WHY DO FISH STRAND? AN ANALYSIS OF TEN YEARS OF FLOW REDUCTION MONITORING DATA FROM THE COLUMBIA AND KOOTENAY RIVERS, CANADA

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ABSTRACT

Stranding of fish due to flow reductions has been documented in the near shore of the Columbia and Kootenay Rivers, Canada, and can result in sub-lethal or lethal effects on fish. Ten years (1999–2009) of monitoring data have been collected at sites below two hydro-electric dams (Hugh-L-Keenleyside and Brilliant Dam) following flow reductions. A generalized linear mixed effects model analysed the probability of a stranding event in relation to environmental and operational variables including the rate of change in the water levels, the duration of shoreline inundation prior to a reduction (wetted history), the river stage, the magnitude of the reduction, distance downstream from the dam, time of day, day of year (season) and whether a site had been physically altered to mitigate stranding. The results demonstrated statistically significant effects on stranding risk from minimum river stage, day of the year and whether a site had been physically re-contoured. The combination of investigated factors giving the highest probability of stranding was a large magnitude reduction completed in the afternoon in midsummer, at low water levels when the near shore had been inundated for a long period. This research is significant in its approach to assessing years of ecosystem scale monitoring data and using the modelling results to determine ways for these findings to be applied in regulated river management to minimize fish stranding. It also highlighted data gaps that require addressing and provides ecosystem scale results to compare with stranding studies carried out in mesocosms. © 2014 The Authors. River Research and Applications published by John Wiley & Sons Ltd.

KEY WORDS: fish stranding; Columbia river; hydropoeaking; GLMM; flow management

INTRODUCTION

Juvenile fish tend to reside in near-shore waters where warmer water and food as well as cover from velocity and predation is abundant (Vehanen et al. 2000). Unfortunately, this puts them at risk of being stranded in isolated pools or the interstices of dewatered substrate by sudden changes in water levels resulting from natural decreases such as flood abatement (Beck and Associates 1989) or human-imposed water level changes such as hydro-electric dam operations (Saltveit 2001, Bragg et al. 2005, Bell et al. 2008, Irvine et al. 2009). Dam operations can increase the frequency and magnitude of flow changes in order to meet storage obligations, or to produce power (Berland 2004). These water fluctuations can affect fish mortality rates (Annear et al. 2002), behaviour (Scruton et al. 2008), short-term stress levels (Flodmark et al. 2002), growth rates (Harvey et al. 2006), habitat use (Vehanen et al. 2000) and movement (Irvine 1986, Heggenes 1988, Krimmer et al. 2011). When a fish strands, it can either succumb to mortality through direct effects of stranding, such as drying (Bradford et al. 1995), or be rewetted (Beck and Associates 1989). Those fish that do not incur mortality may suffer non-lethal stress effects such as decreased growth (Korman and Campagna 2009) or depletion of energy reserves key to winter survival (Cunjak et al. 1998, Scruton et al. 2008) or, alternately, may habituate to the stress of the fluctuating environment (Taylor et al. 2012). These various effects can have detectable impacts on adult fish densities in highly affected reaches (Ugedal et al. 2008).

Several operational and environmental factors may affect levels of fish stranding. These include altered water velocity (Irvine 1986), time of day and season (Vehanen et al. 2000, Robertson et al. 2004), the reduction rate (Bradford et al. 1995), the size and species of fish (Irvine 1986, Heggenes 1988), the inundation duration (Irvine et al. 2009), and the number of sequential reductions (Irvine 1986). Understanding how these environmental and operational factors affect fish downstream of dams could enable minimization of stranding through improved management. Fish behaviour, competition and species-specific life histories (Saltveit...
2001, Flodmark et al. 2002, Huusko et al. 2007) can also affect stranding risk, but are not assessed here.

The present study assessed the relationship between selected environmental and operational variables and the probability of juvenile fish stranding events in the Columbia and Kootenay Rivers. Models statistically assessed the risk of stranding events and how the risk was affected by reduction rate and magnitude, distance from the dam, time of day, day of the year, river stage and the time the site had been inundated (wetted history). The effectiveness of physical habitat alteration of high-risk sites was also assessed.

Much of the fish stranding data are obtained from mesocosms as either flume experiments or in situ net pens with variable and often contradictory results. Decreases in stranding were noted with shorter habituation times, slower ramping rates (tested range 10–60 cm/h), but no effect of time of day (Halleraker 2003) in one set of experiments. In contrast, lower rates of stranding were observed at night in another mesocosm experiment (Bradford et al. 1995), and net pen experiments completed (2004–2006) in the Columbia and Kootenay Rivers found no statistically significant effect of either ramping rate (tested range 4–35 cm/h) or time of day, but found that the period of inundation and the natural fish density in the net pen area were predictive of pool stranding rates (Irvine et al. 2009). More recent flume experiments noted 8% stranding rates in small flumes when compared with larger flumes and also noted that flumes are unlikely to reproduce the full range of conditions observed in nature (Cocherell et al. 2012). Fish stranding data from ecosystem scale, long-term monitoring are therefore significant for understanding patterns of stranding responses in large river ecosystems, determining significant trends across years and species, corroborating or refuting patterns observed in mesocosms and providing scientifically relevant management advice.

METHODS

Study area
The Columbia River is 2044 km long with a mean discharge of ~7500 m³/s and a mean width of 257 m in the study area and is the largest dammed hydro-electric producing river in North America with 14 dams on its mainstem and over 100 dams on tributaries. The Kootenay River (Kootenai in the USA), a tributary of the Columbia, is 731 km long with a mean discharge of ~838 m³/s and an average width of 164 m within the study area. Dams on the two rivers regulate the flows in the study area near the Canada–USA border (Figure 1). Hugh-L-Keenleyside Dam (HLK) is an 185-MW capacity dam ~52 km upstream of the border on the Columbia River. Brilliant Dam (BRD/X) is a 265-MW capacity dam ~2.6 km upstream of the confluence of the Columbia and Kootenay Rivers (Figure 1). HLK flow changes typically occur on a weekly or biweekly basis and are coordinated under the Columbia River Treaty with the USA to provide for power, flood control, and environmental and social objectives. BRD/X is primarily managed to meet power demands and can change flows multiple times per day.

Within the approximately 55 km of potential sampling area, 29 sites were sampled and 27 had sufficient data for analysis (Figure 1). Two sites were visited <3 times so did not have adequate data and were dropped from analysis. Sampling occurred after every major flow reduction event since 2001, and although not all sites are visited after each reduction, the overall data set is well distributed spatially (Table I). A major reduction was any change greater than 4 m³/s from starting to ending discharge that would expose areas known to strand fish, and the reductions within the data had an average size of 224 m³/s.

Sampling methodology and data
After a reduction was completed at one or both dams, sampling crews worked in a downstream direction from various entry points along the river. The number of fish stranded,
size and species of all fish at a site was assessed; a subsample was taken if more than 30 fish were found. To sample interstitial habitat, quadrats (0.5 m²) were placed randomly and all substrate within was moved to search. Each isolated pool (or a subsample) at a site was assessed visually and with backpack electrofishing. The biological and physical data from 1684 site surveys were entered into an Access database and then linked with the river elevation, discharge, temperature and operational data for each flow reduction event. All fish species were combined for the analysis. Fish species or families included in the pooled data were Suckers (Catostomidae), Sculpin species group (Cottidae), Rainbow Trout (Oncorhynchus mykiss), Mountain Whitefish (Prosopium williamsoni), Umatilla Dace (Rhinichthys utah), Longnose Dace (Rhinichthys cataractae), Northern Pikeminnow (Ptychocheilus oregonensis), Peamouth Chub (Mylocheilus caurinus) and Redside Shiner (Richardsonius balteatus). The data were assessed to determine if it was possible to run the model with provincially listed species (http://www.env.gov.bc.ca/cdc/) and were found to be insufficient.

Magnitude of reduction, rate of change (m³/s/h) and the minimum discharge reached (a surrogate for river stage) were calculated from the Birchbank Water Survey of Canada gauge at river kilometre ~29 because this gauge’s location integrates both dams’ output. Wetted history was the number of whole days the site had been inundated and was capped at 90 days because of small sample sizes at longer periods. Four sites (3, 6, 15 and 17 – Table I) along the Columbia and Kootenay River were re-contoured in an attempt to reduce fish stranding. Once a site was re-contoured, it was permanently considered in the ‘after’ state. Re-contouring consisted of using heavy machinery to smooth out potholes and provide a draining gradient on known stranding sites.

Data analysis
A model using a binomial distribution with a logistic link function and varying definitions of what constitutes a stranding event was utilized (Collett 2003) to assess risk and the effects of operational and environmental variables for stranding at a typical site. The logistic regression outcomes were either a stranding event occurring or no event occurring, with a defined number of fish required to

Table I. Site index for Figure 1 including name, number of sampling visits (1999–2009), the distance downstream from Hugh-L-Keenleyside dam and the UTM locations

| Map ID | Site name | River | Number of site visits | River kilometre | Easting | Northing |
|--------|-----------|-------|-----------------------|-----------------|---------|----------|
| 1      | REA Side Channel (HLK) | Columbia | 9 | 0.50 | 444402 | 5465391 |
| 2      | Lions Head (U/S of Norns Fan) (RUB) | Columbia | 83 | 0.00 | 450816 | 546439 |
| 3      | Norns Creek Fan (RUB) | Columbia | 185 | 7.00 | 451697 | 5464523 |
| 4      | CPR Island (MID) | Columbia | 45 | 8.50 | 452104 | 5464450 |
| 5      | Waldie’s Island (MID) | Columbia | 7 | 9.00 | 452344 | 5464604 |
| 6      | Millenium Park (Tin Cup LUB) | Columbia | 140 | 10.00 | 452669 | 5463651 |
| 7      | Tin Cup Rapids (RUB) | Columbia | 115 | 9.00 | 452903 | 5463263 |
| 8      | Millenium Bridge (LUB) | Columbia | 41 | 10.20 | 452480 | 5463132 |
| 9      | Kootenay River (LUB) | Kootenay | 111 | 10.10 | 453133 | 5462671 |
| 10     | Kootenay River (RUB) | Kootenay | 149 | 10.11 | 453233 | 5462556 |
| 11     | Zuckerberg Island (LUB) | Columbia | 138 | 11.00 | 452280 | 5462896 |
| 12     | Kinnaird Rapids (RUB) | Columbia | 11 | 14.00 | 452977 | 5459854 |
| 13     | Waterlo Eddie (RUB) | Columbia | 3 | 17.00 | 453275 | 5456865 |
| 14     | Blueberry Creek (LUB) | Columbia | 23 | 20.00 | 453045 | 5456958 |
| 15     | Genelle (Mainland) (LUB) | Columbia | 175 | 24.00 | 449600 | 545087 |
| 16     | Genelle Upper Cobble Island (MID) | Columbia | 26 | 25.00 | 449216 | 5450403 |
| 17     | Genelle Lower Cobble Island (MID) | Columbia | 35 | 26.00 | 448694 | 5449770 |
| 18     | Birchbank (LUB) and Gauging Station | Columbia | 5 | 29.00 | 447675 | 5447470 |
| 19     | Gyro Boat Launch | Columbia | 33 | 38.00 | 448375 | 5438989 |
| 20     | Trail Bridge (RUB) (D/S) | Columbia | 25 | 39.00 | 448514 | 5438675 |
| 21     | Casino Road Bridge, Trail (LUB) (U/S) | Columbia | 41 | 40.00 | 448948 | 5438062 |
| 22     | Casino Road Bridge, Trail (LUB) (D/S) | Columbia | 46 | 40.10 | 449306 | 5438068 |
| 23     | Korpack (Trail) (LUB) | Columbia | 22 | 40.00 | 450243 | 5438167 |
| 24     | Rock Island (RUB) | Columbia | 40 | 43.00 | 452532 | 5438346 |
| 25     | Bear Creek (RUB) | Columbia | 32 | 44.00 | 453257 | 5437512 |
| 26     | Beaver Creek (RUB) | Columbia | 28 | 47.00 | 455351 | 5435191 |
| 27     | Beaver Creek (LUB) | Columbia | 14 | 47.01 | 455048 | 5434857 |
| 28     | Fort Shepherd Eddy (LUB) | Columbia | 22 | 52.00 | 455980 | 5430177 |
| 29     | Fort Shepherd Launch (RUB) | Columbia | 79 | 54.00 | 455966 | 5429943 |

The temperature and flow gauge at Birchbank is located at site 18.
constitute a stranding event. Four definitions of stranding levels were modelled with 1, 50, 200 and 1000 stranded fish required to constitute an event. As the minimum number of fish stranded to define an event increased, there was a decrease in statistical power (Table II).

The definition of a significant stranding event is a biological and statistical challenge. In regional hydro-electric industry definitions, a significant event is one with more than 5000 fish (Vonk 2003, Wilson 2005). Insufficient data were available for this definition, so a minimum stranding level of 200 fish per site was used.

Generalized linear mixed effects models with a binomial distribution and a logistic link function were utilized to account for the fixed and random effects and the error distribution of the data. Variables were considered statistically significant at the $p < 0.05$ level. Fixed effects included river kilometre, day of year, time of day, magnitude and rate of reduction, minimum discharge reached, wetted history and whether the event was before or after re-contouring. River kilometre was modelled to capture the attenuation in rate of stage change downstream. Day of year represented season and water temperature, which are related to species presence due to timing of spawning and emergence. Time of day was used to determine effects on stranding probability of the diel cycle. A penalized cubic regression spline with a restricted number of degrees of freedom (1–6) was used to fit day of year and hour (Wood 2006) forcing the end values of the range to correspond. Differences among sites and years were modelled as random effects (Wood 2006). The random effect of year was removed from the fixed effects. All analyses were conducted in R version 2.9.1 (R Development Core Team 2009).

Table II. The number of fish found per site in a stranding survey, the number of events where at least that number of fish was stranded and the percentage of the total sample of stranding events comprised by each of the minimum stranding levels used in the analysis.

| Number of fish found in a stranding survey (n) | Number of events where $n$ or more fish stranded (x) | Percentage ($x/1684$) * 100 |
|-----------------------------------------------|-----------------------------------------------------|-----------------------------|
| 0                                            | 1217                                                | 72.3                        |
| 1                                            | 467                                                 | 27.7                        |
| 50                                           | 162                                                 | 9.6                         |
| 200                                          | 74                                                  | 4.4                         |
| 1000                                         | 31                                                  | 1.8                         |

RESULTS

At all tested levels of what constituted a stranding event (1, 50, 200 or 1000 fish), the statistically significant variables were minimum discharge level (river stage), day of the year and whether a site had been physically re-contoured. The duration of inundation was significant at the 1, 50 and 200 fish levels. The magnitude of the flow reduction and the time of day of the end of the reduction were statistically significant only at the 1 fish level. The rate at which a flow reduction occurred and the distance of a site downstream from the dam were not significant at any defined level of stranding (Table II) and were therefore not plotted. Because of the large spatial scale of this analysis (>55 km of river), river kilometre was used as a surrogate for ramping rate because the rates experienced at sites differing distances from the dams vary because of damping of the reduction effect when moving downstream. The rates throughout the study area are correlated to the rate of the reduction at Birchbank gauging station, and the data had rates ranging from 0.48 to 130 cms/h.

The plots for each significant variable are shown with the remaining fixed and random variables held at their typical values and at the Genelle Mainland site in its post-re-contouring state (Figures 2–7). For the four variables significant at minimum stranding levels of 200 fish or less (minimum discharge, day of year, re-contoured status and wetted history), the plotted results defined a stranding event as one with 200 fish (Figures 2–5). For the two variables significant at the minimum stranding level of 1 fish (time of day and magnitude of the reduction), that level of stranding is shown (Figures 6 and 7).
The higher the minimum discharge reached at completion of the flow reduction, the lower the probability of a stranding event occurring (Figure 2). The probability of a significant stranding event occurring drops from 0.36 to 0.1 when the minimum discharge increases 500 m$^3$/s from 1000 to 1500 m$^3$/s and approaches zero at a minimum discharge of 2500 m$^3$/s (Figure 2).

Day of year was a significant predictor variable with increased stranding risk throughout January to July. The highest probability of stranding occurred in spring and summer months and the lowest in November and December (Figure 3). The peak probability of a stranding event is between June 24 (Julian Day 175) and July 19 (Julian Day 200) (Figure 3).

The physical habitat re-contouring at the four high-risk sites of Genelle Mainland, Genelle Cobble Island, Norm’s Fan and Millenium Park (Figure 1, Table I) had a statistically significant effect at all defined levels of a stranding event with decreased stranding associated with the physical restructuring of the habitat (Figure 4).

The time that the near-shore area is wetted is positively correlated with the probability of a stranding event with an approximate doubling in probability with an increase in wetted history from 0 to 90 days (Figure 5). Wetted history was a significant variable at all levels of stranding (Table III).

The smaller the flow reduction, the lower the probability of a stranding event, although this effect of halving...
the probability over the range of reduction sizes sampled over the ten years (Figure 6) was only significant at the 1 fish level.

Time of day was a significant predictor of the probability of a stranding event at the 1 fish level with the highest risk in the late afternoon (Figure 7). The probability of stranding was the lowest overnight and in the early morning, although data were biased because stranding surveys are rarely carried out at night and most reductions are timed for morning where possible to allow adequate sampling.

DISCUSSION

Models were applied to ten years of stranding survey data from two large river systems to determine the risk of a stranding event, and this risk was affected by operational and environmental variables. The findings allow dam operations to be managed to minimize the rate of stranding on fish in these rivers and to refine the ongoing monitoring programmes to address remaining uncertainties. They also provide a long-term ecosystem scale result to compare with the more numerous mesocosm and flume experiments on stranding in the literature to assess what variables show significant effect across species and years. Of the eight variables tested, the day of the year, the river stage and whether a site had been physically re-contoured were significant at all tested levels of stranding; wetted history was significant at 200 fish or less; magnitude of reduction and time of day were significant at the ‘1 fish stranded’ level; and rate of reduction and distance downstream of the dam were not significant at any defined level of stranding event. The worst general combination of the assessed factors (including statistically non-significant results) that would cause the highest number of fish stranding events based on these results would be a large magnitude reduction carried out with a fast ramping rate in the afternoon in midsummer, at low levels of water in the system when the near-shore habitat had been inundated for a long time. These results are broadly similar to net pen experiments carried out in the Columbia and Kootenay Rivers from 2004 to 2006, although not all of the same variables were assessed. In the net pen experiments assessing pool stranding, the wetted history, the ramping rate, the presence of a conditioning reduction (a rapid decrease and increase in flow prior to a planned reduction) and the natural density of fish prior to the reduction were all considered statistically predictive of mesocosm pool stranding of juvenile fish (Irvine et al. 2009).

The river stage showed a strong inverse relationship with probability of stranding. Habitat characteristics that may increase stranding at low river stages in the Kootenay and Columbia Rivers are low angle banks, larger substrate and

Table III. Model output for generalized linear mixed effects model logistic regression assessing probability of stranding

| Variable                               | Minimum stranding level below which stranded fish were considered a ‘null effect’ | p-value |       |       |       |
|----------------------------------------|--------------------------------------------------------------------------------|---------|-------|-------|-------|
|                                        | 1                               | 50      | 200   | 1000  |       |
| Magnitude of reduction                 | 1.18e–03**                      | NS      | NS    | NS    | NS    |
| Rate of reduction                      | NS                              | NS      | NS    | NS    | NS    |
| Minimum discharge level                | 6.37e–13***                     | 2.89e–09*** | 3.11e–11*** | 6.76e–14*** |       |
| Time of day                            | 2.0e–02*                        | NS      | NS    | NS    |       |
| Day of year                            | 2.67e–08***                     | 3.74e–11*** | 1.12e–11*** | <2e–16*** |       |
| River kilometre from HLK               | NS                              | NS      | NS    | NS    |       |
| Wetted history                         | 2.64e–03**                      | 4.77e–06*** | 1.04e–02*   | NS    |       |
| Re-contoured status (before vs after)  | 1.73e–09***                     | 8.49e–10*** | 1.98e–05*** | 1.51e–02* |       |

NS indicates that the variable was not statistically significant in the model at that level. p-values significant at the 0.05 level are marked with *, at the 0.01 level are marked with ** and are italicized and at the 0.001 level are marked with *** and bolded.
large numbers of shallow pools. Slopes greater than 4% are associated with reduced stranding (Bauersfeld 1978, Flodmark 2004) or slopes less than 6% are associated with higher rates of stranding (Bell et al. 2008). Large substrate is associated with increased stranding due to juvenile fish being unwilling to relinquish key holding territories when the water drops (Linnansaari et al. 2008). The number of pools present in the study area was assessed in relation to river stage, and lower river stages did result in more pools.

A seasonal effect was observed with the peak probability of stranding from June 24 to July 19 and the lowest risk in November and December. This is partly due to the life history of the species in the Columbia and Kootenay Rivers (i.e., more juveniles are resident in the near-shore areas at certain times of year) and partly due to the seasonal needs for power and the resulting patterns of fluctuation. Juvenile trout tend to seek more shelter in winter months and select for areas of low velocity to minimize energy demands (Cunjak and Power 1987). Fish are likely adapted to move into habitats securing them more shelter from increasing flows seasonally in spring when freshet begins (Linnansaari et al. 2008), but likely are not adapted to move into habitats giving them shelter at the frequency of dam related flow fluctuations. Flow affected cover use by juvenile brown trout in flume experiments especially in winter, with trout moving to more shelter when the first high flow period occurred (Vehanen et al. 2000).

A lower risk of stranding occurred after a site had been re-contoured to remove potholes that could entrap fish. The effect is likely more striking than the models imply because it has been several years since the work was carried out and no dissipation of effect was modelled. Results from studies in a reservoir recommended re-contouring to increase the steepness of the slope to decrease the stranding risk (Bell et al. 2008).

The risk of stranding increased with increased wetted history up to the imposed limit of 90 days. This may be related to processes such as increased cover or forage availability that lead to increased fish density in the near-shore area (Cushman 1985). Wetted history may also affect the behaviour of the fish and thereby the probability that an individual fish may strand. Dominance may prevent fish from moving particularly in winter (Huukso et al. 2007). Wetted history is a factor difficult to manage, but is of interest when assessing the potential risk of stranding prior to a reduction. The concept of dropping flows for a short period then raising them back up within 2 h was previously explored to mitigate the increased stranding risk associated with long wetted histories. These ‘conditioning reductions’ initially showed promise for reducing stranding (Irvine et al. 2009), but upon further experimentation, the effect was less than initially observed and Mountain Whitefish succumbed to direct mortality within 20 min (Irvine and Hildebrand 2010) demonstrating that even a short-term drop could cause high mortality. Frequent fluctuations make the near-shore area less appealing and therefore reduce the stranding risk; however, there are costs to this type of dam operation, including loss of riverine productivity (Winterbottom et al. 1997).

The differences in stranding rates between night and day have been variable with some experimental studies finding more fish stranding in daytime (Bradford et al. 1995), when fish were posited to be stranding due to use of the interstitial spaces prior to a reduction, and other studies finding higher foraging activity and movement in the near-shore area at night (Linnansaari et al. 2008, Scruton et al. 2008) and higher stranding at night (Irvine and Hildebrand 2010; Bradford 1997). Other experiments have found no effect of time of day (Irvine et al. 2009). This analysis found the probability of stranding highest in the afternoon.

The magnitude of the reduction was significant only at the lowest stranding level with larger reductions associated with higher probability of stranding. This variable could interact with the stage of the river as well because a small drop on steep banks will expose less area than if the habitat has a shallow slope. The morphology of the Columbia and Kootenay rivers is such that the first drops from bank full expose generally shallowly sloping cobble and gravel substrate and at a lower river stages, the habitat is more steeply sloping and with larger boulder and cobble substrate.

The river kilometre of the site and the rate of reduction were not significant. Previous studies have shown a proximity effect with the most severe decreases in salmon densities proximal to the dam (Ugedal et al. 2008). The lack of effect of distance downstream may be genuine or may be a result of insufficient data, because 20 years of focused collection was required to observe the Alta River trend (Ugedal et al. 2008). Rate of reduction has been significant in some flume experiments (e.g. Flodmark et al., 2002), but has never been statistically significant in experiments or monitoring on the Columbia and Kootenay Rivers (Irvine et al. 2009). Olson (1990) suggested that a ramping rate of less than 2.5 cm/h would prevent stranding more universally, but this would have to be tested given species differences in behavioural responses (Flodmark et al. 2006) and site-specific characteristics that influence fish responses to ramping (e.g. Bradford 1997).

The difficulty with using monitoring data is that there may be sampling biases that would not occur with a balanced experimental design. The power of using monitoring data is that the data are from real operational events occurring when and how flow reductions occur so are representative of the risk incurred by the resident fish in the Columbia and Kootenay Rivers, and responses are measured at an ecosystem scale over many years.

To define what is generally accepted about fish stranding risk and still retain objectivity in assessing the data in an analytic framework useful for management was the challenge. The results provided a link between operational and
environmental variables and the probability of stranding events in the Columbia and Kootenay Rivers, with concrete directives for mitigating fish stranding. Recommendations that emerged were (1) maintaining the re-contouring of high-risk sites, (2) carrying out reductions at night or early morning, (3) minimizing the reduction size, and if a large reduction is required, carry out a smaller reduction prior to the larger one within 10 days, and (4) avoid large operational reductions during the May to August period. As more data are obtained and analysed, these recommendations may alter to continue to minimize the impacts of flow reductions on fisheries.

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