Bridge River Project Water Use Plan

Seton River Habitat and Fish Monitoring

Implementation Year 1

Reference: BRGMON-09

BRGMON-09 Addendum 1 Report: 2019 Lower Fraser River Fish Stranding Risk Assessment

Study Period: February 21, 2019 to April 3, 2019

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December 17, 2019

BC Hydro

Seton Generating Station

BRGMON-9 Addendum 1 – Lower Fraser River Fish Stranding Risk Assessment Year 8 (2019)

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EXECUTIVE SUMMARY

BC Hydro (BCH) operates the Seton Generating Station (the Facility) in Lillooet, BC. During low flows on the Fraser River, Facility shut-downs have the potential to cause salmon egg or alevin dewatering within redds, and fry stranding, in the lower Fraser River gravel reach located ~300 km downstream of the Facility. To address this concern, the Seton Generating Operation Order (the Order) states "When Fraser River flow at the Water Survey of Canada (WSC) Hope gauge [08MF005] is below 700 m^3/s during the low flow period from November 15th to the following Fraser River freshet, BC Hydro will make best efforts not to load factor, shut-down or undertake maintenance outages of the Seton power plant." However, there are uncertainties over the effectiveness of the Order and the risk posed by Facility shut-downs to the gravel reach of the Fraser River. To address these uncertainties, BCH retained Ecofish Research Ltd. (Ecofish) to conduct a desktop risk assessment on the effects of winter Facility shut-downs on egg and alevin dewatering within redds in the Fraser River gravel reach, which was conducted in 2018. An outcome of the desktop-based assessment was recommendations for a more detailed assessment that included field data collection. This was captured in the BRGMON-9 Terms of Reference (TOR) Addendum 1 (BCH 2018) that addresses management question 5 of the original BRGMON-9 TOR:

5) Does discharge from Seton Generating Station impact fish habitat in Fraser River above and beyond natural variation in Fraser River discharge?

This report presents the results of the field data collection in February 21 to April 3, 2019 and provides an updated interim risk assessment based on these additional data to address this management question.

The focus of data collection in 2019 was to collect stage data at representative spawning habitat instead of relying on the single, previously established Ferry Island site data, while redd surveys were completed opportunistically to help inform model inputs. Further field data collection is planned for the 2019/2020 spawning and incubation period, which will also be integrated to make further refinements to the risk assessment; therefore, the assessment included in this report should be considered an interim update. Field data were also collected opportunistically during a Facility shut-down during the winter low flow period to allow further understanding of effects of the shut-down on ramping rate and fish stranding in the gravel reach.

Eight Stranding Sensitive Monitoring Sites (SSMSs) were established in the gravel reach and temporary water level loggers were installed at these sites. Stage discharge relationships for these SSMSs were calculated using WSC Hope gauge data. The most sensitive site (FRA-DSSD08) showed a relationship that was 0.97 times less sensitive than Ferry Island (i.e., the site would show an 0.97 m stage change with a 1 m stage change at Ferry Island) while the least sensitive site (FRA-DSSSD05) showed a relationship that was 0.47 times less sensitive than Ferry Island (i.e., the site would show an 0.47 m change with a 1 m stage change at Ferry Island). The stage discharge relationships at these sites were used to update model inputs.

During the field surveys, a total of 39 redds were identified and surveyed at SSMSs. Based on the redd surveys and back calculation of the spawning depth using the stage discharge curves, it is estimated that spawning depths at the redds varied from 65 cm to 153 cm. These spawning depth estimates provide general support to the generic HSI curves used for Chum Salmon spawning in the 2018 assessment. However, the number of redds identified and assessed for this study were considered relatively low and it is unknown if this was due to ice and snow cover (limiting the areas that could be assessed), a low spawning year for Chum Salmon in 2018 or potential limitations in effectively identifying redds in water deeper than could be safely waded at SSMSs (approximately 1.2 m). A total of 13 redds were excavated; however, no eggs, alevins or pre-emerging fry were detected. The lack of detected in redds and presence of emerged Chum Fry observed on March 2, may suggest that fry may have emerged from the gravel in the assessed areas before the field surveys were completed.

The Facility ramped down on February 28, 2019 and was completely shut-down on March 5, 2019. On February 28, 2019 discharge through the Facility was reduced from 77.5 m^3/s to 41.4 m^3/s but Seton Dam flow was increased from 3.05 m^3/s to 12.7 m^3/s with an overall decrease of 26.5 m^3/s. On March 5, 2019, discharge through the Facility was reduced from 37.9 m^3/s to 0 m^3/s but Seton Dam flow was increased from 13.2 m^3/s to 32.3 m^3/s with an overall decrease of 18.8 m^3/s. No stranded or isolated fish or dewatered eggs or alevin were observed as a result of the Facility down-ramping events during searches conducted on March 1, March 2 and March 5, 2019. Total search effort was 14 hours and 52 minutes. One Chum Salmon fry mortality was observed but was not determined to be due the ramp down given the wetted history and location where it was found (in 10 cm depth).

Based on model update using the lowest and highest sensitive SSMSs stage-discharge relationships, the percent of eggs dewatered within redds were estimated for natural dewatering and during Facility shut-downs. The model outputs predict that under the stage change conditions at FRA-DSSD08, there is naturally a high level of egg dewatering for Pink Salmon (median 99%; 10%tile = 69%; 90%tile = 100%), but a relatively low level of egg dewatering of Chum Salmon (median 22%; 10%tile = 8%; 90%tile = 43%). The model predictions under FRA-DSSD05 stage sensitivity scenario show a reduction in natural dewatering for Pink Salmon (median = 84%; 10%tile = 35%; 90%tile = 97%) with lower natural dewatering predicted for Chum Salmon (median = 7%; 10%tile = 2%; 90%tile = 22%). These values are similar to those in the 2018 assessment. The natural dewatering estimates for Pink Salmon still remain higher than expected, which may be because of limitations in the model input data. Specifically, the estimated high natural egg dewatering may be a reflection of the generic HSI curves used for Pink Salmon spawning.

Also similar to the 2018 assessment, a shut-down on a single randomly chosen date is unlikely to cause additional dewatering of salmon redds in the gravel reach. However, the analysis also predicted that in the worst year (shutdown under lowest flow conditions), a shutdown could cause an incremental dewatering of 26% of Pink Salmon eggs and 13% of Chum Salmon eggs based on the relationship at FRA-DSSD08 and 26% of Pink Salmon eggs and 10% of Chum Salmon eggs based on the relationship at FRA-DSSD05. The model also predicted that no eggs of either species were incrementally dewatered in years of typical spawning flow, provided flows at the time of shutdown were >850 m^3/s based on the relationship at FRA-DSSD08 and FRA-DSSD05. However, in years when spawning flows were high, the eggs of both Pink Salmon and Chum Salmon were incrementally dewatered when flows at the time of shutdown were <1,050 m^3/s based on the relationship at FRA-DSSD08 and FRA-DSSD05. The analysis of shutdowns of 1 to 8 weeks duration found that incremental egg dewatering increases with the duration of the shutdown for both stage change scenarios, which is due to the general trend of decreasing flows through the incubation period.

Overall, these results suggest that there may be an incremental risk of egg dewatering caused by Facility shut-down below a median flow of 850 m^3/s for both species and sensitivity scenarios. Regardless of the uncertainties in this assessment, the high range in percentile flows is reflective of natural annual flow variability. Based on the field data collection during the shutdown that occurred in early March below 640 m^3/s there was no evidence of dewatering mortality of eggs/alevin or stranding; however, the assessment area was limited by ice/snow cover on slow moving side channels and backchannels. Additionally, the field studies were conducted in an even year where no Pink Salmon spawning was occurring.

Recommendations are presented for collection of additional data to help address uncertainties associated with potential egg dewatering resulting from Facility shut-downs.

- Because no Chum Salmon egg/alevins were found during the redd surveys, we recommend conducting additional surveys in 2019/2020 to better understand distribution of alevins within egg pocket of the redd and to determine the emergence time for Chum Salmon. These data would be used to integrate life stage into the stranding assessment.
- This study was conducted in an even year, therefore Pink Salmon redds were not present. We recommend conducting additional surveys in 2020 to study these parameters for Pink Salmon. The proportion of Pink Salmon egg dewatering is unrealistically high, and is expected to be improved with site specific data.
- Additional work is recommended to account for backwatered and smaller side channels that were inaccessible due to icing during the 2019 assessment, to allow a better overall assessment of dewatering risk throughout spawning habitat in the braided reach.
- Additional redd information should be collected during 2019/2020 spawning season with a focus on deeper habitat and may require snorkeling to ensure potential redds in deeper water are assessed, if present, to allow more accurate estimating of spawning depth preferences
- Additional water temperature data should be collected within redds to compare to water temperature data at Ferry Island and multiple years of water temperature data for Ferry Island should be analyzed in order to account for annual variability in the developmental rate of eggs to allow better estimation of hatch dates and emergence times. These data can be correlated with redd observations to allow life stage presence, timing and habitat use to be incorporated into the assessment.

Table 1. Status of objectives, management questions and hypotheses after Year 8

Study Objectives	Management Question	Management Hypotheses	Year 8 (2019) Status
Assess the risk of eggs and alevin stranding in the gravel reach of the Fraser River in response to Seton Dam operations.	Does discharge from Seton Generating Station impact fish habitat in Fraser River above and beyond natural variation in Fraser River discharge?	N/A*	Management question is being answered through: Collection of data (i.e. redd surveys, stranding searches, monitoring of the stage change in the gravel reach and assessment of ramping rates) during winter low flow period to start of freshet and opportunistically during Facility shut-down during the winter low flow period to allow further understanding of effects of the shut-down on ramping rate, stranding and dewatering in the gravel reach (~300 km downstream of the Facility).

* Management hypotheses were not developed for BRGMON-9.

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1. INTRODUCTION

BC Hydro (BCH) operates the Seton Generating Station (the Facility) in Lillooet, BC (Map 1). During winter low flows on the Fraser River (typically, November to March), Facility shut-downs have the potential to cause fry stranding in the lower Fraser River gravel reach located ~300 km downstream of the Facility from Laidlaw to Sumas Mountain (hereafter referred to as the "gravel reach"). To address this concern, the Seton Generating Operation Order (the Order) states "When Fraser River flow at the Water Survey of Canada (WSC) Hope gauge [08MF005] is below 700 m^3/s during the low flow period from November 15th to the following Fraser River freshet, BC Hydro will make best efforts not to load factor, shut-down or undertake maintenance outages of the Seton power plant." However, there are uncertainties over the effectiveness of the Order and the risk posed by Facility shut-downs to the gravel reach of the Fraser River. Consequently, the BRGMON-9 TOR Addendum 1 expanded the Fraser River stranding risk assessment to include the lower Fraser River gravel reach (BCH 2018). Significant Pink Salmon and Chum Salmon spawning occurs in the gravel reach and incremental stranding of eggs, alevin and fry on spawning grounds can occur if Facility shut-downs decrease Fraser River flows below normal winter low flows. Preliminary gravel reach stranding assessments and habitat modelling have been completed outside of the BRGMON-9 program (Ramos-Espinoza 2016, Putt and Wilson 2017, Faulkner *et al.* 2018).

To address these uncertainties, BCH retained Ecofish Research Ltd. (Ecofish) to conduct a desktop stranding risk assessment on the effects of winter Facility shut-downs on egg and alevin dewatering within redds in the Fraser River gravel reach in 2018 (Faulkner *et al.* 2018). An outcome of the desktop-based assessment was recommendations for a more detailed assessment that included a field study of site-specific spawning depth preferences from back-calculation of redd depths, developing site-specific stage-discharge relationships at spawning locations. This report presents the results of the field study conducted from February 21 to April 3, 2019 and provides an updated interim risk assessment based on these additional data. Field data collection was delayed due to contract award in early February followed by icing conditions on the Fraser River in early to mid-February, which limited safe access. Field data were also collected opportunistically during a Facility shut-down during the winter low flow period to allow further understanding of effects of the shut-down on ramping rate and fish stranding in the gravel reach ~300 km downstream. Further field data will be collected in the 2019/2020 spawning and incubation period and integrated to refine the interim risk assessment provided herein.

1.1. Background

During typical operational conditions, the Facility discharges between 80 to 120 m^3/s to the Fraser River at Lillooet. However, Facility shut-downs are required periodically to complete planned maintenance and testing of the generating unit or power canal, and forced shut-downs occasionally occur due to unexpected issues such as line trips. Shut-downs during low flow conditions in the lower Fraser River, result in stage decreases that have the potential to dewater spawning gravels if they occur during low flow conditions.

Past studies have been completed to evaluate redd dewatering and stranding risk at Ferry Island (Map 1) following a Facility shut-down by measuring the rate and magnitude of stage changes over a range of Fraser River flows (e.g., Higgins 2010, Ramos-Espinoza *et al.* 2016, Putt and Wilson 2017, Faulkner *et al.* 2018). To support these analyses, a hydrometric gauge was installed to monitor stage in 2012 by BC Hydro at Ferry Island near the Rosedale Bridge in Agassiz, BC (Ramos-Espinoza *et al.* 2016). This report addresses management question 5 of the BRGMON-9 program, which pertains to Fraser River fish habitat, specifically:

5) Does discharge from Seton Generating Station impact fish habitat in Fraser River above and beyond natural variation in Fraser River discharge?

1.2. Environmental Setting

The gravel reach is a 50 km long reach of the Fraser River where coarse sediment (coarse sand, gravel, and cobble) is deposited annually during spring flooding (Map 1). The location and form of these gravel bars and islands shift annually in response to erosion and deposition during freshet, when flows average 8,766 m^3/s (Rempel and Church (2002), Water Survey of Canada Stn. 08MF005 at Hope). This reach has high ecological productivity, providing valuable fish habitat that is used by at least 28 native fish species, including 11 species of salmonids (Lewis and Hatfield 2010). Species of greatest cultural, commercial and/or recreational significance are Chinook Salmon (*Oncorhynchus tshawytscha*), Chum Salmon (*O. keta*), Coho Salmon (*O. kisutch*), Pink Salmon (*O. gorbuscha*), and Sockeye Salmon (*O. nerka*), Cutthroat Trout (*O. clarkii*), Steelhead/Rainbow Trout (*O. mykiss*), White Sturgeon (*Acipenser transmontanus*), and eulachon (*Thaleichthys pacificus*). All species of anadromous Pacific salmon utilize habitat within the reach to varying during adult migration to the spawning grounds, and downstream smolt migration to the estuary. Large numbers of Chinook Salmon rear in the Fraser River gravel reach for up to one year before migrating to the ocean. Significant numbers of Pink Salmon and Chum Salmon spawn within gravel bars in the main channel of the Fraser River gravel reach, which is the focus of this field assessment.

Fraser River Risk Assessment Overview

Legend

- Water Survey of Canada Gauge (08MF005)
- Seton Powerhouse
- Seton Canal
- Gravel Reach

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 10 20 30 40 km

Scale: 1:1,000,000

NO.	DATE	REVISION	BY
1	26/11/2019	1349_FraserRiskAssessmentOverview_3507_20191125	CGA
2			
3			
4			
5			

Date Saved: 26/11/2019
Coordinate System: NAD 1983 UTM Zone 10N

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Map 1

Path: M:\Projects-Active\1349\MXD\1349_FraserRiskAssessmentOverview_3507_20191125.mxd

2. METHODS

2.1. Field Data Collection 2019

2.1.1. Stage Change at Spawning Locations

In-situ level loggers were installed at eight representative Pink Salmon and Chum Salmon spawning sites throughout the gravel reach that were identified using the available historical information (Palmer 1972), and local knowledge (Layne, pers. comm. 2019). These sites are referred to as Stranding Sensitive Monitoring Sites (SSMSs) as they also possess characteristics similar to stranding sensitive habitat, being located on gravel bars with shallow sloping banks posing a high risk of stranding. These SSMSs were identified during a reconnaissance survey on February 21 and February 22, 2019 (Map 2). These SSMSs were selected to allow the development of stage-discharge relationships at typical spawning locations where stranding and dewatering risk for redds is the greatest. Site-specific stage-discharge relationships at the SSMSs/spawning locations for Pink and Chum Salmon throughout the gravel reach were developed using the Water Survey Canada (WSC) gauge at Hope.

Stage data at SSMSs were collected by installing temporary water level recorders (Solinst Levelogger) for the period of February 21 and February 22, 2019 to April 2, 2019. Water level was recorded at 5-minute intervals over this time period. The level recorders were downloaded on March 28, 2019 and moved to ensure they could be recovered under higher flow conditions. Water surface elevations were collected and surveyed relative to benchmarks during the installation, servicing and removal of the loggers. Stage data were then related to discharge from Water Survey Canada (WSC) gauge at Hope. Discharge at this WSC gauge was used to calculate the stage-discharge relationship for the gravel reach SSMSs. Tidal influence in lower portion of the study area was obvious during the SSMS site selection and was considered during the logger installation, to capture potential tidal influence on the gravel reach and selected SSMSs during low flow periods in the Fraser River.

Discharge data for WSC Hope were adjusted to account for the time lag between the WSC gauge location and the SSMSs. These stage discharge relationships were used along with the existing stage-discharge relationship at Ferry Island hydrometric gauge to assess potential dewatering at known spawning locations and to update the dewatering risk assessment (Faulkner *et al.* 2018).

The uncharacteristic cold weather prior to and during site selection in winter 2019 and related ice presence limited the locations that could be assessed and selected for logger placement. In particular, ice cover excluded backwater channels and some slow-moving side channels. The SSMSs selected had larger percentage of river flow and higher velocities than ice covered locations and may overestimate stage changes in backchannels and side channels with limited connection to the mainstem habitat.

2.1.2. Redd Surveys

Redd surveys were conducted opportunistically during logger installation and removal of level loggers at SSMSs in addition to opportunistic searches after the stranding searches conducted during the shut-down of the Facility. Representative redds were excavated to confirm the presence of eggs and alevins. Redds were characterized as wetted (water covered the entire estimated egg pocket), moist (the substrate at the top of the estimated egg pocket remained wet and for excavated redds hyporheic flow was detected within the lower section of the estimated egg pocket) or dewatered (the top of egg pocket was dry and for excavated redds hyporheic flows were not detected through the estimated egg pocket). Elevation and water depth of redds was also surveyed relative to benchmarks to allow back-calculation of spawning depths during the prior spawning period. Pink Salmon and Chum Salmon are the species known to utilize the gravel reach for spawning and since adult Pink Salmon are absent from the Fraser River in even years, the redd surveys are focused on Chum Salmon only in 2019. The median flow during the Chum Salmon spawning period was used for this assessment was October 15 to November 30 (based on the 2018 data, Faulkner *et al.* 2018). The spawning depths estimated at the median flow level were used to confirm the adequacy of the generic HSI curves used for Chum Salmon in the 2018 assessment (Faulkner *et al.* 2018) and to estimate habitat suitability based on these curves.

2.1.3. Stranding Searches

Stranding searches were conducted at SSMSs on March 1, March 2 and March 5 following the Facility shut-down. Stranding searches were conducted during and following shut-downs as flows were dropping.

Two types of searches were conducted: broad-based and hotspot. Broad-based searches, which are completed prior to hotspot searches, covered the length of the SSMS and were conducted by a crew of two walking along the shoreline while scanning the substrate surface for stranded or isolated fish, with attention focussed on microhabitats that may strand fish (i.e., low gradient areas, large interstitial spaces, pools likely to become isolated). Hotspot (hand) searches were subsequently conducted in smaller areas within the broad-based search area where stranding risk is identified to be particularly high, such as in isolated depressions. Hotspot searches were conducted by delineating an area of dewatered substrate within a quadrat of known area, and using hands or feet (for larger rocks) to search for any fish stranded within the quadrat. Cobbles were physically overturned and substrate gently excavated to look for fish. Once searched, excavated material was replaced to minimize impacts to fish habitat.

For both types of searches, the following information was recorded: search area (length/width in m), start/end time, number of crew members searching, depth searched (m), weather, air and water temperature (°C), and water transparency (m). If fish were observed during searches, the number of fish and species were recorded, along with information on each individual fish including: location (depth of water and distance from the wetted edge), fork length, whether dead or alive, and stranding status (stranded/isolated/present in the mainstem). The same information was recorded for any fish observed at the SSMSs outside of the defined stranding search time while crews perform additional monitoring tasks (e.g., measurements of wetted width change); these observations were recorded as "incidental observations".

2.1.4. Ramping Rate Assessment During the Facility Shut-down

Ramping rates and stage changes resulting from the Facility shut-down were calculated using the stage data collected at the SSMSs, Ferry Island Logger and WSC gauge at Hope.

Ramping rates at the WSC gauge and SSMSs for each data point were calculated as the difference between that stage (cm) and the maximum stage in the previous hour (cm), using the following procedure:

1. The maximum stage observed over the past hour for each data point i was calculated as:

$$hmax(t_i) = \max\big(h(t_{i-k}), \ldots, h(t_{i-1})\big)$$

where h is stage, k is the number of data points recorded per hour, and t is time.

2. The maximum stage decrease over the past hour relative to time t_i, $\Delta hmax(t_i)$, was calculated as:

$$\Delta hmax(t_i) = h(t_i) - hmax(t_i)$$

2.2. Redd Dewatering Risk Assessment Model

2.2.1. Model Update

Faulkner *et al.* (2018) developed a simple habitat model to quantify the percentage of redds dewatered by calculating redd depth at the time of spawning and estimating the decrease in depth caused by natural seasonal flow changes and the Facility shut-down. Model inputs were:

1. mean daily discharge as measured at WSC Hope gauge (1997 to 2017);
2. relationship between Fraser River stage at Ferry Island (assumed to be representative of spawning habitat) and discharge in the Fraser River at WSC Hope gauge;
3. timing of spawning of Pink Salmon and Chum Salmon in the gravel reach (Table 2);
4. distribution of Pink Salmon and Chum Salmon spawning depths inferred from habitat suitability indices (HSI; Figure 1 and Figure 2); and
5. egg burial depth from the literature (15 cm and 35 cm beneath the redd surface; DeVries 1997).

Further details on the modelling approach can be found in Faulkner *et al.* (2018).

Data collected during the field assessments in 2019 were used to update the model. The priority for 2019 was to collect stage data at representative spawning locations that could be used to confirm the appropriateness of the stage-discharge relationship from Ferry Island to represent actual spawning locations referred to as SSMSs above. Stage discharge relationships developed for SSMSs were compared to Ferry Island and the model was run with the SSMSs found to be most (FRA-DSSD08) and least (FRA-DSSD05) sensitive to stage change to provide a range of conditions that could be expected.

Opportunistic redd surveys were also conducted in 2019 to estimate spawning depths and confirm the appropriateness of HSI curves used for spawning Chum Salmon. Pink Salmon were not present because they do not spawn in the Fraser in even years. Redd excavation was also attempted in 2019 to confirm the site-specific development stage, egg/alevins depth in egg pocket; however, limited redds were detected and no eggs/alevins were present in excavated redds. Conditions were atypically cold during 2019 and therefore, more data collection during the spawning season of 2019/2020 is recommended prior to updating assumptions on depth within pocket and emergence.

The Pink Salmon spawning period used for model input was September 15 to October 15, while the Chum Salmon spawning period of October 15 to November 30 was selected. Despite the difference in spawning times, emergence and downstream migration timing for Pink Salmon and Chum Salmon overlap (March 15 to May 31; Fisheries and Marine Service 1976). For model application, we defined the emergence period for both species as beginning on March 15 and ending on April 30; however, we note the observation of emerged Chum Salmon fry on March 2 suggest the period may be earlier.

Table 2. Spawning and emergence periodicity for Pink Salmon and Chum Salmon in the Fraser River gravel reach, based on a literature review.

Fish Species	Life History Stage	Time Period											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pink Salmon	Spawning[1]												
	Emergence[2]												
	Emergence[1]												
Chum Salmon	Spawning[1]												
	Spawning[3]												
	Emergence[1]												
	Emergence[3]												

[1]Fisheries and Martine Service (1976)

[2]Vernon (1966)

[3]Palmer (1972)

Critical Time

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Figure 1. Pink Salmon Habitat Suitability Index (HSI) curve from Raleigh and Nelson (1985).

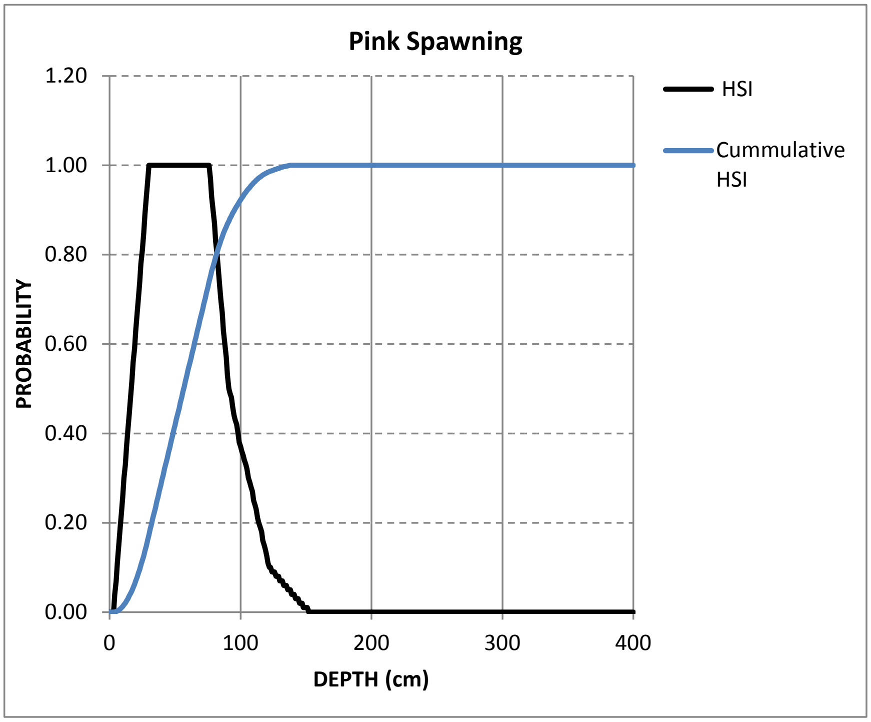
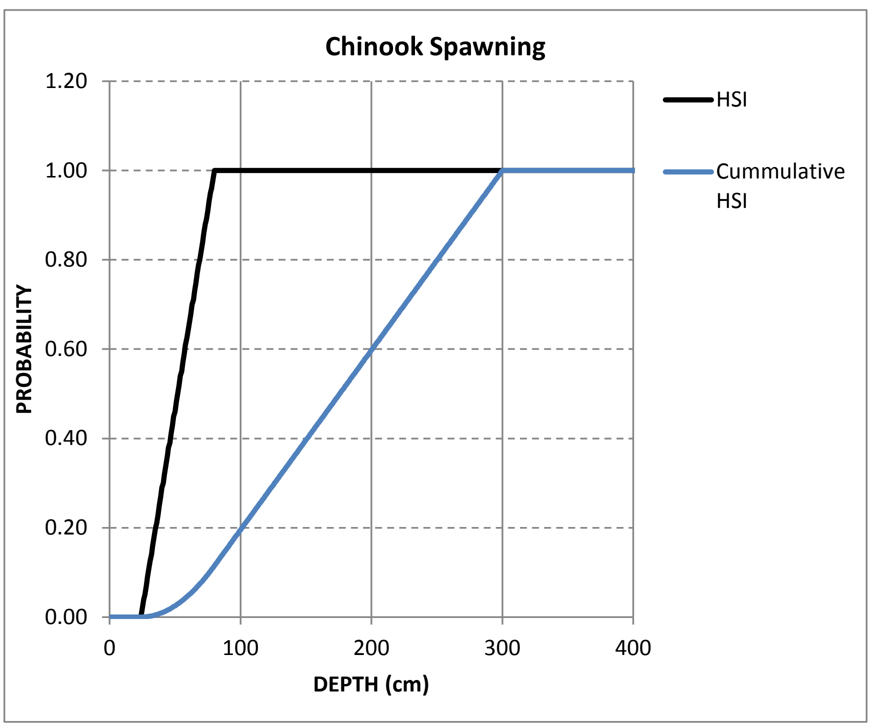


Figure 2. Chinook Salmon Habitat Suitability Index (HSI) curve from Ptolemy (2001) used as a surrogate for Chum Spawning.



2.2.2. Model Implementation

The redd dewatering risk assessment model was used to calculate the percentage of eggs dewatered during natural stage changes and during shut-down events for the period of spawning until emergence. Following Faulkner *et al.* (2018), model application focussed on dewatering of the egg pocket assuming that most eggs were found at the bottom of the egg pocket and assumed the same distribution of alevins and that alevins were immobile. Neither eggs nor alevins were detected in redds excavated in February and March 2019 while Chum Fry were observed in stream margins on March 2. Although these data may indicate earlier emergence only 13 redds were assessed and ice and snow limited the locations that could be sampled. Accordingly, this analysis focuses on eggs alone but would apply to alevins that remained stationary in the egg pocket.

Model implementation followed these steps:

1. Four key flows at WSC Hope were calculated:
    a. Median spawning flow;
    b. Minimum average weekly flow during incubation;
    c. Flow at start of a simulated shut-down event of 120 m^3/s; and
    d. Minimum flow during 120 m^3/s shut-down (depending on simulated duration).
2. The stage-discharge relationship at FRA-DSSD08 and FRA-DSSD05 were used to calculate stage at SSMSs for the above flow values.
3. Percent of eggs dewatered within redds were estimated for natural dewatering and during Facility shut-downs. This involved:
    a. Adding the top and bottom of the egg pocket depths to the spawning depth cumulative HSI to create egg depth cumulative HSI.
    b. Calculating the difference in stage between spawning and the minimum incubation flow, and looking up the egg depth cumulative HSI for both top and bottom of the pockets depths to determine the percent of eggs dewatered. Due to the shape of salmonid egg pockets (e.g., as reported by Hawke 1978), the distribution of eggs within the egg pocket is expected to be skewed downwards, with more eggs near the bottom of the egg pocket). Consequently, the results for eggs were prorated to the median distance between the top and the bottom of the egg pocket (i.e., 0.8) to represent the percentage of redds where 50% of the eggs within the egg pocket were expected to be dewatered.
4. The percent of eggs dewatered was calculated under natural conditions and under shut-downs of 1-day duration for every day in the incubation period across the 21 years of data (1997 to 2017).

5. The percent of eggs dewatered was calculated under natural conditions and under shut-downs of 1 to 8-week duration in the incubation period weekly starting on October 1 across the 21 years of data (1997 to 2017).
6. Using the flow at the start of the event, the simulation results were separated into flow bins of 100 m^3/s between 500 m^3/s and 3,000 m^3/s (presented as midpoint in bin, e.g., 150 m^3/s).
7. Median, 10%tile, and 90%tile of dewatered eggs were calculated for each flow bin and these were graphed.
8. The median value for percent eggs dewatered each year was calculated and plotted.
9. Egg dewatering under all scenarios was compared to natural dewatering that occurred in that year to determine incremental dewatering as a result of Facility shut-down.

3. RESULTS AND DISCUSSION

3.1. Field Data Collection 2019

3.1.1. Stage Change at Spawning Locations

Hydrometric WSC gauge data at Hope and Ferry Island for the period of February 21 to April 3, 2019 is provided in Figure 3. The stage data at each SSMS are presented in Figure 4 and the stage-discharge relationships for each SSMS are presented in Figure 5. Due to high velocities and erosion the logger at FRA-DSSD05 shifted, thus only data that could be confirmed using field surveys (February 21 to March 16 and March 28 to April 4) were used to calculate the stage-discharge relationship. Stage-discharge relationships were similar but varied across the spawning locations, and in comparison, to the Ferry Island location. The stage-discharge relationship at Site FRA-DSSD06, the most downstream SSMS, was not calculated because of the tidal influence at this site (Figure 4). Sensitivity to stage change was calculated as the ratio of stage change for a given flow change between the SSMS and Ferry Island over the range of flows assessed. The most sensitive site (FRA-DSSD08) showed a relationship that was 0.97 times less sensitive than Ferry Island (i.e., the site would show an 0.97 m stage change with a 1 m stage change at Ferry Island) while the least sensitive site (FRA-DSSSD05) showed a relationship that was 0.47 times less sensitive than Ferry Island (i.e., the site would show an 0.47 m change with a 1 m stage change at Ferry Island; Table 3). The relationships for these two most extreme sites were used to better characterize the dewatering risk.

Figure 3. **Stage at Ferry Island and Discharge at WSC Fraser River at Hope gauge (WSC 08MF005) for the period of February 21 to April 3, 2019.**

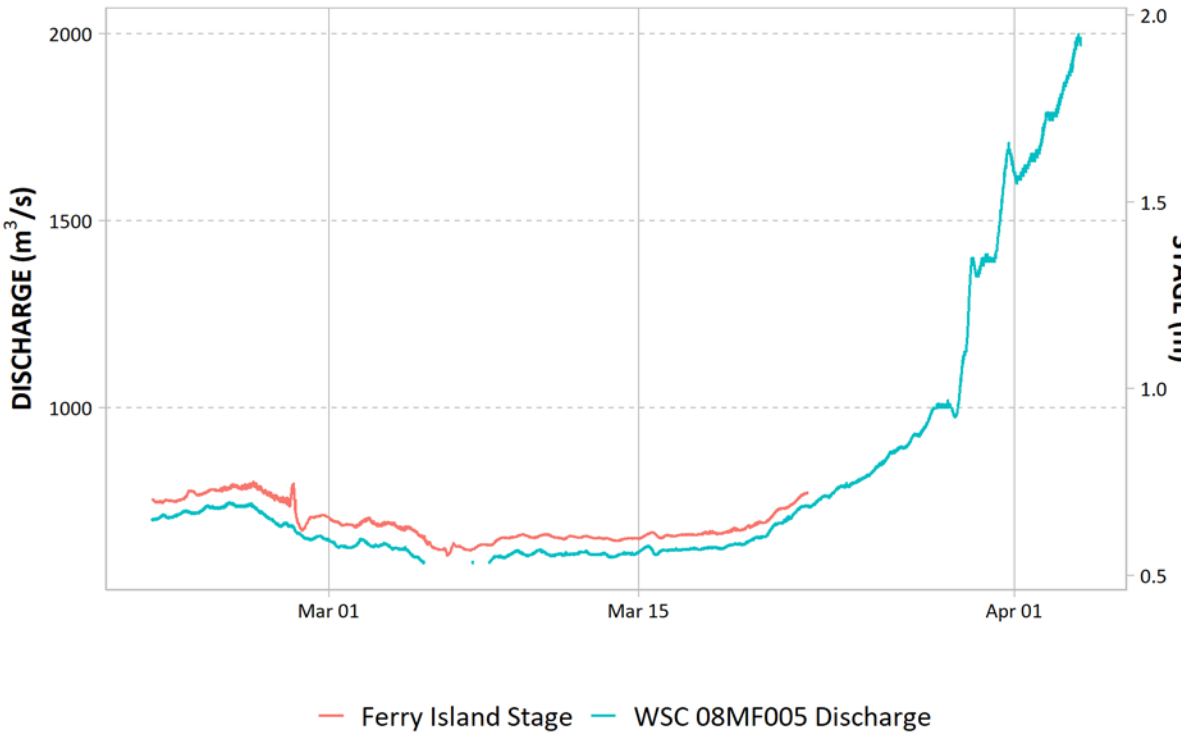


Figure 4. Relative water surface elevation at SSMSs in the gravel reach for the study period.

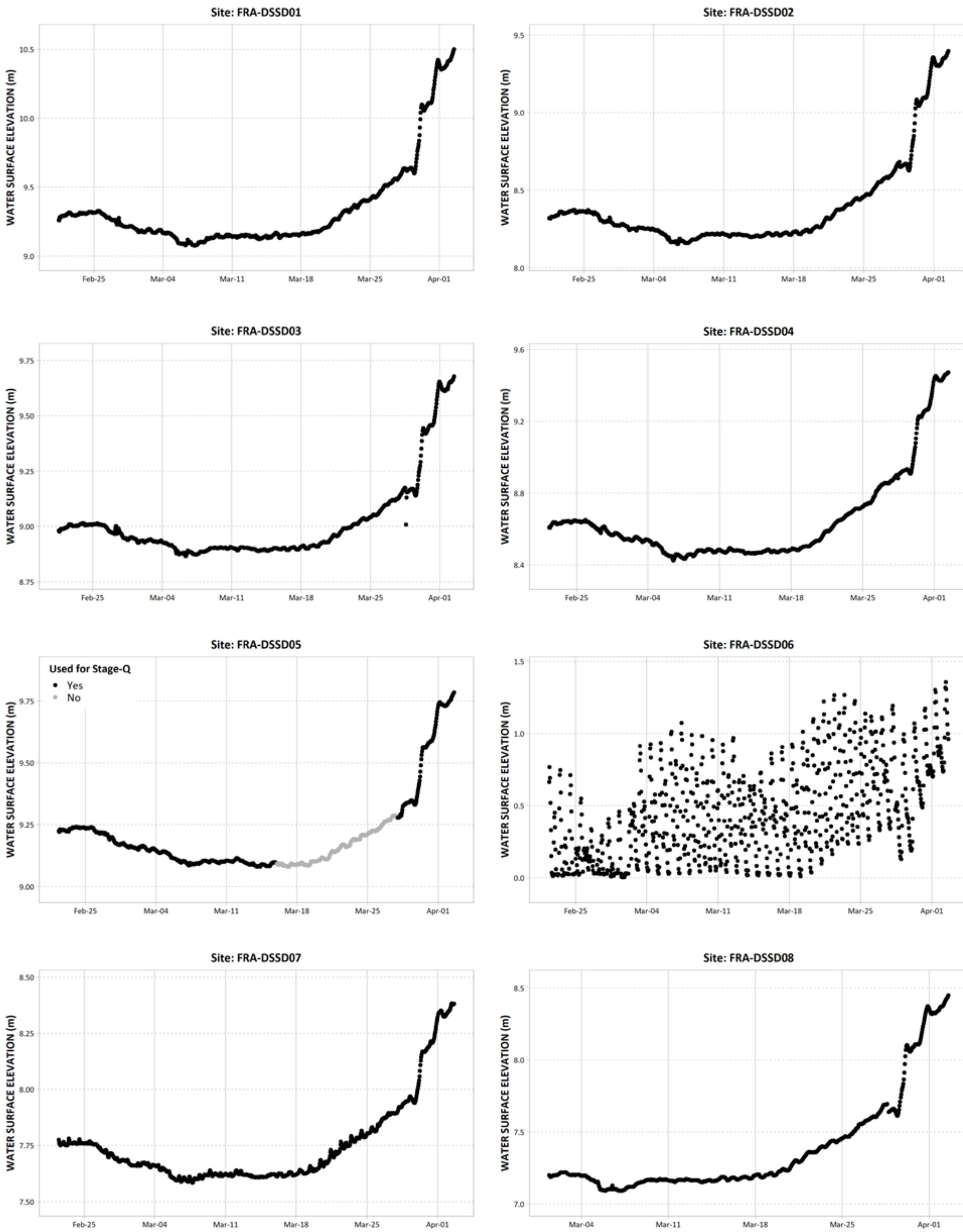


Figure 5. **Stage-Discharge relationships at SSMSs relative to the WSC gauge at Hope. Note that the stage-discharge relationship could not be calculated for the site FRA-DSSD06 as a result of the tidal influence at this site.**

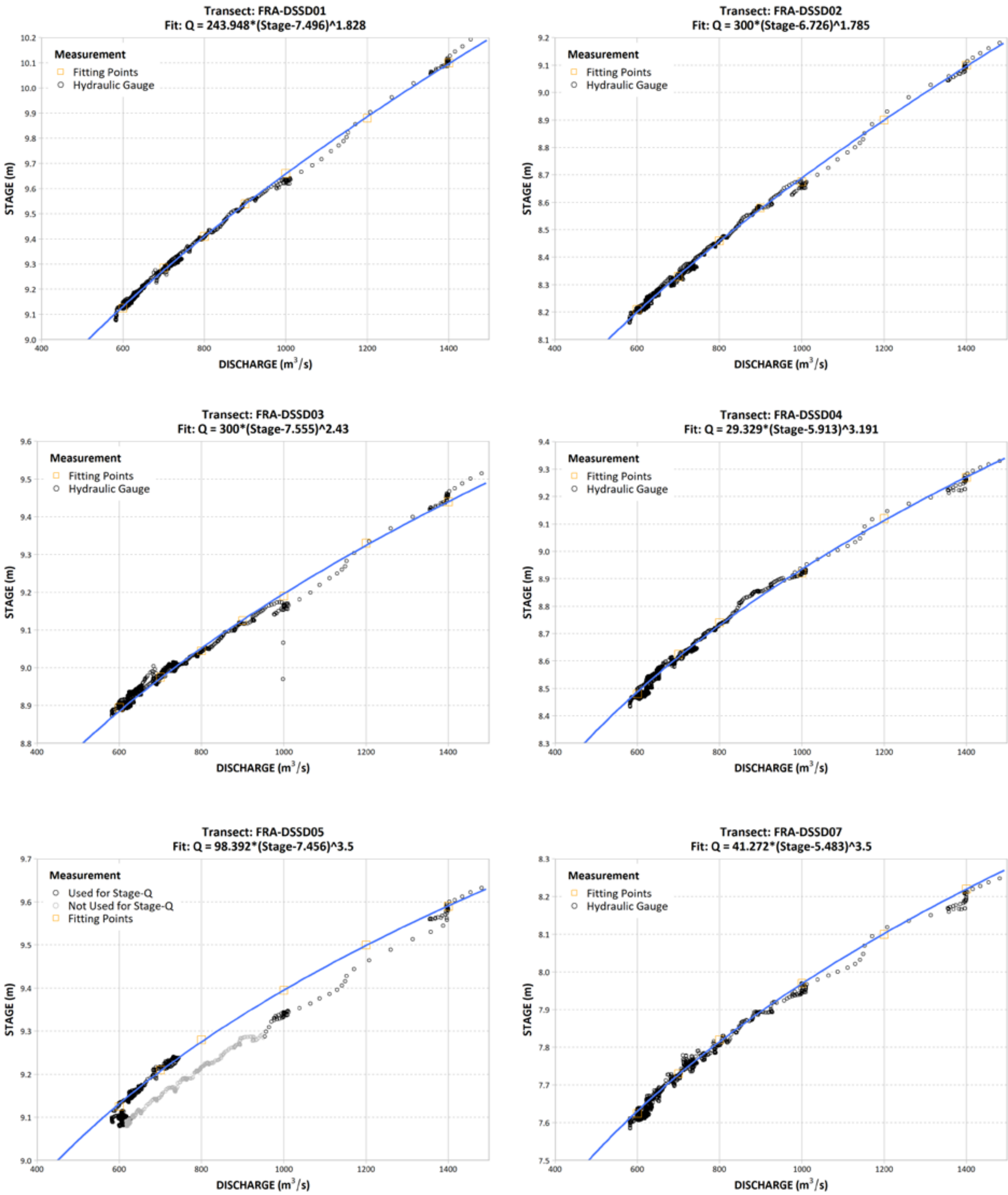


Figure 5. Continued.

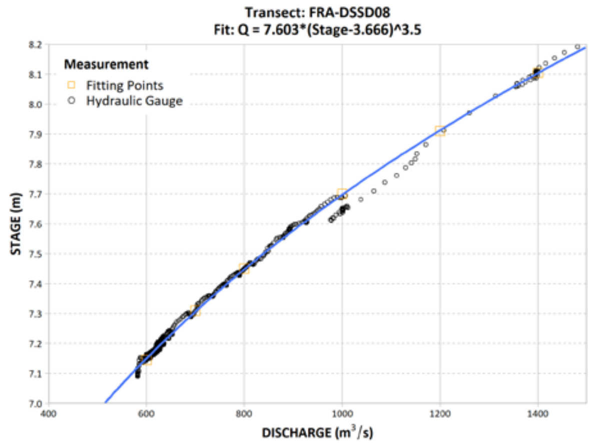


Table 3. Comparison of SSMS and Ferry Island stage-discharge relationships. Sensitivity was calculated as the ratio of stage change for a given flow change between the SSMS and Ferry Island over the range of flows assessed.

SSMS	Sensitivity to Ferry Island		
	Min	Max	Average
FRA-DSSD01	0.73	1.18	0.95
FRA-DSSD02	0.67	1.10	0.89
FRA-DSSD03	0.49	0.60	0.54
FRA-DSSD04	0.78	0.80	0.79
FRA-DSSD05	0.47	0.46	0.46
FRA-DSSD07	0.60	0.59	0.60
FRA-DSSD08	0.98	0.96	0.97

3.1.2. Redd Surveys

In total, 39 redds were surveyed during the study period, which were distributed at six SSMSs (no redds were identified at FRA-DSSD02 and FRA-DSSD03; Table 2). A total of 21 of these redds (54%) were found to be dewatered at the time of assessment, however, this overestimates redd dewatering because not all wetted redds could be found due to the depth of the Fraser River and limitations of wading-based observation. Based on the redd surveys and back calculation of the spawning depth using the stage discharge curves, it is estimated that spawning depths at the redds varied from 65 cm to 153 cm. These spawning depth estimates provide general support to the generic HSI curves used in the Faulkner *et al.* (2018) assessment (Figure 6). Overall, the number of redds identified and assessed for this study were considered relatively low, partly because ice and snow cover limiting the locations that could be sampled, and because redds in water deeper than could be safely waded at SSMSs (approximately 1.2 m) could not be identified nor sampled. Based on WSC Hope preliminary data, flow during the periods of assessment was ~710 to 720 m^3/s during February 21 to 22, 2019, ~627 to 658 m^3/s for March 1 to 2, 2019 and <588 m^3/s on March 5, 2019. Flow data are currently unavailable from the morning of March 5 to March 8 and available data may be subject to change as they are finalized through WSC.

During the redd surveys, a total of 13 redds were excavated; however, no eggs, alevins or pre-emerging fry were detected, which suggests that the alevins may have moved out of the egg pockets during decreasing flows or fry had emerged from the gravel prior to the study period on February 20 and 21, 2018. Live free-swimming salmon fry (were observed at some sites on March 2, 2019 (at FRA-DSSD05) and March 5, 2019 (at FRA-DSSD05 and FRA-DSSD07). These salmon fry were likely buttoned up Chum Salmon based on the confirmed identification of a mortality on March 2, 2019. Based on Ferry Island daily average temperature data and a spawning date of October 15, 2018 50% hatch (510 accumulated thermal units (ATU; Fedorenko and Bailey 1980)) would have been estimated to occurred on January 29, 2019, with 50% emergence/fry migration anticipated on May 18, 2019 (961 ATU; Fedorenko and Bailey 1980). Based on flow history these redds would have been wetted until the estimated hatch date. However, temperatures within redds may be influenced by hyporheic flows and differ from surface flows, in particular this can lead to underestimation of temperatures during winter, which is not accounted for in these estimates.

The spawning depth estimates are based on median flow through the spawning period from October 15, 2018 to November 30, 2018 (1,480 m^3/s) and there was variability in flow during this time, which ranged from ~1,050 m^3/s to 2,610 m^3/s, which creates uncertainty in actual spawning depth depending on the date of spawning. Nevertheless, these spawning depth estimates provide general support for the use of the Chinook Salmon HSI curve from Ptolemy (2001) as a surrogate for Chum Salmon spawning as per Faulkner *et al.* (2018). However, the maximum spawning depth implied by the Chinook HSI is 3 m (Figure 7), a value that could not be confirmed by the methods of this study, which relied on wading to identify. Additional field surveys planned for 2019/2020 to collect additional redd information for both Pink and Chum Salmon spawning and incubation will employ snorkeling to sample deeper habitats.

Table 4. Redd survey information collected from February 21 to March 5, 2019.

Date	Site	Redd #	Dewatered (D), Moist (M), Wetted (W)	Redd Pit Depth (m)[1]	Tail Depth (m)[1]	Survey Time (hh:mm)	Redd excavated (Y) or (N)	Eggs or Alevins observed? (Y) or (N)
21-Feb-2019	FRA-DSSD01	1	W	0.004	-0.039	11:44	N	N
21-Feb-2019	FRA-DSSD01	2	W	0.014	-0.022	11:47	Y[2]	N
21-Feb-2019	FRA-DSSD01	3	W	0.095	-0.089	11:48	Y[2]	N
21-Feb-2019	FRA-DSSD01	4	W	0.070	-0.064	11:50	Y[2]	N
21-Feb-2019	FRA-DSSD01	5	W	0.040	-0.123	11:52	Y[2]	N
21-Feb-2019	FRA-DSSD01	6	W	0.040	-0.143	11:53	Y[3]	N
22-Feb-2019	FRA-DSSD06	16	W	0.380	NC[5]	10:55	N	N
22-Feb-2019	FRA-DSSD06	17	W	0.382	NC[5]	10:58	N	N
22-Feb-2019	FRA-DSSD06	18	W	0.475	NC[5]	11:03	N	N
22-Feb-2019	FRA-DSSD07	3	W	0.542	0.476	12:43	Y[4]	N
01-Mar-2019	FRA-DSSD08	1	W	0.520	0.490	11:18	N	N
01-Mar-2019	FRA-DSSD08	2	W	0.560	0.550	12:19	N	N
01-Mar-2019	FRA-DSSD01	7	M	0.005	-0.248	14:17	N	N
02-Mar-2019	FRA-DSSD05	1	W	0.138	0.085	9:12	N	N
02-Mar-2019	FRA-DSSD05	2	W	0.125	0.069	9:36	Y	N
02-Mar-2019	FRA-DSSD05	3	W	0.145	0.085	9:41	N	N
02-Mar-2019	FRA-DSSD06[6]	1	D	-0.437	-0.496	12:20	N	N
02-Mar-2019	FRA-DSSD06[6]	2	D	-0.419	-0.476	12:22	N	N
02-Mar-2019	FRA-DSSD06[6]	3	M	-0.407	-0.455	12:25	N	N
02-Mar-2019	FRA-DSSD06[6]	4	M	-0.395	-0.451	12:28	N	N
02-Mar-2019	FRA-DSSD06[6]	5	D	-0.395	-0.463	12:30	N	N
02-Mar-2019	FRA-DSSD06[6]	6	D	-0.411	-0.469	12:34	N	N
02-Mar-2019	FRA-DSSD06[6]	7	M	-0.266	-0.313	12:37	N	N
02-Mar-2019	FRA-DSSD06[6]	8	M	-0.293	-0.347	12:39	Y	N
02-Mar-2019	FRA-DSSD06[6]	9	D	-1.250	-1.414	12:43	N	N
02-Mar-2019	FRA-DSSD06[6]	10	D	-1.246	-1.420	12:46	N	N
02-Mar-2019	FRA-DSSD06[6]	11	D	-1.076	-1.197	12:53	N	N
02-Mar-2019	FRA-DSSD06[6]	12	D	-1.063	-1.155	12:53	N	N
02-Mar-2019	FRA-DSSD06[6]	13	D	-0.671	-0.828	12:58	N	N
02-Mar-2019	FRA-DSSD06[6]	14	M	-0.196	-0.295	13:01	Y	N
02-Mar-2019	FRA-DSSD06[6]	15	M	-0.059	-0.121	13:03	Y	N
02-Mar-2019	FRA-DSSD07	1	W	0.410	0.370	14:56	N	N
02-Mar-2019	FRA-DSSD07	2	W	0.140	0.088	14:58	Y	N
02-Mar-2019	FRA-DSSD04	1	M	-0.116	-0.218	17:11	N	N
02-Mar-2019	FRA-DSSD04	2	M	-0.134	-0.173	17:12	N	N
02-Mar-2019	FRA-DSSD04	3	M	-0.073	-0.128	17:14	Y	N
05-Mar-2019	FRA-DSSD04	4	W	0.250	0.200	16:30	N	N
05-Mar-2019	FRA-DSSD04	5	W	0.360	0.280	16:36	N	N
05-Mar-2019	FRA-DSSD04	6	W	0.390	0.350	16:36	Y	N

[1] Negative depths are distance above the water elevation based on Redd survey elevations

[2] Redd #2 to #5 at FRA-DSSD01 were excevated on March 1, 2019

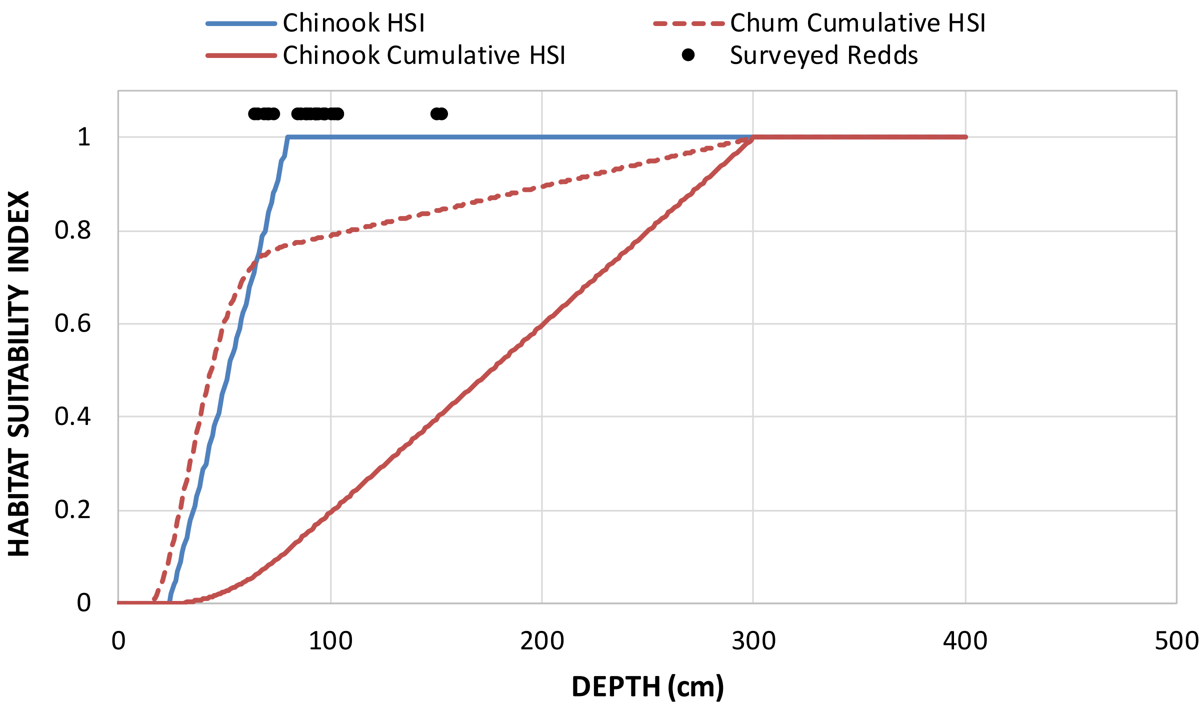
[3] Redd #6 at FRA-DSSD01 was excevated on March 5, 2019

[4] Redd #3 at FRA-DSSD07 was excevated on March 2, 2019

[5] NC - Data not collected

[6] FRA-DSSD06 is tidally influenced and measurements at this site are not representative of other sites

Figure 6. Chinook Salmon spawning depth HSI and measured redd depths for Chum Salmon in the Fraser River gravel reach.



3.1.3. Stranding Searches

No stranded or isolated fish were observed as a result of the Facility down-ramping events during searches conducted on March 1, March 2 and March 5, 2019 (Table 5). Total search effort was 14 hours and 52 minutes and included 7,290 m^2 of broad based and 625 m^2 of hotspot searches; however, the locations that could be searched were limited due to ice cover. One Chum Salmon fry mortality, which appeared to be recent was observed on March 2, 2019 at site FRA-DSSD05 (Table 5, Figure 7); however, it was recovered in 10 cm deep water, whereas only 1.8 cm was dewatered at this location during the event in relation to the time of observation. Based on the depth it was detected in relation to dewatering it was considered to be unlikely a result of the Facility shut-down.

Table 5. Stranding search results for March 1, March 2 and March 5, 2019.

Date	SSMS	Arrival Time (PDT)	Search Type	Number of Searches	Total Area (m²)	Total Search Time (h:mm)	Fish Observed		Fish Location			Total Fish Observed
							Alive	Dead	Stranded	Isolated	Mainstem	
01-Mar-19	FRA-DSSD08	10:15	Broadbase	1	450	0:20	0	0	0	0	0	0
			Hotspot	0	0	0:00	0	0	0	0	0	0
	FRA-DSSD01	13:15	Broadbase	1	560	0:40	0	0	0	0	0	0
			Hotspot	0	0	0:00	0	0	0	0	0	0
	FRA-DSSD02	15:03	Broadbase	1	1,000	0:40	0	0	0	0	0	0
			Hotspot	2	30	1:20	0	0	0	0	0	0
	FRA-DSSD03	17:09	Broadbase	1	400	0:10	0	0	0	0	0	0
			Hotspot	3	8	0:10	0	0	0	0	0	0
Daily Total			**Broadbase**	**4**	**2,410**	**1:50**	**0**	**0**	**0**	**0**	**0**	**0**
			Hotspot	**5**	**38**	**1:30**	**0**	**0**	**0**	**0**	**0**	**0**
02-Mar-19	FRA-DSSD05	7:45	Broadbase	2	380	0:20	0	1	0	0	1	1
			Hotspot	3	11	0:22	0	0	0	0	0	0
	FRA-DSSD06	10:40	Broadbase	1	450	0:15	0	0	0	0	0	0
			Hotspot	3	66	0:12	0	0	0	0	0	0
	FRA-DSSD07	15:21	Broadbase	1	400	0:30	0	0	0	0	0	0
			Hotspot	1	32	0:56	0	0	0	0	0	0
	FRA-DSSD04	15:59	Broadbase	2	550	1:22	0	0	0	0	0	0
			Hotspot	2	40	1:20	0	0	0	0	0	0
Daily Total			**Broadbase**	**6**	**1,780**	**2:27**	**0**	**1**	**0**	**0**	**1**	**1**
			Hotspot	**9**	**149**	**2:50**	**0**	**0**	**0**	**0**	**0**	**0**
05-Mar-19	FRA-DSSD01	11:04	Broadbase	1	450	0:12	0	0	0	0	0	0
			Hotspot	3	71	0:34	0	0	0	0	0	0
	FRA-DSSD03	12:02	Broadbase	1	400	0:24	0	0	0	0	0	0
			Hotspot	1	12	0:08	0	0	0	0	0	0
	FRA-DSSD05	12:52	Broadbase	1	600	0:30	9	0	0	0	9	9
			Hotspot	2	88	0:32	0	0	0	0	0	0
	FRA-DSSD06	13:51	Broadbase	1	450	0:25	0	0	0	0	0	0
			Hotspot	1	58	0:22	0	0	0	0	0	0
	FRA-DSSD07	15:15	Broadbase	1	600	0:44	5	0	0	0	5	5
			Hotspot	4	99	0:50	0	0	0	0	0	0
	FRA-DSSD04	16:28	Broadbase	1	600	0:42	0	0	0	0	0	0
			Hotspot	3	110	0:52	0	0	0	0	0	0
Daily Total			**Broadbase**	**6**	**3,100**	**2:57**	**14**	**0**	**0**	**0**	**14**	**14**
			Hotspot	**14**	**438**	**3:18**	**0**	**0**	**0**	**0**	**0**	**0**
Grand Total			**Broadbase**	**16**	**7,290**	**7:14**	**14**	**1**	**0**	**0**	**15**	**15**
			Hotspot	**28**	**625**	**7:38**	**0**	**0**	**0**	**0**	**0**	**0**

* Fish mortality observed at FRA-DSSD05 on March 2, 2019 is unlikely to be related to the shut down test.

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Figure 7. Photograph of the dead juvenile Chum Salmon observed at FRA-DSSD05 on March 2, 2019.

3.1.4. Facility ramp down and shut-down in February and March 2019

The Facility ramped down on February 28, 2019 and was completely shut-down on March 4, 2019. The first event occurred on February 28, 2019 during which discharge through the Facility was reduced from 77.5 m^3/s to 41.4 m^3/s but Seton Dam flow was increased from 3.05 m^3/s to 12.7 m^3/s with an overall decrease of 26.5 m^3/s (Table 6, and Figure 8). The second shut-down occurred on March 5, 2019, during which discharge through the Facility was reduced from 37.9 m^3/s to 0 m^3/s but Seton Dam flow was increased from 13.2 m^3/s to 32.3 m^3/s with an overall decrease of 18.8 m^3/s (Table 6, Figure 10, and Figure 11). The changes in flow in the gravel reach are shown in Figure 8 and Figure 10.

During the first event (on February 28, 2019), the observed ramping rates at Hope and Ferry Island gauging stations were -1.1 cm/hr and -0.5 cm/hr respectively (equivalent to stage change of -1.9 cm and -0.5 cm respectively). Ramping rates estimated at SSMSs during this shut-down test ranged from -0.8 cm/hr to -1.0 cm/hr (Figure 9).

During the second event (on March 5, 2019), the observed ramping rate at Ferry Island gauging station was -1.0 cm/hr (equivalent to stage change of -1.1 cm). Ramping rates estimated at SSMSs during this shut-down test ranged from -0.8 cm/hr to -3.2 cm/hr. During this event, the estimated ramping rates observed at Hope and Ferry Island gauging stations and SSMSs were all lower than the DFO generic ramping rates of -2.5 cm/hr for the fry-present period (Cathcart 2005), except for FRA-DSSD01 and FRA-DSSD08 (with -3.1 cm/hr and -3.2 cm/hr ramping rates respectively). Overall, the stage change and ramping rates at the SSMSs due to the shutdowns was difficult to distinguish from natural flow reductions and estimated lag times and professional judgement was required to assign ramping rates. The combined 45.3 m^3/s shutdown monitored here would represent an estimated 5.5% of the total decline in flows from the time of spawning (median spawning flow 1,410 m^3/s) to the lowest estimated flow at the WSC gauge of March 5 (588 m^3/s).

The flow data for the WSC Hope gauge is preliminary for this period and was unavailable due to low flows/icing from the morning of March 5, to March 8, 2019. Updates to this analysis will be required once data from this gauge are finalized.

Table 6. Stage change at hydrometric gauges and SSMSs during February 28 and March 5, 2019 events (see also Figure 4).

Date	Site	Start Date Time	Discharge (m^3/s) Start	Discharge (m^3/s) End	Discharge (m^3/s) Change	Ramping Rate (cm/hr)	Total Stage Change (cm)
1-Mar-19	Facility	Feb-28 15:00	77.5	41.4	-36.1	n/a	n/a
	Seton Dam	Feb-28 15:00	3.05	12.7	9.65	n/a	n/a
	08MF005	Mar-01 05:25	640	627	-13.0	-1.1	-1.9
	Ferry Island	Mar-01 09:30				-0.5	-0.5
	FRS-DSSD01	Mar-01 09:34				-0.6	-0.6
	FRS-DSSD02	Mar-01 10:32				-1.0	-0.7
	FRS-DSSD03	Mar-01 11:04				-0.8	-0.5
	FRS-DSSD04	-				-	-
	FRS-DSSD05	-				-	-
	FRS-DSSD07	-				-	-
	FRS-DSSD08	n/a				n/a	n/a
5-Mar-19	Facility	Mar-04 16:00	37.9	0	-37.9	n/a	n/a
	Seton Dam	Mar-04 16:00	13.2	32.3	19.1	n/a	n/a
	08MF005[1]	n/a	n/a	n/a	n/a	n/a	n/a
	Ferry Island	Mar-05 09:50				-1.0	-1.1
	FRS-DSSD01	Mar-05 09:44				-3.1	-3.1
	FRS-DSSD02	n/a				n/a	n/a
	FRS-DSSD03	Mar-05 09:46				-2.4	-2.0
	FRS-DSSD04	-				-	-
	FRS-DSSD05	Mar-05 12:48				-0.8	-0.7
	FRS-DSSD07	-				-	-
	FRS-DSSD08	Mar-05 09:18				-3.2	-2.4

[1] WSC gauge data was unavailable at low flow and is preliminary and subject to change

"-" signifies event could not be identified at this site due to noise or a lack of identifiable response.

"n/a" signifies that data was unavailable at this site.

Figure 8. Facility, Seton Dam, and Fraser River discharge during February 28, 2019 shutdown.

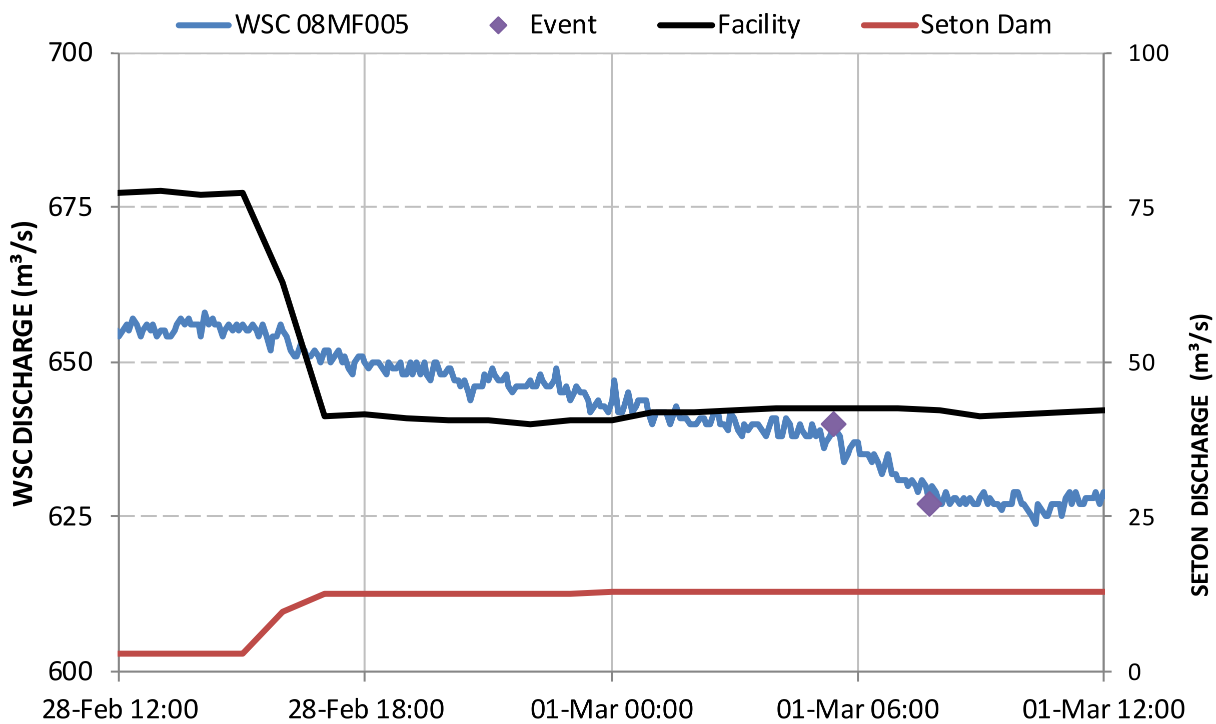


Figure 9. Ramping rates at SSMSs during February 28, 2019 Seton shutdown

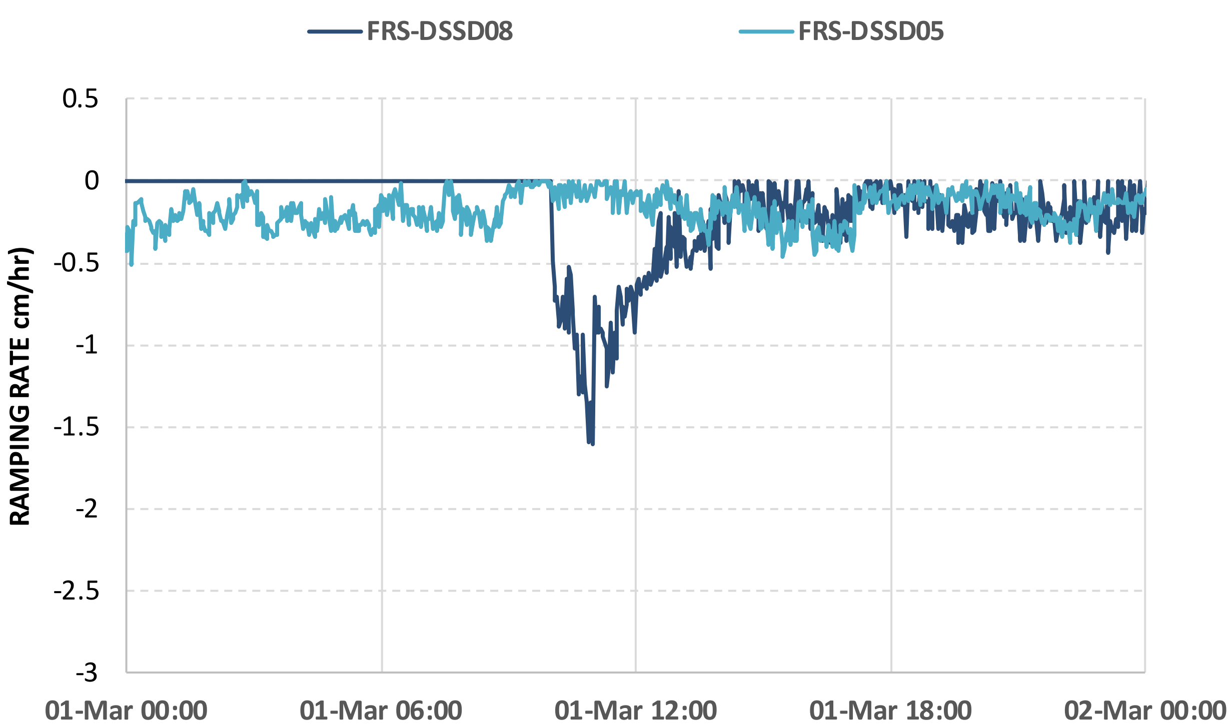


Figure 10. Facility, Seton Dam, and Fraser River discharge during March 4, 2019 shutdown. WSC discharge data were unavailable March 5 to March 8 2019.

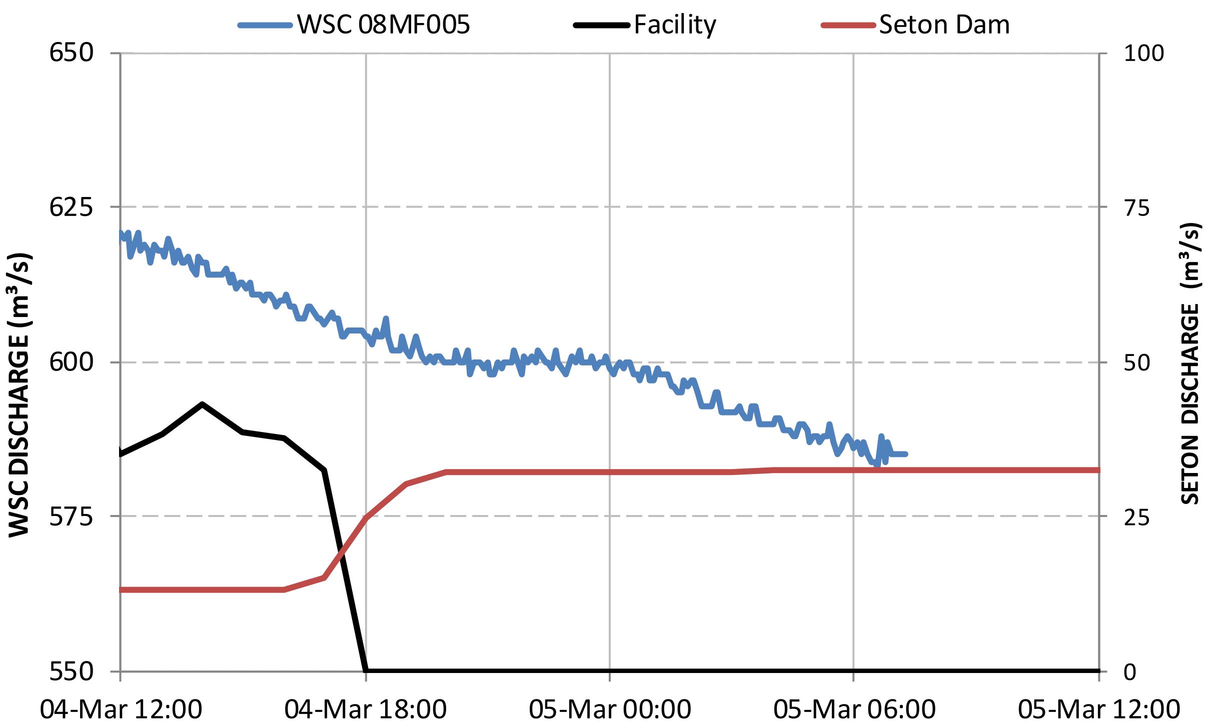
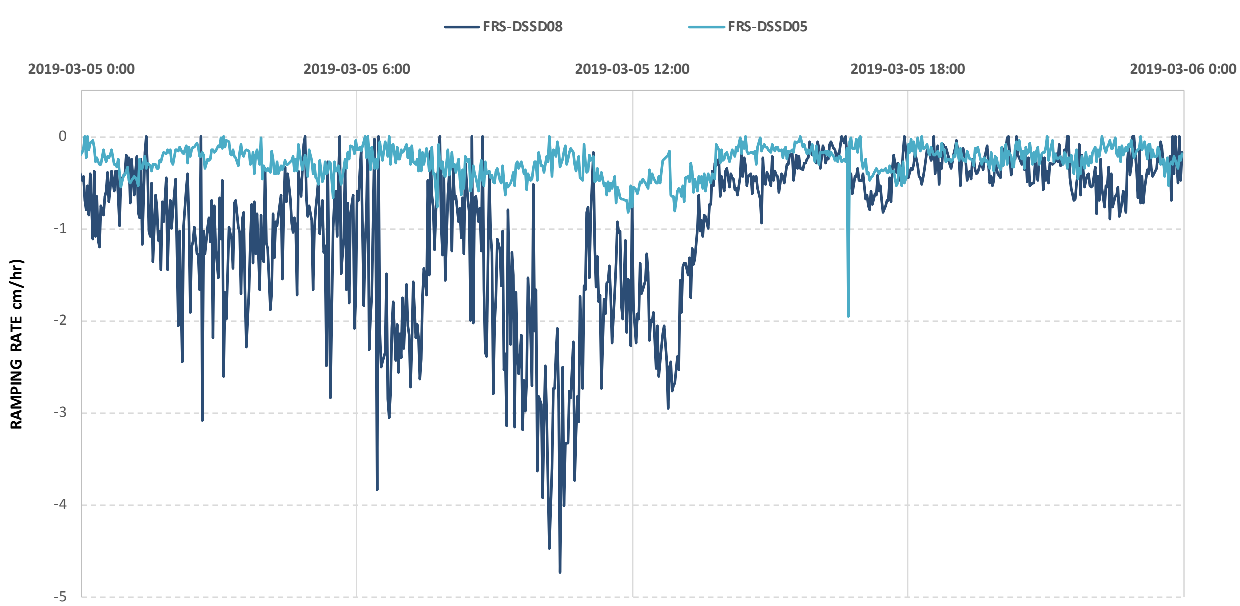


Figure 11. Ramping rates at SSMSs during March 4, 2019 Seton shutdown.



3.2. Redd Dewatering Risk Assessment Model

3.2.1. Natural Dewatering

Model outputs predict that under the stage change conditions at FRA-DSSD08, there is a naturally high level of egg dewatering for Pink Salmon (median 99%; 10%tile = 69%; 90%tile = 100%), but a relatively low level of egg dewatering of Chum Salmon (median 22%; 10%tile = 8%; 90%tile = 43%; Table 7). The model predictions under FRA-DSSD05 stage sensitivity scenario show lower but still high natural dewatering for Pink Salmon (median 84%; 10%tile = 35%; 90%tile = 97%) and lower natural dewatering predicted for Chum Salmon (median 7%; 10%tile = 2%; 90%tile = 22%; Table 8). These estimates are similar to those calculated in 2018 (Faulkner *et al.* 2018).

The natural dewatering estimates for Pink Salmon at FRA-DSSD08 appear unreasonably high, probably due to the unrealistic generic HSI curves used for Pink Salmon spawning, as described in Faulkner *et al.* (2018). Other factors affecting egg mortality caused by dewatering are the duration of dewatering and the developmental stage when dewatering occurs. These factors are not considered in our model. Further discussion on these limitations can be found in Faulkner *et al.* (2018).

A total of 54% of the Chum Salmon redds assessed were dewatered; however, the redd excavations that were conducted also did not result in the detection of eggs, alevins or pre-emerged fry. This provided support that alevins may have moved out of egg pockets or possibly emerged, as emerged Chum Salmon fry were also observed on March 2, 2019.

3.2.2. Shut-down Assessment

Model outputs predict that under the stage change conditions at FRA-DSSD08, there is an incremental dewatering for Pink Salmon eggs that ranges from 0 to 21% (median 0 to 10%; 10%tile 0%; 90%tile 0 to 21%), but a relatively lower level of incremental egg dewatering of Chum Salmon ranging from 0 to 9% (median 0 to 10%; 10%tile 0 to 8%; 90%tile 0 to 13%; Table 7; Figure 12). The model predictions under FRA-DSSD05 stage sensitivity scenario in general showed lower incremental dewatering for Pink Salmon (median 0 to 10%; 10%tile 0 to 2%; 90%tile 0 to 21%) and Chum Salmon (median 0 to 6%; 10%tile 0 to 8%; 90%tile 0 to 9%; Table 8; Figure 13) compared to the relationship at FRA-DSSD08. Total egg dewatering under these scenarios including natural and shutdown related dewatering are provided in Figure 13 and Figure 15 for context.

Using the data from high sensitivity site FRA-DSSD08, results of the modelling showed that following one-day shut-downs, no eggs of either species were incrementally dewatered during years of typical spawning flow, provided flows at the time of shut-down were approximately >850 m^3/s based on the relationship at FRA-DSSD08 and FRA-DSSD05 (Figure 12; Figure 14). However, in years when spawning flows were high, the eggs of both Pink Salmon and Chum Salmon were incrementally dewatered when flows at the time of shutdown were <1,050 m^3/s based on the relationship at FRA-DSSD08 and FRA-DSSD05. The flows at the time of shut-down cited here represent the middle of the 100 m^3/s flow bin used in the assessment, but can serve as close approximations of a flow threshold at Hope on the Fraser River below which egg dewatering is unlikely to occur. There is uncertainty in the actual amount of incremental dewatering predicted in this assessment, due to uncertainties in actual spawning depths and stage data at representative spawning locations (as discussed in Section 3.2.1). However, the thresholds indicate flows at which incremental mortality from shut-downs occurs.

Similar to the 2018 assessment the analysis of shut-downs of 1 to 8 weeks duration found total and incremental egg dewatering increases with the duration of the shut-down for FRA-DSSD08 (high sensitivity; Figure 16 and Figure 17) and FRA-DSSD05 (low sensitivity; Figure 18; and Figure 19) sites, which is due to the general trend of decreasing flows through the incubation period. For Pink Salmon, only shutdowns in November of 7 weeks and longer, December 4 weeks or longer, January 2 weeks or longer and February of 1 week or longer, resulted in dewatering above natural conditions with stage reductions at FRA-DSSD08. Based on stage reductions at FRA-DSSD05, for Pink Salmon, only shutdowns in November of 7 weeks and longer, December 3 weeks or longer, and January and February of 1 week or longer, resulted in dewatering above natural conditions. For Chum Salmon, only shutdowns in November of 6 weeks or longer, December of 3 weeks and longer and January and February of 1 week or longer, resulted in dewatering above natural conditions with stage reductions at FRA-DSSD08 and FRA-DSSD05.

Although we simulated conditions required to dewater eggs to make inferences on Facility shut-down effects, we did not specifically consider time or duration of dewatering that would be required to cause mortality of dewatered eggs as discussed in Faulkner *et al.* (2018). We emphasize that the simulations evaluated the frequency of egg pocket dewatering, but ignore effects on alevins that may have migrated up from the egg pocket prior to emergence. Data collected during 2019, although limited to 13 redds, suggested that alevins may not be present in redds by late February to early March, at least in redds in mainstem and large side channel habitat. If alevins move to deeper water the effect of shut-downs that occur late in incubation period may be less than predicted.

Overall, these results suggest that there may be an incremental risk of egg dewatering caused by Facility shut-down below a median flow of 850 m^3/s for both species and sensitivity scenarios similar to the 2018 assessment (Faulkner *et al.* 2018). Regardless of the uncertainties in this assessment, there is large natural annual flow variability. This natural annual flow variability makes determining the flow at which operational shut-downs will increase the risk to eggs difficult. This annual variability suggests that an annual approach to a target threshold may be appropriate; however, this would need to be combined with site-specific data on spawning depth and timing to determine an effective approach to protecting redds from dewatering.

During our assessment in 2019 we did not identify any egg/alevin dewatering or stranding during the shutdown that occurred over March 1 to 5, which was initiated when flows were below 700 m^3/s at the WSC Hope gauge. Preliminary flows at the WSC Hope gauge during this time ranged were below 640 m^3/s; however, the minimum flow is not available at this time due to potential icing effects at the gauge. Further assessment of these flow data may be required once finalized by WSC.

Table 7. Annual estimated spawning and incubation conditions in the Fraser River gravel reach along with estimated natural and potential Facility related stage changes and egg dewatering using FRA-DSSD08 stage sensitivity.

Year	Pink Salmon								Chum Salmon							
	Flow (m^3/s)		Stage (m)[2]			Incremental Stage Change (m)	Proportion Dewatering		Flow (m^3/s)		Stage (m)[2]			Incremental Stage Change (m)	Proportion Dewatering	
	Median Spawning	Minimum Natural[1]	Median Spawning	Minimum Natural	Stage Change		Natural	Incremental Range	Median Spawning	Minimum Natural[1]	Median Spawning	Minimum Natural	Stage Change		Natural	Incremental Range
1998	1,294	661	8.01	7.25	-0.76	-0.20 to 0.0	0.70	0.0 - 0.22	1,247	661	7.96	7.25	-0.71	-0.20 to 0.0	0.07	0.0 - 0.10
1999	1,846	710	8.47	7.33	-1.15	-0.19 to 0.0	0.99	0.0 - 0.01	1,642	710	8.32	7.33	-0.99	-0.19 to 0.0	0.22	0.0 - 0.10
2000	1,982	533	8.57	7.04	-1.53	-0.24 to 0.0	1.00	0.0 - 0.00	1,817	533	8.45	7.04	-1.41	-0.24 to 0.0	0.46	0.0 - 0.13
2001	1,617	567	8.29	7.10	-1.20	-0.23 to 0.0	0.99	0.0 - 0.01	1,469	567	8.17	7.10	-1.07	-0.23 to 0.0	0.26	0.0 - 0.13
2002	2,577	551	8.95	7.07	-1.88	-0.23 to 0.0	1.00	0.0 - 0.00	1,272	551	7.99	7.07	-0.92	-0.23 to 0.0	0.18	0.0 - 0.13
2003	1,485	617	8.18	7.18	-1.00	-0.21 to 0.0	0.95	0.0 - 0.05	1,620	617	8.30	7.18	-1.12	-0.21 to 0.0	0.29	0.0 - 0.12
2004	2,573	823	8.95	7.48	-1.47	-0.17 to 0.0	1.00	0.0 - 0.00	2,361	823	8.82	7.48	-1.34	-0.17 to 0.0	0.41	0.0 - 0.08
2005	1,948	749	8.55	7.38	-1.17	-0.18 to 0.0	0.99	0.0 - 0.01	2,096	749	8.65	7.38	-1.27	-0.18 to 0.0	0.38	0.0 - 0.10
2006	1,176	615	7.89	7.18	-0.71	-0.21 to 0.0	0.64	0.0 - 0.26	1,195	615	7.91	7.18	-0.73	-0.21 to 0.0	0.08	0.0 - 0.12
2007	2,106	743	8.66	7.37	-1.29	-0.18 to 0.0	1.00	0.0 - 0.00	2,592	743	8.96	7.37	-1.59	-0.18 to 0.0	0.55	0.0 - 0.10
2008	1,699	743	8.36	7.37	-0.99	-0.18 to 0.0	0.94	0.0 - 0.05	1,697	743	8.36	7.37	-0.99	-0.18 to 0.0	0.22	0.0 - 0.10
2009	1,520	784	8.21	7.43	-0.78	-0.17 to 0.0	0.74	0.0 - 0.18	1,523	784	8.22	7.43	-0.79	-0.17 to 0.0	0.11	0.0 - 0.10
2010	1,969	742	8.56	7.37	-1.19	-0.18 to 0.0	0.99	0.0 - 0.01	1,532	742	8.22	7.37	-0.85	-0.18 to 0.0	0.14	0.0 - 0.10
2011	2,387	880	8.84	7.56	-1.28	-0.16 to 0.0	1.00	0.0 - 0.00	1,563	880	8.25	7.56	-0.69	-0.16 to 0.0	0.06	0.0 - 0.08
2012	1,633	826	8.31	7.49	-0.82	-0.17 to 0.0	0.79	0.0 - 0.15	1,638	826	8.31	7.49	-0.82	-0.17 to 0.0	0.13	0.0 - 0.09
2013	1,873	652	8.49	7.24	-1.26	-0.20 to 0.0	1.00	0.0 - 0.00	1,320	652	8.03	7.24	-0.80	-0.20 to 0.0	0.11	0.0 - 0.11
2014	1,924	1,245	8.53	7.96	-0.57	-0.12 to 0.0	0.38	0.0 - 0.21	2,404	1,245	8.85	7.96	-0.89	-0.12 to 0.0	0.16	0.0 - 0.07
2015	2,168	819	8.70	7.48	-1.22	-0.17 to 0.0	0.99	0.0 - 0.01	1,861	819	8.48	7.48	-1.01	-0.17 to 0.0	0.23	0.0 - 0.09
2016	2,206	865	8.72	7.54	-1.19	-0.16 to 0.0	0.99	0.0 - 0.01	2,489	865	8.90	7.54	-1.36	-0.16 to 0.0	0.43	0.0 - 0.09
Median	1,924	743	8.53	7.37	-1.19	-0.18 to 0.0	0.99	0.0 - 0.01	1,638	743	8.31	7.37	-0.99	-0.18 to 0.0	0.22	0.0 - 0.10
10%tile	1,446	564	8.15	7.09	-1.48	-0.23 to 0.0	0.69	0.0 - 0.00	1,267	564	7.98	7.09	-1.37	-0.23 to 0.0	0.08	0.0 - 0.08
90%tile	2,424	868	8.86	7.54	-0.75	-0.16 to 0.0	1.00	0.0 - 0.21	2,421	868	8.86	7.54	-0.73	-0.16 to 0.0	0.43	0.0 - 0.13

[1] Minimum natural flow during incubation includes January - April of the following year

[2] Stage at FRA-DSSD08 is arbitrary stage

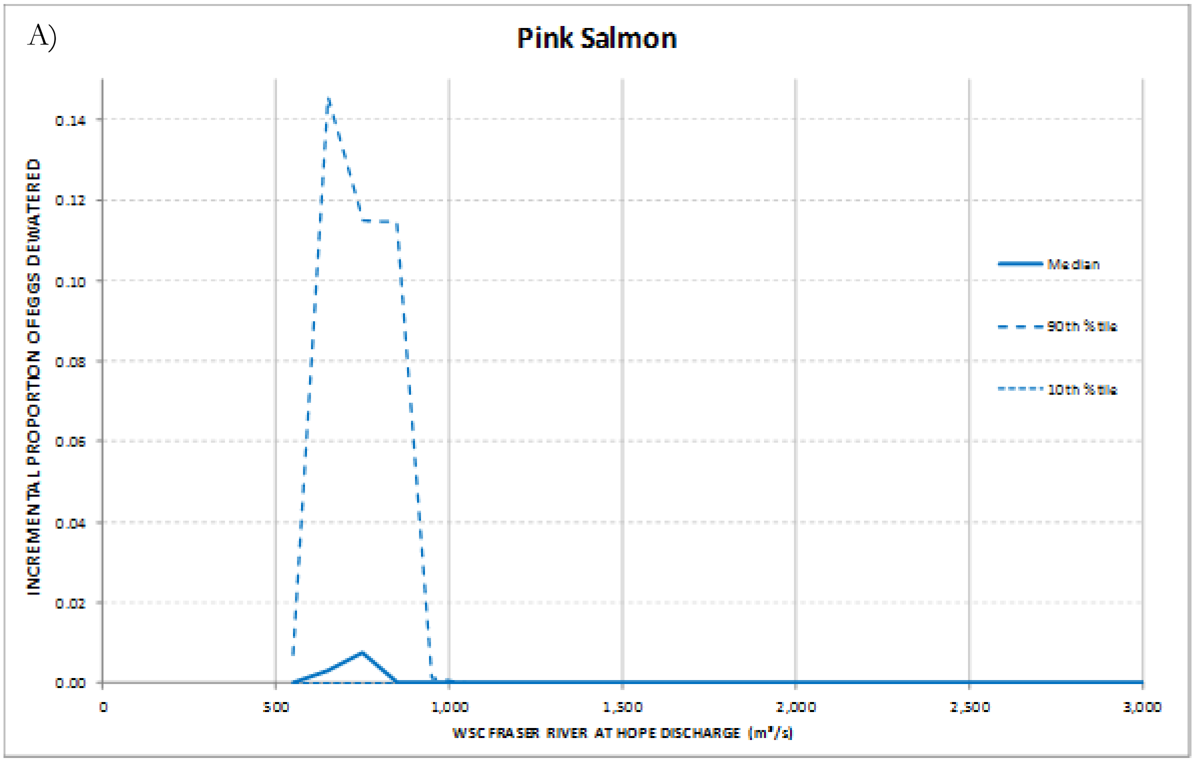
Table 8. Annual estimated spawning and incubation conditions in the Fraser River gravel reach along with estimated natural and potential Facility related stage changes and egg dewatering using FRA-DSSD05 stage sensitivity.

Year	Pink Salmon									Chum Salmon									
	Flow (m^3/s)		Stage (m)[2]			Incremental Stage Change (m)	Proportion Dewatering		Flow (m^3/s)		Stage (m)[2]			Incremental Stage Change (m)	Proportion Dewatering	
	Median Spawning	Minimum Natural[1]	Median Spawning	Minimum Natural	Stage Change		Natural	Incremental Range	Median Spawning	Minimum Natural[1]	Median Spawning	Minimum Natural	Stage Change		Natural	Incremental Range
1998	1,294	661	9.54	9.18	-0.36	-0.10 to 0.0	0.36	0.0 - 0.24	1,247	661	9.52	9.18	-0.34	-0.10 to 0.0	0.01	0.0 - 0.04
1999	1,846	710	9.77	9.21	-0.55	-0.09 to 0.0	0.81	0.0 - 0.12	1,642	710	9.69	9.21	-0.48	-0.09 to 0.0	0.07	0.0 - 0.07
2000	1,982	533	9.81	9.08	-0.74	-0.11 to 0.0	0.98	0.0 - 0.02	1,817	533	9.76	9.08	-0.68	-0.11 to 0.0	0.24	0.0 - 0.10
2001	1,617	567	9.68	9.11	-0.58	-0.11 to 0.0	0.85	0.0 - 0.11	1,469	567	9.62	9.11	-0.52	-0.11 to 0.0	0.10	0.0 - 0.09
2002	2,577	551	10.00	9.09	-0.91	-0.11 to 0.0	1.00	0.0 - 0.00	1,272	551	9.53	9.09	-0.44	-0.11 to 0.0	0.05	0.0 - 0.08
2003	1,485	617	9.63	9.15	-0.48	-0.10 to 0.0	0.66	0.0 - 0.21	1,620	617	9.68	9.15	-0.54	-0.10 to 0.0	0.12	0.0 - 0.08
2004	2,573	823	10.00	9.29	-0.71	-0.08 to 0.0	0.97	0.0 - 0.02	2,361	823	9.94	9.29	-0.64	-0.08 to 0.0	0.21	0.0 - 0.06
2005	1,948	749	9.80	9.24	-0.56	-0.09 to 0.0	0.83	0.0 - 0.10	2,096	749	9.85	9.24	-0.61	-0.09 to 0.0	0.18	0.0 - 0.07
2006	1,176	615	9.49	9.14	-0.34	-0.10 to 0.0	0.31	0.0 - 0.26	1,195	615	9.50	9.14	-0.35	-0.10 to 0.0	0.02	0.0 - 0.05
2007	2,106	743	9.86	9.24	-0.62	-0.09 to 0.0	0.90	0.0 - 0.07	2,592	743	10.00	9.24	-0.76	-0.09 to 0.0	0.31	0.0 - 0.07
2008	1,699	743	9.71	9.24	-0.47	-0.09 to 0.0	0.64	0.0 - 0.20	1,697	743	9.71	9.24	-0.47	-0.09 to 0.0	0.07	0.0 - 0.07
2009	1,520	784	9.64	9.27	-0.38	-0.08 to 0.0	0.39	0.0 - 0.21	1,523	784	9.64	9.27	-0.38	-0.08 to 0.0	0.02	0.0 - 0.04
2010	1,969	742	9.81	9.24	-0.57	-0.09 to 0.0	0.85	0.0 - 0.09	1,532	742	9.65	9.24	-0.41	-0.09 to 0.0	0.04	0.0 - 0.05
2011	2,387	880	9.94	9.33	-0.62	-0.08 to 0.0	0.90	0.0 - 0.06	1,563	880	9.66	9.33	-0.33	-0.08 to 0.0	0.01	0.0 - 0.03
2012	1,633	826	9.69	9.29	-0.39	-0.08 to 0.0	0.43	0.0 - 0.21	1,638	826	9.69	9.29	-0.40	-0.08 to 0.0	0.03	0.0 - 0.04
2013	1,873	652	9.78	9.17	-0.60	-0.10 to 0.0	0.89	0.0 - 0.08	1,320	652	9.56	9.17	-0.38	-0.10 to 0.0	0.03	0.0 - 0.05
2014	1,924	1,245	9.79	9.52	-0.27	-0.06 to 0.0	0.13	0.0 - 0.14	2,404	1,245	9.95	9.52	-0.43	-0.06 to 0.0	0.05	0.0 - 0.04
2015	2,168	819	9.88	9.29	-0.59	-0.08 to 0.0	0.87	0.0 - 0.08	1,861	819	9.77	9.29	-0.48	-0.08 to 0.0	0.08	0.0 - 0.06
2016	2,206	865	9.89	9.32	-0.57	-0.08 to 0.0	0.84	0.0 - 0.09	2,489	865	9.97	9.32	-0.66	-0.08 to 0.0	0.22	0.0 - 0.07
Median	1,924	743	9.79	9.24	-0.57	-0.09 to 0.0	0.84	0.0 - 0.10	1,638	743	9.69	9.24	-0.47	-0.09 to 0.0	0.07	0.0 - 0.06
10%tile	1,446	564	9.61	9.10	-0.71	-0.11 to 0.0	0.35	0.0 - 0.02	1,267	564	9.53	9.10	-0.66	-0.11 to 0.0	0.02	0.0 - 0.04
90%tile	2,424	868	9.95	9.32	-0.36	-0.08 to 0.0	0.97	0.0 - 0.21	2,421	868	9.95	9.32	-0.35	-0.08 to 0.0	0.22	0.0 - 0.09

[1] Minimum natural flow during incubation includes January - April of the following year

[2] Stage at FRA-DSSD05 is arbitrary stage

Figure 12. Estimated incremental proportion of eggs dewatered following a one-day Facility shut-down at different Fraser River event start discharges (x-axis) for A) Pink Salmon and B) Chum Salmon using FRA-DSSD08 stage sensitivity.



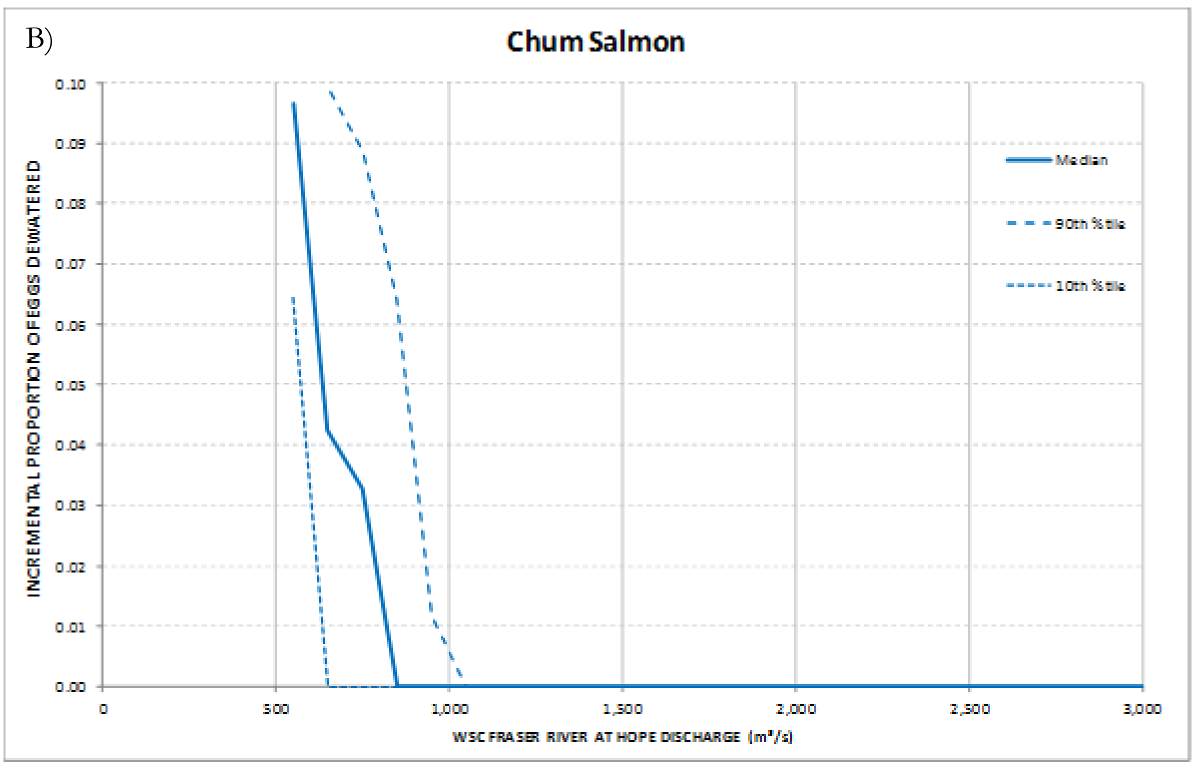
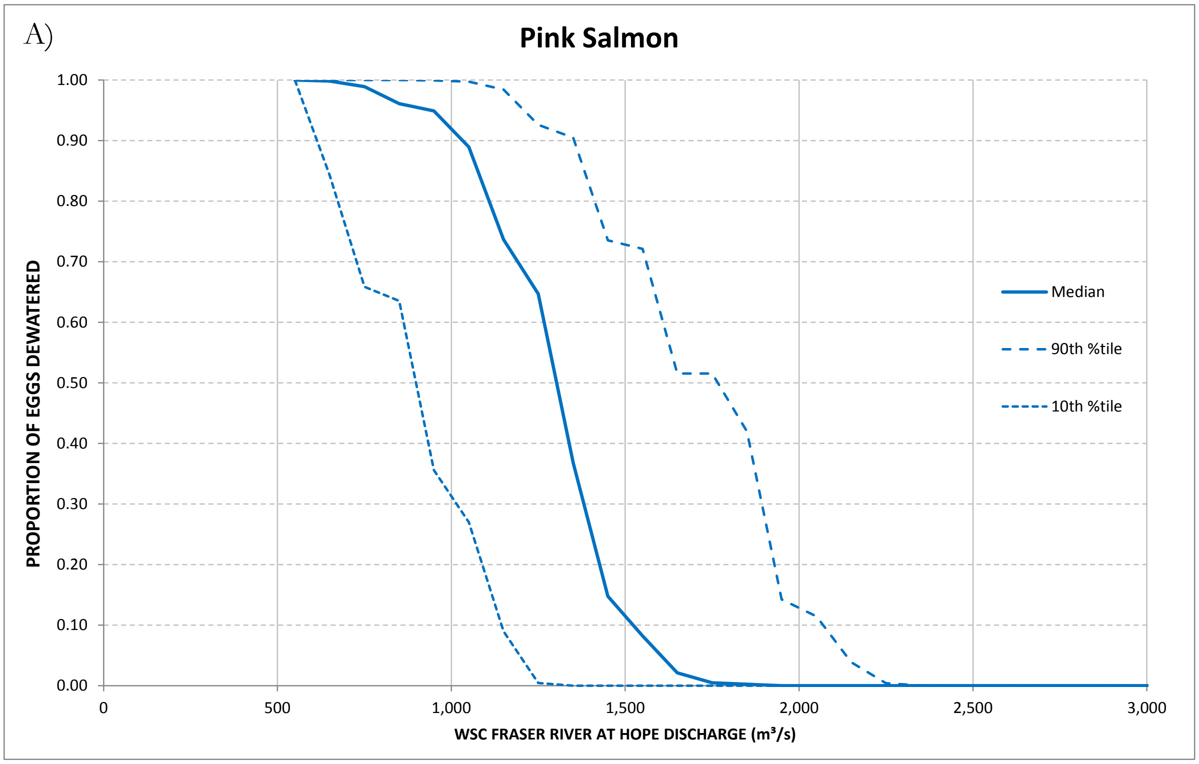


Figure 13. Estimated total proportion of eggs dewatered following a one-day Facility shut-down at different Fraser River event start discharges (x-axis) for A) Pink Salmon and B) Chum Salmon using FRA-DSSD08 stage sensitivity.



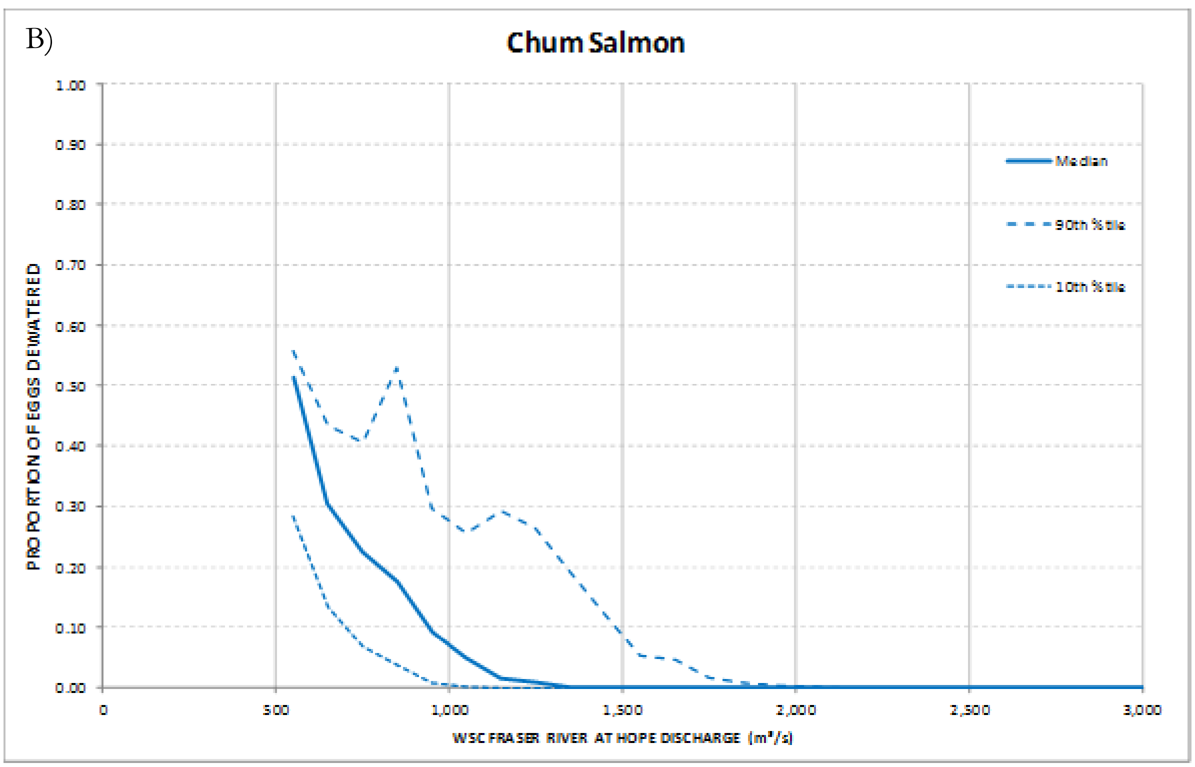
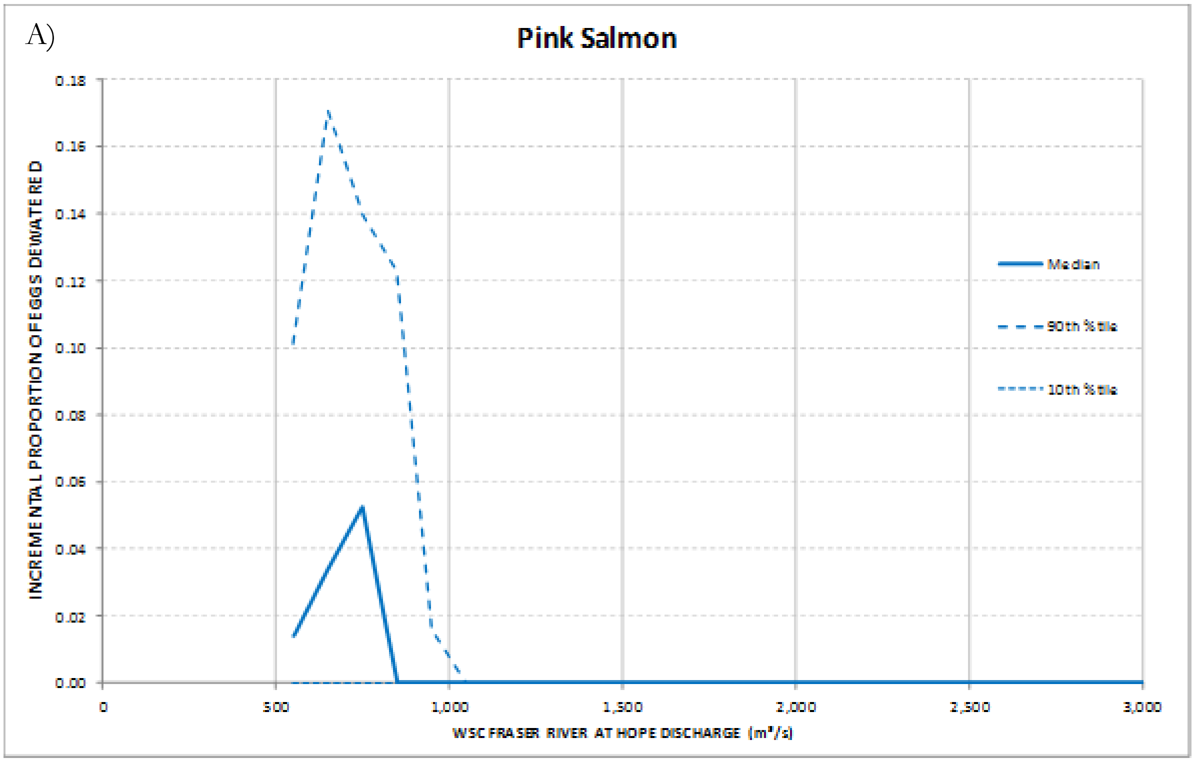


Figure 14. Estimated incremental proportion of eggs dewatered following a one-day Facility shut-down under different Fraser River event start discharges (x-axis) for A) Pink Salmon and B) Chum Salmon using FRA-DSSD05 stage sensitivity.



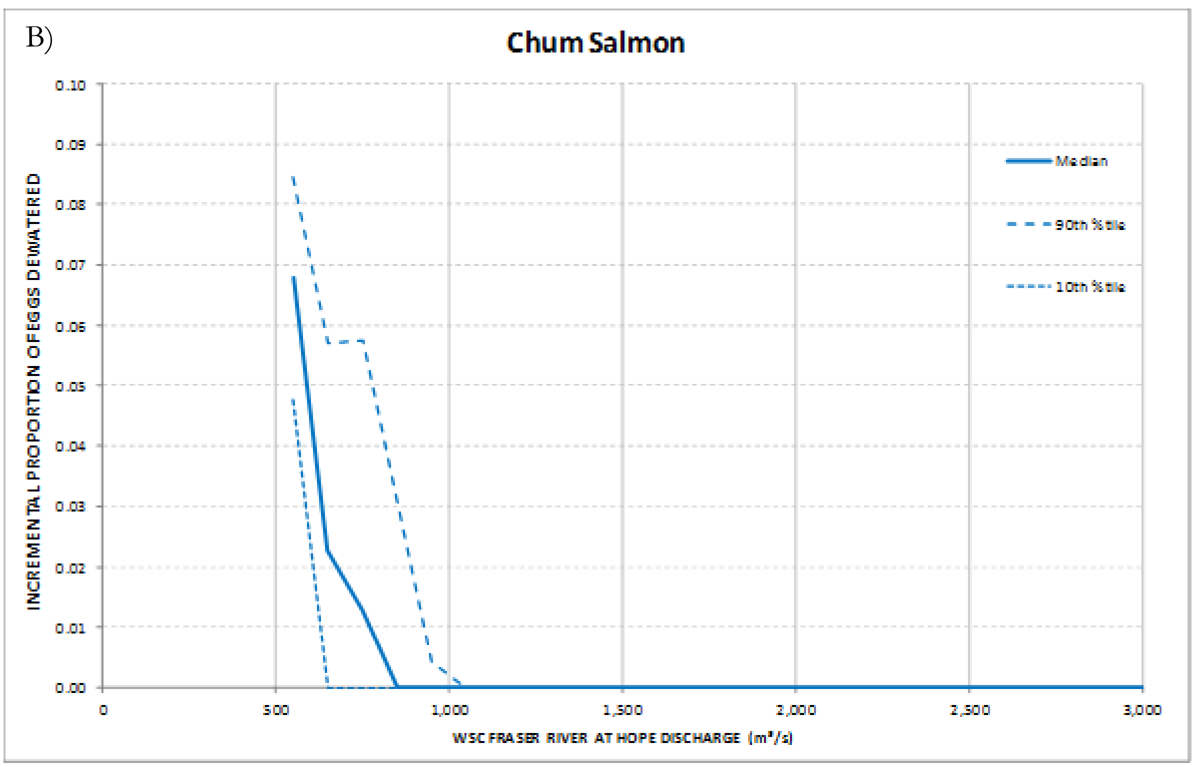
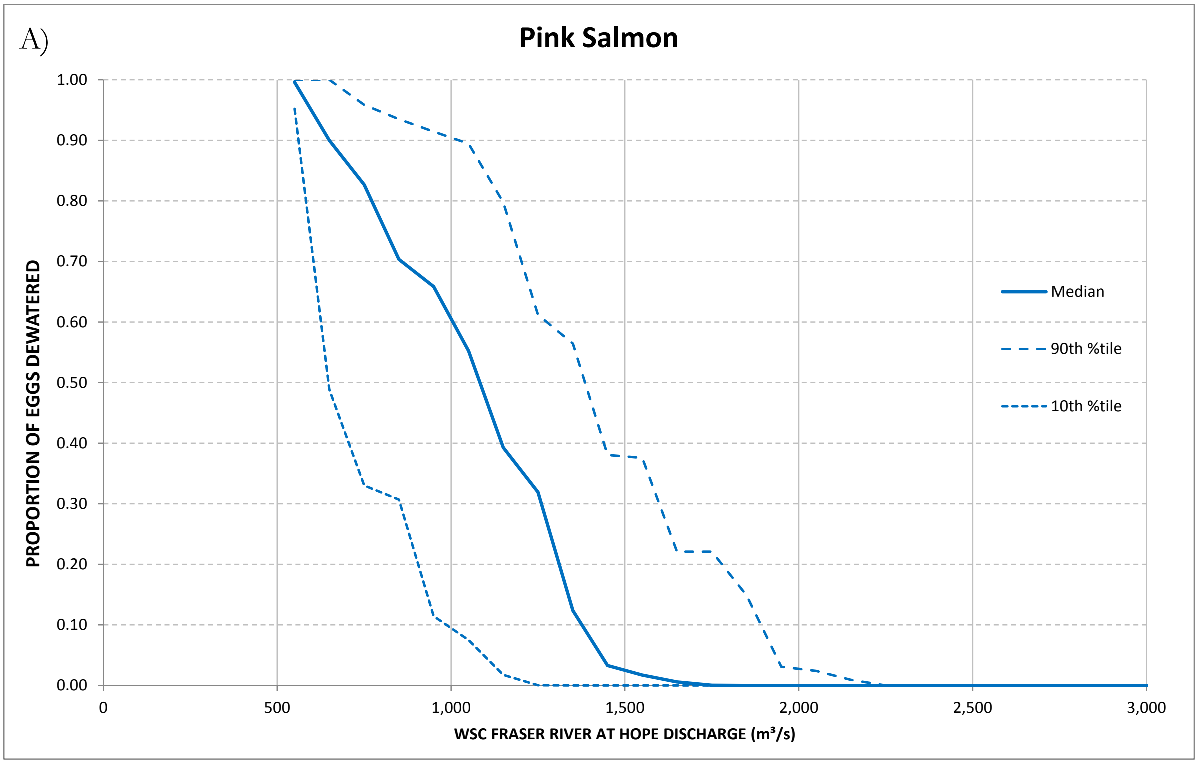


Figure 15. Estimated total proportion of eggs dewatered following a one-day Facility shut-down under different Fraser River event start discharges (x-axis) for A) Pink Salmon and B) Chum Salmon using FRA-DSSD05 stage sensitivity.



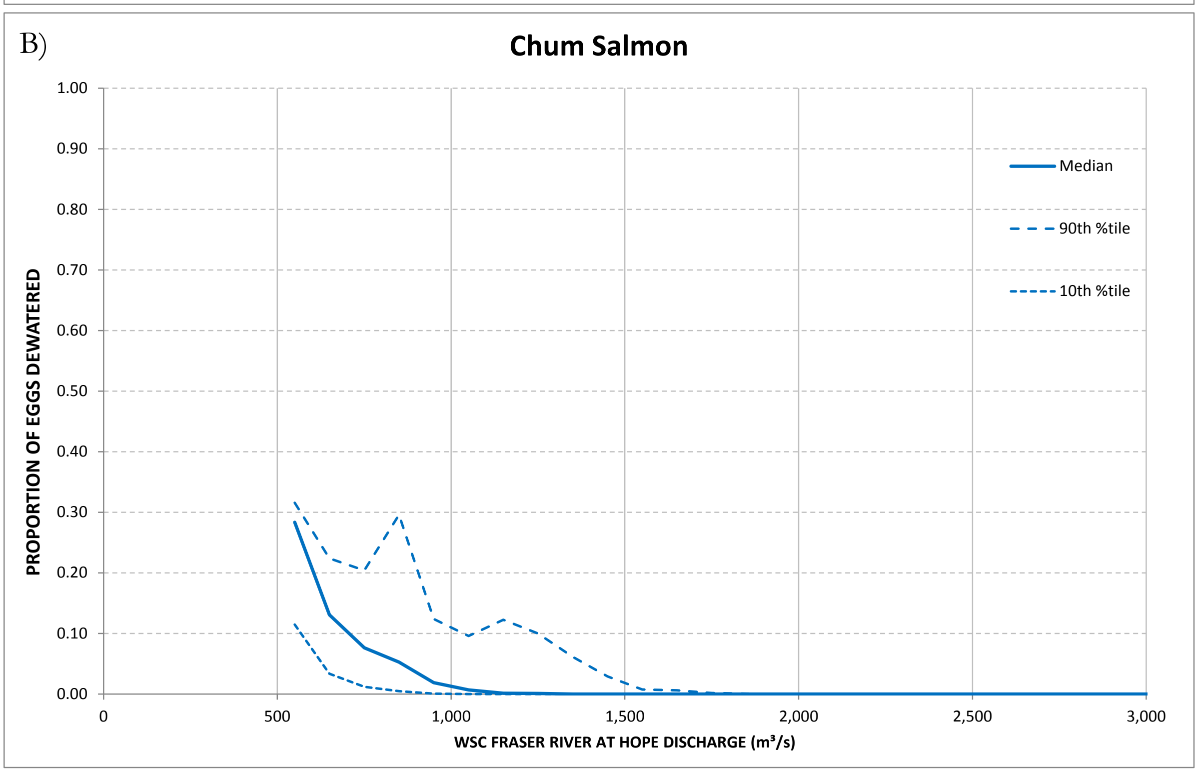
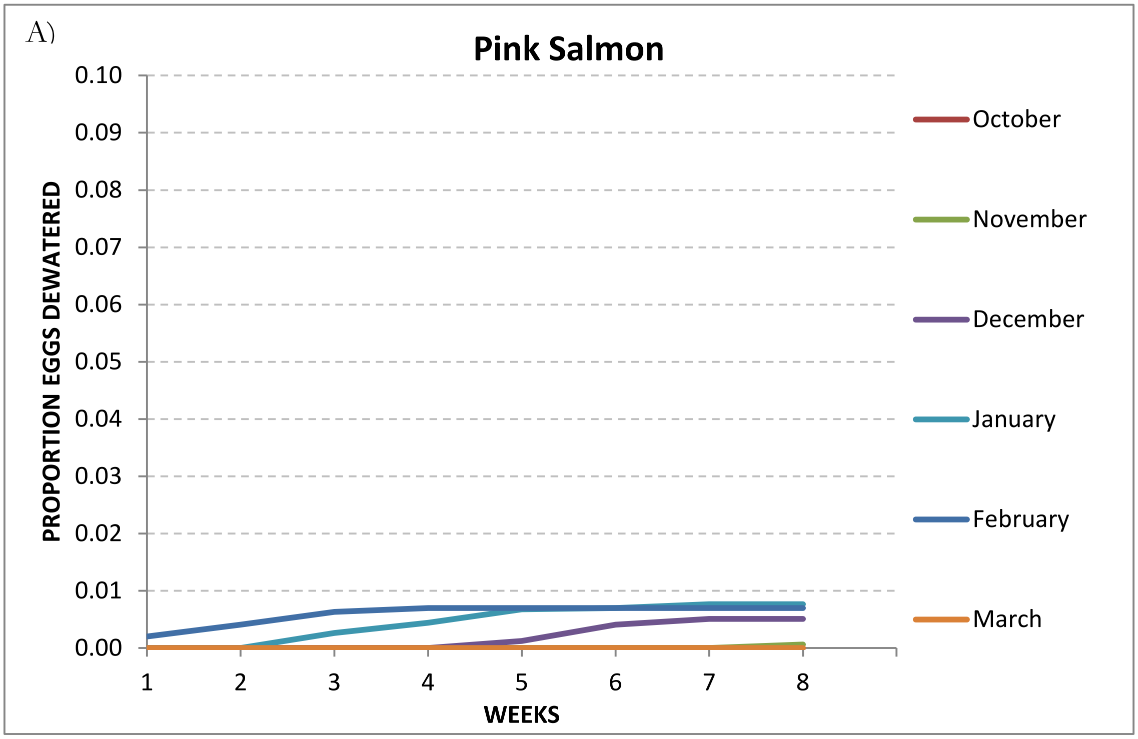


Figure 16. **Estimated median proportion of incremental eggs dewatered following Facility shut-downs of durations of 1 to 8 weeks by shut-down month and median of the yearly maximum incremental difference for A) Pink Salmon and B) Chum Salmon using FRA-DSSD08 stage sensitivity.**



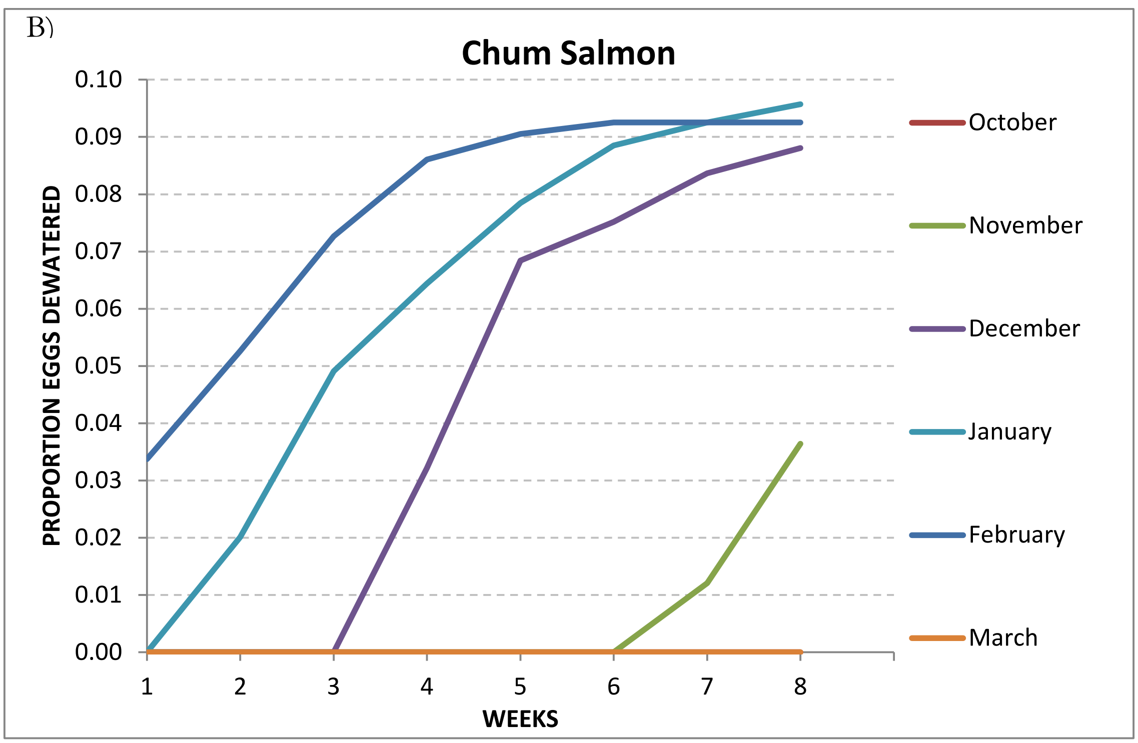
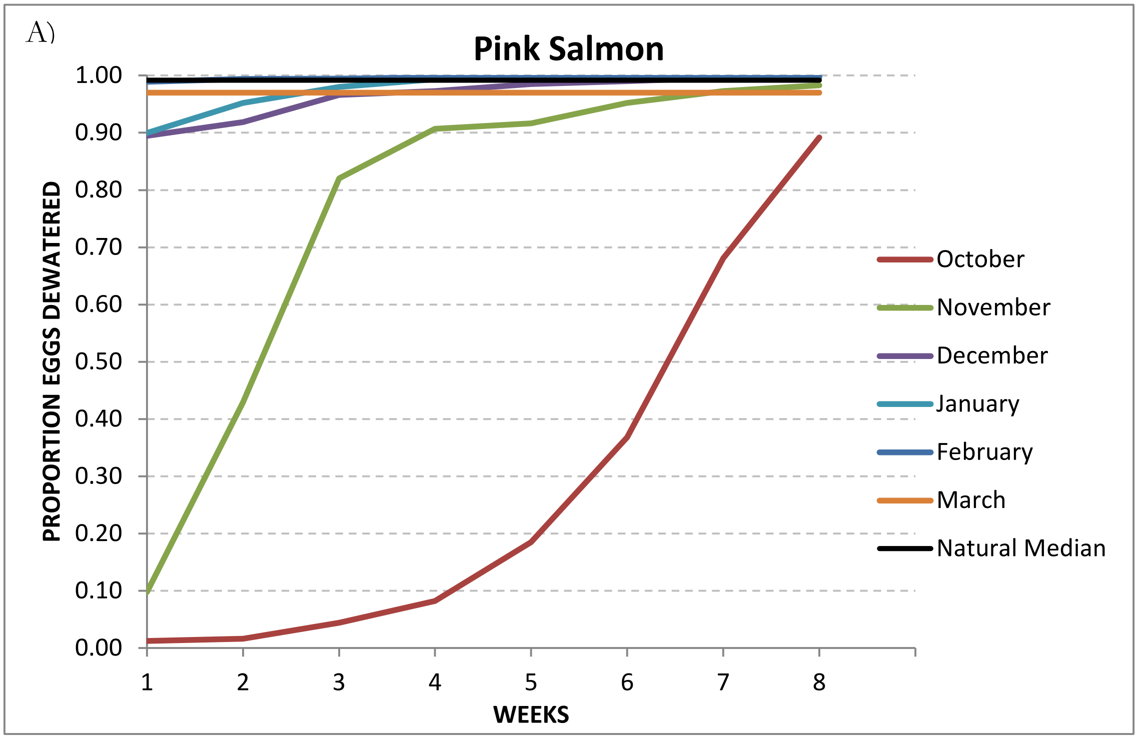


Figure 17. Estimated median proportion of total eggs dewatered following Facility shut-downs of durations of 1 to 8 weeks by shut-down month and median of the yearly maximum incremental difference for A) Pink Salmon and B) Chum Salmon using FRA-DSSD08 stage sensitivity.



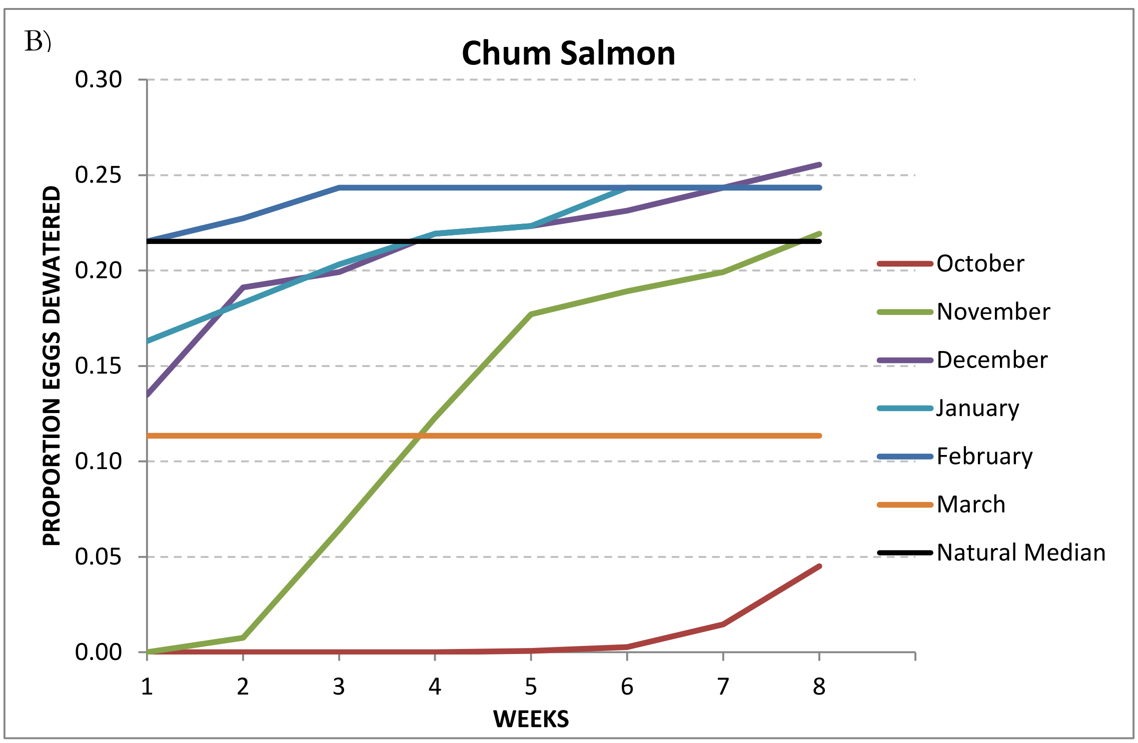


Figure 18. **Estimated median proportion of incremental eggs dewatered following Facility shut-downs of durations of 1 to 8 weeks by shut-down month and median of the yearly maximum incremental difference for A) Pink Salmon and B) Chum Salmon using FRA-DSSD05 stage sensitivity.**

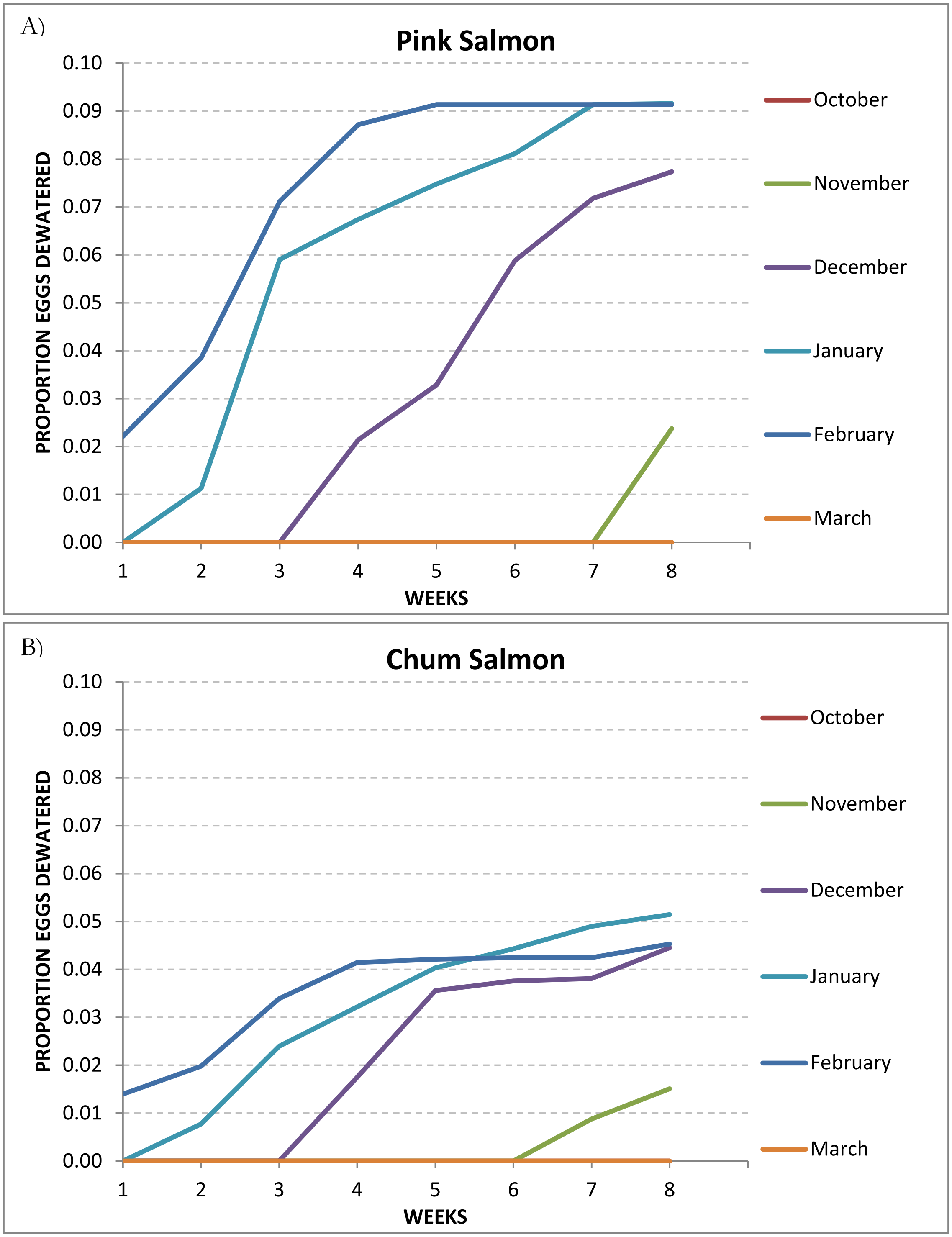
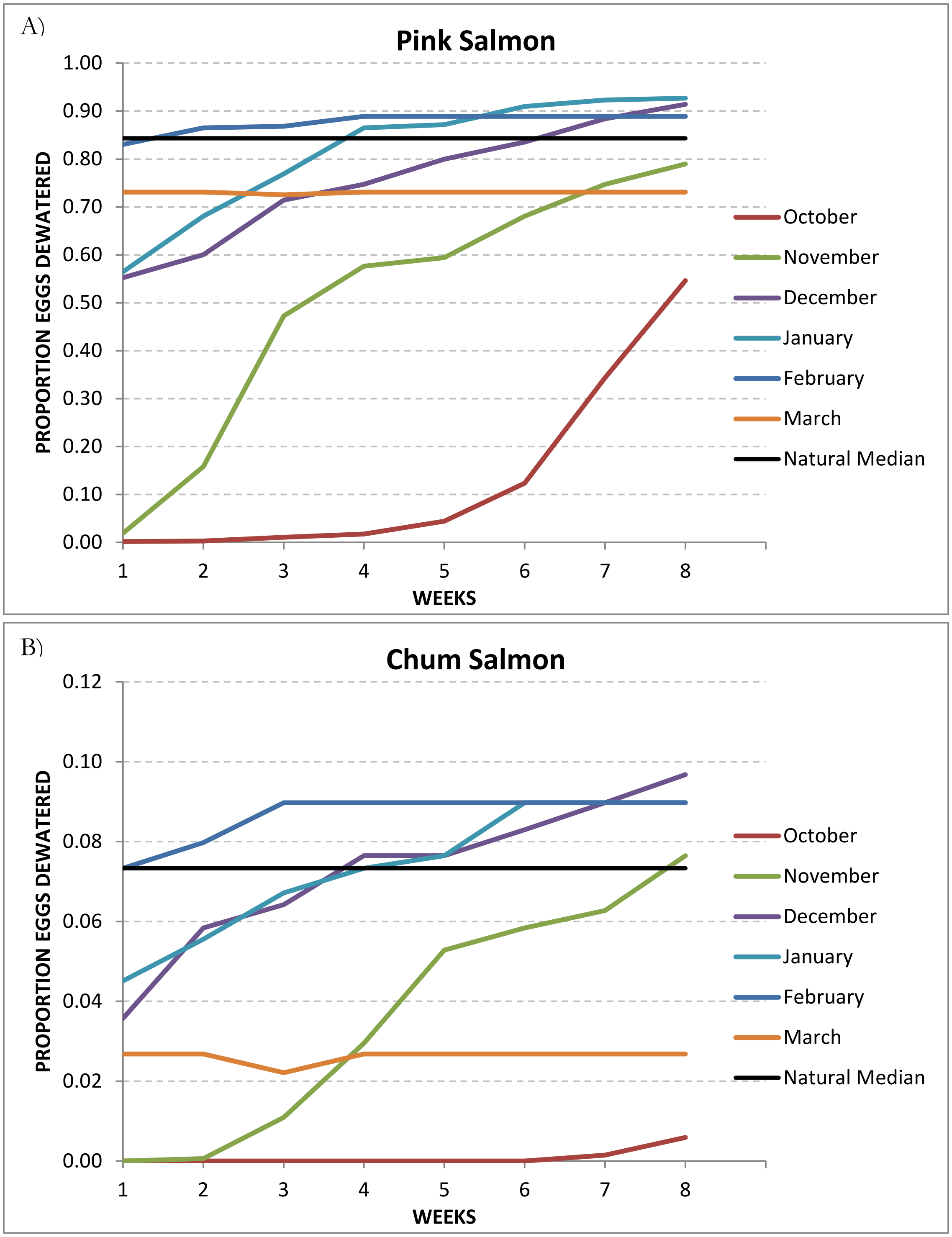


Figure 19. Estimated median proportion of total eggs dewatered following Facility shut-downs of durations of 1 to 8 weeks by shut-down month and median of the yearly maximum incremental difference for A) Pink Salmon and B) Chum Salmon using FRA-DSSD05 stage sensitivity.



4. RECOMMENDATIONS

Recommendations are presented for collection of additional data to help address uncertainties associated with potential egg dewatering resulting from Facility shut-downs:

- Because no Chum Salmon egg/alevins were found during the redd surveys, we recommend conducting additional surveys in 2019/2020 to better understand distribution of alevins within egg pocket of the redd and to determine the emergence time for Chum Salmon. These data would be used to integrate life stage into the stranding assessment.
- This study was conducted in an even year, therefore Pink Salmon redds were not present. We recommend conducting additional surveys in 2020 to study these parameters for Pink Salmon. The proportion of Pink Salmon egg dewatering is unrealistically high, and is expected to be improved with site specific data.
- Additional work is recommended to account for backwatered and smaller side channels that were inaccessible due to icing during the 2019 assessment, to allow a better overall assessment of dewatering risk throughout spawning habitat in the braided reach.
- Additional redd information should be collected during 2019/2020 spawning season with a focus on deeper habitat and may require snorkeling to ensure potential redds in deeper water are assessed, if present to allow more accurate estimating of spawning depth preferences.
- Additional water temperature data should be collected within redds to compare to water temperature data at Ferry Island and multiple years of water temperature data for Ferry Island should be analyzed in order to account for annual variability in the developmental rate of eggs, to allow better estimation of hatch dates and emergence times. These data can be correlated with redd observations to allow life stage presence, timing and habitat use to be incorporated into the assessment.

5. CLOSURE

The additional field data collected during February to April of 2019 allowed for updates to the desktop-based model used in 2018 (Faulkner *et al.* 2018). In specific, improvements were made with using site specific stage discharge relationships and confirming appropriateness of the Chum Salmon HSI curve employed. Similar to the previous assessment, this assessment found that a Fraser River discharge of 850 m^3/s at the WSC Hope gauge would avoid dewatering in years where the differences between spawning and incubation flows were typical, but that values varied among years. This report provides an interim update with additional field studies planned for the 2019/2020 spawning season to further inform the model and recommendations for this additional data collection are also provided.

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PROJECT MAPS

FRASER RIVER RISK ASSESSMENT

Stranding Sensitive Monitoring Sites

Legend

- Stranding Sensitive Monitoring Sites
- Ferry Island Stage Monitoring Site
- Water Survey of Canada Gauge (08MF005)
- Gravel Reach

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 1 2 4 6 8 Km

Scale: 1:150,000

NO.	DATE	REVISION	BY
1	17/07/2019	1349_FRA_SSMS_3329_20190717	[illegible]
2			
3			
4			
5			

Date Saved: 17/07/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 2

Path: M:\Projects-Active\1349\MXD\1349_FRA_SSMS_3329_20190717.mxd