Stave River Project Water Use Plan

Diel Pattern of Fry Out-migration

Reference: SFLMON#7

Stave River Project Water Use Plan: Diel Pattern of Fry Out-migration

Study Period: February 2008 – April 2008

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Lower Stave River - Monitoring of Chum Fry Out-migration, 2008

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EXECUTIVE SUMMARY

A monitoring survey was conducted to assess whether chum salmon out-migrating fry between mid-February and early April, 2008, would respond to the rapid flow changes resulting from current hydro operations in the Lower Stave River. The findings from this study will be used by BC Hydro to consider if there is a need to improve operational strategies to minimize impact on chum fry out-migration.

There were clear diurnal patterns in chum fry emergence behaviour. A distinct periodicity of out-migrating chum fry was recorded, with catches being higher during the night (51.7 fry/h) than during the day (2.9 fry/h). The number of out-migrating chum fry peaked soon after dark, with catches declining overnight, and being negligible during the day. The mean peak capture time for ‘buttoned’ fry was 22:47 h (95% CI: 22:42 - 22:52 h).

Behaviour of emerging chum fry did not change noticeably relative to changes in flow. During periods of fry movement, the rate of fry captured was similar between periods of rising, steady, and falling water levels (high flow: 25.3 fry/h; low flow: 25.0 fry/h). The mean peak capture time for ‘buttoned’ fry did not vary significantly with flow (95% CI high flow: 23:09 - 23:24 h; 95% CI low flow: 22:11 - 22:24 h).

Our assessment of fry movements in response to flow treatments remains inconclusive. Emergent ‘buttoned’ fry and sac-fry (alevin) were observed buried under cobbles and gravels during low flows during the day. However, direct observations comparing day versus night periods in relation to rising, steady, and falling water levels were not achieved due to the difficulties associated with sampling at higher flows (200 m³/s), particularly during the night.

Chum fry showed a heterogeneous spatial distribution during out-migration. Catch-per-unit-effort (CPUE) in paired nearshore driftnets (mean = 0.8 fry/h) was lower than in nets located farther offshore (1.0 fry/h). The difference between nearshore and offshore driftnet pairs was affected by flow, but not by time of day. Differences in chum fry catch were also observed between vertical pairs of drift nets. CPUE of fry in paired surface driftnets (mean = 6.6 fry/h) was greater than in nets located on the river bottom (2.5 fry/h). The difference between surface and bottom driftnet pairs was affected by time of day, but not by flow.

The findings of the present study indicate that rapid flow changes in the Lower Stave River did not appreciably affect chum fry out-migration behaviour. It is recommended that a minimum of three years of monitoring is required to adequately examine annual variation in fry out-migration in relation to changes in flow from hydro operations. In addition, further consideration should be given to examining sac-fry (alevin) behaviour in response to flow treatments and different substrates.
INTRODUCTION

In 1999, a Water Use Plan (WUP) was completed for the Stave River (Stave Falls and Ruskin projects) that identified operational changes for the Ruskin Generating Station (BC Hydro 2003; Failing 1999). One of the operational changes adopted in the Stave River WUP process for the Ruskin Generating Station was a spring-block loading strategy between 15 February and 15 May, during which time the generating station would operate at a set output (BC Hydro 2003). The purpose of spring-block loading is to maintain relatively constant flow from the Ruskin Generating Station during the main period of emergence for salmon fry. When the flow is below the 100 m$^3$/s threshold, the Plan specifies a maximum one plant load change per 48-h period, whereas when the 100 m$^3$/s minimum is maintained, the limitation on peaking operations does not apply. In reality, however, due to fluctuations, discharges through the spring block load period are not as simple as maintaining a set output or minimum flow. The Consultative Committee of the Stave River WUP therefore identified the need to develop and implement several monitoring programs to address a number of information gaps related to the potential impact of flow fluctuations on the reproductive life cycle of salmonids downstream of Ruskin Dam.

The present fish monitoring project was intended to address two questions, namely:

1. Do out-migrating chum salmon fry show a diurnal (24-h period) migration pattern, and if so, is it primarily at night, crepuscular, or during the day?

2. Does the behaviour of emerging fry change during rising, steady, and falling water levels, and if so, do these changes occur at certain times of the day and vary with distance from channel margins?

GOALS & OBJECTIVES

The goal of the present monitoring program was to collect data on the behaviour of out-migrating chum fry in response to rapid flow changes using specific netting techniques, direct observation, and underwater video. The study was designed to provide a better understanding of fry migratory behaviour, and, if necessary, devise improved operational strategies to minimize impacts on fry while maintaining operational flexibility.

The study objectives were to:

1. Estimate relative catch-per-unit-effort (CPUE; fish/ trap/h) of out-migrating fry, across all periods of the day, using two inclined-plane traps (IPTs) operated in the Lower Stave River between 15 February and 10 April 2008;

2. Use direct observations and underwater video recordings to determine where chum fry are located during periods of no movement (e.g., at rest on the bottom, burrowed in the streambed);
(3) Estimate fry density (fry/m²) in shallow nearshore and deep offshore habitats during periods when fry are moving and not moving;

(4) Estimate CPUE of out-migrating chum fry captured in IPTs during periods of rising, steady, and falling water levels; and

(5) Obtain underwater video recordings (and to a lesser extent direct observation) to determine whether fry exhibit behavioural changes during periods of rising, steady, and falling water levels.

STUDY METHODOLOGY

Lower Stave River Study Area

BC Hydro’s Alouette-Stave Falls-Ruskin generating complex is located approximately 64 km east of Vancouver on the north side of the Fraser River near Mission, BC. The lowermost site in this complex is Ruskin Dam, located approximately 3 km upstream from the confluence of the Stave and Fraser rivers (Figure 1).

The Lower Stave River, a 2.8-km long, relatively broad and braided section of river located downstream of Ruskin Dam, supports a spawning population of chum salmon (*Oncorhynchus keta*) and cutthroat trout (*O. clarki clarki*) (BCFWRP 1998). Spawning escapements of chum salmon have ranged from approximately 100,000 to over 600,000 fish between 2000 and 2006. Recent increases in Stave River chum salmon abundance have been attributed to various habitat restoration and enhancement works, reduced harvest pressure, and improved flows at BC Hydro facilities (Bailey 2002). Chum salmon spawn in the Stave River during the October-November period, and fry out-migration occurs from mid-February through mid-May, with the peak occurring in April (MOE 2007; BC Hydro 2005).

The powerhouse at Ruskin Dam (completed in 1930) comprises three generators capable of producing a total 105.6 MW (BC Hydro 2003). Stave Lake serves as the main storage reservoir for the Stave Falls and Ruskin generating stations, and reaches its highest water levels during the fall and late spring due to high inflows. The main purpose of the Ruskin Generating Station is to supplement the needs of urban users in the Greater Vancouver Regional District. In addition to water storage for power generation, the lake is managed for flood control, recreational use, and enhancement of fisheries and wildlife values.

The flow associated with tidal and non-tidal areas are distinctly different. Unlike the relatively constant flow in the upper reach, the flow in the lower reach varies depending on backwatering effects and tidal events from the Fraser River. For purposes of this analysis, the study area has been divided into the upper (non-tidal/non-backwatered area) and lower (tidal/backwatered area) reaches.
Field Schedule

Adult chum spawner distribution and flows were assessed on 17 December 2007 (Plate 1). Site safety features and trap anchoring systems were installed between 14 and 18 February 2008. Intensive continuous fry monitoring was conducted over four separate time periods: 19-21 February, 18-20 March, 24-26 March, and 1-3 April. Prior to the main monitoring period, test sampling was conducted on 4, 7, 11 and 14 March to identify the onset of fry migration.

![Plate 1: Measuring water depth and velocity in the Lower Stave River, 17 December 2007](image)

Catch Operations, Direct Observations, Underwater Videography, and Sampling Sites

Two, two-person crews were involved in the Lower Stave River operations for each of the four sampling periods. All sampling occurred in the most westerly channel of the Lower Stave River. Inclined plane traps, drift nets, direct observation and underwater videography were used to monitor fry out-migration and behaviour. However, visual techniques were generally not effective, and so were discontinued 18 March onward.

Inclined Plane Traps

Inclined-plane trapping (IPT) was the primary method used to monitor the effects of flows and time of day on fry out-migration (Plate 2).
Two IPT sampling sites were located: one at 750 m and the other at 1200 m downstream of the Ruskin Power Station (Figure 1; Table A-1). The criteria used in site selection were as follows:

1. It was located downstream of known areas of high density chum spawning;
2. It was located within the 1.5-km section of the Stave River immediately downstream of Ruskin Dam. One site was located close to Ruskin Dam where daily water level fluctuations were greatest; the second site was located farther downstream where tidal effects would attenuate water level changes.
3. It had a minimum water velocity of 0.5 m/s;
4. It had a minimum water depth of 0.7 m;
5. It had suitable anchoring sites (embedded logs; well-rooted trees; large, stable boulders);
6. It was readily accessible from shore; and
7. The area immediately upstream of the site was free from rocks and other debris that might alter the pattern of flow to the traps, damage the nets, or jeopardize crew safety.
IPT Sampling

The IPTs were constructed entirely of aluminum, with each trap secured in position with a 10-mm diameter steel cable bridle fastened to a 10-mm diameter steel cable stretched across the river channel, anchored securely at both ends. The IPT was based on the design described by Todd (1994); each trap floated on two welded aluminum rectangular pontoons, each 240 cm long, joined together with aluminum brackets. The mouth of the trap was 92 cm wide and 65 cm high, and the opening at the downstream end was 92 cm wide and 15 cm high. The live box was 92 cm wide, 50 cm long and 65 cm deep. Along the bottom of the trap was a perforated aluminum plate with 6 mm diameter holes evenly spaced 16 mm apart; the plate was folded into longitudinal V-shaped corrugations (20 cm between ridges, with a 7.5 cm rise/ridge).

IPT Site 1 (Plate 3; upper, non-backwatered site) was located approximately 30 m from the true left bank during low flow, and was moved to approximately 15 m from the left bank during high flow. Hazardous swift water conditions prevented the crew from accessing this site at a fixed location. IPT Site 2 (lower, backwater site) required minor repositioning (1-2 m) and was accessible during high and low flows.
Drift Net Sampling

To assess the horizontal and vertical distribution of migrating chum fry with respect to changing water levels (rising, steady, falling), drift nets (Plate 3) were operated in duplicate over four 24-hour periods. The nets were made of 500 micron mesh plankton netting, tapering from front to back, and were anchored with rebar along a selected transect in line with the IPTs at Sites 1 and 2. One pair of nets was deployed in an horizontal array, with one net located 1 m from shore, and the other 4 m from shore. The other pair was deployed in a vertical array, with one net set on the bottom, and the other at the surface (Table A-1).
Direct Observations

Visual inspections of dewatered gravel bars, nearshore areas, and offshore areas were completed on 24 March to assess conditions that may have resulted in stranding fish, and to characterize fry resting behaviour (above the streambed versus in the gravel). Five snorkel surveys (each at 10 m lengths of streambed) were conducted along a selected transect at Sites 1 & 2 during low water levels and daylight hours. The observer manually excavated a given area of streambed (1 m long and 20-30 cm deep) across the channel, and recorded fry or egg presence. Also, open pits (1m x 1m x 0.5 m) were excavated at each bank along transects 1 m, 3 m and 5 m from the wetted edge, and inspected for presence of fry, and then backfilled.

Underwater Videography

A fixed underwater video system was used to record the possibility of fish stranding during periods of different flow treatments (rising, steady, falling) and fry behaviours (active versus resting). Two colour video cameras, a Pentax Optio W60 and a Sealife 600C, were used, each placed in an underwater housing, which was mounted on custom-made brackets and anchored 5-7 m from the edge of the channel. The lenses of both cameras had a focal length of 3.5 to 5.5 mm; the cameras were depth-rated to 10 m. Demarcated benchmarks within view of the camera at 1, 2, and 3 m allowed the observer to assess distances on the recordings. Two lights, operated by a DC-AC generator, were mounted 2 m above each of the cameras, and oriented directly
behind the cameras, pitched at approximately 45 degrees to the horizontal. The light housings were fitted with 300 watt wide-angle halogen bulbs. Fifteen minutes of video was recorded per sampling session, which was stored on a 500-gigabyte external hard drive, and later viewed for fish presence and behaviour.

**Fry Enumeration and Biosampling**

All fish captured in the IPTs and drift nets were counted and identified to species. Chum salmon that were completely ‘buttoned-up’ were recorded as fry. A subsample of chum fry captured in the IPTs, and drift nets, was measured (fork length). As a comparison of fish sizes between gear types was not an objective of this study, subsampling was not randomized with respect to gear type.

**Physical Observations**

Several environmental variables were recorded hourly during trapping operations, including water temperature, air temperature, river water level, Ruskin discharge, Ruskin tailwater elevation, light intensity (LUX), and percent cloud cover. Staff gauges were positioned at both IPT sites to measure water level (to the nearest 0.01 m) during each observation period. Air and water temperatures were recorded with a handheld alcohol thermometer. The percentage cloud cover was visually assessed. Ruskin discharge and tailwater elevation data were provided by BC Hydro. Light intensity data were provided by Greater Vancouver Regional District (Abbotsford Airport Station). Flows <100 m$^3$s$^{-1}$ and >200 m$^3$s$^{-1}$ were recorded as low and high flows, respectively, and those between the above were termed “flux.” The time of day was categorized as “day”, “night”, and “dawn or dusk” periods.

**Chum Fry Behavioural Analysis**

To assess the effects of flow and time of day on chum fry migration, the two IPTs were operated continuously for 48 h/week over a four week period between 19 February and 30 April, 2008. The catch in each trap was assessed approximately hourly, and CPUE was calculated by dividing the number of fish caught by the number of minutes of sampling since the last trap check. Since catch data tended to follow the negative binomial distribution, and cannot typically be normalized using standardized transformation techniques, a Poisson-distribution log-link general linear model was used for statistical analyses. CPUE data were fitted with a full-factorial two-way model including ‘flow condition’ (categorized as low or high) and time of day (categorized as day or night) as factors. Catch of alevins and fry was analyzed separately.

During the overall study period, the traps were checked 384 times (48 hourly checks × 4 replicate periods × 2 traps). Of these, 285 trap checks were included in the two-way model (68 daytime high flows; 83 nighttime high flows; 87 daytime low flows; and 47 nighttime low flows). The remaining 99 trap checks was ignored, either because flows were in flux (>100 m$^3$s$^{-1}$ and <200 m$^3$s$^{-1}$) or the time of day was crepuscular (i.e., dusk/dawn twilight periods).

To further examine the effects of time of day, the CPUE data were analyzed using Rayleigh’s test for circular uniformity (Batschelet 1981). Rayleigh’s test was used to estimate the mean
migration time, and to determine whether the timing of catches was significantly different from random. At first, all 384 trap checks were included in this analysis. Subsequently, the analysis was repeated two more times, once using only the high flow data, and once using only the low flow data.

The effect of tides on chum fry and alevin catch rates were estimated by modelling IPT catch rates as a function of two variables - one continuous, and one categorical. For the continuous model, the water level readings from the Site 2 staff gauge were used as a predictor of CPUE. For the categorical model, staff gauge readings were categorized as either “low tide” (≤1.7 m) or “high tide” (>1.7 m). All analyses were carried out using Poisson-distribution log-link general linear models. Analyses were restricted to the downstream IPT (Site2), during periods when flow from the dam was categorized as ‘low’ (<100 m³·s⁻¹).

To assess the horizontal and vertical distributions of migrating chum fry, pairs of drift nets were operated over four 24-hour replicate periods. Several pairs of traps were deployed in horizontal arrays (one inshore, one offshore), and several other pairs of traps were deployed in vertical arrays (one at the surface, one at the bottom). Catch in each drift net was recorded approximately hourly, and CPUE was calculated by dividing the number of fry caught by the number of minutes fished since the last net check. Although catch data tend to be negative-binomially distributed, the difference between catches within pairs tends to be normally distributed, thus standard parametric statistics could be used. Paired t-tests were used to test for significant inshore versus offshore catch differences, and for bottom versus surface catch differences. The 'paired t-tests' take the difference in catch between the two traps within a pair (i.e., the ‘effect’), and asks whether the distribution of these effects is significantly different from zero (the method treats each pair of traps as a repeated measure 'subject', thus attempting to control for regional catch differences to determine, for example, if 'horizontal trap array 1' is in a better fishing location than 'horizontal trap array 2'). Where significant differences existed, the paired differences were modeled using standard parametric ANOVA techniques as a function of ‘flow condition’ (categorized as low or high) and time period (categorized as day or night). Note that there is only one value per pair of traps (i.e., the 'effect' -- either 'horizontal' or 'vertical' depending on the deployment of the trap array), and that the value is used as the dependent variable in the ANOVA. Using this method, we were able to explore whether any horizontal or vertical effects can be explained by changes in flow or light levels. Catch of alevins and fry was analyzed separately.

RESULTS

Environmental Observations

During the period in which the traps and nets were operational, water level at Sites1 and 2 ranged from 0.2 to 0.6 m and from 1.5 to 2.3 m, respectively (see Table A-2). Ruskin Generation Station discharge ranged from a low 74.6 m³/s to a high 302.9 m³/s (see Table A-2). For the total 208 hours of monitoring, flow levels were recorded as ‘low’ for 103 h (49.5 %), ‘high’ for 85 h (40.8%), and ‘in flux’ (rising or falling) for 20 h (9.7%). Water temperatures ranged from 4-6
°C, and averaged 5 °C (see Table A-2). There was no difference in water temperature between Sites 1 & 2.

**Effort**

**Stationary Traps**

The IPTs were operated from 19-21 February, 18-20 March, 24-27 March, and 1-3 April (Table 1; also see Table A-3). During the 208 h of monitoring effort, IPT 1 and IPT 2 were operated for 197.2 h (94.8%), and 188.5 h (90.6%), respectively. Site 1 IPT (30 m from bank) performed well at low to high flows with minimal fry mortality (<1%). However, hazardous, swift water conditions during high flows required the trap to be re-positioned to within 15 m from the bank for ease of sampling and crew safety. A deflector net-panel was temporarily installed at Site 1 (19 February), but did not function well during high flow and so was removed. Site 2 IPT performed very well at low to high flows with minimal fry mortality (<1%), and required only minor adjustments or maintenance throughout the sampling periods. A natural deflector log securely anchored at the true left bank provided excellent flow pattern for guiding fish into the trap. A minor problem was that the flows to the trap were minimal during high tide backwater periods, which may have resulted in some trap avoidance by fry.

The drift nets were operated from 19-21 February, 18-20 March, 24-27 March, and 1-3 April, the same as for the scheduled sampling sessions of the IPTs (see Table A-3). Due to low fry counts in the February sampling period, test sampling was conducted with the use of these nets on 4 March, 7 March, 11 March, and 14 March to determine when best to initiate routine sampling to include peak fry outmigration. The test sampling occurred between 19:00 and 21:00 h at Site 2 (drift nets 5-8). During routine sampling, the effort varied for different pairs of driftnets: operation time for bottom drift nets (4 pairs) ranged from 117.0 h (Drift Net 6) to 162.2 h (Drift net 3), and for surface drift nets from 27.9 h (Drift Net 4z) to 38.4 h (Drift net 3z) (see Table A-3). All drift nets performed well, with minimal fish mortality (<1%).
### Table 1: Chum fry sampling effort, Lower Stave River, 2008.

<table>
<thead>
<tr>
<th>Site 1 Method</th>
<th>Effort (hours)</th>
<th>Effort (hours)</th>
<th>Effort (hours)</th>
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<th>Total (hours)</th>
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<tbody>
<tr>
<td></td>
<td>Period 1</td>
<td>Period 2</td>
<td>Period 3</td>
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<tr>
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<td>18-20 Mar</td>
<td>24-27 Mar</td>
<td>1-3 Apr</td>
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<td>24.1</td>
<td>25.8</td>
<td>46.0</td>
<td>27.2</td>
</tr>
<tr>
<td>Drift Net 6 Down</td>
<td>24.9</td>
<td>25.8</td>
<td>39.1</td>
<td>27.2</td>
<td>117.0</td>
</tr>
<tr>
<td>Drift Net 7 Down</td>
<td>24.1</td>
<td>25.2</td>
<td>59.6</td>
<td>50.4</td>
<td>159.3</td>
</tr>
<tr>
<td>Drift Net 8 Down</td>
<td>-</td>
<td>-</td>
<td>13.6</td>
<td>24.3</td>
<td>37.9</td>
</tr>
<tr>
<td>Drift Net 7 surface Down</td>
<td>24.8</td>
<td>25.2</td>
<td>59.7</td>
<td>50.6</td>
<td>160.3</td>
</tr>
<tr>
<td>Drift Net 8 surface Down</td>
<td>-</td>
<td>-</td>
<td>12.8</td>
<td>24.6</td>
<td>37.3</td>
</tr>
<tr>
<td>IPT</td>
<td>44.2</td>
<td>44.3</td>
<td>54.3</td>
<td>45.7</td>
<td>188.5</td>
</tr>
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<td>UW video</td>
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<td>0.2</td>
<td>-</td>
<td>-</td>
<td>2.9</td>
</tr>
<tr>
<td>Direct Observation</td>
<td>2.7</td>
<td>-</td>
<td>2.0</td>
<td>-</td>
<td>4.7</td>
</tr>
<tr>
<td>Grand Total</td>
<td>297.9</td>
<td>295.8</td>
<td>578.4</td>
<td>502.7</td>
<td>1674.9</td>
</tr>
</tbody>
</table>

**Direct Observation & Underwater Video**

A total of 9.8 h of observations by snorkelling was completed on 19-20 February, 18 March, and 24 March. On 24 March, five hours of snorkelling along selected transects at both sites were performed, all during low flow conditions and daylight hours (see Table A-4); the remaining 4.8 h included paired visual-video counts from the true right bank at Sites 1 and 2.
The video system was operated for a total of 4.8 h between 19 February and 18 March (Table A-4). Visibility was limited to within 2 m of the camera during ‘ideal’ conditions. The video-monitoring system generated good quality video records for enumerating chum fry that passed within view during daylight hours and low flow conditions.

**Biosampling**

In total, 97 fry (47 at IPT 1, 50 at IPT 2) were opportunistically sampled for fork length (measured to nearest mm) between 26 March and 2 April (Figure 2; see Table A-8). The average fork length of chum fry at IPT 2 (FL = 37.4 mm) was significantly ($t_{95} = -5.7; P < 0.0001$) longer than those at IPT 1 (FL = 35.9 mm).

![Histogram](image-url)

**Figure 2:** Length frequency of chum fry at IPT 1 and IPT 2
Stationary Trap Catches

Overall, 9137 chum fry and 382 alevins were captured and processed (Table 2; see Table A-5 and Table A-6). Of these totals, the IPTs accounted for the majority of the fry (79%) and alevins (73%) captured. However, the catch rates in the two IPTs differed appreciably: IPT 2 caught 4.5 times more fry, and 3.5 times more alevins than IPT 1. Despite the difference in catch, the catch rates for the two IPTs were highly covariable for fry ($r = 0.80, P < 0.0001$), but not for alevins ($r = -0.031, P = 0.66$).

Other fish captured included low numbers of Chinook salmon (Oncorhynchus tshawytscha) and pink salmon (O. gorbuscha) fry, three-spined stickleback (Gasterosteus aculeatus), sculpins (Family Cottidae), and northern pikeminnow (Ptychocheilus oregonensis) (see Table A-7).

Table 2: Summary of chum salmon alevin and fry captured in stationary nets/traps, Lower Stave River, 2008

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Alevin</th>
<th>Fry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift Net 1</td>
<td>8</td>
<td>29</td>
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<td>Drift Net 2</td>
<td>8</td>
<td>63</td>
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<td>Drift Net 3</td>
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<td>17</td>
<td>166</td>
</tr>
<tr>
<td>IPT</td>
<td>63</td>
<td>1319</td>
</tr>
<tr>
<td>Drift Net 3</td>
<td>1</td>
<td>138</td>
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<tr>
<td>surface</td>
<td>4</td>
<td>65</td>
</tr>
<tr>
<td>Drift Net 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface</td>
<td></td>
<td></td>
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<tr>
<td>Site 1 Total</td>
<td>111</td>
<td>1929</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Site 2</th>
<th>Alevin</th>
<th>Fry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift Net 5</td>
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<td>25</td>
</tr>
<tr>
<td>Drift Net 6</td>
<td>8</td>
<td>56</td>
</tr>
<tr>
<td>Drift Net 7</td>
<td>11</td>
<td>279</td>
</tr>
<tr>
<td>Drift Net 8</td>
<td>20</td>
<td>211</td>
</tr>
<tr>
<td>IPT</td>
<td>217</td>
<td>5930</td>
</tr>
<tr>
<td>Drift Net 7</td>
<td>7</td>
<td>371</td>
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<tr>
<td>surface</td>
<td>2</td>
<td>336</td>
</tr>
<tr>
<td>Drift Net 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site 2 Total</td>
<td>271</td>
<td>7208</td>
</tr>
</tbody>
</table>

Grand Total 382 9137

Direct and Underwater Video Observations

Reduced visibility during high flows made it impossible to identify or count fry. An observer efficiency trial conducted on 18 March indicated low efficiency in visual counts in the Lower Stave River at higher flows, despite sampling during daylight and in clear water. Of a total 60
fry released in less than 0.5 m/s water velocity nearshore and upstream of the camera, 68% (41) were detected; however, when fry were released into water of velocities exceeding 1 m/s, only 16% (17 of a total 105 fry released) were detected (see Table A-4). No fry were observed stranded in the gravel (n = 60) following dewatering after high flows.

**Chum Catches in Relation to Time of Day and Flow**

Chum fry showed a greater response in outmigration with respect to time of day than did alevins (Figure 3 and Figure 4). Rayleigh’s test for circular uniformity (Batschelet 1981) showed that timing of capture was significantly different from random ($P < 0.0001$), and the trend was stronger for chum fry ($r = 0.67$) than for alevins ($r = 0.35$). Chum fry catches peaked soon after dusk, with catches declining during the night, and remaining negligible throughout the day (Figure 5; see Table A-9). The peak capture time for fry was 22:47 h (95% CI: 22:42 - 22:52 h). Chum alevin catches were more variable during the night, with minor peaks during daylight (Figure 6; see Table A-10). The peak capture time for alevins was 23:50 h (95% CI: 23:03 - 00:36 h).

![Figure 3: Average CPUE of chum fry per IPT in relation to time of day (day vs. night) and river flow (high: >200 m$^3$/s; low: <100 m$^3$/s). Error bars are standard error of the means.](image-url)
Figure 4: Average CPUE of chum alevins per IPT in relation to time of day (day vs. night) and river flow (high: >200 m³s⁻¹; low: <100 m³s⁻¹). Error bars are standard error of the means.
Figure 5: Vanishing bearings diagram showing chum fry CPUE by hour. Bars show hourly CPUEs averaged over four 48-h sampling periods. For relative scale, the longest bar (at 20:00 h) shows 105 fry/h. The blue arrow shows the mean vector, with its length related to the strength of the trend and its direction pointing to the average capture time.
Figure 6: Vanishing bearings diagram showing chum alevin CPUE by hour. Bars show hourly CPUEs averaged over four 48-h fishing periods. For relative scale, the longest bar (at 21:00 h) shows 2.9 alevins/h. The blue arrow shows the mean vector, with its length related to the strength of the trend and its direction pointing to the average capture time.

For a more detailed description of the flow treatments for each of the four trial periods, the IPT catches (sum of IPT 1 + IPT 2) of chum fry are superimposed on Flow Condition and Light Levels for the day, night, and twilight periods (Figure 7). These plots show that the catch of fry outmigrants peaked soon after dusk, declined during the night, and remained virtually zero during the day. There is no consistent evidence of the catch being influenced by flow conditions. The occurrence of peaks during flux in a few instances is considered to be due to coinciding dusk conditions, which is the over riding factor initiating the onset of fry movement daily.
Figure 7: Catch of chum fry for both IPTs combined superimposed on Flow Conditions and Light Levels for each of the four trial periods during 19 February-3 April, 2008. Flow Conditions are shown by the shaded areas (white = Low Flow; light gray = flux, dark gray = High Flow). Light Levels are shown as Lux (W/m²), where Lux = 0 at night.
A further analysis of the catch in relation to flow changes was not easily addressed as there are little data available for periods of flux (total = 20 h), flux-1h, and flux+1h, and observations were sensitive to coincidental chum migration pulses (e.g., during twilight). A typical solution would be to use “hour” as a factor in the analysis, but it is inappropriate as a continuous variable (ANCOVA, in which ‘hour’ is factored out of the analysis by ‘adjusting’ observed catch values along the catch-by-time slope) because the catch-by-hour relationship is ‘circular’, not linear. It also would not work as a categorical variable (two-factor ANOVA), as there is not complete replication between flow and hour (e.g., there are no observations of the “flux-1” flow category during fishing sets when “hour = 5”).

The way around this problem was to ‘factor out the effect of hour’ manually. To do this, the median catch was calculated for each hour. Then, for each trap check, we calculated the difference between the observed catch and the ‘expected’ (median) catch for the hour during which the trap-check was performed. The distribution of these residuals was not normal, so non-parametric tests were used. These statistical analyses (Wilcoxon Tests) showed a significant difference among the Flow Conditions ($\chi^2 = 11.0, P = 0.026$). Note, that there are now 5 “flow condition” categories: low, high, flux, flux-1 {1 h before flux}, and flux+1 {1 hour after flux}). The only significant pairwise comparison was between the “flux” and “low” flow categories, which will be discussed in the Discussion section.

There are no statistical differences among flux, flux-1, and flux+1. The lack of pattern lends validity to the idea of excluding flux data from other analyses. Note also that the largest catch values occurred in the hour preceding flow increases, which was clearly an artefact (due to coinciding dusk conditions), since the fish would not have been able to predict flow changes before they occurred.

For graphical representation, the average residual value for each of the 5 “Flow Conditions” was plotted, along with the 95% CI of the means (Figure 8). However, the plot is completely unrelated to the analysis (Wilcoxon Rank Test), which does not use means or 95%CI, rather, it works off ranked data.
Chum Fry Behaviour in Relation to Flow & Diurnal Effects

For chum fry, the two-way Poisson model was highly statistically significant ($\chi^2 = 8114.6, P < 0.001$; Figure 7). Chum fry catches were significantly higher during the night (51.7 fry/h) than during the day (2.9 fry/h; $\chi^2 = 7956.0, P < 0.001$). There was no significant effect of flow on catch rates (high flow: 25.3 fry/h; low flow: 25.0 fry/h; $\chi^2 = 1.8, P = 0.18$). There was, however, a significant interaction effect on chum fry catch ($\chi^2 = 109.7, P < 0.0001$).

For chum alevins, the two-way Poisson model was highly statistically significant ($\chi^2 = 147.4, P < 0.0001$, Figure 9). Alevin catches were significantly higher during the night (1.78 alevin/h) than during the day (0.46 alevin/h, $\chi^2 = 124.6, P < 0.0001$), and significantly greater during high flow (1.32 alevin/h) than low flow conditions (0.77 alevin/h; $\chi^2 = 20.3, P < 0.0001$). There was a significant interaction effect on alevin catch ($\chi^2 = 21.9, P < 0.0001$).

Mean peak capture time did not vary significantly with flow for fry (95% CI high flow: 23:09 - 23:24 h; 95% CI low flow: 22:11 - 22:24 h), or for alevins (95% CI high flow: 23:45 - 2:44 h; 95% CI low flow: 21:23 - 00:29 h).
Figure 9: Average CPUE (IPT 1 and IPT 2 combined) of chum fry and alevins by time of day and river flow (high: >200 m3s-1; low: <100 m3s-1). Error bars are standard error of the means, and do not reflect the statistical tests used.

Chum Fry Catches in Relation to Tides

During periods of low flow there was a significant effect of tides on fry catch rates in IPT 2 (the downriver site). The Poisson regression model was statistically significant ($\chi^2 = 269.5$, $P < 0.0001$), though it explained very little of the variance (correlation between predicted and observed values: $r = 0.16$, $P = 0.18$). The Poisson ANOVA ($\chi^2 = 96.2$, $P < 0.0001$) showed that mean fry CPUE at low tide (40.5 fry/h) was significantly greater than at high tide (23.2 fry/h) (Figure 10). In contrast, there was no significant effect of tides on alevin CPUE (Poisson regression: $\chi^2 = 1.7$, $P = 0.19$; Poisson ANOVA: $\chi^2 = 0.11$, $P = 0.74$); mean CPUE at low tide (1.0 alevin/h) was not significantly different from that at high tide (0.9 alevin/h).
Chum Fry Distribution

Active Migratory Period

Chum fry were heterogeneously dispersed between nearshore (shallow habitats) and deeper offshore areas, whereas alevins were homogeneously dispersed between these areas during active migration.

Horizontal Effects

Significant differences in chum fry catches were observed between horizontal pairs of drift nets. CPUE in nearshore driftnets (mean = 0.8 fry/h) was significantly lower than in nets located farther offshore (1.0 fry/h; \( t_{514} = 2.2, P = 0.031 \)). A two-way ANOVA (Table 3; \( F_{3,390} = 2.9, P = 0.035 \)) showed that the difference between nearshore and offshore driftnet pairs was significantly affected by flow condition (Figure 11; \( F_{1,390} = 4.9, P = 0.027 \)), but not by time of day (\( F_{1,390} = 2.8, P = 0.10 \)); refer to annotations in Figure 11 for further explanation. There was no significant interaction term in the ANOVA model (\( F_{1,390} = 2.6, P = 0.11 \)).

No significant differences in alevin catch were observed between horizontal pairs of drift nets (Figure 11). CPUE in nearshore driftnets (mean = 0.10 alevin/h) was not significantly different from that in nets located farther offshore (0.08 alevin/h; \( t_{514} = -1.0, P = 0.34 \)). Also, there were no significant effects in the two-way ANOVA (\( F_{3,390} = 0.19, P = 0.90 \)).
Table 3. ANOVA test showing differences of chum alevin and fry distributions captured using stationary nets, Lower Stave River, 2008

<table>
<thead>
<tr>
<th>Flow Condition</th>
<th>Low</th>
<th>High</th>
<th>Diff</th>
<th>df</th>
<th>SE (diff)</th>
<th>prec</th>
<th>CI Low</th>
<th>CI Upp</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chum Fry</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>(nearshore - 'offshore')</td>
<td>-0.50</td>
<td>0.02</td>
<td>-0.53</td>
<td>390</td>
<td>0.24</td>
<td>0.46588</td>
<td>-0.99</td>
<td>-0.06</td>
<td><strong>0.027</strong></td>
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<tr>
<td>(bottom - surface)</td>
<td>1.92</td>
<td>4.91</td>
<td>-2.99</td>
<td>102</td>
<td>1.99</td>
<td>3.94115</td>
<td>-6.93</td>
<td>0.95</td>
<td>0.14</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(nearshore - 'offshore')</td>
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<td>0.052</td>
<td>-0.04</td>
<td>390</td>
<td>0.06</td>
<td>0.11293</td>
<td>-0.15</td>
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<td>0.46</td>
</tr>
<tr>
<td>(bottom - surface)</td>
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<td>-0.019</td>
<td>0.04</td>
<td>102</td>
<td>0.09</td>
<td>0.18274</td>
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<table>
<thead>
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<th>Diurnal Period</th>
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<th>Night</th>
<th>Diff</th>
<th>df</th>
<th>SE (diff)</th>
<th>prec</th>
<th>CI Low</th>
<th>CI Upp</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chum Fry</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(nearshore - 'offshore')</td>
<td>-0.04</td>
<td>-0.44</td>
<td>0.39</td>
<td>390</td>
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<td>0.46588</td>
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<td>3.94115</td>
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<td>(nearshore - 'offshore')</td>
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<td>390</td>
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<td>0.11293</td>
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<td>0.11</td>
<td>0.92</td>
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<tr>
<td>(bottom - surface)</td>
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<td>0.035</td>
<td>-0.07</td>
<td>102</td>
<td>0.09</td>
<td>0.18274</td>
<td>-0.25</td>
<td>0.11</td>
<td>0.45</td>
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Figure 11: Average difference in ‘Horizontal Effect’ between Flow Conditions (‘low’ versus ‘high’), and between Time Periods (‘day’ versus ‘night’). The ‘Horizontal Effect’ is the difference in CPUE (catch per hour) between two drift nets deployed as a pair in an horizontal array (one located near shore, and the other farther offshore). Data are shown for fry and alevins. River Flow Conditions were defined as: ‘high’, >250 m³s⁻¹; and ‘low’, <100 m³s⁻¹).

**Vertical Effects**

Significant differences in chum fry catch were observed between vertical pairs of drift nets. Chum fry CPUE in surface driftnets (mean = 6.6 fry/h) was significantly greater than in nets located on the river bottom (2.5 fry/h; t₁₃₄ = 5.0, P < 0.0001). A two-way ANOVA (Table 3; F₃,₁₀₂ = 6.1, P = 0.0007) showed that the difference between surface and bottom driftnets was significantly affected by time of day (Figure 12; F₁,₁₀₂ = 10.3, P = 0.0018), but not by differences in flow (F₁,₁₀₂ = 2.3, P = 0.14); refer to annotations in Figure 12 for further explanation. There was no significant interaction term in the ANOVA model (F₁,₁₀₂ = 1.5, P = 0.23).

No significant differences in alevin catch were observed between vertical pairs of drift nets (Figure 12). CPUE in surface driftnets (mean = 0.10 alevin/h) did not differ significantly (t₁₃₄ = 0.2, P = 0.80) from that in nets located on the river bottom (0.09 alevin/h). There were no significant effects in the two-way ANOVA analysis (F₃,₃₉₀ = 0.34, P = 0.79).
Figure 12: Average difference in ‘Vertical Effect’ between Flow Conditions (‘low’ versus ‘high’), and between Time Periods (‘day’ versus ‘night’). The ‘Vertical Effect’ is the difference in CPUE (catch per hour) between two drift nets deployed as a pair in a vertical array (one located near the bottom, the other at the surface). Data are shown for fry and alevins. River Flow Conditions were defined as: ‘high’, >250 m$^3$/s; and ‘low’, <100 m$^3$/s).

Resting Period

Observations of fry and alevins during periods of rest (no movement) in response to flow treatments were inconclusive since valid day versus night period comparisons could not be made. Poor viewing conditions and safety risks made it difficult to observe fish behaviour at night, especially during high flow (>200 m$^3$/s) (see Table A-11).

DISCUSSION

Daily Periodicity of Migration and Effects of Changing Flows

The primary aim of this study was to gather information to address two key management issues identified by the Consultative Committee for the Stave River Water Use Plan in 1999, namely

1. Do chum salmon fry show a daily pattern of outmigration, and if so is it primarily at night, crepuscular, or during the day?
2. Does the behaviour of emerging fry change in relation to rising, steady, and falling flows, and if so do these changes differ with time of day and locations in the river channel?

With respect to the first issue, the results obtained in this study provide clear evidence that chum fry show a daily pattern of outmigration that occurs primarily at night, with their numbers peaking soon after dusk, declining overnight to near negligible levels by dawn, and remaining at low levels from dawn to dusk; fry catches in the inclined plane traps were almost 20 times higher during the night than during the day. Alevins showed a similar daily migration pattern as did fry, although the difference between their night and day catches was far less pronounced, with
evidence of a minor peak occurring around mid-day. The daily periodicity of chum fry outmigration documented in this study is consistent with that reported by others on the seaward movement of juvenile salmonids (Hoar 1951; Keenleyside and Hoar 1954; Riley et al. 2002).

The second management issue, however, is not as clear-cut to address mainly because fry behavioural observations were not possible during/at all flow conditions and times of day and river channel locations. In particular, even during the day it was difficult to reliably record fry and alevin counts and behavioural responses during high flows, especially in the deeper and faster areas farther away from shore, and at night it was virtually impossible to do so. Due to this information deficiency, assessment of the effects of changing flow conditions on fry and alevin migration and behaviour is limited to the findings based on one year of IPT and drift net catches. Tentatively, these results indicated that

- neither the periodicity nor quantity of chum fry movement downstream was significantly affected by the daily fluctuating flow regime (~100-300 m$^3$/s) imposed by operation of the Ruskin Generating Station;

- the quantity, but not the periodicity of alevin movement downstream was significantly affected by the Ruskin Generating Station’s daily fluctuating flows;

- the catch of chum fry in the water column (surface vs bottom) is unlikely to be affected by the fluctuating flows, whereas the catch ‘offshore’ is likely to be greater than that ‘inshore due to higher water velocities ‘offshore’; in contrast, the catch of alevins is not likely to be affected in either of the two comparisons above.

The differences observed between fry and alevin responses in relation to changing flow conditions are probably largely due to fry being stronger and more active swimmers than alevins, and as such alevins living at the substrate/water interface are prone to being swept downstream with sudden rises in flow. Such an effect is likely to result in premature displacement downstream into the Fraser River mainstem and ultimately reduced survival. The significantly smaller size of fry caught at IPT 1 than at IPT 2 suggest that fry at the IPT 1 site are spending less time rearing in the area, probably because the higher water velocities are flushing them downstream soon after emergence; the IPT 2 site, with its major backwater may provide more suitable habitat for young fry.

In respect to the various impact hypotheses that were to be tested with the data gathered, at this stage it cannot be stated with reasonable certainty that

- during periods of no movement (i.e., during the day) the fry are mainly at rest on the bottom, as relatively few fry were observed;

- the fry are evenly dispersed across the channel, though most likely they are not as other factors (e.g., substrate composition, interstitial cover) besides flow will vary across the channel;
• the behaviour of fry during periods of movement (i.e., during the night) and no movement is the same for all flow conditions, which it most probably is not; this issue cannot be adequately addressed solely from field observations as it is impossible to observe fish behaviour under high flows, particularly at night – observations are needed in stream tank experiments (e.g., Glova 1986a, 1986b; Glova and Field-Dodgson 1995) allowing full observation of the fish under a range of flows and light levels.

Consideration of Methodological Aspects

Site Selection

Differences in chum fry catch rates between the two IPT sites may have been affected to some extent by differences in site features. IPT Site 2 (the backwater site) was ideally located in the thalweg, with an embedded deflector log tending to direct flow from the true left bank to the trap. On the other hand, gravel movement and scouring during high flows at IPT Site 1 (the non-backwater site) may have had some effect on the behaviour of fry out-migration; in contrast, gravel movement and bed scouring was less apparent at Site 2. Initially, it was intended that each of the trap sites would be located in separate channels to avoid possible ‘inter-trap’ effects on fish behaviour and catches; however, the higher costs associated with increased logistical efforts and use of heavy-duty anchoring materials (because large, well-rooted trees were not present) negated doing so.

In addition to the above, differences in tidal effects between the two IPT sites may have contributed to some of the variation observed in fry catch between the two sites. As already mentioned, the fry captured at Site 1 were smaller than those taken at Site 2, which may largely be attributable to fry holding/rearing at Site 2 (favourable backwater) for longer than those at Site 1 (no backwater present) which were being flushed-out during high flows.

Operating an IPT solely at the backwater site (Site 2), or securely embedding a deflector log in the bank at Site 1 (as presently exists at Site 2) to help direct flow to the trap, is recommended for future monitoring of fry outmigration in the lower Stave River. Despite the differences in catch and size of fry caught between the two traps, the results obtained at both traps are considered representative of the response of chum fry outmigrants to fluctuating flows and time of day.

The Traps

Inclined-plane traps are commonly used to capture out-migrating juvenile salmon (Cope 2002; Decker 2006; McMenemy 1988; Todd 1994). The advantages of using IPTs for this study included: 1) relatively simple installation; 2) ability to capture salmon fry less than 50 mm fork length; 3) ability to operate in variable water depths (10-90 cm) and velocities; and 4) ability to be removed quickly during high water events. Unfortunately, without using mark-recapture techniques, we were not able to determine with any degree of certainty whether the changes in catch rates between IPT 1 and IPT 2 were due to changes in the catch efficiency of the traps or to changes in fry migration behaviour (e.g., abundance, distribution). In addition to the stationary traps used in 2008, subsequent studies could make use of the new ‘emergent’ metal hoop traps.
(Radtke 2008) to capture ‘resting’ fry which emerge from the streambed. The advantages of using metal hoop nets fixed to the substrate include: 1) hoop traps eliminate trap avoidance, 2) hoop traps increase encounter rate by preventing fry from swimming out of the trap in low flow areas (e.g., nearshore or backwatered areas, during high tide), and 3) hoop traps could be used to test whether chum fry are evenly dispersed among substrate types (cobble versus gravel) during low, rising, and high flows.

**Visual Observation**

Video imaging and recording is considered to be an appropriate and cost effective method of monitoring fish passage when good viewing conditions prevail. However, suitable conditions were generally not available during this study due to poor water clarity and high flows. Observer trials conducted during the day showed that less than 20% of chum fry released into the immediate area upstream of the video camera were counted when water velocities were greater than 1 m/s, even when water clarity was acceptable. These problems were compounded when attempting to conduct video counts of fry at night.

It may have been possible to improve nighttime video images using artificial illumination. However, the migratory response of fish has been shown to vary with the level and type of illumination. Moreover, depending on the species and environmental conditions, artificial illumination may influence fish behaviour, (Turner et al. 1984, Smith 1985). As these sorts of influences are undesirable, infrared lights may be more appropriate than visible light (Hiebert et al. 2000) for video-based applications at night.

**RECOMMENDATIONS**

Based on the findings of this first year of study, the following is recommended for further study to improve assessment of the effects of changing flow conditions on chum fry and alevin movements and behaviour:

- Monitor fry out-migration for 2 more years using Site 2 only; if objective of study includes comparison of tidal effects, then both Sites 1 and 2 should be monitored;

- If Site 1 is used in future monitoring, site modifications should include installation of a deflector log to better direct the flow into the trap and modification to the IPT mouth so that the trap can be fished within 15 m from the shore;

- Install stationary fry emergent traps at random locations to test the hypothesis that chum fry prefer deeper, faster water areas, with cobble substrates (i.e., sample at high and low flows in areas with cobble and gravel substrates); and

- Conduct mark-recapture trials of fry released upstream as a means of monitoring their response to changes in flow and time of day (this would be an alternative to direct observation by snorkeling and underwater video counts which have been found to have low success in these conditions).
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REFERENCES


APPENDICES

Raw data appendices are available on CD or via file transfer from BC Hydro.