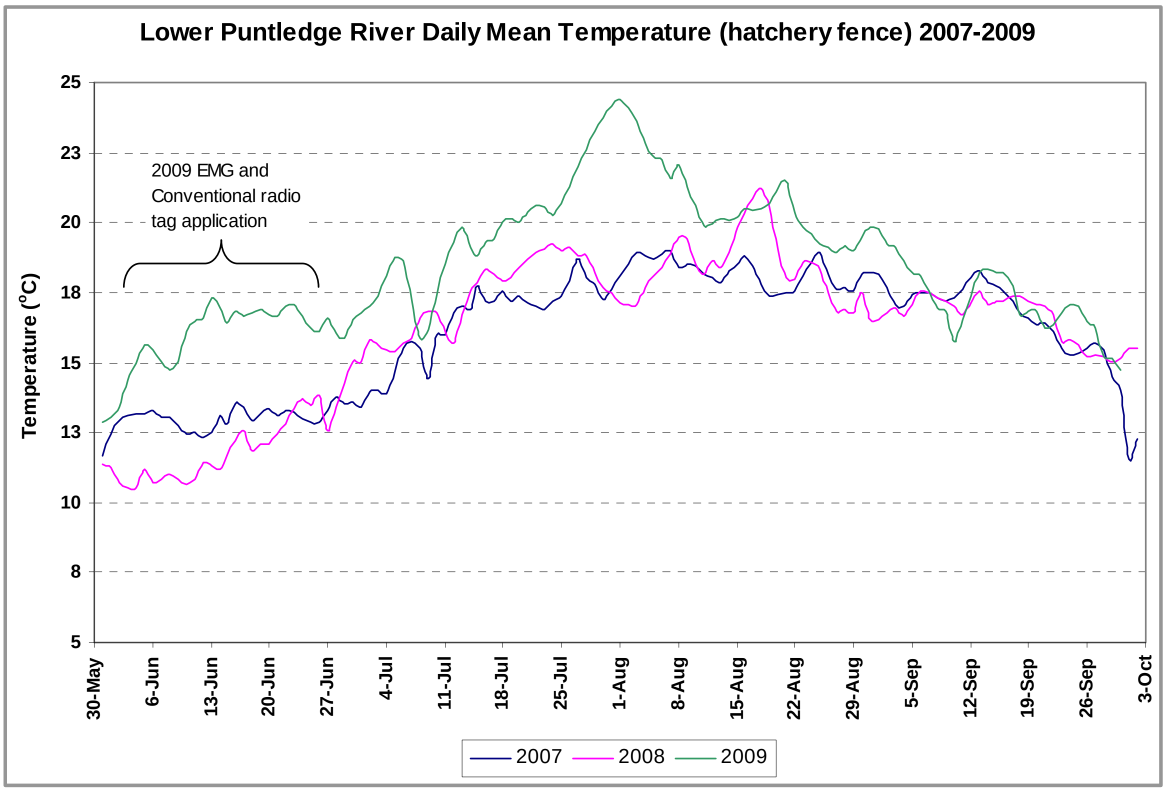

Figure 3. Mean daily temperature in the Puntledge River recorded at the barrier fence at the Lower Puntledge Hatchery using Tidbit temperature loggers for June – October 2007-2009.

4.3 Movement of fish in Reach C

The progress of chinook migrating through the Puntledge River in 2009 is summarized in Table 2 for fish tagged with electromyogram (EMG) and conventional radio-transmitters. Although the sample size was low for EMG tags (there was a total of only 8 releases) it is apparent that the fate of these fish was much different than the conventionally tagged chinook.

A quarter of EMG releases failed to progress upstream after tagging versus 14% of conventional tags, together representing 16% of all tagged fish. However, only 1 out of 6 EMG chinook that reached Stotan Falls managed to progress upstream to Nib Falls, a success rate of only 17%. The survivor failed to negotiate Nib Falls and none of the original releases reached the upper Hatchery site. In contrast, conventionally tagged fish had a 90% success rate migrating to Stotan and 89% to Nib falls, with 16 out of 29 releases (i.e. 55%) able to migrate to, at least, the upper Hatchery.

Table 2. Furthest extent of migration for chinook tagged with EMG and Conventional radio transmitters in 2009, showing number of fish to fail to pass specific points in the system, proportional losses from total tags applied and site specific estimates of failure to proceed.

2009		EMG			Conventional			Combined tags		
Furthest upstream progress	**Distance (km)**	**# of fish**	**% of total releases**	**failure rate at this site**	**# of fish**	**% of total releases**	**failure rate at this site**	**# of fish**	**% of total releases**	**failure rate at this site**
Lower Hatchery	6.4	2	25.0%	25.0%	4	13.8%	13.8%	6	16.2%	16.2%
Powerhouse pool	6.8	0	0.0%	0.0%	2	6.9%	8.0%	2	5.4%	6.5%
Mortality/regurgitation Reach C1 (6.8-9.2 km)	9.2	0	0.0%	0.0%	2	6.9%	8.7%	2	5.4%	6.9%
Stotan Falls	9.6	5	62.5%	83.3%	2	6.9%	9.5%	7	18.9%	25.9%
Nib Falls	11.8	1	12.5%	100%	2	6.9%	10.5%	3	8.1%	15.0%
Barbers Pool	13	0	0.0%		1	3.4%	5.9%	1	2.7%	5.9%
Upper Hatchery Pool	13.3	0	0.0%		7	24.1%	43.8%	7	18.9%	43.8%
Reach B	>13.3	0	0.0%		9	31.0%		9	24.3%	-

The Stotan and Nib falls are known as difficult areas for chinook passage (for a background summary see Guimond and Taylor 2009). It is, perhaps, surprising that these sites are so similar, in terms of the degree of difficulty to chinook upstream movement, as shown in Table 3. On average, over the 2003 to 2009 programs, 19% of chinook that reached Stotan and 18% at Nibs failed to migrate further. These numbers represent 17% of all tagged fish at Stotan and 13% of the previously successful migrants that reached Nib.

Table 3. Attrition rates at Stotan and Nib Falls including losses expressed as a proportion of total tag releases.

		Stotan Falls			Nibb Falls			Failure as a % of total releases	
Year	Viable tags	# reached	# passed	% failure	# reached	# passed	% failure	Stotan	Nibb
2003	31	28	24	14.3%	24	20	16.7%	12.9%	12.9%
2004 (1)	17	17	15	11.8%	14	10	28.6%	11.8%	23.5%
2004 (2)	17	17	14	17.6%	14	13	7.1%	17.6%	5.9%
2004 combined	34	34	29	14.7%	28	23	17.9%	14.7%	14.7%
2005 (1)	23	21	17	19.0%	17	15	11.8%	17.4%	8.7%
2005 (2)	23	22	14	36.4%	14	11	21.4%	34.8%	13.0%
2005 combined	46	43	31	27.9%	31	26	16.1%	26.1%	10.9%
2007	19	16	14	12.5%	14	11	21.4%	10.5%	15.8%
2008	26	17	16	5.9%	15	11	26.7%	3.8%	15.4%
2009	29	27	20	25.9%	20	17	15.0%	24.1%	10.3%
Average losses				**19.2%**			**18.3%**	**17.4%**	**13.1%**

There are two opposing assumptions that provide starting points from which to examine the mechanism by which these sites might constrain chinook migration. The first is that weaker fish and those most affected by sub-optimal river conditions will fail to progress at the first barrier. Therefore, Stotan should have a higher attrition rate than Nib.

Conversely, it might be reasonable to assume that longer exposure to high river temperatures would result in greater physiological stress. Therefore, being the first of the two obstacles, Stotan should have a consistently lower failure rate due to the better condition of the fish on reaching it.

Overall, although the migration failure rates are similar at the two falls, ranging from 6% to 36% at Stotan compared with 7% to 29% at Nib, these rates have not been consistent between the sites every year (Figure 4). Stotan displayed better migration success in only 4 of 8 study years (Table 3). This suggests that hydrological conditions are not the primary factor dictating migration success. Corroborative evidence is provided by Hasler et al. (2010), who found that passage over each of the falls was most frequent during base flow conditions (i.e. during the flow which was most frequent).

Consequently, altering the flow regime (i.e. pulse flows) did not produce a measurable increase in migration success.

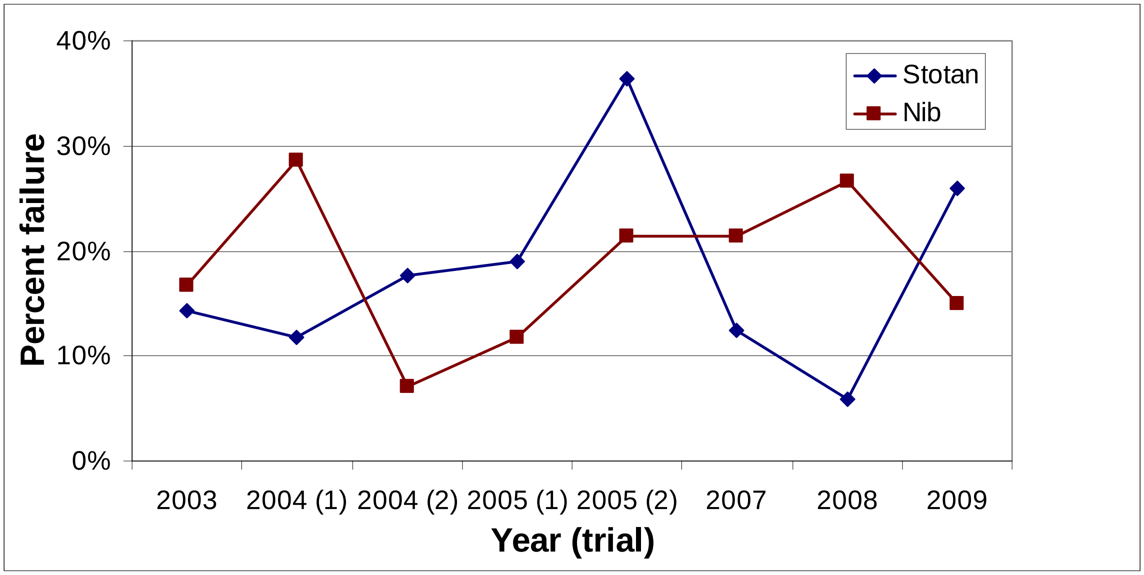

Figure 4. Attrition rate of radio-tagged chinook ascending Stotan and Nib Falls in studies conducted between 2003 and 2009.

Additional reasons for the lack of consistency in migration success have not been determined from the variety of physical and physiological variables that have been documented in the various studies. Hasler et al. (2009) found that fish tagged in 2008 displayed varying levels of physiological condition and that fish condition at the beginning of riverine migration was indicative of their willingness to initiate migration. However, physiological variables were unable to explain migratory fate (i.e. maximum distance travelled), although fall back (failure to progress after tagging) was potentially correlated. The very high failure of migrants in the lower river in 2008, shown in Table 4, where almost 30% of conventionally tagged chinook did not move past the Powerhouse pool, likely resulted from thermal stress due to transmitter application at 18°C (Hasler et al. 2009).

Table 4. Furthest extent of migration for Chinook tagged with EMG and Conventional radio transmitters, showing number of fish to fail to pass specific points in the system during the 2008 project.

2008		EMG			Conventional			Combined tags		
Furthest upstream progress	Distance (km)	# of fish	% of total releases	failure rate at this site	# of fish	% of total releases	failure rate at this site	# of fish	% of total releases	failure rate at this site
Lower Hatchery	6.4	0	0.0%	0.0%	6	37.5%	37.5%	6	22.2%	22.2%
Powerhouse pool	6.8	0	0.0%	0.0%	2	12.5%	20.0%	2	7.4%	11.8%
Mortality/regurgitation Reach C1 (6.8-9.2 km)	8.6	1	9.1%	9.1%	0	0.0%	0.0%	1	3.7%	6.7%
Stotan Falls	9.2	1	9.1%	10.0%	0	0.0%	0.0%	1	3.7%	7.1%
Nib Falls	11.7	2	18.2%	25.0%	3	18.8%	37.5%	5	18.5%	38.5%
WSC Gauge 6	12.7	0	0.0%	0.0%	1	6.3%	20.0%	1	3.7%	12.5%
Upper Hatchery Pool	13.3	2	18.2%	66.7%	3	18.8%	75.0%	5	18.5%	71.4%
Reach B	>13.3	1	9.1%	-	1	6.3%	-	2	7.4%	-

Guimond and Taylor (2009) suggested that earlier migrants had a greater success rate in moving past Stotan and Nib, but this was not evident from the 2009 data. Although tagging was conducted in June 2009 to avoid elevated summer temperatures, the river was warmer earlier, and tagging temperatures were equivalent to those in July, in previous years. Stotan experienced the third worst attrition rate (26%) on record, in that year. Similarly, thermal stress, as a potential factor associated with date of tagging, does not consistently explain migration success since the mean distance upstream achieved by 5 EMG tags released on 11 June 2009 was 8.4 km compared to 12.7 km by 5 conventional tags released on the same date and 9.4 km by 6 fish tagged on 2 June. It seems unlikely that the difference in success rates migrating past these choke points is due to the physiological condition of the fish or in physical parameters such as river temperature. Hasler et al. (2010) indicated that chinook tagged with EMG transmitters did not display altered energetics in response to flow alteration (pulse flows) which may indicate that the flow regime at the falls would similarly have little effect. They also noted that some chinook showed evidence of subtle behavioural thermoregulation and holding in the deep pools associated with both Stotan and Nib falls may provide some protection against thermal effects.

Failure to migrate through the falls may, therefore, lie with more fundamental challenges faced by individual fish, such as locating a suitable route to progress upstream. Patterns of failures by individual chinook in 2007 and 2008 were examined using survival analysis (Guimond and Taylor 2009). This showed that Stotan Falls is clearly different between years, showing more rapid transit and greater successes by chinook in 2008 versus 2007.

In contrast, at Nib Falls, early successes were associated with similar survival probability levels in both years, with greater divergence as the delay time for some fish increased in 2008. This was not sufficient to create a significant difference between the years. However, the median delay, which was three times greater in 2008 at Nib, was associated with a small increase in success rate (81% versus 78%; Guimond and Taylor 2009). Consequently, it appears that there is no threshold for speed of ascent, above which greater migration success is achieved. This would indicate that there is no simple route through the falls that needs to be found for best migration success. The patterns of probability of migration success were not significantly different between Stotan and Nib in 2008; therefore, it is likely that both sites share the same type of physical challenge and some additional factor is responsible for the discrepancies among years.

One possibility that has been identified in previous reports (e.g. Taylor and Guimond 2004) is the influence of human recreational activities, concentrated on the Stotan Falls area. Guimond and Taylor (2008) examined the patterns of movement of chinook below Stotan Falls to assess the degree to which sunshine, and by association, human activity, might influence migration. The initial hypothesis was that a high degree of human activity during sunny weather would result in fish being startled into moving downstream, hence movement out of the range of the antenna would indicate greater difficulty in ascending the falls. The daylight conditions that fish moved under were depicted by light conditions measured in the hour that movement occurred and characterized as Dark, Cloudy or Sunny. These data did not suggest that sunny periods contained a disproportionate share of movements that might result from an increase in recreation levels. For this year, at least, fixed station telemetry did not reveal an overall migration pattern that would support human disturbance as a contributing factor based on the indirect relationship between sunny conditions and recreational use of the Stotan area.

Since recreational activities are concentrated on Stotan and are negligible at Nib falls, we re-examined chinook movement through the falls areas on the basis of night versus day migration timing. Night was considered to be 9:00 pm to 4:00 am. Fixed station records were available for both sites from 2008 (see Guimond and Taylor 2009 for a discussion on defining passage time from these records). These showed that 11 out of 17 chinook that ascended Stotan did so during night time. At Nib, only 2 out of 10 migrants ascended the falls under cover of darkness. While there was no significant difference between the two results (Liddell's exact test R=3 p=0.14) due to the small sample size, the power of the test (0.45) was quite low, so we have a 55% chance that an actual difference existed between the responses of fish at the two sites (Type 2 error). We were able to increase the sample size, and hence power of the test, by incorporating the 2009 fixed site telemetry records in this analysis. These data provided a further 18 records of movement past Stotan and 9 records for Nib. The totals for night time movement through Stotan and Nib are then 20 and 3 fish, respectively, from 35 and 19 successful passages. Statistical comparison reveals a highly significant difference between the choice of passage time at the two sites (Liddell's exact test R=5 p=0.004) and, in part due to the larger sample size, the power of the test exceeded 0.95, so that there is less than a 5% probability that this result arose from chance. It appears that fish moving past Stotan select for hours of darkness while at Nib timing of movement is less specific. This suggests that there may be a difference in movement timing that could be ascribed to avoidance of human activity at Stotan during daylight hours.

As we have found when looking at other variables, there is a lack of consistency between years that extends to timing of migration. While we do not have accompanying data for Nib in 2007, over 50% of fish at Stotan (12 out of 23) ascended the falls between 5:00 am and 8:59 pm in this year; most moved in late morning and afternoon (7 fish) when they would have potentially been exposed to high levels of recreational activity. Similarly, in 2008, 6 of 17 fish (35%) moved during this time period at Stotan, while 7 out of 10 chose daytime movement at Nib (70%). In contrast, data from an area upstream of the falls show greater uniformity among years. Chinook migration through the diversion dam fishway demonstrated a consistent peak in activity in the early morning (Figure 5) over the years 2005 to 2007. We examined the movement of fish through Stotan and Nib, using the fixed telemetry records from 2007 (Stotan) and 2008 and 2009 (Stotan and Nib) to see if this overall pattern was also evident at these sites.

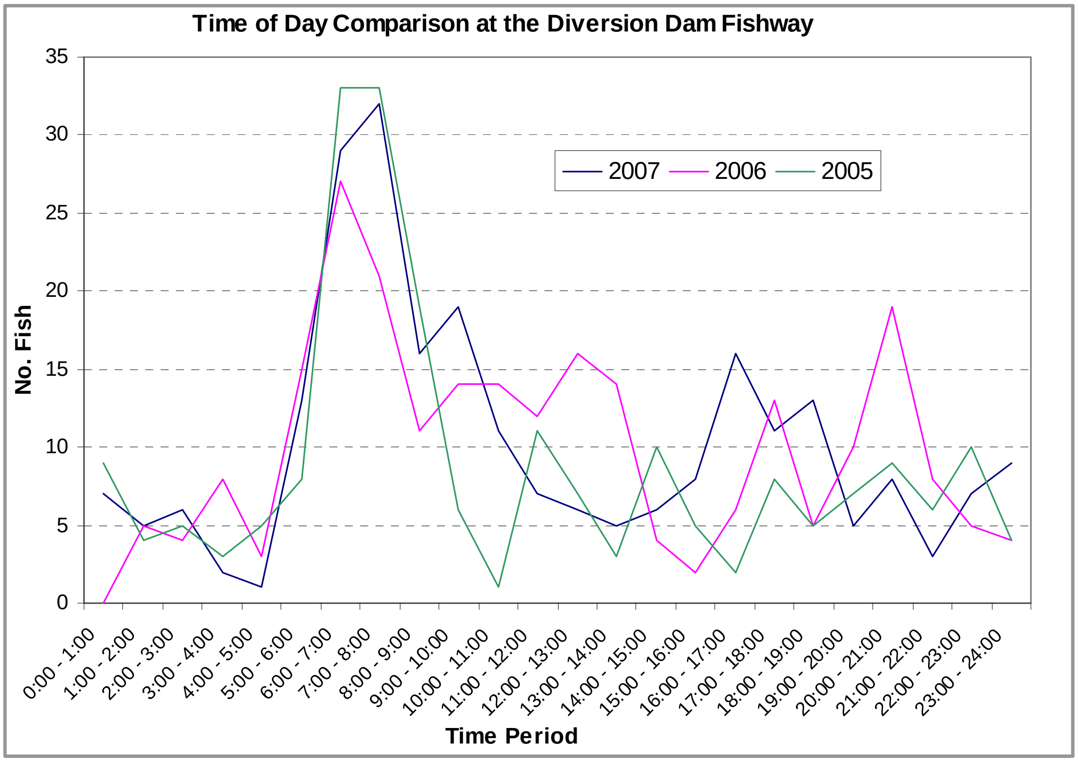

Figure 5. Migration activity by time period through the diversion dam fishway.

A total of 77 records were available from the falls sites combined. The frequency of movement timing is illustrated in Figure 6 and shows that the most active period of movement occurred between 9:00 pm and 10:00 pm, primarily due to movement over Stotan. However, considering all records, this frequency of movement just failed to achieve statistical significance over any other (Pearson chi-square 20df p=0.52). It is interesting that this time period was not represented by a peak in any year at the diversion dam fishway; the closest was the second highest peak in 2006 at 8:00 pm to 9:00 pm. One of the two second highest frequencies at the falls, 4:00 pm to 5:00 pm, had an equivalent peak at the fishway in 2007 (Figure 5), but otherwise there was little agreement between the sets of sites.

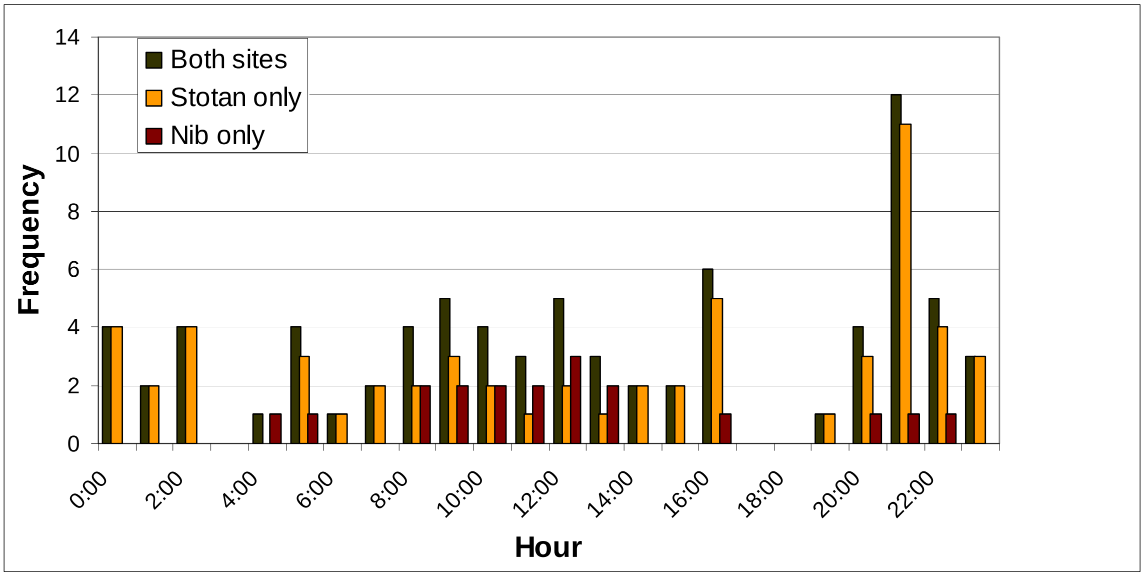

Figure 6. Frequency distribution of movement timing through Stotan and Nib falls in 2007 and 2008.

There is also poor agreement between Stotan and Nib falls. It is clear from Figure 6 that movement through Nib is concentrated during daylight hours, with reduced frequency in the evening and none in the early morning. Conversely, fish passage through Stotan accounts for almost all movement at night, although 46% of successful migrants here chose daylight hours. However, the degree of movement, specifically between 9:00 pm and 10:00 pm at Stotan, was significantly greater than in any other hour at this site (Pearson chi-square 19df p=0.03). This particular time at this location may represent the period when most fish are comfortable in resuming migration following the departure of people at the end of the day. Successful migration was not constrained to periods of the day when people were absent; in 2009 a total of 6 fish moved through Stotan between 8:00 am and 5:00 pm. However, only one of these was recorded on a Sunday, the others occurred during mid-week, perhaps corresponding to lower levels of human activity.

Even after several years of intensive data gathering, albeit for a different primary purpose than the fate of fish moving through the falls areas, the reasons that these areas affect migrants differently remain elusive. We know that migration success is highly variable at both sites and that each can pose the greater obstacle in a given year. The observable effects of the parameters that drive this variability are likely obscured by subtle interactions among a number of contributing variables that influence behaviour in individual chinook. Evidently, a more focused effort providing larger datasets with inherently greater power will be required to address this topic in any further studies.

4.4 Observations of non-tagged chinook migration

There has been speculation that early migrating chinook (i.e. adults that arrive in the river between early May and late June) have a greater success of migrating through Reach C and negotiating the Stotan and Nib falls areas compared to later migrants (i.e. adults arriving in the month of July. Indeed, in 2008, it was estimated that 96% of the early arriving chinook had successfully reached the diversion dam pool or had entered the upper hatchery raceways by the beginning of August, compared to only a 28% success rate for later arriving radio tagged chinook (Table 4).

During previous migration studies and video monitoring in the fishways, it was determined that, even when access upstream is prohibited, fish arriving at the barrier fence at the lower hatchery are able to bypass the fence during high river flows (flows likely exceeding 75-80 m^3/s at Gauge 8). As per recommendations from the previous year's telemetry study (Guimond and Taylor 2008), the hatchery completed some minor repairs to the barrier fence in late May, prior to the 2009 telemetry study. The purpose of this work was to prevent fish access at the fence during the high flows so that a greater proportion of the early chinook migrants could be collected at the lower hatchery for the enhancement program, as well as for the final year of the WUP migration study. Following the release of juveniles from the lower facility at the end of May, the hatchery began allowing adults into the hatchery raceways and access to the river above the fence remained closed for the duration of the summer chinook migration (until mid August).

The effectiveness of the fence repairs can be evaluated by the number of untagged chinook observed during snorkel surveys in Reach C. Prior to the kayak pulse flow on June 6-7, hatchery staff conducted spot snorkel surveys at a few key chinook holding pools in the river to obtain a rough estimate of the number of fish below and above the barrier fence. These included the pool below the fence, Stotan falls pools and the diversion dam pool. No adult chinook were observed in the river upstream of the barrier fence, and approximately 26 chinook were counted in the pool below the fence. The river was next surveyed on July 7 before the first migration pulse flow as part of the WUP Steelhead Production monitoring program. During this snorkel survey, approximately 113 chinook were counted upstream of the barrier fence, between the powerhouse pool and the diversion dam, plus there were 35 untagged chinook that were recorded (from video surveillance) passing through the fishway into the headpond (Table 5). Subtracting the number of radio-tagged fish that were released at the lower hatchery provides an estimate of the number of early arriving chinook migrants that had likely successfully negotiated the barrier fence during high flows (kayak pulse and smolt release flow releases), or approximately 118 fish, with the majority of these fish possibly passing the barrier fence during the higher kayak flow. Snorkel surveys conducted on later dates yield higher numbers, likely due to variations in fish distribution in the river, visibility in pools and observer accuracy. Regardless, the estimates of chinook calculated from snorkel counts and video surveillance indicate that the fence repairs were only marginally successful in preventing access at high flows, when compared to previous year's data (> 200 chinook based on video surveillance and snorkel records). However, it remains clear that chinook migration success to or above the diversion dam is very high for adults entering the river before July (Table 5). Similar to 2008, the success rate was above 90% (Guimond and Taylor 2009).

Table 5. Number of chinook counted at several locations in the Puntledge River during four separate snorkel surveys conducted during the 2009 WUP Steelhead Production monitoring program.

Location of snorkel count	7-Jul	10-Jul	4-Aug	7-Aug
Diversion Dam pool (13.3 km)	72	85	86	39
Diversion to Stotan (13.2 – 9.7 km)	9	16	4	5
Upper Stotan Falls (9.6 km)	7	6	0	0
Mid Stotan Falls (9.4 km)	1	1	0	0
Stotan to Powerhouse (9.3 – 6.9 km)	1	4	0	0
Powerhouse pool (6.8 km)	23	0	0	1
Total Snorkel Count	**113**	**112**	**90**	**45**
Subtract Viable radio-tagged fish in Reach C (6.8-13.3 km) [a]	30	28	11	10
Add Number of untagged CN that accessed Headpond	**35**	**43**	100	110
Total Count (Untagged early migrants)	**118**	**127**	**179**	**145**
Total # at or above diversion dam vs. total count	**107/118**	**128/127**	**186/179**	**149/145**

[a] Radio-tagged fish may or may not have been observed by snorkelers

4.5 Movement of fish in Reach B

Of the 37 radio-tagged chinook (EMG and conventional) released at the Lower Puntledge Hatchery, 16 successfully reached the diversion dam pool representing a 43% success rate overall. Of these 16 fish, nine migrated into the headpond (Table 2). Access into the headpond through the fishway was open from early May until August 17th. Of the 9 tagged fish that accessed the headpond, 5 migrated further into Comox Lake and all of these fish returned to spawn below Comox Dam between Sept 30 and Oct 27. Transmitters from two of these fish were recovered and temperature data from the iButtons is provided in Figure 7, along with temperature data recorded at the outlet of Comox Lake. The time of entry into Comox Lake is clearly noted in the thermal history of these two fish, indicated by a rapid drop in fish temperature compared to the lake outlet temperature data.

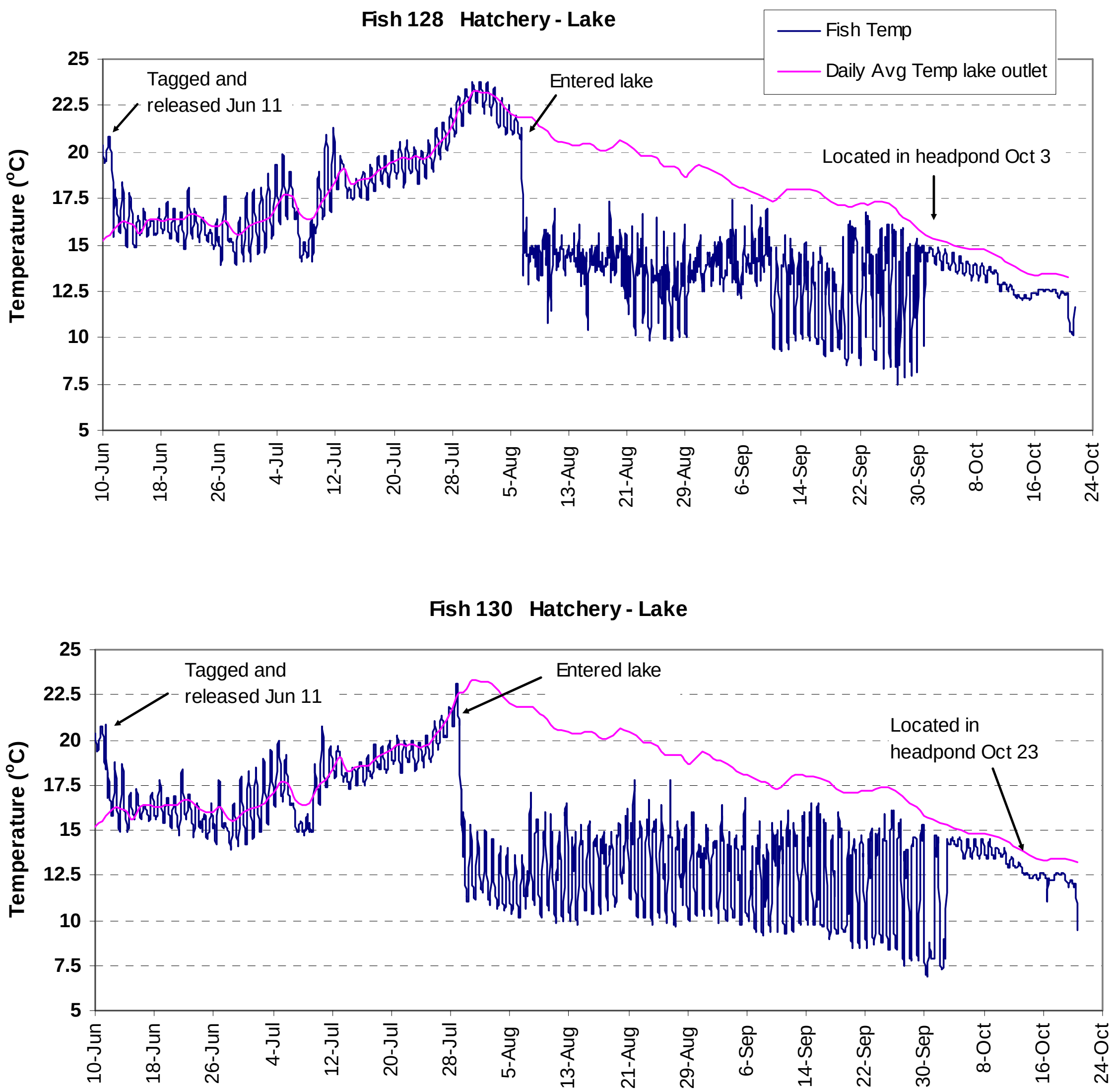

Figure 7. Temperature history of Fish # 128 and 130 released at the lower hatchery on June 11, 2009 relative to the Puntledge River daily average temperature measured at the Comox Lake outlet.

4.6 Movement of fish released into Comox Lake

Of the 10 tagged chinook that were released directly into Comox Lake on June 26, all but one fish (tag #40) remained in the lake until the onset of spawning (early October). Tag #40's signal was located in the headpond from mid August until early October. Six of the remaining 9 fish dropped below Comox dam between Oct 5 and Oct 9 while two other fish were located in the Upper Puntledge River on Oct 23 - one in Willemar Lake and the other at its outlet (Figure 1 inset). The tenth fish was not located. Interestingly, one of the fish located in the Upper Puntledge River was subsequently located in the headpond 4 days later on Oct 27. Although not a record for salmon, the fact that this fish was able to migrate downstream and through Comox Lake to the headpond (km 14.5), a distance of 20 km, in such a short time and so late in the spawning period provides some evidence of the benefits of holding in Comox Lake on the stamina and survival of summer chinook adults. The overall survival of chinook that held in Comox Lake, including those that volitionally accessed the lake from the headpond, is 93%.

Recovered temperature data from 3 of the 10 thermal loggers in chinook that were released in Comox Lake, and from the two chinook that migrated into the lake from Reach B (Figure 8) indicates that there was a general preference for chinook to hold in the lake within a temperature range of between 10 ^{o}C and 15 ^{o}C. Chinook infrequently remained at temperatures above 15 ^{o}C or below 10 ^{o}C for any length of time.

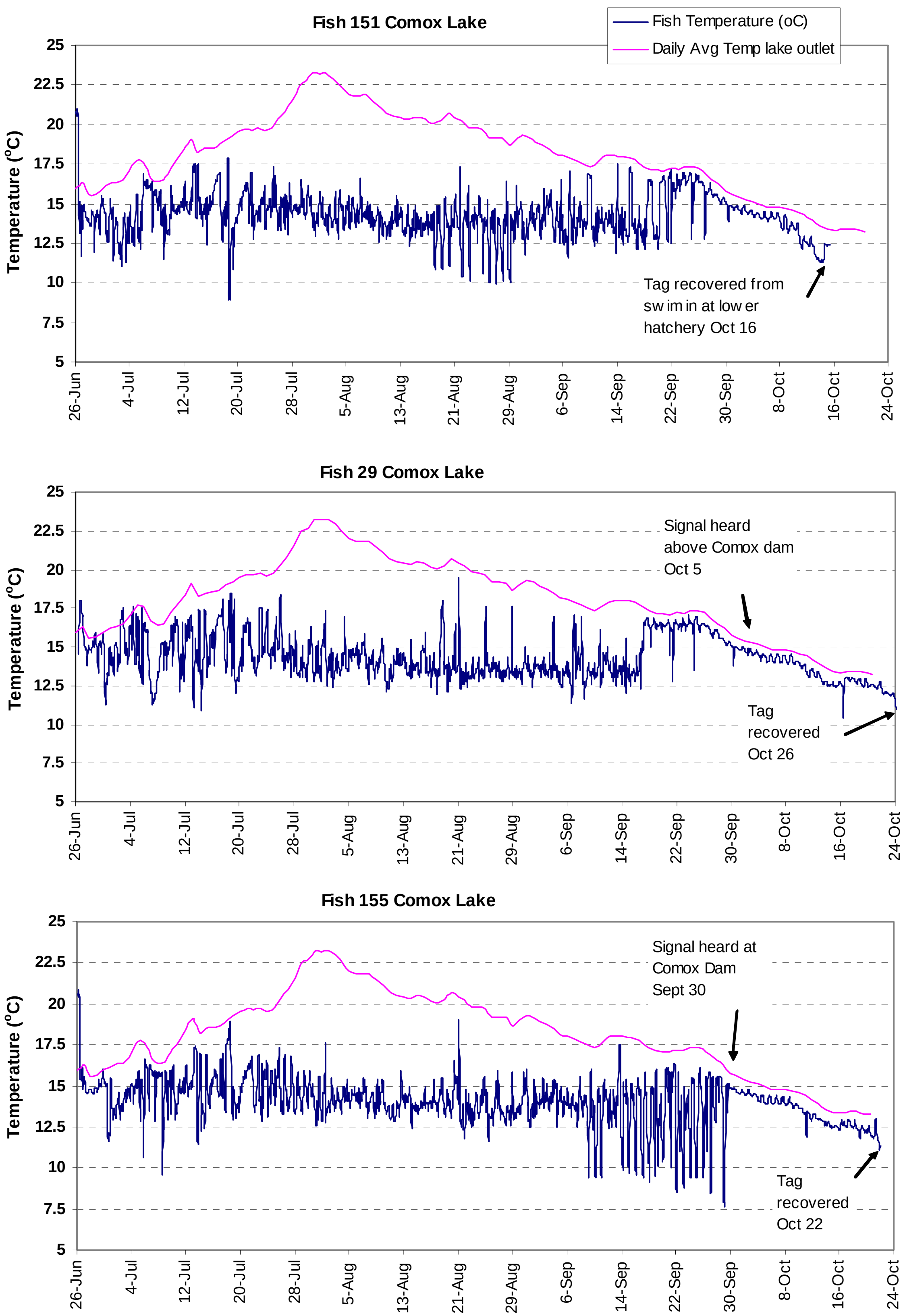

Figure 8. Temperature history of Fish #151, 29, and 155 released in Comox Lake on June 26, 2009, relative to the Puntledge River daily average temperature measured at the Comox lake outlet.

5 CONCLUSIONS AND RECOMMENDATIONS

Based on the results from the past 3 years of radio telemetry migration studies on Puntledge summer chinook, and the 7 studies completed since 2002, the interactions of the various factors influencing summer chinook migration success in the Puntledge River remain unclear. Some key findings from these studies include:

1. Early migrating chinook appear to have much better success in reaching the upper river than later arriving fish.
2. Chinook prefer to hold in temperatures between 12 and 15 ^{o}C.
3. Chinook that are able to hold in the cooler temperatures of Comox Lake during the summer have a greater survival to spawn than those fish that hold in the river below the diversion dam.

The past studies have clearly demonstrated that the most productive strategy for summer chinook adults is to migrate into Comox Lake during the most favourable conditions (pre-July), hold in the lake during the summer and then spawn in the upper watershed or the headpond reach above the diversion dam. With the current state of decline of summer chinook returns in the Puntledge watershed, DFO has begun implementing changes to the hatchery program using information gained from these and other studies. Briefly, the hatchery should optimize broodstock collection such that a larger portion of the early summer chinook migrants are incorporated in the enhancement program. If run timing is hereditary, then using a larger proportion of summer chinook broodstock from the later arriving migrants may contribute to poorer migration success into the upper watershed. Adult hatchery broodstock should be held in cool water temperatures to maximize survival of the broodstock and ensure production of viable offspring. The chinook juvenile release strategy should support the development of a summer chinook population that is imprinted on Comox Lake and will return there as adults where they will have the greatest chance of survival to spawn. Addressing these species requirements will be critical to the overall recovery of the summer chinook population to historical levels.

6 ACKNOWLEDGEMENTS

We are grateful for the financial support for this study from BC Hydro Bridge Coastal Fish and Wildlife Restoration Program (BCRP), and technical support from Fisheries and Oceans Canada. Special thanks are also given to Puntledge Hatchery staff for their assistance in capturing, holding and radio tagging summer chinook; University of Carleton for technician support, telemetry equipment use and data sharing; Ecodynamic Solutions for conducting snorkel surveys during the study; T. Sweeten (DFO) for providing river temperature data; and BC Hydro for discharge data.

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APPENDICES

APPENDIX A: BCRP Financial Statement **Project #: 09.Pun.04**

	BUDGET			ACTUAL		
INCOME	**BCRP**	**Other (Cash)**	**Other (in-kind)**	**BCRP**	**Other (cash)**	**Other (in-kind)**
Total by Source	$32,230.00	$0.00	$36,850.00	$32,230.00	$0.00	$36,850.00
Grand Total Income (BCRP + Other)	**$69,080.00**			**$69,080.00**		
EXPENSES						
Project Personnel						
Biologist - Project Coordination	$8,000.00			$8,253.00		
Technicians	$11,200.00			$9,498.75		
Statistician	$4,000.00			$3,937.50		
DFO and Carleton University (Biologist)			$5,000.00			$5,000.00
DFO (Technicians)			$10,500.00			$10,500.00
Communications	$2,250.00			$2,368.75		
Material and Equipment						
Radio Transmitters	$1,500.00		$1,500.00	$1,726.20		$1,500.00
Rental of Lotek receivers			$10,500.00			$10,500.00
Rental of video surveillance equip.			$6,000.00			$6,000.00
Receiver servicing	$500.00			$895.65		
Boat Rental	$150.00			$40.00		
Misc field, safety supplies, permits	$400.00			$158.21		
Travel	$660.00			$636.90		
Geocache Workshop	$640.00			$480.00		
Administration						
Admin Fees (10%)	$2,930.00		$3,350.00	$2,799.50		$3,350.00
Total Expenses	**$32,230.00**	**$0.00**	**$36,850.00**	**$30,794.46**	**$0.00**	**$36,850.00**
Grand Total Expenses (BCRP + others)	**$69,080.00**			**$67,644.46**		
Balance (Grand Total Income - Grand Total Expenses	**$0.00**			**$1,435.54**		

APPENDIX B - Performance Measures

Project # 09.Pun.04

Performance Measures – Target Outcomes												
			Habitat (m^2)									
Project Type	**Primary Habitat Benefit Targeted of Project (m^2)**	**Primary Target Species**	Estuarine	In-Stream Habitat – Mainstream	In-stream Habitat – Tributary	Riparian	Reservoir Shoreline Complexes	Riverine	Lowland Deciduous	Lowland Coniferous	Upland	Wetland
Impact Mitigation												
Fish passage technologies	Area of habitat made available to target species	Summer chinook and steelhead		**3.7 km**	**>8 km**							
Drawdown zone revegetation/stabilization	Area turned into productive habitat											
Wildlife migration improvement	Area of habitat made available to target species											
Prevention of drowning of nests, nestlings	Area of wetland habitat created outside expected flood level (1:10 year)											
Habitat Conservation												
Habitat conserved – general	Functional habitat conserved/replaced through acquisition and mgmt											
	Functional habitat conserved by other measures (e.g. riprapping)											
Designated rare/special habitat	Rare/special habitat protected											
Maintain or Restore Habitat forming process												
Artificial gravel recruitment	Area of stream habitat improved by gravel plmt.											
Artificial wood debris recruitment	Area of stream habitat improved by LWD plcmt											
Small-scale complexing in existing habitats	Area increase in functional habitat through complexing											
Prescribed burns or other upland habitat enhancement for wildlife	Functional area of habitat improved											
Habitat Development												
New Habitat created	Functional area created											

APPENDIX C: Confirmation of BCRP Recognition

Article on the BCRP and WUP Summer Chinook Radio Telemetry Study, appearing in the ***Comox Valley Echo***, November 13, 2009.

Cool waters of Comox Lake may be essential for summer chinook survival

Comox Valley Echo
Published: Friday, November 13, 2009

The radio telemetry study of summer chinook migration patterns in the Puntledge River Watershed is finishing up its third year.

The radio telemetry study has two components with separate objectives. One objective is to determine if the summer pulse flows in July and August are beneficial to these fish.

A second objective is to increase understanding of the role that the upper watershed and Comox Lake play in contributing to survival and successful spawning of this threatened species.

The radio telemetry study of summer chinook response to pulse flows was led by Carleton University and DFO and funded by BC Hydro's Water Use Plan Monitoring Program.

The second component, monitoring of summer chinook migration and survival rate in the upper watershed, was funded by BC Hydro's Bridge Coastal Fish and Wildlife Restoration Program and led by Project Watershed.

Since 1912, beginning with the construction of the impoundment dam and compounded in the 1950's by raising the diversion dam and increasing the amount of flow diverted for power generation, summer chinook access to the upper reaches of the Puntledge River and Comox Lake has been severely reduced.

To compensate for this and to assist fish migration in the Puntledge River, BC Hydro's Water Use Plan (WUP) allows for short periods of increased flows or "pulse flows".

Throughout the year there are seventeen two day fish migration pulse flows for chinook salmon and steelhead.

To determine if pulse flows aid fish migration the WUP telemetry monitoring program focused on studying the migration patterns, below the diversion dam, of summer chinook in response to summer pulse flows. Results of the study are still tentative.

To better understand the role of the upper watershed in contributing to summer chinook survival, the second component of the study monitored chinook migration after pulse flows and to their spawning habitats in the upper river.

Historically, Comox Lake played a significant role in the life history of summer-run chinook stock, by providing cool water refuge during the summer months until they spawn in the fall.

The lake's cooler temperatures and proximity to spawning grounds at the lake outlet, as well as lake tributaries such as the Cruickshank River, increased their chances of surviving and successfully spawning.

Telemetry results from last year's study have indicated that reaching Comox Lake and the upper river or head pond will be a key factor in the long term sustainability of these unique fish.

The biologist for the project Esther Guimond, states that, "Nine out of ten radio-tagged summer chinook that were released into Comox Lake in the summer returned to the lake outlet or head pond, to spawn in October."

Previous radio telemetry studies of summer chinook migration indicated that those fish that enter the Puntledge River earlier in the summer, May through early June, have a greater chance of reaching the upper watershed and therefore an increased chance of surviving to spawn.

To determine if early arrivals have better success in accessing the upper watershed, the 2009 Water Use Plan telemetry study implanted radio transmitters into summer chinook three to four weeks earlier than in previous years.

The results of the radio telemetry studies will help identify other access problems for summer chinook and aid in determining the role of pulse flows in summer chinook migration.

This information will be used to guide future operations and restoration activities on the Puntledge River with the aim of rehabilitating summer chinook stocks.

APPENDIX D: Photos

Photo 1. Summer chinook tagged with a conventional transmitter (antenna protruding from the mouth) recovering in the fishway at the lower hatchery prior to release.

Photo 2. One of the many unusual places that tagged chinook carcasses were recovered. This fish (tag #130) was released at the lower hatchery, spent 2 months in Comox Lake and was recovered in the headpond in December