Campbell River Project Water Use Plan

JHTMON-15 Elk Canyon Smolt and Spawner Abundance Assessment

Implementation Year 5

Reference: JHTMON-15

JHTMON-15 Year 5 Monitoring Report

Study Period: 2018-2019

Laich-Kwil-Tach Environmental Assessment Ltd. Partnership and Ecofish Research Ltd.

March 13, 2020

JHTMON-15: Smolt and Spawner Abundance Assessment

Year 5 Annual Monitoring Report

Prepared for:

BC Hydro Water License Requirements
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EXECUTIVE SUMMARY

The Elk Canyon on the lower Campbell River is used by seven salmonid species for at least part of their life history. The Campbell River Water Use Plan (WUP) prescribed a flow regime with the intent of maximizing fish habitat in Elk Canyon, including:

1) A minimum base flow of 4 m^3/s;
2) 2-day pulse flows of 10 m^3/s every two weeks in spring (February 15 to March 15) as an attraction flow, primarily for spawning Steelhead;
3) A two-week minimum spawning flow of 7 m^3/s (April 1-15); and
4) 2-day pulse flows of 7 m^3/s every week in the fall (September 15 to November 15) as an attraction flow for all fall spawners that could potentially use this reach.

There remains uncertainty over the extent to which fish use of the canyon by juveniles and spawners is affected by the implemented flow regime. The *Elk Canyon Smolt and Spawner Abundance Assessment* (JHTMON-15) is designed to assess the extent to which fish production is driven by flow in Elk Canyon and how this relates to BC Hydro operations.

JHTMON-15 is scheduled for 10 years from 2014 to 2024 and is to be carried out as a series of interconnected parts, each focused on addressing a specific hypothesis and with different durations over the course of the monitor. Two of the main sampling techniques to be employed in the monitor are snorkel swim counts of spawning adults and rearing juveniles, and rotary screw trap (RST) enumerations of out-migrating fry and smolts. This report presents Year 5 of monitoring in Elk Canyon, which includes the third year of the smolt enumeration component and the fifth year of the fall and spring spawning enumeration and overwintering assessments. Year 5 is also the final year of the fall and spring pulse flow assessments and the Steelhead spawning flow assessment.

A broad diversity of fish species, including all BC coast salmonids, were observed using Elk Canyon for spawning and/or rearing during the fifth year of sampling (2018-2019) of the JHTMON-15 program. Although many of these species occur in low abundance, this corroborates the same findings in Year 1 to Year 4 of sampling, indicating that habitats in Elk Canyon are used by a diversity of salmon and trout. This includes the key species Chinook Salmon, Coho Salmon and Steelhead.

Instream Flow Study

An instream flow study (IFS) was conducted to test how the carrying capacity of the habitat in Elk Canyon varies with flow and addresses hypotheses H_01, H_06, H_07, and H_08 of the TOR. The IFS fieldwork was completed in 2017 and includes a Fish Habitat Assessment Procedure, habitat suitability criteria validation, empirical habitat modelling, and habitat simulation modelling at different flows. This study has been prepared as an independent report and was submitted to BCH in August 2018 (Healey *et al.* 2018). Overall, IFS results suggest that habitat carrying capacity of Elk Canyon does vary as a function of discharge and that the prescribed flow regime has increased habitat available to salmon compared to pre-WUP conditions.

Smolt Enumeration

The smolt enumeration component of JHTMON-15 uses an RST to monitor fry and smolt outmigration from Elk Canyon to assess if the carrying capacity of Elk Canyon is affected by the magnitude of base flows (e.g., 4 m^3/s) provided in the flow prescription (hypothesis H_01):

> H_01: Carrying capacity of the Elk Canyon reach, as measured by annual smolt out-migrant counts, does not vary as a function of discharge.

Smolt enumeration is to be undertaken each year of JHTMON-15 with synthesis analyses planned for Year 6 and Year 10 to address H_01.

In Year 5, the RST operated for a total effort of approximately 130 days or 3,110 hours between March 1, 2019 to July 11, 2019. In total, 18,167 fish were captured in the RST in 2019. Similar to previous years, catches in 2019 were primarily composed of Chum Salmon (73.1%), Chinook Salmon (17.5%), and Coho Salmon (4.6%). Steelhead/Rainbow Trout and Sockeye Salmon represented 0.4% and 0.04% of the catch, respectively. The combined catch of all salmonids (17,690 fish) accounted for 97.4% of the total catch while the catch of the key target species of Chinook Salmon, Coho Salmon, and Steelhead/Rainbow Trout (4,081 fish) accounted for 22.5% of the total catch.

Total salmonid outmigration by species was estimated by standardizing the RST catch by the capture efficiency of the RST, which was determined from mark recapture experiments. As in Year 2 and 3, Chum Salmon outmigration was the highest of all salmonid species, with an estimated total outmigration of 149,399 fry. Coho Salmon total outmigration was estimated to be 8,339 fry and 296 age 0+ smolts, and 13 age 1+ smolts. Chinook Salmon total outmigration was estimated to be 32,031 fry and 975 age 0+ smolts. Steelhead/Rainbow Trout outmigration was estimated to be 11 age 0+ fry, 16 age 1+ parr, 100 age 2+ parr, and 89 3+ smolts. Pink Salmon and Sockeye Salmon total outmigration was estimated at 3,512 and 93 fry, respectively. Overall, outmigration estimates in 2019 were similar to 2016 values but generally higher than 2017. It is likely that the low outmigration estimates in 2017 result from the large spill event between November 4 and 24, 2016, which may have scoured out many of the redds within Elk Canyon.

Outmigration timing information by life stage is evident within and across species from the RST data. Similar to previous years, all of the Chinook Salmon that were caught in the RST are likely to be 0+ fish based on scale age analysis. This indicates that they are exclusively 'ocean type', meaning that they rear for only a few months in freshwater and then migrate to the estuary to continue rearing. Two peaks in Chinook outmigration were observed, an early peak in March of Chinook fry that may rear downstream in the Campbell River system, and a later peak in June of larger individuals that have reared for a few months in Elk Canyon. A small number of these larger fish may have originated from the Quinsam Hatchery similar to what was observed in Year 3 (~3%).

Two primary Coho Salmon life stages were observed including an early migration of Coho fry in March and April, and a later migration of larger 0+ Coho smolts from May through July. In addition, three 1+ Coho Salmon smolts and one 2+ smolt were observed in Year 5 compared to zero ≥1+ observed in Year 3.

Five age classes of Steelhead/Rainbow Trout were identified in the RST catch, including 0+, 1+, 2+, 3+, and >3+ fish. The majority of captured Steelhead/Rainbow Trout were 2+ (~48%) (148-199 mm) and 3+ (~42%) (200-256 mm), which were captured between April and June and peaked between early May and early June. Steelhead/Rainbow Trout 0+ (≤80 mm), 1+ (85-146 mm), and adult >3+ individuals (>257 mm) made up small proportions of RST captures (~2%, ~8%, and ~1% respectively). Steelhead/Rainbow Trout 0+ and 1+ did not have a clear peak in outmigration timing, suggesting that catches of these age classes represented more localized movements rather than outmigration.

Overwintering Assessment

The overwintering assessment component of JHTMON-15 is designed to test if juvenile fish rear for their entire life history in Elk Canyon or if a portion of the population consists of immigrant juveniles ($H_0$2):

> $H_0$2: The number of rearing residents deemed likely to smolt the following spring, as measured during late summer, is not significantly different from the abundance estimate obtained in late winter just prior to the onset of their out-migration.

This was the final year of overwintering assessment data collection. Night snorkeling mark/re-sight methods were used to estimate Steelhead/Rainbow Trout and Coho Salmon parr densities in fall and in early spring, which were then compared to determine the extent of parr overwintering in Elk Canyon. A synthesis analysis was also completed across all four years of data collection (Year 2, 3, 4, and 5) to address Management Question #1 and $H_0$2 of the TOR as no further overwintering assessment fieldwork is planned in future years.

Across all four years of overwintering assessment data collection, the effect of season on the density of Steelhead/Rainbow Trout was not significant, i.e., the 95% credible intervals of the mean posterior estimate of the parameter encompasses zero. Average Steelhead/Rainbow Trout density was 10.8 fish/100m^2 (SE: 1.4 fish/100m^2) in the fall and 10.2 fish/100m^2 (SE: 1.2 fish/100m^2) in the early spring prior to outmigration. The number of rearing residents deemed likely to smolt the following spring, as measured during September, is not significantly different from the abundance estimate obtained in February prior to the onset of their outmigration. Therefore, we conclude that Steelhead/Rainbow Trout overwinter in Elk Canyon, and the hypothesis $H_0$2 is retained for Steelhead/Rainbow Trout parr.

Coho Salmon juveniles were observed during fall surveys in all four years of the monitoring program. Across all sites, estimates of Coho Salmon density in the fall ranged from 3 to 45 fish/100 m^2. Mean Coho Salmon density was 23.6 fish/100 m^2 during fall 2016 and 11 fish/100 m^2 during fall 2017. Coho density could not be calculated for fall 2015 or 2018 as no marked fish were observed during the re-sight swim. In comparison, in the spring, three Coho Salmon were observed during the 2016 spring survey, 0 were observed in 2017 and 2018, and five were observed during the 2019 spring survey. The low abundance of Coho Salmon parr in the spring surveys of 2016 and 2019 coupled with their absence in 2017 and 2018 indicate that very few Coho Salmon overwinter in Elk Canyon. We therefore reject $H_0$2 for Coho Salmon parr.

Fall and Spring Pulse Flow Assessment

Part of the flow prescription for Elk Canyon is to provide 2-day pulse flows of 7 m^3/s every week in the fall (September 15 to November 15) and 2-day pulse flows of 10 m^3/s every two weeks in the spring (February 15 to March 15) as an attraction flow primarily for spawning salmonids. Hypotheses $H_0$3, $H_0$4, and $H_0$5 were developed to test the effectiveness of these pulse flows in attracting spawning salmonids and attracting and retaining Steelhead in Elk Canyon. Hypothesis $H_0$4 is not testable using the current sampling method of snorkel surveys immediately prior to and after the pulse flows.

Year 5 is the final year of pulse flow assessment surveys to address $H_0$3 and $H_0$5:

> $H_0$3: The rate of spawning salmonid in-migration (No./day) during the 2-day pulse flow release operation is not significantly different from that during the base flow operation.
>
> $H_0$5: The estimated number of spawning salmonids following pulse flow release operation is not significantly different from that just prior to the release.

No strong evidence was found to indicate that the fall or spring pulse flows are attracting salmon into Elk Canyon across all three years of data collection (2015, 2016, and 2018 for fall spawners; spring 2016, 2017, and 2019 for Steelhead). The abundance of all fall spawners in Elk Canyon measured using snorkel surveys pre- and post pulses, did not differ the day after the 2-day 7 m^3/s fall pulse release compared to the day prior the pulse release. This means that the null hypothesis $H_0$5 is retained for all fall spawning species including Coho Salmon, Chinook Salmon and Chum Salmon. The rate of fall spawning salmonid in-migration per day also did not differ between periods of pulse flows and periods of base flows for all fall spawners, which retains $H_0$3 for Coho Salmon, Chinook Salmon and Chum Salmon. These results were confirmed in a supplemental analysis where only counts during the buildup to peak abundance were considered.

The count of Steelhead in Elk Canyon in the spring was similar the day after the 2-day 10 m^3/s spring pulse releases compared to the day prior to the pulse releases, which retains $H_0$5 for Steelhead. The rate of Steelhead in-migration per day was significantly higher during the base flow than during the pulse flow, which is a rejection of $H_0$3 for Steelhead but is opposite to the hypothesized effect direction. The magnitude of this increase in Steelhead during base flows was small (0.4 fish/day higher during base flows).

Overall, we conclude that there is no current evidence to suggest that pulse flows are attracting key salmonids into Elk Canyon, including Coho Salmon, Chinook Salmon, Chum Salmon and Steelhead.

Steelhead Spawning Flow Assessment

The flow prescription for Elk Canyon also includes a two-week 7 m^3/s spring spawning flow (April 1-15) aimed at increasing available spawning habitat for Steelhead. Hypotheses $H_0 6$, $H_0 7$, and $H_0 8$ were developed to test the effectiveness of the spawning flow at increasing the numbers of spring spawners, as well as available Steelhead spawning habitat:

> $H_0 6$: The estimated number of spawning Steelhead during the two-week, 7 m^3/s spawning release period in spring is not significantly different from that observed just prior to the operation.
>
> $H_0 7$: The number of redds found above the base flow water level (minus a nominal depth to take into account that Steelhead will not spawn in very shallow water, e.g., 10 cm) following the two-week spawning release is not considered significantly different when compared to the total number of redds in the reach.
>
> $H_0 8$: Following resumption of base flow operations, the number of Steelhead redds found above the water line and therefore, at risk of egg mortality from stranding, is not considered significant compared to the total number of redds in the reach.

Using snorkel survey methodology, the abundance of Steelhead in Elk Canyon was found to be not significantly different prior to the two-week spawning flow release than during the release across all three years of data collection (2016, 2017, 2019), which retains null hypothesis $H_0 6$. In contrast, habitat modeling from the IFS predicts that more Steelhead spawning habitat is available at 7 m^3/s (96-97% of maximum) compared to 4 m^3/s (69-71% of maximum) (Healey *et al.* 2018). These combined results suggest that another factor (such as marine conditions) may be limiting Steelhead populations in Elk Canyon than spawning habitat.

A total of 5 Steelhead redds were observed during 2019 spring surveys, while none were observed in 2016 or 2017. Redds were first observed during the 7 m^3/s spawning flows and all redds remained wetted when flows returned to base flows (4 m^3/s). The IFS results highlight that at 7 m^3/s, 96-97% of the available Steelhead spawning habitat is predicted to be present, and that 97-99% of that habitat is predicted to remain wetted once flows return to base flows at 4 m^3/s.

Overall, we conclude that few Steelhead spawn in Elk Canyon and that current data suggest that Steelhead abundance is not affected by 7 m^3/s spawning flows in Elk Canyon, which retains the null hypothesis $H_0 6$. Observational and habitat modeling results also suggest that the majority of redds (97-99%) will remain wetted at 4 m^3/s, which retains the null hypotheses of $H_0 7$ and $H_0 8$.

Fall and Spring Spawner Enumeration

Spawner counts in both fall and spring are to be conducted annually for the full JHTMON-15 program. Area under the curve (AUC) estimates of abundance are calculated each year to determine spawner abundance in Elk Canyon. Redd counts are also performed and compared to annual outputs of fry and smolts estimated from RST catch. After 10 years of data collection estimates of spawner abundance are compared to smolt enumeration data to test if the annual abundance of 'resident' smolts is correlated with spawner abundance (H_09):

> H_09: Annual abundance of 'resident' smolts is not correlated with an index of Steelhead spawner abundance.

This is a final check to make sure that the assumption of 'full seeding' needed to test Hypothesis H_01 is satisfied.

Snorkel surveys and area under the curve methods were used to estimate the abundance of Chinook, Coho, Pink, Chum, and Sockeye Salmon fall spawners in Elk Canyon in fall 2018. Chinook and Coho Salmon adult abundance were estimated to be 103 and 1,083 individuals, respectively. Pink Salmon had the highest estimated abundance of 1,432 individuals. A population of 672 Chum Salmon and 273 Sockeye Salmon were also estimated. Few Steelhead were observed in fall with a peak observed abundance of only seven individuals.

As in previous years, the peak spawning time was variable across salmon species. Pink and Sockeye Salmon had the earliest peaks, with observed spawner counts peaking in late September and late September and early October respectively. The peak was not as clear for Sockeye Salmon as other species. Chinook Salmon had a peak in mid-October. Chum and Coho Salmon had the latest peak in spawning in late October/early November. A maximum of seven Steelhead were observed in mid-September.

Chinook, Chum, Coho, Pink and Sockeye Salmon redds were counted during fall spawning surveys, and the estimated fry and smolt production from these redds was compared to the estimated outmigration from the RST data. Chum, followed by Sockeye Salmon had the highest numbers of redds at 42 and 30 redds, respectively, while a maximum of 10 Chinook Salmon redds, 20 Pink Salmon redds, and 12 Coho Salmon redds were observed. Pink and Coho Salmon predictions for juvenile production based on redd counts were similar to outmigration estimates from the RST, while Chum, Chinook and Sockeye Salmon estimates diverged. These differences could be attributed to multiple factors, including redd superimposition, where redds constructed from early spawners such as Sockeye Salmon are superimposed by later spawners. For Chum Salmon and Chinook Salmon, the results suggest that redd counts may have been underestimated, and/or that egg-to-fry survival was high. For example, even if redd counts for Chum Salmon have been underestimated by a half, the production of Chum Salmon fry from the RST suggests that egg-to-fry survival for Chum Salmon was high (>25%) in winter 2018-2019.

The following represents a summary of considerations for Year 6.

Smolt enumeration component:

1. The RST is an effective method to inventory juvenile salmonids (fry and smolts) that are migrating out of Elk Canyon and provides valuable life history information. In Year 5, the mark-recapture experiments included wild Chinook and Chum fry in addition to Quinsam

hatchery Chinook fry and smolts. These experiments with wild fry will continue if sufficient catches are observed in Year 6.

2. In the mark-recapture experiments, most wild fry releases were marked with Bismarck Brown. All hatchery Chinook fish used were clearly marked with a unique fin clip (adipose, ventral, or caudal fin) to help distinguish them from wild fish. This is recommended to continue in Year 6.
3. Based on the catch results of the target fish species, it remains appropriate for the RST sampling period to remain open until the end of July to ensure that the Coho and Chinook Salmon outmigration periods are captured.

Overwintering assessment component:

1. Year 5 was the fourth and final year that overwintering assessments were conducted. Night snorkeling mark/resight methods worked well again in Year 5 and were successful in addressing H_02 of the TOR for Steelhead/Rainbow Trout and Coho Salmon. A summary analysis was completed which showed that average Steelhead/Rainbow Trout parr abundance is not significantly different both fall and early spring seasons. This suggests that the majority of the population of Steelhead/Rainbow Trout is resident in the canyon during the winter months with little immigration or emigration during this period. Coho Salmon were observed during the fall in Elk Canyon, with only a few observed during the spring mark/resight swims. These low numbers of observed Coho Salmon parr match the observations from the RST, in which only three 1+ Coho Salmon smolts were captured from Elk Canyon in spring 2019. Overwintering assessments will not be completed in subsequent years.

Pulse flow assessment component:

1. Year 5 was the third and final year that pulse flow assessments were conducted. Snorkel surveys were successful in addressing H_03 and H_05 of the TOR, and results were similar to those in Years 2 and 3. A synthesis analysis across years was conducted which showed the pulses did not affect the counts or migration rates of any of the species considered (Steelhead, Chinook, Coho, Chum). There is no evidence to indicate that the pulses are effective at attracting fish.

Steelhead spawning flow component:

1. Year 5 was the third year that spawning flow assessments were conducted. Snorkel surveys were successful in testing H_06, H_07, and H_08 of the TOR. A total of 5 Steelhead redds were observed in 2019 during the 7 m^3/s spawning flow that remained wetted at 4 m^3/s. Redds were not deposited in the additional habitat created by the increase in water level/flow. Mean Steelhead abundance was higher during pre-spawning flows than during spawning flows, although this effect was small and statistically not significant. There is no evidence to suggest that maintaining spring spawning flows attract Steelhead into Elk Canyon.

Spawner enumeration component:

1. Adult Steelhead and Chinook, Chum, Coho, Pink and Sockeye Salmon and were all observed in Elk Canyon; Chinook, Chum, Coho, Pink and Sockeye redds were also counted. Year 5 was the third year that estimates of production derived from RST catches were compared to estimates of production predicted from redd counts by species. This was a useful component of the analysis, which showed that egg-to-fry survival for Chum and Chinook Salmon was high in 2018-2019.

JHTMON-15 Objectives, Management Questions, Hypotheses and Status after Year 5.

Study Objective	Management Questions	Management Hypotheses	Year 5 Status
The main objective of JTHMON-15 is to assess the extent to which fish production is driven by flow in Elk Canyon and how this relates to BC Hydro operations. The fish technical committee designed the following flow prescription: 1) Provide a minimum base flow of 4 m^3/s; 2) Provide two-day pulse flows of 10 m^3/s every two weeks in spring (Feb 15 to Mar 15) as an attraction flow primarily for spawning Steelhead; 3) Provide a two-week spawning minimum flow of 7 m^3/s starting April 1-15; and, 4) Provide two-day pulse flows of 7 m^3/s every week in the fall	**MQ 1.** Is the prescribed 4 m^3/s base flow sufficient to increase juvenile rearing habitat to near maximum values? If not, by how much should the base release increase (or decrease) and what would be the expected gain in habitat area?	$H_0 1$: Carrying capacity of the Elk Canyon reach, as measured by annual smolt out-migrant counts, does not vary as a function of discharge. $H_0 2$: The number of rearing residents deemed likely to smolt the following spring, as measured during late summer, is not significantly different from the abundance estimate obtained in late winter just prior to the onset of their outmigration. $H_0 9$: Annual abundance of 'resident' smolts is not correlated with an index of Steelhead spawner abundance.	Management question #1 and associated hypotheses are being addressed through several project components: a) an instream flow study (IFS), b) smolt enumeration, c) fall spawner abundance, d) spring spawner abundance, and e) juvenile overwintering assessment. The IFS was completed in Year 3 and Year 4 to determine the amount of habitat available to salmon at different flows (Healey *et al.* 2018). Results suggest that habitat carrying capacity of Elk Canyon does vary as a function of discharge, which is a rejection of $H_0 1$. A summary analysis for the overwintering assessment was completed in Year 5 confirming $H_0 2$ for Steelhead/Rainbow Trout and rejecting $H_0 2$ for Coho Salmon. Steelhead/Rainbow Trout overwinter in Elk Canyon with little immigration or emigration

Study Objective	Management Questions	Management Hypotheses	Year 5 Status
(Sept 15 to Nov 15) as an attraction flow for all fall spawners. JTHMON-15 consists of a series of interconnected parts designed to test how the flow prescription affects salmon productivity in Elk Canyon.			between the fall and early spring period. In contrast, very few Coho Salmon overwinter in Elk Canyon. The remaining components (b, c, and d) are being conducted each year to determine fish productivity of Elk Canyon. Year 5 results confirm that we are on track to address $H_0$1 and $H_0$9. A synthesis analysis for the first five years of JHTMON-15 will be conducted after Year 6 of sampling.
	MQ 2. Does the 2-day 10 m^3/s pulse release every two weeks trigger the upstream migration of spring spawners as expected? If not, is this the result of inadequate pulse magnitude, duration or some combination of both attributes? Or conversely, is the pulse attraction release unnecessary?	$H_0$3: The rate of spawning salmonid in-migration (No./day) during the 2-day pulse flow release operation is not significantly different from that during the base flow operation. $H_0$4: The rate of spawning salmonid in-migration (No./day) during the first day of the pulse flow release operation is not significantly different from that during the second day. $H_0$5: The estimated number of spawning salmonids following pulse flow release	Management question #2 and associated hypotheses were addressed through the spring pulse flow assessment component. Based on a synthesis analysis in Year 5, there is no evidence that the 10 m^3/s pulse flows are attracting Steelhead into Elk Canyon. The count of Steelhead in Elk Canyon in the spring was not significantly different the day after the 2-day 10 m^3/s spring pulse releases compared to the day prior to the pulse releases, which retains $H_0$5. The rate of Steelhead in-migration per day was significantly higher during the base flow than during the pulse flow, which is a rejection of $H_0$3

Study Objective	Management Questions	Management Hypotheses	Year 5 Status
		operation is not significantly different from that just prior to the release.	but is opposite to the hypothesized effect direction. Because the WUP pulse flow prescription does not vary in magnitude or duration, we will be unable to determine if upstream migration of spring spawners would be improved if an alternate flow pulse prescription is used. Hypothesis $H_0 4$ is not testable using the current sampling method of snorkel surveys immediately prior to and after the pulse flows.
	MQ 3. Is the two-week long 7 m³/s spawning flow effective at increasing available spawning habitat for spring spawners? If not, by how much should the spawning release increase (or decrease) and what would be the expected gain in habitat area?	$H_0 6$: The estimated number of spawning steelhead during the two-week, 7 m³/s spawning release period in spring is not significantly different from that observed just prior to the operation.	Management question #3 and associated hypothesis are being addressed through: a) the IFS, and b) the Steelhead spawning flow assessment. The IFS was completed in Year 3 and Year 4 to determine the amount of habitat available to salmon at different flows (Healey *et al.* 2018). The IFS predicts that more Steelhead spawning habitat is available at 7 m³/s (96-97% of maximum) compared to 4 m³/s (69-71% of maximum). Using snorkel survey methodology, the abundance of Steelhead in Elk Canyon was found to be not

Study Objective	Management Questions	Management Hypotheses	Year 5 Status
			significantly different prior to the two-week spawning flow release than during the release across all three years of data collection (2016, 2017, 2019), which retains null hypothesis H_06.

Study Objective	Management Questions	Management Hypotheses	Year 5 Status
	MQ 4. Does the resumption of base flows following the spawning release keeps redds adequately wetted throughout the egg incubation period as expected? If not, what should the spawning release be to ensure all redds are wetted at the base flow?	$H_0$7: The number of redds found above the base flow water level (minus a nominal depth to take into account that Steelhead will not spawn in very shallow water, e.g., 10 cm) following the two-week spawning release is not considered significantly different when compared to the total number of redds in the reach. $H_0$8: Following resumption of base flow operations, the number of Steelhead redds found above the water line and therefore, at risk of egg mortality from stranding, is not considered significant compared to the total number of redds in the reach.	Management question #4 and associated hypotheses are being addressed through: a) the IFS, and b) the spring spawner abundance assessment. The IFS was completed in Year 3 and Year 4 to determine the amount of habitat available to salmon at different flows (Healey *et al.* 2018). The IFS predicts that the majority of redds (97-99%) will remain wetted when flows return to 4 m^3/s from 7 m^3/s. Five Steelhead redds were observed during 2019 and none were observed in previous years. Redds observed during the 7 m^3/s spawning flow remained wetted when flows were reduced to baseline flows (4 m^3/s). Observational and habitat modelling results suggest that the majority of redds will remain wetted at 4 m^3/s, which retains the null hypotheses of $H_0$7 and $H_0$8.
	MQ 5. Does the 2-day 7 m^3/s pulse release every week trigger the	$H_0$3: The rate of spawning salmonid in-migration (No./day)	Management question #5 and associated hypotheses are being addressed through

Study Objective	Management Questions	Management Hypotheses	Year 5 Status
	upstream migration of fall spawners as expected? If not, is this the result of inadequate pulse magnitude, duration or some combination of both attributes? Or conversely, is the pulsed attraction release unnecessary?	during the 2-day pulse flow release operation is not significantly different from that during the base flow operation. $H_0$4: The rate of spawning salmonid in-migration (No./day) during the first day of the pulse flow release operation is not significantly different from that during the second day. $H_0$5: The estimated number of spawning salmonids following pulse flow release operation is not significantly different from that just prior to the release.	the fall pulse flow assessment component. The rate of fall spawning salmonid in-migration per day did not differ between periods of pulse flows and periods of base flows for all fall spawners, which retains $H_0$3 for Coho Salmon, Chinook Salmon and Chum Salmon. These results were confirmed in a supplemental analysis where only counts during the buildup to peak abundance were considered Because the WUP pulse flow prescription does not vary in magnitude or duration, we will be unable to determine if upstream migration of fall spawners would be improved if an alternate flow pulse prescription is used. Hypothesis $H_0$4 is not testable using the current sampling method of snorkel surveys immediately prior to and after the pulse flows.
	MQ 6. Following implementation of the WUP flow prescription to the Elk Canyon reach, has the general fish productivity of the reach increased as expected? If a change is apparent, whether positive or negative,	This management question is a synthesis question associated with all of the hypotheses and project components listed above.	Since there are no fish population data available before the WUP was implemented it will not be possible to address these questions directly in terms of fish productivity. The IFS was completed in Year 3 and Year 4 to determine the amount of

Study Objective	Management Questions	Management Hypotheses	Year 5 Status
	can it be attributed to WUP operations? Conversely, if no change is apparent, are some or all elements of the flow prescription still necessary?		habitat available to salmon at different flows (Healey *et al.* 2018). Results suggest that the carrying capacity of Elk Canyon does vary as a function of discharge. Other components of JHTMON-15 (e.g., the RST study) will provide important measures of fish productivity that will allow informed discussions of the benefits of the WUP operations and will establish a productivity reference point for these discussions. Synthesis analyses will be presented in Year 6 and Year 10 to address this management question.

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1. INTRODUCTION

1.1. Background to Water Use Planning

Water use planning exemplifies sustainable work in practice at BC Hydro. The goal is to provide a balance between the competing uses of water that include fish and wildlife, recreation, and power generation. Water Use Plans (WUPs) were developed for many of BC Hydro's hydroelectric facilities through a consultative process involving local stakeholders, government agencies, and First Nations. The framework for water use planning requires that a WUP be reviewed on a periodic basis and there is expected to be monitoring to address outstanding management questions in the years following the implementation of a WUP.

As the Campbell River Water Use Plan (BC Hydro 2012) process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. A key question throughout the WUP process was "what limits fish abundance?" For example, are fish abundance and biomass in the Campbell system limited by flow? Resolving this uncertainty is an important step to better understanding how human activities in a watershed affect fisheries, and to effectively managing water uses to protect and enhance aquatic resources. To address this uncertainty, monitoring programs were designed to assess whether benefits to fish are being realized under the WUP operating regime and to evaluate whether limits to fish production could be improved by modifying operations in the future.

The Elk Canyon on the lower Campbell River is used by all salmonid species for at least part of their life history. The WUP prescribed a flow regime with the intent of maximizing fish use in the canyon. However, there remains uncertainty over the extent to which the use of the canyon by juvenile and spawning fish is affected by the implemented flow regime. The *Elk Canyon Smolt and Spawner Abundance Assessment* (JHTMON-15) is part of wider monitoring of the Campbell River WUP. JTHMON-15 and is designed to assess the extent to which fish production is driven by flows in Elk Canyon, and how this relates to BC Hydro operations. This report presents results from Year 5 of the JHTMON-15 study.

1.2. BC Hydro Infrastructure, Operations, and the Monitoring Context

The Campbell River WUP project area is complex and includes facilities and operations in the Campbell and Quinsam watersheds. In addition to the mainstem rivers, there are three large reservoirs, nine diversion lakes influenced by water diverted from the Quinsam River (and until 2017, the Salmon River), and many tributaries and small lakes in these watersheds that are not directly affected by operations (Map 1). Details of BC Hydro's Campbell River infrastructure and operations are provided in the Campbell River System WUP report (BC Hydro 2012).

1.2.1. Elk Canyon

The Elk Canyon consists of a reach of the Lower Campbell River from Elk Falls below the John Hart Dam to the John Hart generating station (Map 2). Water in John Hart Reservoir is diverted via three

1,767 m long penstocks to the John Hart Generating Station, with water returning to the Lower Campbell River below Elk Canyon; flows to the canyon are released through the John Hart Dam spillway gates. The value of Elk Canyon as fish habitat was not fully appreciated until a base flow of 3.5 m^3/s was provided as part of an interim flow management strategy developed in 1997 (Campbell River Hydro/Fisheries Advisory Committee 1997). Field investigations since the flow release have shown an increase in the use of the canyon by fish as both juvenile rearing and salmonid spawning habitat. Despite this increase in the use of the canyon by salmonids, it was hypothesized that further increases in habitat were possible with additional flow releases. Therefore, during the Campbell River WUP process, a flow prescription was developed for Elk Canyon based primarily on the professional opinion of several biologists (all members of the Fish Technical Subcommittee or FTC). Recognizing that the release of water to the canyon reach comes at considerable cost in terms of lost generation, the FTC recommended that the flow prescription be the start of a long term 'titration' study with the aim of modifying the prescription at regular intervals (i.e., WUP Review intervals) based on the results of the preceding interval's monitoring program.

Based on the available information at the time, the FTC recommended that the following flow prescription be implemented as an attempt to maximize fish use in the canyon:

1) A minimum base flow of 4 m^3/s;
2) 2-day pulse flows of 10 m^3/s every two weeks in spring (February 15 to March 15) as an attraction flow, primarily for spawning Steelhead (though other spring spawners may benefit);
3) A two week minimum spawning flow of 7 m^3/s (April 1-15); and
4) 2-day pulse flows of 7 m^3/s every week in the fall (September 15 to November 15) as an attraction flow for all fall spawners that could potentially use this reach.

The prescription above was considered by the FTC as a starting point in a titration type study that would progressively change the flow regime as new information is gathered; alterations are only to be considered during WUP reviews when trade-offs with other values in the system can be examined. To successfully conduct this titration approach to flow setting, it was recommended that a monitoring program be developed and implemented to track the success or failure of the flow prescription in meeting its management objectives. JHTMON-15 is the monitoring study program implemented to increase the knowledge and understanding of flow relationships with fish in the Elk Canyon reach.

1.3. Management Questions and Hypotheses

There are six key management questions (or sets of questions) to be addressed by JHTMON-15:

1) Is the prescribed 4 m^3/s base flow sufficient to increase juvenile rearing habitat to near maximum values? If not, by how much should the base release increase (or decrease) and what would be the expected gain in habitat area?

2) Does the 2-day 10 m^3/s pulse release every two weeks trigger the upstream migration of spring spawners as expected? If not, is this the result of inadequate pulse magnitude, duration or some combination of both attributes? Or conversely, is the pulse attraction release unnecessary?
3) Is the two-week long 7 m^3/s spawning flow effective at increasing available spawning habitat for spring spawners? If not, by how much should the spawning release increase (or decrease) and what would be the expected gain in habitat area?
4) Does the resumption of base flows following the spawning release keep redds adequately wetted throughout the egg incubation period as expected? If not, what should the spawning release be to ensure all redds are wetted at the base flow?
5) Does the 2-day 7 m^3/s pulse release every week trigger the upstream migration of fall spawners as expected? If not, is this the result of inadequate pulse magnitude, duration or some combination of both attributes? Or conversely, is the pulsed attraction release unnecessary?
6) Following implementation of the WUP flow prescription to the Elk Canyon reach, has the general fish productivity of the reach increased as expected? If a change is apparent, whether positive or negative, can it be attributed to WUP operations? Conversely, if no change is apparent, are some or all elements of the flow prescription still necessary?

The following hypotheses were developed to answer these management questions:

$H_0$1: Carrying capacity of the Elk Canyon reach, as measured by annual smolt out-migrant counts, does not vary as a function of discharge.

$H_0$2: The number of rearing residents deemed likely to smolt the following spring, as measured during late summer, is not significantly different from the abundance estimate obtained in late winter just prior to the onset of their outmigration.

$H_0$3: The rate of spawning salmonid in-migration (No./day) during the 2-day pulse flow release operation is not significantly different from that during the base flow operation.

$H_0$4: The rate of spawning salmonid in-migration (No./day) during the first day of the pulse flow release operation is not significantly different from that during the second day.

$H_0$5: The estimated number of spawning salmonids following pulse flow release operation is not significantly different from that just prior to the release.

$H_0$6: The estimated number of spawning Steelhead during the two-week, 7 m^3/s spawning release period in spring is not significantly different from that observed just prior to the operation.

$H_0$7: The number of redds found above the base flow water level (minus a nominal depth to take into account that Steelhead will not spawn in very shallow water, e.g., 10 cm) following the two-week spawning release is not considered significantly different when compared to the total number of redds in the reach.

$H_0$8: Following resumption of base flow operations, the number of Steelhead redds found above the water line and therefore, at risk of egg mortality from stranding, is not considered significant compared to the total number of redds in the reach.

$H_0$9: Annual abundance of 'resident' smolts is not correlated with an index of Steelhead spawner abundance.

1.4. Scope of the JHTMON-15 Study

1.4.1. Overview

The study area for JHTMON-15 consists of the Elk Canyon reach of the Lower Campbell River from its entrance by the John Hart generating station (at the first riffle above the pedestrian bridge) to Elk Falls below John Hart Dam. The species of primary concern are Steelhead, Chinook Salmon and Coho Salmon, though other salmonid species known to use the system will also be considered.

JHTMON-15 is scheduled for 10 years and is to be carried out as a series of interconnected parts, each focused on addressing a specific hypothesis and with different durations over the course of the monitor. Two of the main sampling techniques to be employed in the monitor are snorkel swim counts of spawning adults and rearing juveniles and rotary screw trap enumerations of out-migrating smolts. The basic data requirements are summarized in Table 1.

Table 1. Summary of TOR Data Requirements

Component	Time of Year	Hypothesis Tested	Program Year									
			1	2	3	4	5	6	7	8	9	10
			2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Instream Flow Study	January to May, August, October to December	$H_0$1, $H_0$6, $H_0$7, $H_0$8			✓							
Smolt Enumeration	March to July	$H_0$1	✓	✓	✓		✓	✓	✓	✓	✓	✓
Overwintering Assessment	September and February	$H_0$2	✓	✓	✓	✓	✓					
Fall Pulse Flow Assessment	September to November	$H_0$3, $H_0$5	✓	✓		✓						
Spring Pulse Flow Assessment	February to April	$H_0$3, $H_0$5		✓	✓		✓					
Steelhead Spawning Flow Assessment	March to April	$H_0$6, $H_0$7, $H_0$8		✓	✓		✓					
Spring Spawner Enumeration	February to April	$H_0$9	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fall Spawner Enumeration [1]	September to November	$H_0$9	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[1] All fall spawner enumeration surveys were completed the previous year (i.e. Year 1 fall spawner enumeration surveys were completed in 2014)

All these components of JHTMON-15 were part of the data collection for Year 5 with the exception of the Instream Flow Study that was completed in Year 3.

1.4.2. Instream Flow Study

The JHTMON-15 IFS was developed to test how the carrying capacity of Elk Canyon varies with flow and addresses hypotheses $H_0$1, $H_0$6, $H_0$7 and $H_0$8 of the TOR. The IFS fieldwork was completed in 2017 and includes a Fish Habitat Assessment Procedure, habitat suitability criteria validation, empirical habitat modelling, and habitat simulation modelling at different flows. This study has been prepared as an independent report and was submitted to BCH in August 2018 (Healey *et al.* 2018).

1.4.3. Smolt Enumeration

The carrying capacity of the Elk Canyon reach is hypothesized to be affected by the magnitude of base flows (e.g., 4 m^3/s) provided in the flow prescription (H_01). This hypothesis will be addressed in part by monitoring salmon fry and smolt production from Elk Canyon using a rotary screw trap (RST) from March to July each year. Priority species for monitoring are Steelhead Trout, Chinook Salmon, and Coho Salmon, although the RST will also capture information for Chum Salmon, Pink Salmon and Sockeye Salmon that have incubated in Elk Canyon. The RST was used successfully in Years 1, 2, 3, and 5 to enumerate out-migrating fry and smolts of all salmon species. The smolt enumeration component of JHTMON-15 was not completed in Year 4 due to commissioning and construction related activities. A 5-year summary analysis will be completed at the end of Year 6.

1.4.4. Overwintering Assessment

The carrying capacity of Elk Canyon can be viewed as consisting of two components; 1) those fish that complete egg to smolt stages within the reach (here referred to as residents), and 2) juveniles that immigrate into the reach (immigrants). For Steelhead and Coho Salmon, there is potential for estimates of carrying capacity to differ during late summer and late winter based on abundance of overwintering immigrants to Elk Canyon (H_02). Therefore, snorkel swim counts of resident juveniles were conducted late in the growing season (September) and prior to smolt out-migration (February) to test if juvenile fish abundance differs between seasons as a result of immigration to Elk Canyon.

Chinook Salmon using the canyon reach are thought to be ocean-type, meaning that fry will spend two to five months in freshwater after emergence, and then move into the estuary. Because the in-river rearing period for these Chinook is relatively short and their first migration takes them to the estuary (Healey 1991), there is little risk that out-migrant counts collected in the canyon will include over-wintering immigrants of this species.

1.4.5. Pulse Flow Assessment

Part of the flow prescription for Elk Canyon is to provide 2-day pulse flows of 7 m^3/s every week in the fall (September 15 to November 15) and 2-day pulse flows of 10 m^3/s every two weeks in the spring (February 15 to March 15) as an attraction flow primarily for spawning salmonids. Hypotheses H_03, H_04, and H_05 were developed to test the effectiveness of these pulse flows in attracting spawning salmonids and attracting and retaining Steelhead in Elk Canyon. Hypotheses H_03 and H_04 test the rate of spawning migration to the canyon during the pulse flows. The preliminary work done by Bruce *et al.* (2003) showed that the fall spawners that migrated into the canyon during a pulse release did not necessarily stay in the reach following the resumption of base flow operations. The reason for this behaviour is uncertain, and it is unknown whether the response would be similar among spring spawners. This leads to hypothesis H_05 that tests the change in salmonid abundance before and after the 2-day pulse flows.

The fall and spring pulse flow assessments were conducted in Year 2, 3, and 5 of JHTMON-15. Year 5 thus represents the third and final year of data collection for the fall and spring pulse flow assessments. In the JHTMON-15 Year 1 pilot study we conducted an options analysis to determine the best method to test the hypotheses associated with the fall and spring pulse flows. It was determined that options such as DIDSON are not likely to be viable in the canyon environment. Instead, snorkel surveys were found to be a viable method to enumerate adult salmon in Elk Canyon.

1.4.6. Steelhead Spawning Flow Assessment

The flow prescription for Elk Canyon also includes a two-week long 7 m^3/s spring spawning flow (April 1-15) aimed at increasing available spawning habitat for Steelhead. Hypotheses H_06, H_07, and H_08 were developed to test the effectiveness of the spawning flow at increasing the numbers of spring spawners, as well as available spawning habitat. The Steelhead spawning flow assessment was completed using snorkel surveys and redd surveys prior to, during, and after the spawning flows in Year 2, 3, and 5 of the JHTMON-15 program. Year 5 thus represents the third and final year of the Steelhead Spawning Flow Assessment.

1.4.7. Spawner Enumeration

Spawner counts in both fall and spring are to be conducted annually for the full JHTMON-15 program. Area under the curve (AUC) estimates of abundance are calculated and used to test if the annual abundance of 'resident' smolts is correlated with spawner abundance (H_09). This is a final check to make sure that the assumption of 'full seeding' needed to test Hypothesis H_01 is satisfied. Note that the hypothesis is concerned only with that portion of the total smolt count that has spent their entire freshwater lifecycle in the Elk Canyon reach.

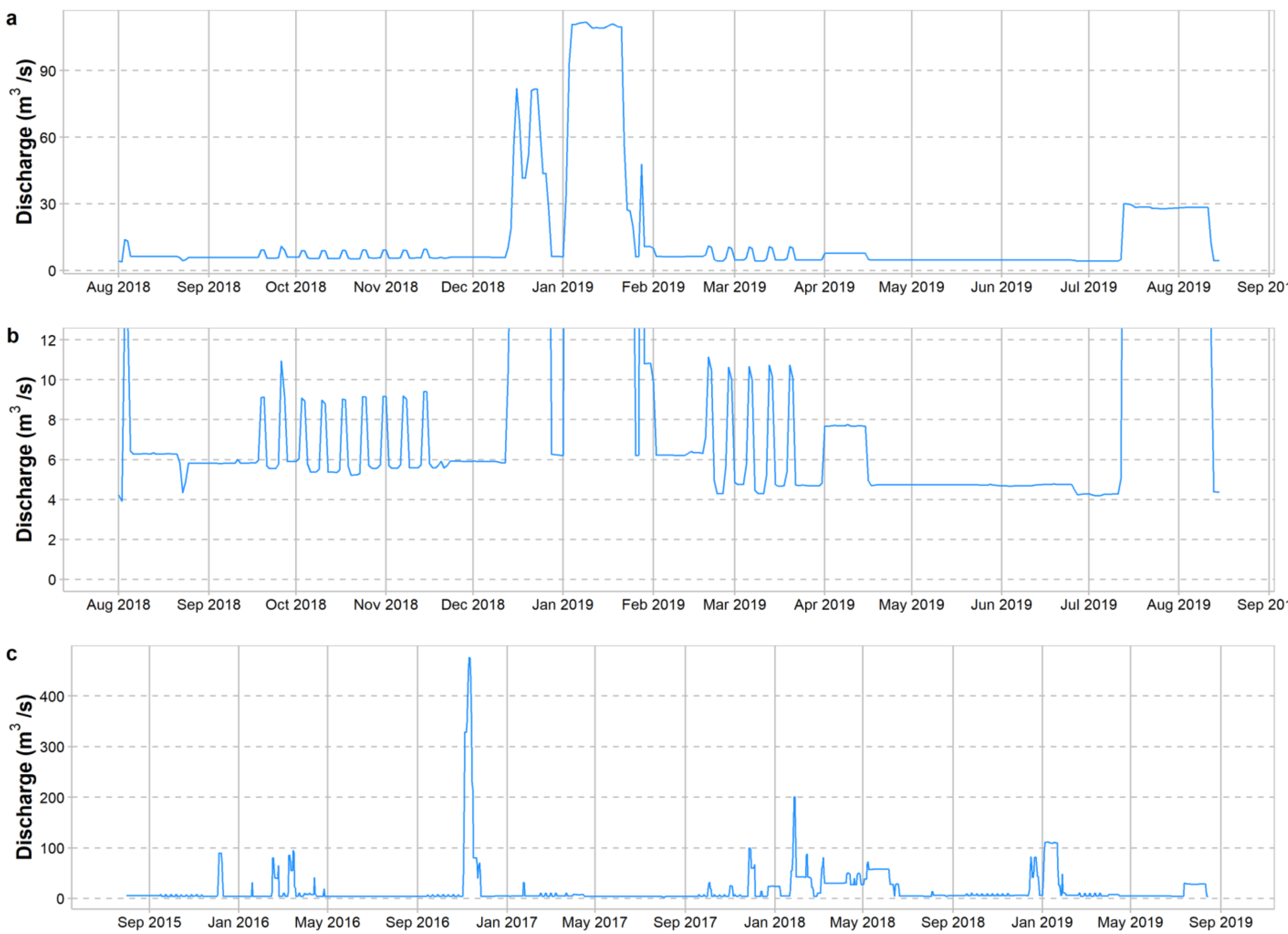
2. METHODS

2.1. Overview of Conditions in Year 5

The Elk Canyon smolt and spawner abundance program involves a series of interconnected components, each focused on addressing a specific hypothesis. The two main sampling techniques employed in Year 5 of the monitor were snorkel swim counts of adults and juveniles and rotary screw trap enumerations of out-migrating juveniles.

Figure 1a and b show the measured flow in Elk Canyon from August 2018 through to the end of July 2019. The 7 m^3/s pulse flows in September through November are evident, as well as the 10 m^3/s pulse flows and 7 m^3/s spawning flow in March and April. Also evident are large spill events that occurred between December 2018 and February 2019 as well as the ~30 m^3/s flow that occurred during an outage period from mid-July to mid-August 2019. Figure 1c shows measured flow in Elk Canyon from September 2015 through to the end of July 2019.

Figure 1. **Discharge (m^3/s) in Elk Canyon August 2018 to July 2019 (a and b) and September 2015 to September 2019 (c). Note different y-axis scales in panels a, b, and c which help view the 7 and 10 m^3/s pulses in fall and spring respectively relative to the larger spills in Elk Canyon.**



2.2. Smolt Enumeration

2.2.1. RST Setup and Operation

Year 5 represented the fourth year of smolt enumeration activities in Elk Canyon, including assessments in Years 1, 2, 3, and 5 of JHTMON-15. Smolt enumeration is planned to occur for five more years from Years 6 to 10. No smolt enumeration was completed in Year 4 due to commissioning activities preventing access into the Elk Canyon.

Smolt enumeration was carried out using a single 1.2 m rotary screw trap (RST) located near the base of the canyon, in the first run type mesohabitat (Figure 2), just around the corner and upstream from the powerhouse at JHT-DVRST (Map 2). Use of the RST followed a standard protocol (U.S. Fish and Wildlife Service 2008).

The RST was secured with the help of a qualified rigging professional. The rigging allowed adjustment of fishing position and included a mechanism for moving the trap if necessary (e.g., in the event of a planned spill) and a breakaway mechanism for recovering the trap safely in the event that it broke free. Operators were trained during the install to manage the rigging under a range of flow conditions.

The trap was installed March 1, 2019 and fished 7 days a week until July 12, 2019 for a total effort of 129.6 days (Table 2). Crews serviced the trap daily each morning. In Year 5 there were 2 main fishing positions for the trap. Position #1 was for base flows of 4 m^3/s (Figure 2) and Position #2 was for the prescribed spawning flow of 7 m^3/s (Figure 3). The new tailrace location caused significant backwatering effect compared to flow conditions created by the old tailrace location. In response to this increased backwatering effect, small adjustments to the fishing location were required dependent on tailrace flows.

Table 2. RST Fishing Effort Years 1, 2,3, and 5.

Year	Total Effort (h:mm:ss)	Total Effort (hrs)	Total Effort (Days)
2015	2624:17:00	2,624.28	109.3
2016	1976:06:00	1,976.10	82.3
2017	3571:32:00	3,571.53	148.8
2019	3110:29:00	3,110.48	129.6

Daily trap servicing consisted of a crew of two accessing the trap to record trap orientation and rotation, water velocity at the trap, and the debris present in the trap. The trap was cleaned, serviced, and all fish were removed for sampling.

All fish caught in the trap were removed and identified to species prior to release. A small semi-permanent fish sampling station was constructed to increase sampling efficiency and allow for fish to be sampled on shore, outside of the active channel. On each catch date, a maximum of ten fish per species and size class were measured for fork length and wet weight and sampled for DNA. If more than ten fish per size class and species were captured, the surplus fish were identified to species in a fish viewer. All fish were released back to the river downstream of the trap.

The condition of the trap was also monitored continuously by a remote camera, which took a series of still pictures each morning (at first light) and afternoon. Pictures were emailed automatically to the trapping crew, so they were aware of any potential issues with the trap prior to arriving onsite. Afternoon pictures were emailed sufficiently early in the day so that any issues could be resolved prior to sunset. For site security, the camera was also programmed to be motion activated to detect tampering or vandalism.

Figure 2. Rotary Screw Trap (RST) during operation at base of Elk Canyon at 4 m^3/s (Position #1).

Figure 3. Rotary Screw Trap (RST) during operation at base of Elk Canyon at 7 m^3/s (Position #2).

2.2.2. Age Analysis

Scale samples were collected for age analysis from RST captured Steelhead/Rainbow Trout, Chinook Salmon, and Coho Salmon that were >50 mm fork length. In total, 53 scale samples from Steelhead/Rainbow Trout, 60 scale samples from Chinook Salmon, and 30 scale samples from Coho Salmon were collected. Of these, 21 Steelhead/Rainbow Trout, 11 Coho Salmon, and 10 Chinook Salmon scales were aged.

In the Ecofish laboratory, scales were examined under a dissecting microscope to determine age. Three representative scales from each sample were photographed and annuli were noted on a digital image. Scales were aged by two independent observers, following Ecofish in-house QA protocols. Where discrepancies were noted, they were discussed, and a final age determination was made based on professional judgment of the senior biologist.

2.2.3. Mark Recapture Experiment

Mark-recapture experiments were completed to measure RST catch efficiency and ultimately to estimate total outmigration from Elk Canyon (Table 3). A total of 18 mark-recapture trials were completed over 12 release days from March 12 to May 13, 2019. The trials included: seven trials of wild Chum fry, one trial of wild Coho fry, five trials of wild Chinook fry, two trials of hatchery Chinook fry, and three trials of hatchery Chinook smolts. Chum, Chinook and Coho Salmon fry were marked by immersion in Bismarck Brown (0.8 g of in 38 L of water) for 1.25 hrs and Chinook Salmon smolts were marked using a unique ventral fin clip for each individual trial.

The number of fish targeted for release per trial (200 fish) was determined by an efficiency analysis conducted for the Year 1 report (Hocking *et al.* 2015). This analysis determined that with 200 fish released the RST catch efficiency is not expected to vary by more than 5% if an additional fish is captured during a given trial, a quality criterion described in U.S. Fish and Wildlife Service (2008).

The hatchery Chinook Salmon were driven to the upper laydown parking lot from the Quinsam hatchery and then transported into the canyon in buckets with battery-powered bubblers. All fish were released approximately 225 m upstream of the RST in batches of ten fish. The release site was consistent through all trials and was located at the top of a cascade which flowed into a pool, run, riffle, and then into the RST.

In total, 369 wild Chinook Salmon fry, 393 hatchery Chinook Salmon fry, 600 hatchery Chinook Salmon smolts, 1,059 wild Chum Salmon fry, and 27 Coho Salmon fry were released over the course of the mark recapture experiment (Table 3).

Two different capture efficiency estimates were calculated based on recaptures of the marked and released fish. First, the trial capture efficiency was based on recapture rates calculated for each trial:

$$CE_t = \frac{\sum_{i=0}^{3} RR_x}{r_x}$$

where CE_t is the trial capture efficiency, RR_x is the total number of recent recaptured fish of trial x, and r_x is the number of released fish at trial x.

Second, because some marked and released fish may not immediately leave Elk Canyon, an overall capture efficiency was calculated based on combining all trials for each species and life stage:

$$CE_o = \frac{R}{r}$$

where CE_o is the overall capture efficiency, R is the total number of recaptured fish, and r is the total number of released fish. Two overall capture efficiencies were determined, one for fry and one for parr/smolts.

2.2.4. Estimating Salmonid Outmigration

Using estimates of overall capture efficiency and CPUE per half month period, total outmigration by fish species and life stage in Elk Canyon can be calculated by:

$$Total\ Out - migration = \frac{\sum CPUE_{ij} \times T_j}{CE_{oi}}$$

where $CPUE_{ij}$ is the average catch per day of a given species and life stage i in half month j, T_j is the number of days each half month j, and CE_{oi} is the overall capture efficiency for each species and life stage i.

Two overall capture efficiencies were used to calculate outmigration, one for fry and one for parr/smolts. Coho fry were excluded from estimates of mean capture efficiency because their overall capture efficiency was much lower than that of other species and life stages. This lower capture efficiency likely reflects a tendency for Coho fry to remain in the canyon after their release rather than moving downstream past the RST. Total outmigration of Coho fry was thus also calculated based on the mean capture efficiency for fry from all other species.

Table 3. Mark-recapture experiment release date and fish numbers.

Species	Origin	Life Stage	Release Date	Number of Fish Marked	Number of Fish Released[1]
Chinook Salmon	Hatchery	Fry	12-Mar-19	200	193
	Hatchery	Fry	19-Mar-19	200	200
	Wild	Fry	15-Mar-19	51	51
	Wild	Fry	22-Mar-19	85	82
	Wild	Fry	26-Mar-19	91	90
	Wild	Fry	1-Apr-19	146	146
	Hatchery	Parr	29-Apr-19	200	200
	Hatchery	Parr	6-May-19	200	200
	Hatchery	Parr	13-May-19	200	200
Chum Salmon	Wild	Fry	19-Mar-19	110	110
	Wild	Fry	22-Mar-19	175	174
	Wild	Fry	26-Mar-19	173	171
	Wild	Fry	1-Apr-19	205	205
	Wild	Fry	15-Apr-19	201	200
	Wild	Fry	23-Apr-19	200	199
Coho Salmon	Wild	Fry	22-Mar-19	28	27

[1] Not all fish survived the marking and/or transport procedure. Only live marked fish were released.

2.3. Overwintering Assessment

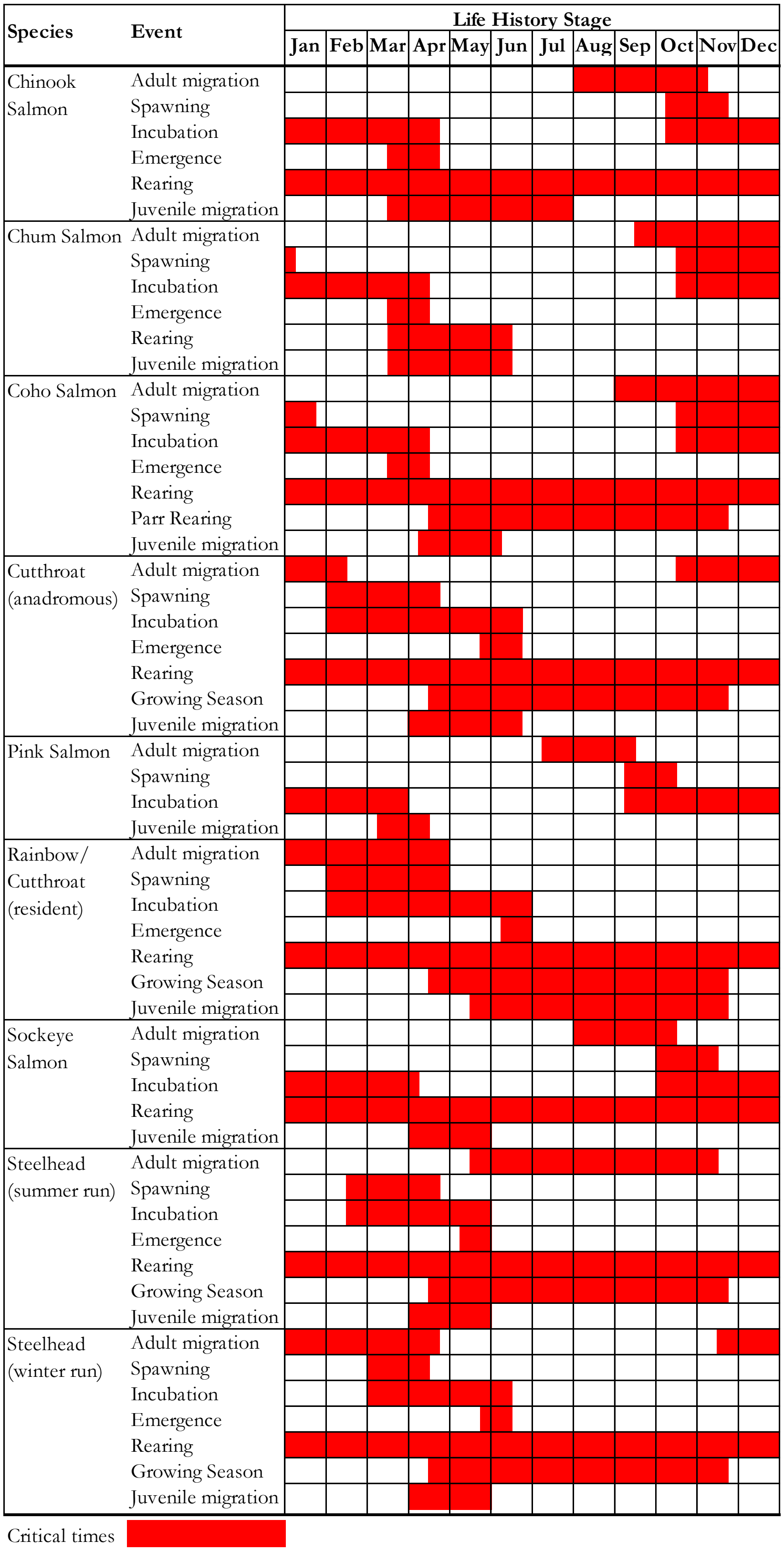
2.3.1. Data Collection

The overwintering assessment was designed to test if juvenile salmonids used Elk Canyon during their entire rearing period or if a significant proportion of the population consisted of immigrant juveniles from below the canyon. This was done by contrasting late summer (mid-September) parr abundance in the canyon with winter (early February) counts of parr just before onset of outmigration. For example, some Coho Salmon may to rear in Elk Canyon for over a full year after hatching and begin juvenile outmigration as 1+ smolts in mid-March (Table 4). Snorkel survey sampling occurred before this outmigration period. For Chinook Salmon, it is currently hypothesized that all Chinook juveniles leave the Campbell watershed by July and are thus an 'ocean type' life history. This would predict that no Chinook parr would be observed in the fall or winter snorkel surveys. The periodicity chart shown in Table 4 was adopted from the WUP for the Lower Campbell River and will be updated with Elk Canyon specific data as the JHTMON-15 program progresses.

The overwintering assessment snorkel surveys completed in Year 1 were highly variable and resulted in no fish being observed during daytime winter snorkels. A single night snorkel confirmed fish presence during the winter, and that day snorkels were not effective for reliably enumerating juvenile fish in the winter. Therefore, Years 2 to 5 overwintering assessment methods were modified from Year 1 to consist of two night snorkel mark/resight trials. The first trial was conducted on September 13 and 14, 2018 and the second trial was conducted on February 4 and 5, 2019. The mark/resight snorkels followed methods established in the Cheakamus River WUP and Puntledge River WUP Steelhead monitoring projects (Korman 2008, Faulkner *et al.* 2011). Year 5 represents the final year of planned field activities for the Overwintering Assessment.

The same 6 sites that were established in Year 2 in the lower 1.0 km of Elk Canyon (sites CBR-NSK01 to CBR-NSK06 in Map 2) were utilized again in Year 5. Sites were approximately 100 m long and encompassed a variety of habitat types (riffles, runs, pools) that parr would utilize. The portion of riffle/run/pool was delineated within each site in order to assess habitat specific preferences. Habitat data including habitat type, length, stream width, depth, primary and secondary cover type, substrate, and gradient were taken from Year 2 data as the canyon habitat remained relatively unchanged between years and flows are at 4 CMS for all overwintering assessments.

Table 4. Periodicity chart for salmonid species using Elk Canyon (source BC Hydro 2003).



Fish were marked at each site using a crew of five on September 13, 2018 and February 4, 2019. Crews started at the upstream site (CBR-NSK01) and finished at the downstream end of the canyon. Within each site, two snorkelers traversed the site in an upstream direction with two underwater dive lights and a handheld dip net. Individual parr were captured using the dip net and were passed to the fourth and fifth crew members on shore. A hook tag consisting of a size 12-16 dry fly hook with a coloured piece of chenille was inserted into each fish at the base of dorsal fin. The estimated fork length was recorded as well as the tag colour. A ruler was placed in the bottom of the holding bucket to visually estimate fork length without excessive handling or use of anaesthetic. The tag colours used in the study are listed in Table 5. Once tags were applied, the parr were released within 5 m of where they were captured. Crews avoided conducting multiple passes through the site to avoid excessive disturbance prior to conducting the recapture snorkel the following day.

Table 5. Size bins and corresponding tag colour and hook size used during the Steelhead/Rainbow Trout, and Coho parr mark-recapture study in the Campbell River in 2018/2019.

Size Range (mm)	Colour	Hook Size
80-99	Red	16
100-119	Green	16
120-139	Sparkle Blue	15
140-159	Orange	14
160-179	Sparkle Green	13
180+	Pink	12

On September 14, 2018 and February 5, 2019 two crews of two conducted resight snorkels in each of the six sites that were marked the previous night. The mark/resight crews accessed the canyon before dark and started surveys one hour after sunset at the most upstream sites (CBR-NSK01, CBR-NSK02). Each crew of two snorkelled three sites each and covered all available habitat >20 cm deep by traversing from each bank and meeting at the centre of the stream, slowly working their way upstream. Each crew member was equipped with two underwater dive lights, one on their wrist and one attached to the dive mask strap. All observed fish were recorded on underwater dive slates in 20 mm size bins. Prior to conducting the surveys, underwater fish models of known sizes were examined underwater to calibrate size estimates. All tagged fish were noted, along with tag colour. In addition, approximately 20 m of habitat above and below the site boundaries were snorkelled to determine if any tagged fish moved out of the site. No untagged fish were enumerated outside of the site boundaries, although any tagged fish were noted.

2.3.2. Data Analysis

A synthesis analyses was completed for Steelhead/Rainbow Trout and Coho Salmon juveniles across all four years of data collection (Year 2, 3, 4, and 5) to address Management Question #1 and $H_0 2$ of the TOR related to the overwintering assessment.

Abundance of overwintering fish at each of the six sites was calculated based on the observer efficiency of marked individuals:

$$Observer\ Efficiency\ (OE) = \frac{R}{(M - O)}$$

where R is the number of marked individuals observed during the resight swim (resights), M is the number of marked individuals during the mark swim, and O is the number of marked individuals observed outside of the site during the resight swim. The mean observer efficiency for the fall and spring sampling was calculated and used to estimate fish density at each site:

$$Fish\ Density = \frac{M}{OE} \times \frac{1}{A}$$

where OE is the observer efficiency and A is the site area in m^2.

In addition to the observer efficiency, fish density was estimated using the Peterson estimator with Chapman modification calculation as outlined in (Chapman 1951). Fish density was calculated from the two approaches and compared.

Hypothesis $H_0 2$: the number of rearing residents deemed likely to smolt the following spring, as measured during late summer, is not significantly different from the abundance estimate obtained in late winter just prior to the onset of their outmigration, was tested using a Generalized Linear Mixed Model (GLMM, Pinheiro and Bates 2000) of the form:

$$\text{Steelhead Density} \sim \text{Season} + (1|\text{TreatmentPair}) + (1|\text{Site})$$

where *Season* refers to either spring or fall. In this framework, we account for the variability introduced by variables whose effects we do not wish to test directly, but rather control statistically. In this case, we accounted for the effects the pair of seasons (i.e., fall in year and winter in year t+1) with the variable *Treatment Pair*, and variability introduced by sampling location (variable *Site*).

This GLMM was fit within a Bayesian framework (Gelman *et al.* 2013), with uninformative priors. The parameter estimate for *Season* is presented as a mean posterior, along with 95% credible intervals; the effect of *Season* is significant if the 95% interval does not bound zero.

GLMMs within a Bayesian framework were fit using the MCMCglmm package (Hadfield 2010), and plots were produced using the ggplot2 package (Wickham 2016), within the R Statistical Language (R Core Team 2019). For Bayesian analyses we used four chains in the Markov chain Monte Carlo process with a burn-in of 1,000 iterations (Zuur *et al.* 2013). To assess convergence, we used the Gelman and Rubin $\hat{R}$ convergence diagnostic (Gelman and Rubin 1992) and visually inspected the mixing of the chains. We found no evidence of autocorrelation among the chains by visually assessing autocorrelation plots.

2.4. Pulse Flow Assessment

2.4.1. Fall Pulse Flow Assessment

Fall pulse flow assessments were initiated in Year 2 and continued in Years 3 and 5. Year 5 represents the final year of planned field activities for the Fall Pulse Flow Assessment.

There were nine fall pulse flow releases conducted weekly through Elk Canyon between September 19 and November 22, 2018 (Table 6). Each pulse lasted 48 hours and occurred at least three days apart on Wednesday and Thursday of each week. Full canyon snorkel surveys were used to assess migration response for fall spawning salmon pre and post pulse. The snorkel counts were carried out by a crew of two swimmers swimming in tandem with a third crew member recording data onshore. For each pulse a snorkel survey was conducted the day before the pulse and the day after the pulse. The next pre-pulse survey (3-4 days later) was used to determine the baseline fish count prior to the next pulse as well as to assess if fish stayed or moved back downstream between the pulses. A total of 21 fall snorkel surveys were completed in 2018.

Table 6. Elk Canyon pulse flow and snorkel survey schedule in fall 2018 including overwintering assessment mark/resight snorkels.

September

1	SA	
2	SU	
3	MO	
4	TU	
5	WE	Snorkel
6	TH	
7	FR	
8	SA	
9	SU	
10	MO	
11	TU	Snorkel
12	WE	
13	TH	Overwintering
14	FR	Overwintering
15	SA	
16	SU	
17	MO	
18	TU	Snorkel
19	WE	Pulse
20	TH	Pulse
21	FR	Snorkel
22	SA	
23	SU	
24	MO	
25	TU	Snorkel
26	WE	Pulse
27	TH	Pulse
28	FR	Snorkel
29	SA	
30	SU	

October

1	MO	
2	TU	
3	WE	
4	TH	
5	FR	
6	SA	
7	SU	
8	MO	
9	TU	Snorkel
10	WE	Pulse
11	TH	Pulse
12	FR	Snorkel
13	SA	
14	SU	
15	MO	Snorkel
16	TU	
17	WE	Pulse
18	TH	Pulse
19	FR	Snorkel
20	SA	
21	SU	
22	MO	
23	TU	Snorkel
24	WE	Pulse
25	TH	Pulse
26	FR	Snorkel
27	SA	
28	SU	
29	MO	
30	TU	Snorkel
31	WE	Pulse

November

1	TH	Pulse
2	FR	Snorkel
3	SA	
4	SU	
5	MO	
6	TU	Snorkel
7	WE	Pulse
8	TH	Pulse
9	FR	Snorkel
10	SA	
11	SU	
12	MO	
13	TU	Snorkel
14	WE	Pulse
15	TH	Pulse
16	FR	Snorkel
17	SA	
18	SU	
19	MO	
20	TU	Snorkel
21	WE	Pulse
22	TH	Pulse
23	FR	Snorkel
24	SA	
25	SU	
26	MO	
27	TU	
28	WE	
29	TH	Snorkel
30	FR	

2.4.1.1. Data Analysis

A synthesis analyses was completed for Coho Salmon, Chinook Salmon, Chum Salmon and Steelhead across all three years of data collection (Year 2, 3, and 5) to address Management Question #5 of the TOR related to the Fall Pulse Flow Assessment. For each salmon species, two separate tests were completed that address hypotheses H_03 and H_05. The null hypothesis for H_05 states: The estimated number of spawning salmonids following pulse flow release operation is not significantly different from that just prior to the release. Given the nonlinear functional relationship between day of year and counts of each salmon species, we addressed this hypothesis through generalized additive mixed models (GAMM) (Wood 2006) of the form:

$$\text{Salmon Count} \sim s(\text{doy}) + \text{Pulse} + (1|\text{year})$$

where *doy* means day of year and is an estimated smooth function, *Pulse* is a categorical variable with levels 'Pre-pulse' and 'Post-pulse', and *1/year* represents that the variability introduced by year is accounted for as a random effect.

There are no apparent nonlinearities in the relationship between Steelhead count and day of year (Figure 19D). Accordingly, Steelhead count was modelled as a GLMM of the form:

$$\text{Steelhead count} \sim \text{doy} + \text{Pulse} + (1|\text{year})$$

This GLMM was fit within a Bayesian framework (Gelman *et al.* 2013), with uninformative priors. The parameter estimate for *Pulse* is presented as point estimate (or mean posterior), along with 95% confidence (or credible intervals); the effect of pulse flow release operations is significant if the 95% interval does not bound zero.

The null hypothesis for H_03 states: The rate of spawning salmonid in-migration (No./day) during the 2-day pulse flow release operation is not significantly different from that during the base flow operation. To address this hypothesis, the pre pulse count of salmon for each pulse was subtracted from the post pulse count of salmon to derive the change in salmon abundance pre versus post pulse ($\Delta\text{salmon}_{\text{pulse flow}}$). Each value for $\Delta\text{salmon}_{\text{pulse flow}}$ was divided by the number of days between snorkel surveys (usually 3 days) to derive the rate of salmon in-migration per day for each pulse event ($\Delta\text{salmon/day}_{\text{pulse flow}}$). The post pulse snorkel for each pulse and the pre pulse snorkel for the subsequent pulse were also separated by three to four days, except they were not divided by a pulse event and instead had consistent base flows. Therefore, these two surveys were assigned as pre base flow and post base flow respectively and acted as a paired control to the pre versus post pulse data. The rate of salmon in-migration per day during base flow ($\Delta\text{salmon/day}_{\text{base flow}}$) was computed in the same fashion and paired with each measure of $\Delta\text{salmon/day}_{\text{pulse flow}}$ from only a few days before. The daily rate of in-migration was modelled as a generalized linear mixed model of the form:

$$\Delta\text{salmon/day} \sim \text{Flow} + (1|\text{year})$$

where *Flow* is a categorical variable with levels: 'Base flow' and 'Pulse flow'. These models were fit within a Bayesian framework with uninformative priors. The parameter estimate for *Flow* is presented as the mean posterior, along with 95% credible intervals; the effect of pulse flow release operations is significant if the 95% interval does not bound zero.

GAMMs were fitted using the gamm4 package (Wood and Scheipl 2017), GLMMs within a Bayesian framework were fit using the MCMCglmm package (Hadfield 2010), and plots were produced using the ggplot2 package (Wickham 2016), within the R Statistical Language (R Core Team 2019).

To test if pulse flow release operation help attract early spawners into Elk Canyon, we repeated tests of $H_0$3 and $H_0$5 for Pacific Salmon, including data up to the date when annual peak counts occurred.

A test of $H_0$4 was not possible using this snorkel design because daily salmon count data was not collected during the pulse flow releases. The null hypothesis for $H_0$4 states: The rate of spawning salmonid in-migration (No./day) during the first day of the pulse flow release operation is not significantly different from that during the second day.

2.4.2. Spring Pulse Flow Assessment

Spring spawning pulse flow assessments were initiated in Year 2 and continued in Years 3 and 5. Year 5 represents the final year of planned field activities for the Spring Pulse Flow Assessment.

There were five spring pulse flow events conducted through the Elk Falls Canyon between February 20 and March 21, 2019 (Table 7). Each pulse lasted 48 hours and occurred at least three days apart. Full canyon snorkel surveys were used to assess migration response for Steelhead pre and post pulse. The snorkel count methods were the same as those used for the fall pulse flow assessment (Section 2.4.1). For each pulse a snorkel survey was conducted the day before and the day after the pulse, with a third snorkel survey conducted two to three days later to assess if fish stayed or moved back down stream. Additionally, seven extra weekly snorkels for the two weeks preceding the first pulse and five weeks after the last pulse were completed, for a total of 18 spring snorkel surveys.

2.4.2.1. Data Analysis

A synthesis analysis was completed for spring spawning Steelhead across all three years of data collection (Year 2, 3, and 5) to address Management Question #2 of the TOR related to the Spring Pulse Flow Assessment. The effect of the spring pulse releases on Steelhead in-migration to Elk Canyon was determined using the same methods as described for the fall pulse flow assessment (Section 2.4.1). Generalized Linear Mixed Models were used to address $H_0$3 and $H_0$5 relating to the number of Steelhead observed in the canyon pre versus post pulse and the rate of Steelhead in-migration per day during the pulse release compared to in-migration during base flows.

Table 7. Spring Field Schedule 2019.

February

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH
			Day Snorkel and Overwintering	Overwintering			Snorkel											Snorkel	Pulse	Pulse	Snorkel			Snorkel		Pulse	Pulse

March

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU
Snorkel				Snorkel	Pulse	Pulse	Snorkel				Snorkel	Pulse	Pulse	Snorkel				Snorkel	Pulse	Pulse	Snorkel				Snorkel					
RST Install	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST Hatchery CH fry	RST	RST	RST Wild CH fry	RST	RST	RST	RST Wild CM fry & Hatchery CH fry	RST	RST	RST Wild CO, CH, CM fry	RST	RST	RST	RST Wild CH & CM fry	RST	RST	RST	RST	RST

April

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU
7 cms Spawning Flow																													
Snorkel							Snorkel							Snorkel								Snorkel							
RST Wild CM & CH fry	RST	RST	RST	RST	RST[1]	RST	RST Wild CM & CH fry	RST	RST	RST	RST	RST	RST	RST Wild CM fry	RST	RST	RST	RST	RST	RST	RST	RST Wild CM fry	RST	RST	RST	RST	RST	RST Hatchery CH parr	RST

May

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR
RST	RST	RST	RST	RST	RST Hatchery CH parr	RST	RST	RST	RST	RST[3]	RST[3]	RST Hatchery CH parr	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST[2]	RST	RST	RST	RST

June

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU
RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST	RST

July

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE	TH	FR	SA	SU	MO	TU	WE
RST	RST	RST	RST	RST	RST	RST[3]	RST	RST	RST	RST Service and move to tailrace	RST Removal																			

1 Tree down on road to site; crew could not safely access the site

2 After servicing, RST was moved to tailrace to accommodate a 20 cms flow through the canyon. RST was moved back into place on May 28.

3 SNC gate key missing; crew unable to access site

2.5. Steelhead Spawning Flow Assessment

Steelhead spawning flow assessments were initiated in Year 2 and continued in Years 3 and 5. Year 5 represents the final year of planned field activities for the Steelhead Spawning Flow Assessment.

A spring spawning flow of 7 m^3/s was maintained through the Elk Falls Canyon from April 1 to April 15, 2019. Twelve snorkel swims were conducted prior to the spring spawning flow regime to act as controls. Three snorkel surveys were conducted during the spawning flow to assess spawning response for Steelhead to the 7 m^3/s spawning flow. The snorkel count methods were the same as those used for the fall and spring pulse flow assessments (Section 2.4).

A synthesis analysis was completed for spring spawning Steelhead across all three years of data collection (Year 2, 3, and 5) to address Management Questions #3 and #4 of the TOR related to the Steelhead Spawning Flow Assessment. Hypothesis H_06 relating to the number of Steelhead observed in the canyon prior to and during the two-week, 7 m^3/s spawning release period in spring, was assessed using a GLMM of the form:

$$\text{Steelhead Count} \sim \text{Flow} + (1|\text{year})$$

where *Flow* is a categorical variable with levels: 'Pre-spawning flow' and 'spawning flow'.

This GLMM was fit within a Bayesian framework (Gelman *et al.* 2013), with uninformative priors. The parameter estimate for *Flow* is presented as a mean posterior, along with 95% credible intervals; the effect of *Flow* is significant if the 95% interval does not bound zero.

2.6. Spawner Enumeration

2.6.1. Fall Spawners

Snorkel surveys were used to enumerate fall spawners in reaches one to six of the Campbell River (Map 2). Data from reach seven were excluded because of the large number of fish that hold in the pool at the base of the canyon that are not actively spawning. In total, 21 snorkel surveys were conducted on September 5, 11, 18, 21, 25, 28, and October 9, 12, 15, 19, 23, 26, 30, and November 2, 6, 9, 13, 16, 20, 23, and 29, 2018 to inventory fall spawning Coho Salmon, Chinook Salmon, Chum Salmon, Pink Salmon, Sockeye Salmon, and Steelhead in Elk Canyon. In each reach, total counts of all species, their spawning condition, and the presence of redds were recorded. Spawning areas were also marked for future data collection. The snorkel count methods were the same as those used for the fall and spring pulse flow assessments (Section 2.4).

Spawner abundance for each salmon species was estimated using an area under the curve (AUC) analysis using the DFO AUC calculator tool. The AUC calculator uses the survey abundance estimates, along with estimates of fish residence time and observer efficiency to estimate the total spawner abundance. Estimates of fish residence times are provided in Perrin and Irvine (1990) (Table 8). Observer efficiency was assumed to be 100%.

The production of fry and smolts was estimated based on the maximum number of redds observed for Chinook, Coho, Chum, Pink, and Sockeye Salmon spawners. Assuming that a female would spawn in a single redd, we estimated the number of eggs produced per redd based on average female fecundity by salmon species (Bradford 1995). We then estimated fry and smolt production by salmon species based on the egg to fry and egg to smolt survival rates provided in Quinn (2005). These estimates of fry and smolt production from observed salmon redds were compared against the fry and smolt outmigration estimates generated from the RST data.

Table 8. Fall spawner residence times (source Perrin and Irvine 1990).

Fish Species	Residence Time (days)
Coho Salmon	11.4
Chum Salmon	11.9
Pink Salmon	17.3
Chinook Salmon	12.1
Sockeye Salmon	13.2

2.6.2. Spring Spawners

Snorkel surveys were also used to enumerate spring spawning Steelhead in reaches one to six of the Campbell River (Map 2). Data from reach 7 were again excluded. In total, 18 snorkel surveys were conducted on February 4, 8, 19, 22, 25, March 1, 5, 8, 12, 15, 19, 22, 26, April 1, 8, 15, and 23, 2019 following the same methods used in the pulse flow assessments and fall spawner surveys. The maximum number of Steelhead observed in a single survey day was used as the spawner abundance estimate rather than using area under the curve.

3. RESULTS

3.1. Smolt Enumeration

3.1.1. RST Capture Data

The RST operated for a total effort of approximately 130 days or 3110 hours between from March 1, 2019 to July 11, 2019. In total, 18,167 fish were captured in the RST in 2019 (Figure 4, Figure 5). Similar to previous RST sampling years, the catches in 2019 were primarily composed of Chum Salmon (73.1%), Chinook Salmon (17.5%), and Coho Salmon (4.6%). Steelhead/Rainbow Trout and Sockeye Salmon were 0.4% and 0.04%, respectively. The combined catch of all salmonids (17,690 fish) accounted for 97.4% of the total catch while the catch of the key target species of Chinook Salmon, Coho Salmon, and Steelhead/Rainbow Trout (4,081 fish) accounted for 22.5% of the total catch.

Clear periods of outmigration were observed for Chinook Salmon, Coho Salmon, and Chum Salmon based on the RST catches (Figure 6, Figure 7, Figure 8). Chinook Salmon outmigration had two main peaks, including a large peak of recently emerged fry in late March and early April, and a second smaller peak in late May to early July of 0+ smolts. Coho Salmon outmigration occurred more intermittently than Chinook. Outmigration of fry occurred from early March until early May with two main peaks occurring late March and late April. Early June through July saw a second peak consisting primarily of 0+ smolts. Steelhead/Rainbow Trout outmigration was low and irregular from mid-April through to early June with a peak occurring around the end of May. Chum Salmon outmigration began in early March and peaked in mid to late April. Catches of Chum Salmon occurred until May 7, after which none were captured in the RST. Pink Salmon outmigration began in early March and peaked late March to early April. Catches of Pink Salmon occurred until April 13, after which none were captured in the RST. Only 8 Sockeye Salmon were captured in the RST with irregular outmigration occurring between mid-March and mid-April.

The Quinsam hatchery releases sub yearling Chinook and Coho Salmon smolts into the Quinsam River, which enters the Campbell River downstream of the RST. There is some uncertainty around whether the Chinook and Coho released from the hatchery could swim upstream and become captured in the RST. Fish origin could not be determined in the field; however, otolith analysis was conducted in Year 3 which resulted in only 1 of 29 fish sampled determined to be of hatchery origin (~3%) suggesting that hatchery fish do not make up a significant proportion of the Chinook outmigration from Elk Canyon.

Of the 17,690 salmonids caught in the RST, 2,186 fish were measured for fork length. The fork lengths of these fish were compared over time to determine if outmigration timing varied by the size and/or age cohort of fish (Figure 9, Figure 10, Figure 11, Figure 12, Figure 13). Chum Salmon fry were captured throughout March to early May, and Pink Salmon were captured in March and April within a narrow range of fork lengths between roughly 30 to 40 mm. Only 8 Sockeye Salmon were captured between mid-March and mid-April with a narrow fork length range between roughly 25 and 35 mm.

Chinook Salmon exhibited two main peaks in outmigration timing and size (Figure 11), while Coho Salmon exhibited three main peaks in outmigration timing and size (Figure 12). Recently emerged Chinook and Coho fry were caught in the RST from March to early May, and ranged in fork length from 25 to 55 mm. A second peak in outmigration composed of larger individuals was observed for both species starting in mid-May until the end of the sampling period. From late May to the end of July, the majority of the Chinook and Coho caught in the RST ranged in fork length from 70 to 100 mm and 60 to 95 mm, respectively (Figure 9, Figure 11, Figure 12). Most of these fish are assumed to be age 0+ smolts that have reared for several months in Elk Canyon prior to their outmigration. The exception to this is three large 1+ Coho Salmon (124 mm to 130 mm fork length) that were captured late April and May. Based on scale ageing it is assumed that these fish overwintered in Elk Canyon and are outmigrating as 1+ smolts.

The peak in Steelhead/Rainbow Trout outmigration occurred between early May and mid-June (Figure 13). The majority of captured Steelhead/Rainbow Trout were age 2+ (~48%) (148-199 mm) and 3+ (~42%) (200-256 mm), which were captured between April and June. Small 0+ (≤80 mm), 1+ (85-146 mm) and adult ≥3+ fish (>257 mm) made up small proportions of RST captures (~2%, ~8%, and ~1% respectively). Average outmigration body size of Steelhead/Rainbow Trout declined steadily from mid-April through to July (Figure 9), which suggests that age 3+ smolts outmigrate earlier than 2+ smolts (Figure 13).

Figure 4. **Total RST catch by species from March 2 to July 11, 2019. ST/RB = Steelhead/Rainbow Trout, CO = Coho Salmon, CH = Chinook Salmon, CM = Chum Salmon, PK = Pink Salmon, SK = Sockeye Salmon, CT = Cutthroat Trout, TR = unknown trout spp., CC = sculpin (*Cottus* spp.), TSB = Threespine Stickleback , UNK = unknown fish species (fry mortalities that were too damaged to identify to species in the field).**

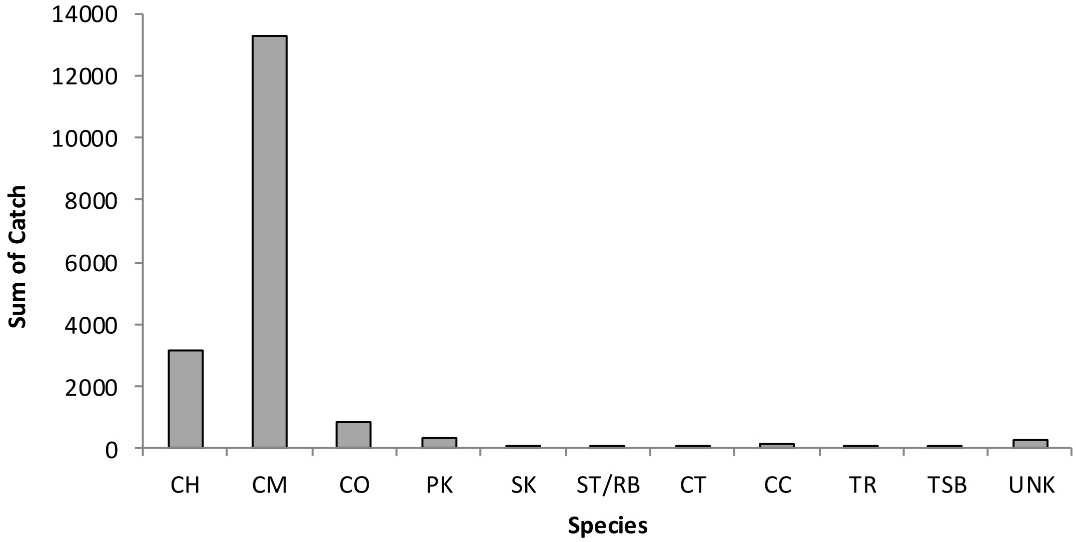


Figure 5. **Total RST catch by species from March 2 to July 11, 2019 excluding Chum and Chinook Salmon. ST/RB = Steelhead/Rainbow Trout, CO = Coho Salmon, PK = Pink Salmon, SK = Sockeye Salmon, CT = Cutthroat Trout, TR = unknown trout spp., CC = sculpin (*Cottus* spp.), TSB = Threespine Stickleback, UNK = unknown fish species (fry mortalities that were too damaged to identify to species in the field).**

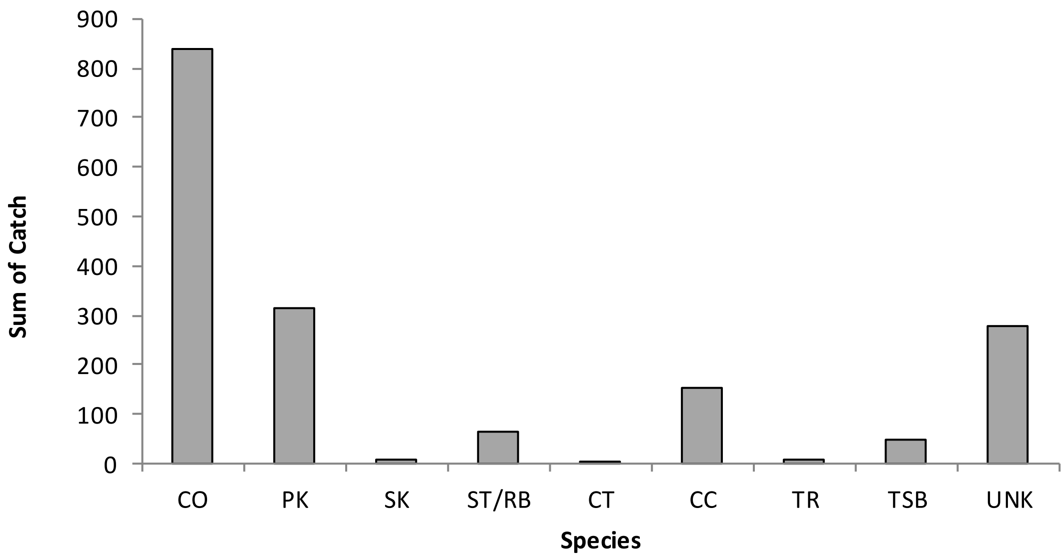


Figure 6. RST catch per-unit-effort of key salmonid species from March 2 to July 11, 2019.

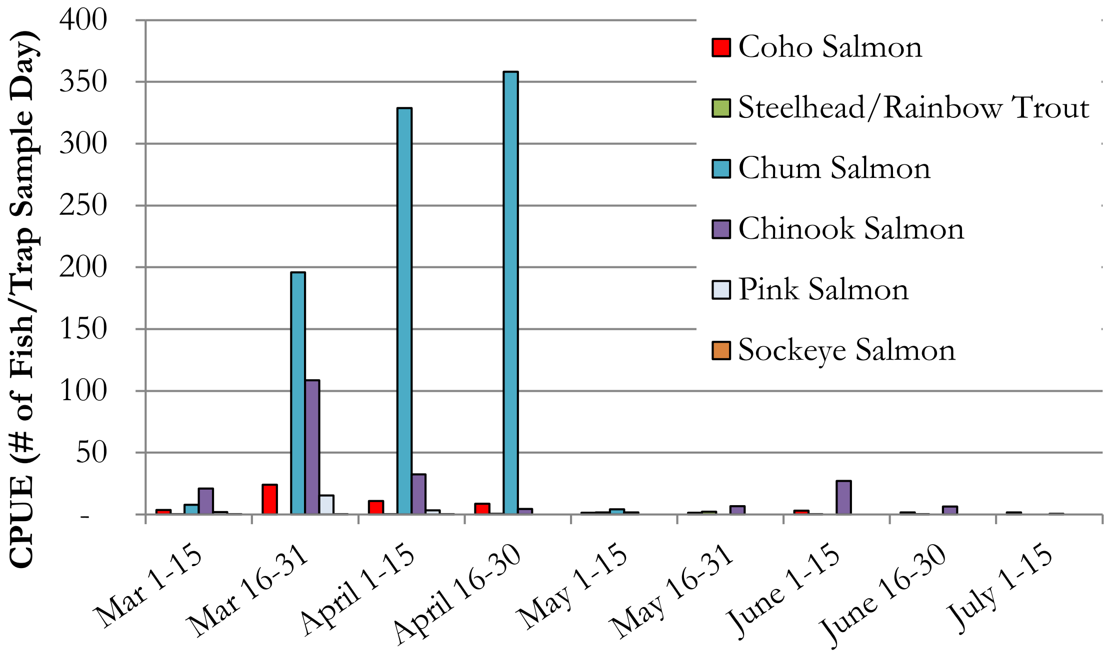


Figure 7. RST catch per-unit-effort of key salmonid species (excluding Chum Salmon) from March 2 to July 11, 2019.

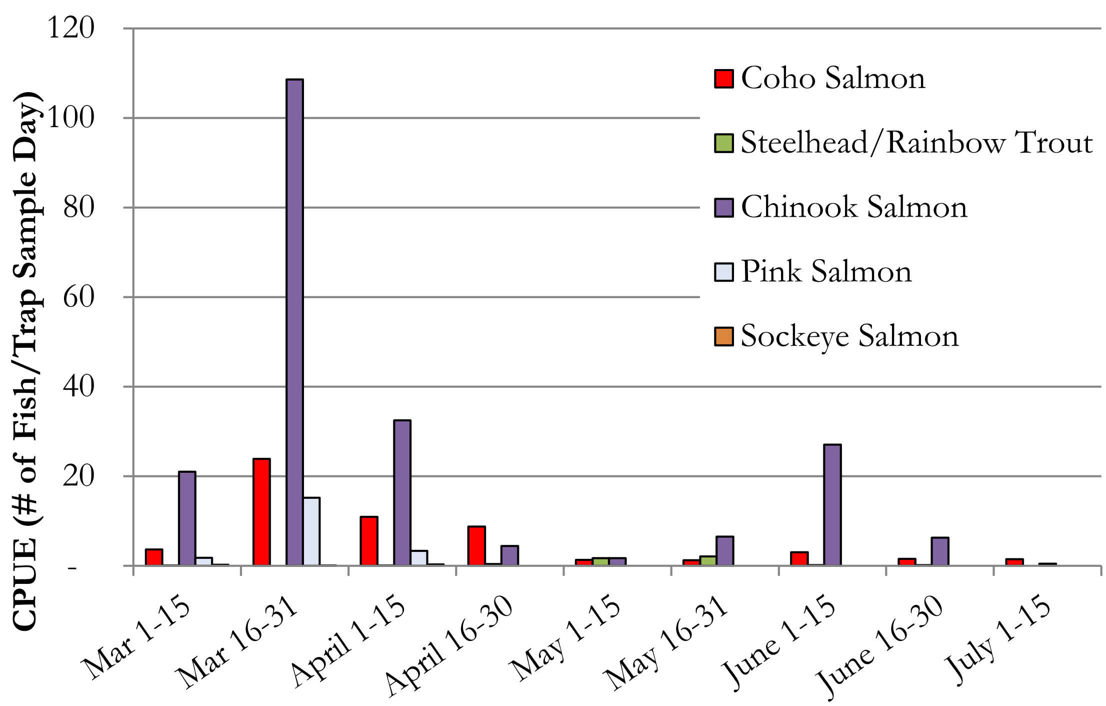


Figure 8. RST catches of a) Chinook Salmon, b) Coho Salmon, c) Steelhead/Rainbow Trout, d) Chum Salmon, e) Pink Salmon, and f) Sockeye Salmon.

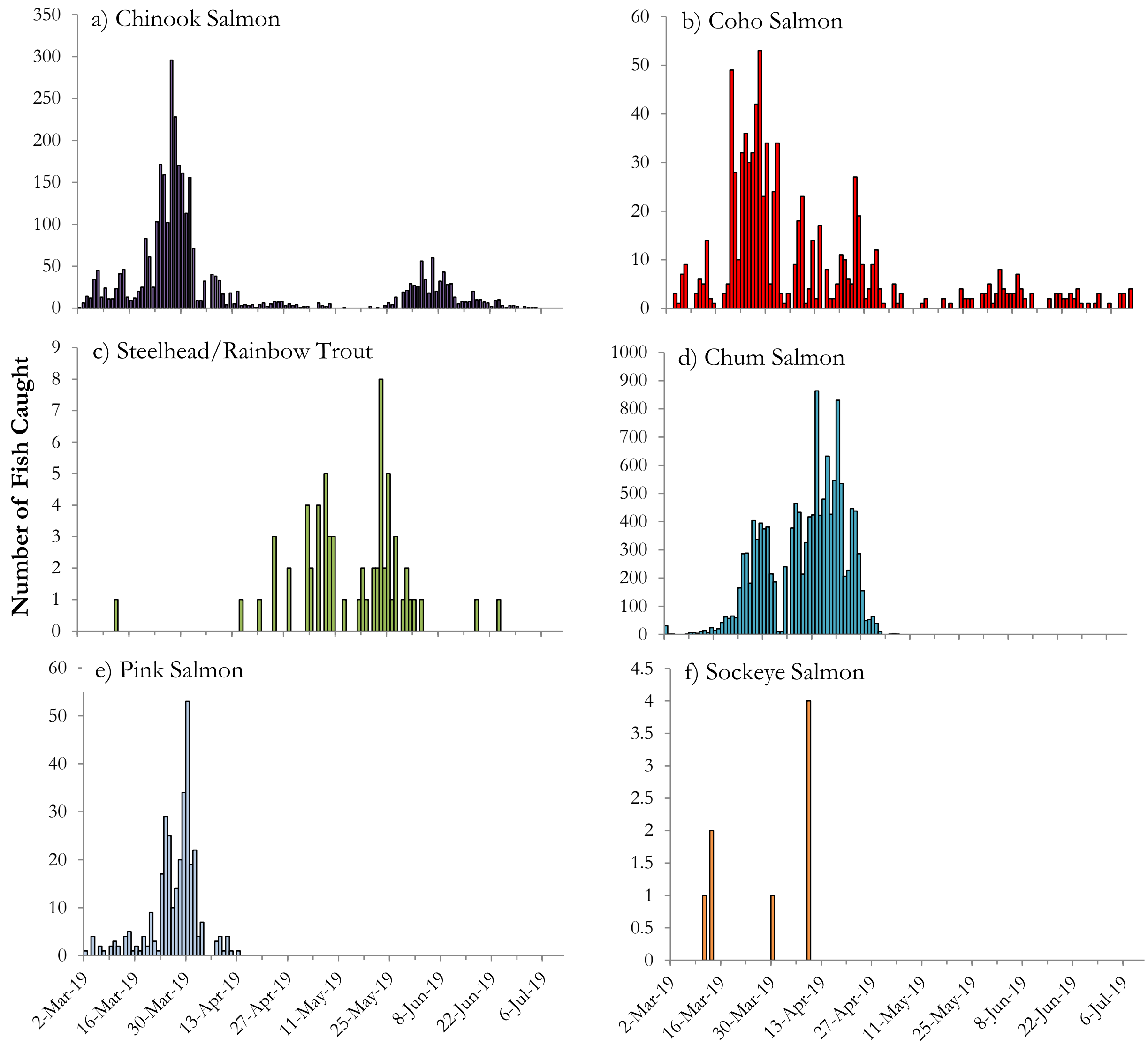


Figure 9. **Average fork length of Coho Salmon, Steelhead/Rainbow Trout, Chum Salmon, Chinook Salmon, Pink Salmon, and Sockeye Salmon during RST sampling period.**

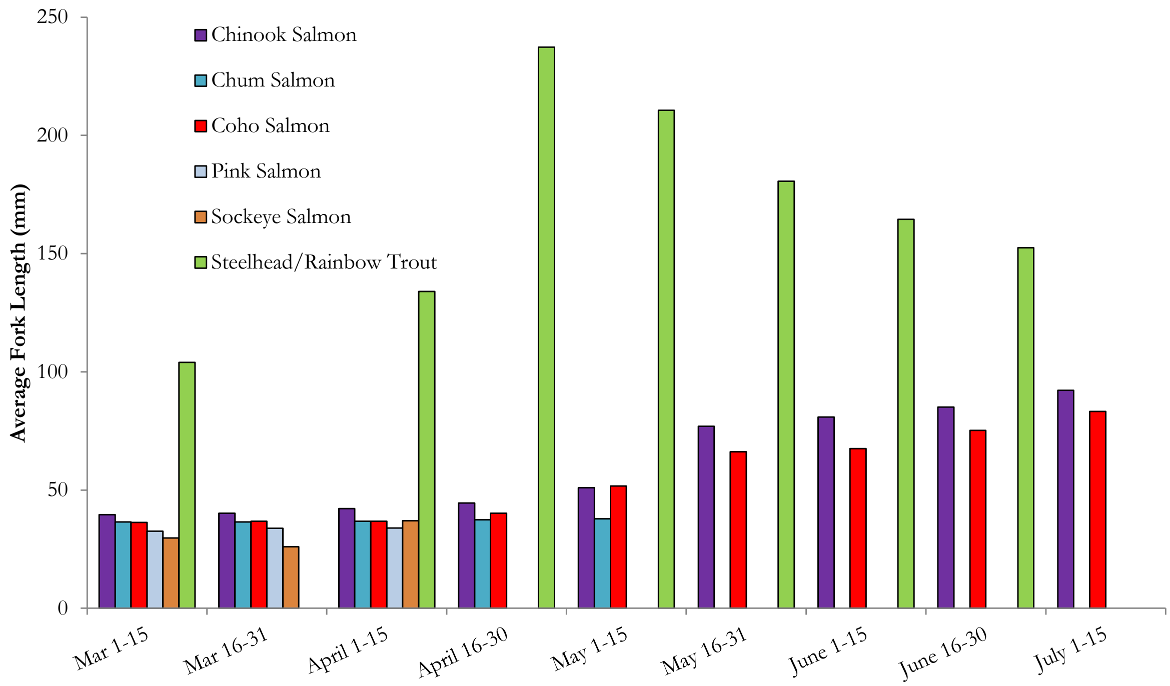


Figure 10. **Length frequency histogram of Chum Salmon captured in the RST by month.**

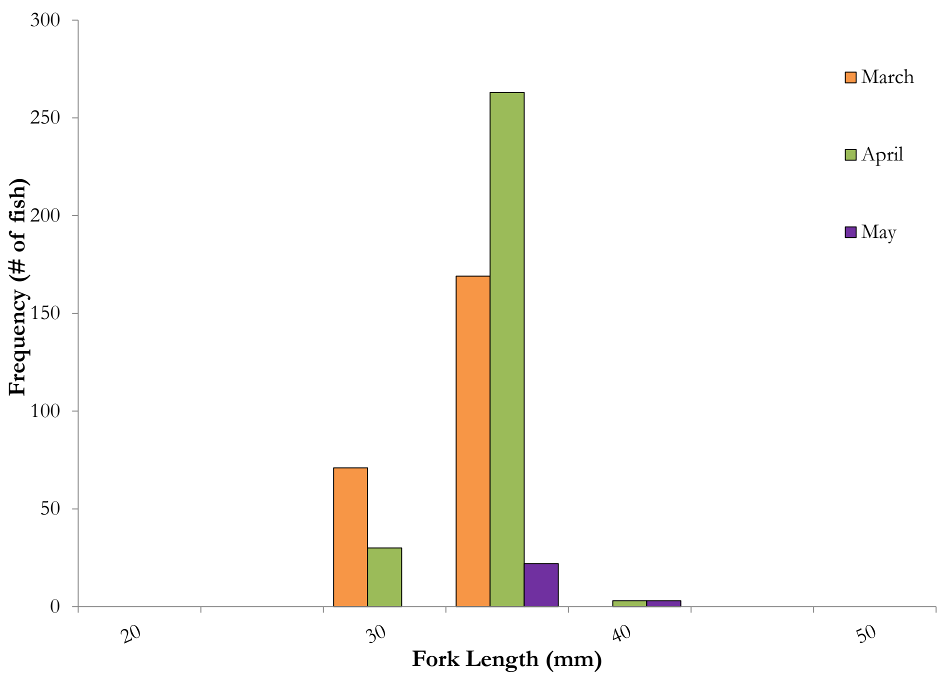


Figure 11. Length frequency histogram of Chinook Salmon captured in the RST by month.

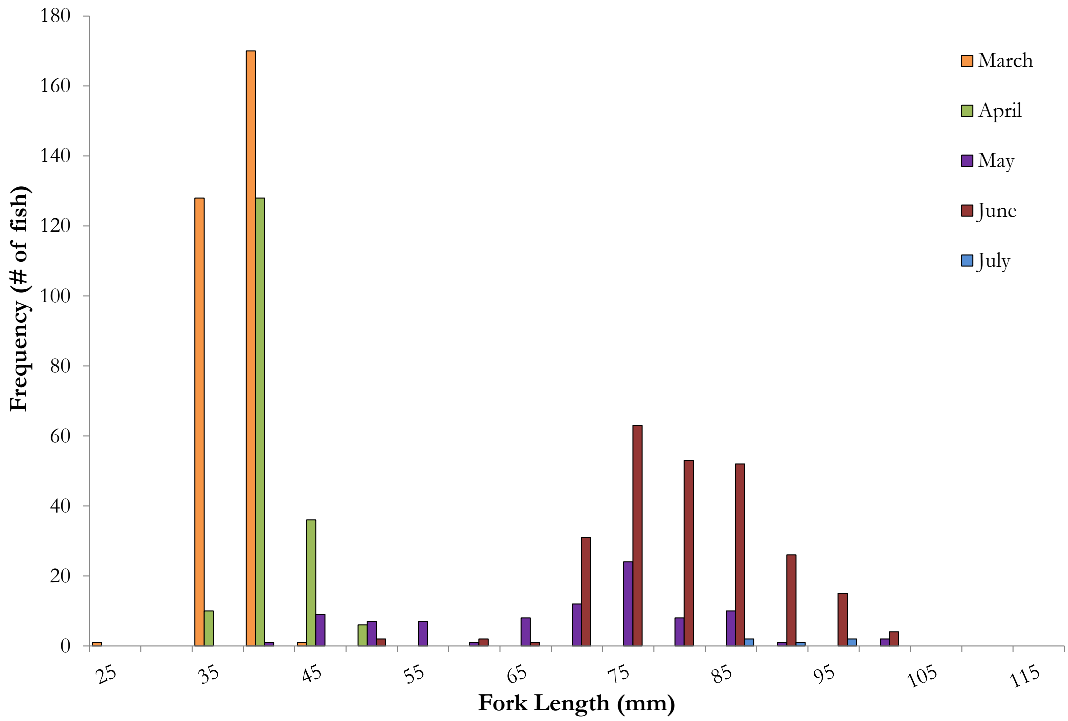


Figure 12. Length frequency histogram of Coho Salmon captured in the RST by month.

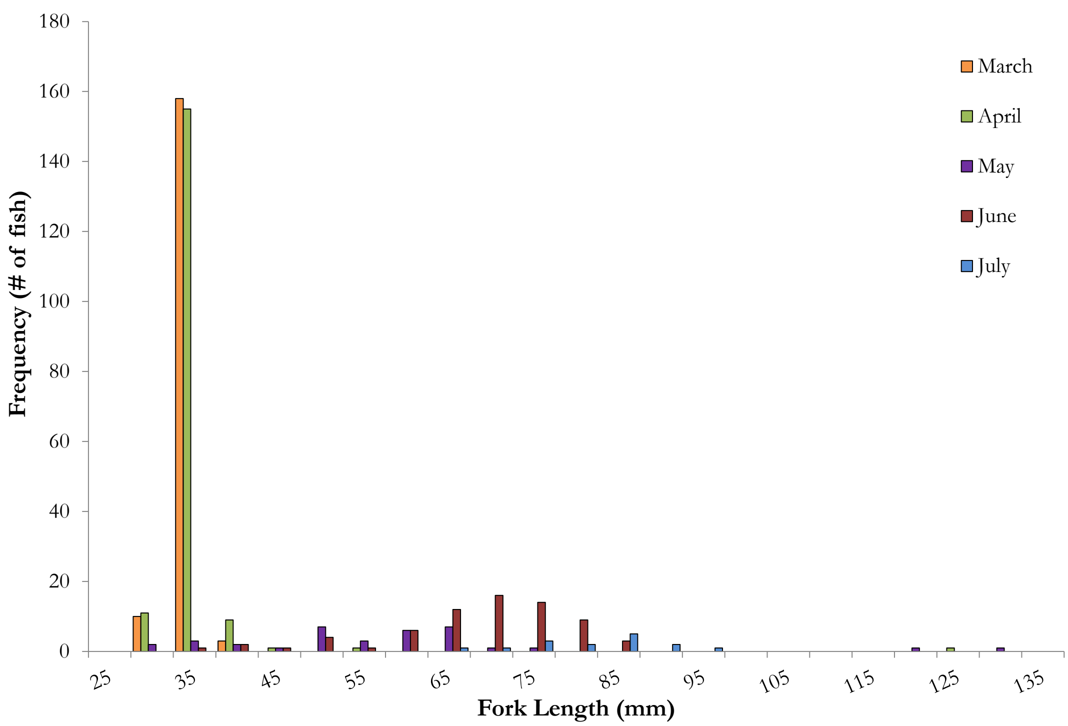
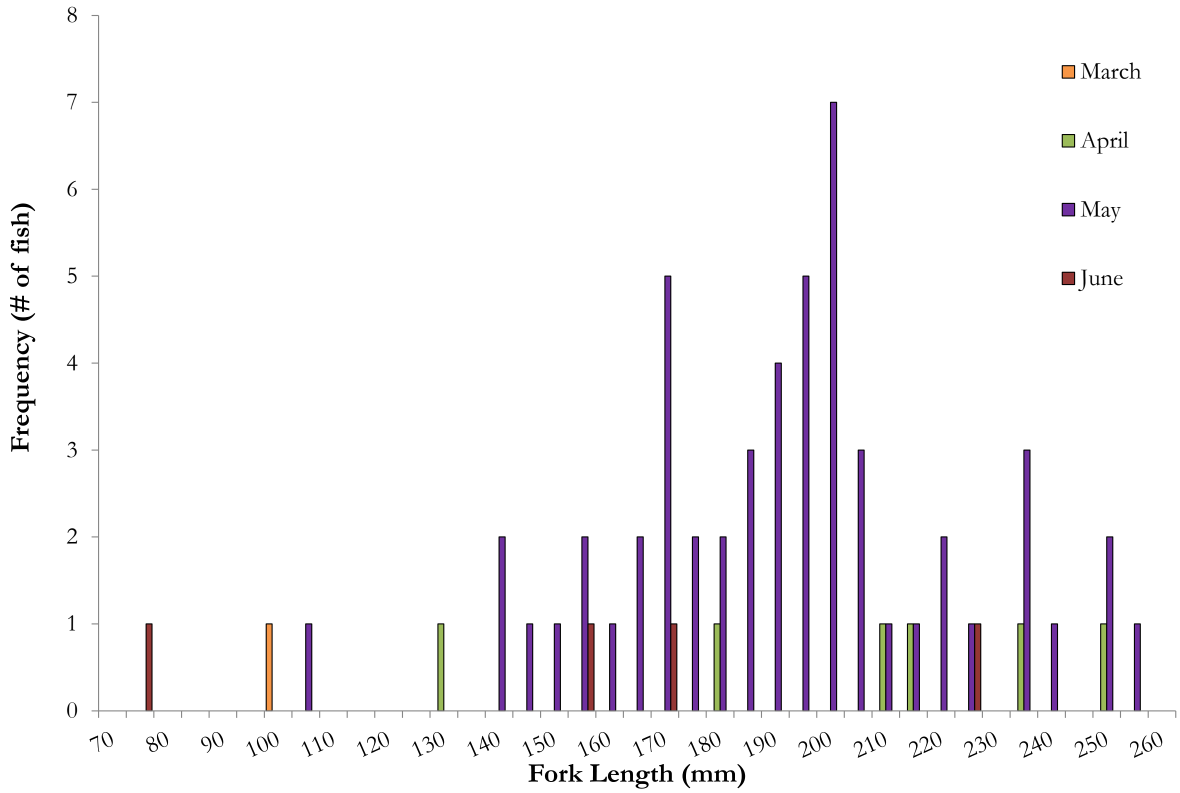


Figure 13. **Length frequency histogram of Steelhead/Rainbow Trout captured in the RST by month.**



3.1.2. RST Fish Age Data

Chinook Salmon caught in the RST that were aged ranged in fork length from 70 mm to 104 mm. Of the 10 Chinook Salmon scales samples that were aged, all were aged as 0+ fish (Figure 14, Table 9). Based on the size distribution of Chinook Salmon caught in the RST, it is concluded that all Chinook Salmon juveniles are 'ocean type' and likely leave Elk Canyon by the end of July.

Of the 11 Coho Salmon scales that were aged, 7 were aged as 0+ fish, 3 aged as 1+, and 1 aged as 2+ (Figure 14, Table 9). Coho Salmon caught in the RST that were aged ranged in fork length from 71 mm to 216 mm. Based on the size distribution of Coho Salmon caught in the RST, it is concluded that most Coho Salmon juveniles caught in the RST in 2019 were 0+ fish. However, three individuals were aged as 1+ and a single individual was aged 2+. This suggests that a small number of Coho Salmon juveniles may be overwintering in Elk Canyon.

Of the 21 Steelhead/ Rainbow Trout scales that were aged, three were aged as 1+, seven were aged as 2+, and eleven were aged as 3+ (Figure 14). Based on this aging data, and the length-frequency histograms from RST catch, all fish ≤80 mm are assumed 0+, fish 85 to 146 mm are assumed 1+, fish 148 to 199 mm are assumed 2+, fish 200 to 256 mm assumed 3+, and all fish >257 mm assumed >3+ (Table 9). There is uncertainty associated with these age break classifications for Steelhead/Rainbow Trout based on the low sample size of fish that were aged, and the relatively narrow range in fork length and date of age sample collection.

Figure 14. Length at age graphs for a) Chinook Salmon, b) Coho Salmon, and c) Steelhead/Rainbow Trout (scales).

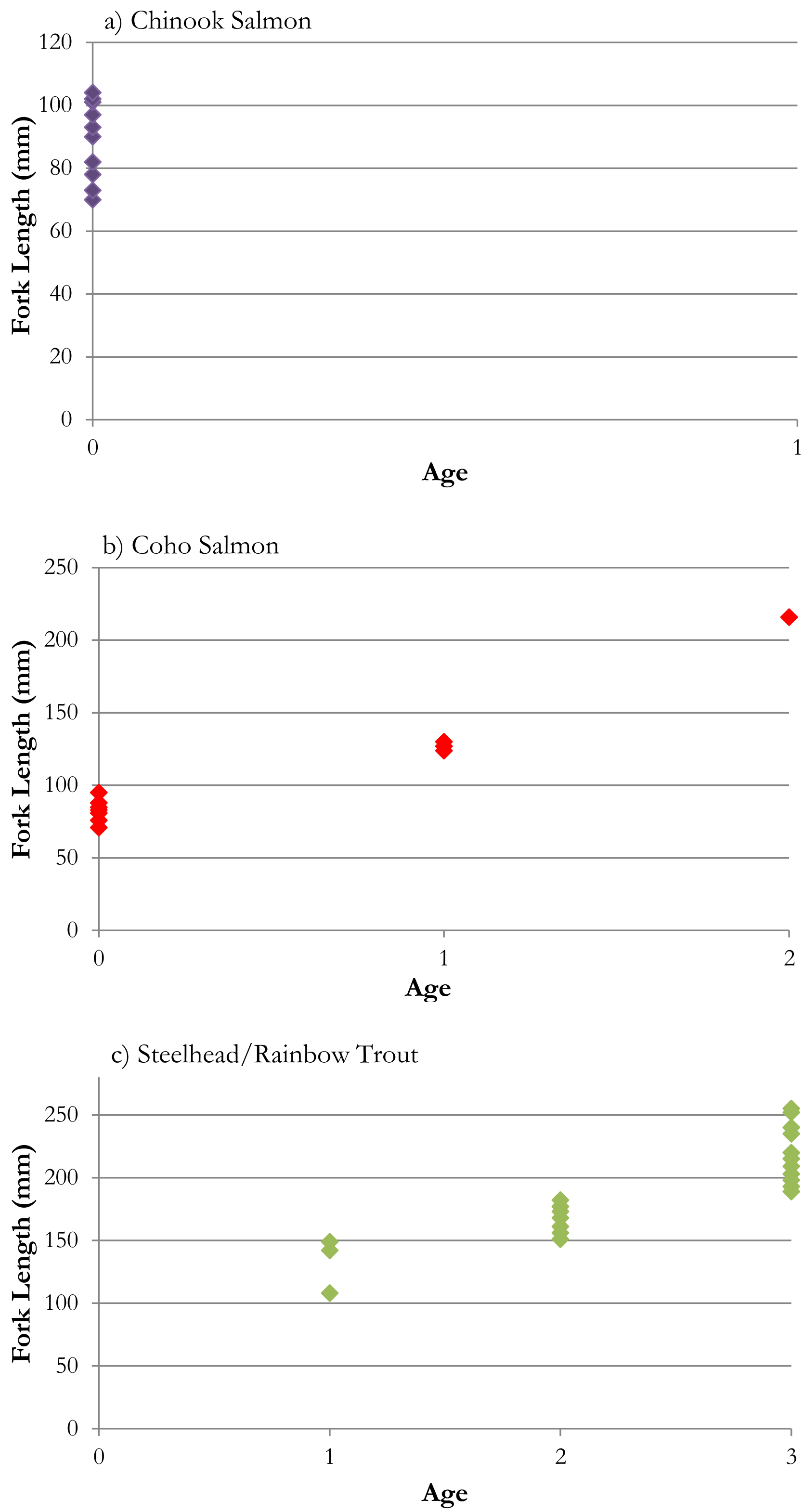


Table 9. Estimated size at age classification for juvenile Chinook Salmon, Coho Salmon, and Steelhead/Rainbow Trout.

Species	Age Class	Length bins (mm)
Chinook Salmon	0+	≤104
Coho Salmon [1]	0+	30-109
	1+	110+
Steelhead/Rainbow Trout	0+	≤80
	1+	85-146
	2+	148-199
	3+	200-256
	Adult >3+	257+

[1] 2+ coho length bins could not be assigned as only one individual was captured.

3.1.3. RST Mark-Recapture Data

The mark-recapture trials for salmon fry and smolts were used to estimate the capture efficiency of the RST and to ultimately generate outmigration abundance estimates from Elk Canyon.

Of the 2,448 released fish, 367 fish (15.0%) were recaptured. The capture efficiencies differed by life stage with fry experiencing lower capture efficiencies (average = 0.091) than smolts/parr (average = 0.333) (Table 10 and Table 11).

The trial capture efficiency estimates were based on recent recapture rates within the release periods (Table 10). Wild Chinook Salmon fry trial capture efficiencies ranged from 0.082 to 0.133 (mean = 0.109), while Hatchery Chinook salmon fry capture efficiencies ranged from 0.067 to 0.095 (mean = 0.081). Only one wild Coho Salmon mark recapture release was conducted with only 27 individuals released and one being recaptured for a capture efficiency of 0.037. Coho fry capture efficiency was not included in the overall average due to low release numbers. Wild Chum Salmon fry trial capture efficiencies ranged from 0.039 to 0.187 (mean = 0.090). The Chinook Salmon hatchery parr/smolt capture efficiencies ranged from 0.300 to 0.380 (mean = 0.333).

The overall capture efficiency estimates varied from 0.090 to 0.333 and were based on grouping the releases and recaptures for each species and life stage (Table 11). Excluding Coho Salmon fry, the overall capture efficiency for fry life stages was 0.091, with parr/smolt overall capture efficiency being 0.333. Overall capture efficiency across all life stages excluding Coho fry was 0.132 which is very similar to the value of 0.135 obtained in 2017 but lower than the average capture efficiencies from 2015 and 2016 of 0.208 and 0.167, respectively.

Table 10. Trial capture efficiency estimates for each corresponding release date during the mark-recapture study.

Species[1]	Fish Lifestage	Origin	Release Date	Total Released Fish	Total Recaptured Fish	Trial Capture Efficiency
Chinook Salmon	Fry	Hatchery	12-Mar-2019	193	13	0.067
			19-Mar-2019	200	19	0.095
		Wild	15-Mar-2019	51	5	0.098
			22-Mar-2019	82	10	0.122
			26-Mar-2019	90	12	0.133
			01-Apr-2019	146	12	0.082
					Average	**0.093**
	Parr	Hatchery	29-Apr-2019	200	64	0.320
			06-May-2019	200	76	0.380
			13-May-2019	200	60	0.300
					Average	**0.333**
Chum Salmon	Fry	Wild	19-Mar-2019	110	11	0.100
			22-Mar-2019	174	17	0.098
			26-Mar-2019	171	32	0.187
			01-Apr-2019	205	8	0.039
			15-Apr-2019	200	8	0.040
			23-Apr-2019	199	19	0.095
					Average	**0.090**
Coho Salmon	Fry	Wild	22-Mar-2019	27	1	0.037
					Overall Capture Efficiency Used (Fry)[2]	**0.091**
					Overall Capture Efficiency Used (Parr/Smolt)	**0.333**

[1] No Pink Salmon or Sockeye Salmon were marked in 2019.

[2] Coho fry were not included in the average due to low release numbers.

Table 11. Overall capture efficiency estimates for the mark-recapture study.

Species[1]	Total Number of Released Fish	Total Number of Recaptured Fish	Overall Capture Efficiency
Chinook Salmon Fry	762	71	0.093
Chinook Salmon Smolt	600	200	0.333
Chum Salmon Fry	1,059	95	0.090
Coho Salmon Fry	27	1	0.037
Overall Capture Efficiency Used (Fry)[2]	**1,821**	**166**	**0.091**
Overall Capture Efficiency Used (Parr/Smolt)	**600**	**200**	**0.333**

[1] No Pink Salmon or Sockeye Salmon were marked in 2019.

[2] Coho fry were not included in the average due to low release numbers.

3.1.4. Estimates of Salmonid Outmigration

Estimates of RST CPUE by half month (Table 12) and total outmigration of salmon smolts and fry (Table 13) were generated for Elk Canyon. Chinook Salmon outmigration was estimated to be 32,031 fry and 975 age 0+ smolts. Coho Salmon outmigration was estimated to be 8,339 fry, 296 age 0+ smolts, and thirteen 1+ smolts. Steelhead/Rainbow Trout outmigration was estimated to be 11 age 0+ fry, 16 age 1+ parr, 100 age 2+ parr, and 89 age 3+ smolts. Chum Salmon outmigration was the highest of all salmonid species with an estimated outmigration of 149,399 fry. Pink Salmon and Sockeye Salmon outmigration was estimated at 3,512 and 93 fry, respectively.

Overall, outmigration estimates in 2019 were similar to 2016 values but generally higher than 2017. It is likely that the low outmigration estimates in 2017 result from the large spill event between November 4 and 24, 2016, which was likely to have scoured out many of the redds within Elk Canyon. Outmigration estimates for Chinook fry were approximately double 2016 and 155 times 2017 estimates. Chinook smolt 0+ estimates were approximately half of 2016 and 2017. Coho fry outmigration estimates were approximately 1.4 times higher than 2016 and 66 times higher than 2017. Coho smolt 0+ were approximately one third of 2016 and two thirds of 2017. Coho smolts 1+ were approximately two thirds of 2016 whereas no 1+ smolts were captured in 2017. Steelhead/Rainbow Trout outmigration estimates for 2019 were generally lower than those obtained in 2016 and 2017 for 0+, 1+ parr and 2+ parr (Table 13). In contrast, outmigration estimates for 3+ smolts were approximately 1.5 times higher than 3+ outmigration in 2017. No 3+ individuals were captured in 2016. Outmigration estimates for Chum in 2019 were approximately half of 2016 but seven times higher than estimates from 2017. Pink Salmon fry outmigration in 2019 was estimated to be higher than in 2016 and 2017 at approximately four and 234 times higher, respectively (Table 13). Sockeye fry outmigration in 2019 was approximately one tenth of 2016 but similar to 2017 estimates.

Table 12. RST catch per-unit-effort (number of fish/day) by half month, salmon species and age class.

Date	Chinook Salmon		Coho Salmon			Steelhead/Rainbow Trout				Chum Salmon	Pink Salmon	Sockeye
	Fry 0+	Smolt 0+	Fry 0+	Smolt 0+	Smolt 1+	0+	1+	2+	3+	Fry 0+	Fry 0+	Salmon Fry 0+
Mar 1-15	21.0	0.0	3.6	0.0	0.0	0.0	0.1	0.0	0.0	7.7	1.8	0.2
Mar 16-31	108.6	0.0	23.9	0.0	0.0	0.0	0.0	0.0	0.0	195.8	15.2	0.1
April 1-15	32.5	0.0	10.9	0.0	0.0	0.0	0.1	0.0	0.0	328.9	3.4	0.3
April 16-30	4.5	0.0	8.6	0.0	0.1	0.0	0.0	0.1	0.3	358.3	0.0	0.0
May 1-15	1.6	0.1	1.2	0.1	0.1	0.0	0.1	0.5	1.2	4.2	0.0	0.0
May 16-31	2.2	4.3	0.3	0.9	0.1	0.0	0.1	1.5	0.5	0.0	0.0	0.0
June 1-15	16.2	10.9	0.5	2.5	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
June 16-30	0.7	5.6	0.1	1.5	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
July 1-15	0.0	0.5	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 13. Estimates of salmonid outmigration from Elk Canyon by salmon species and life stage based on RST catch.

Species	Life Stage	2016				2017				2019			
		Total RST Catch	Estimated Total Catch (# of fish)	Capture Efficiency	Estimated Outmigration (# of fish)	Total RST Catch (# of fish)	Estimated Total Catch (# of fish)	Capture Efficiency	Estimated Outmigration (# of fish)	Total RST Catch (# of fish)	Estimated Total Catch (# of fish)	Capture Efficiency	Estimated Outmigration (# of fish)
Chinook Salmon	Fry 0+	1,458	2,697	0.154	17,554	34	34	0.165	206	2,861	2,920	0.091	32,031
	Smolt 0+	191	330	0.182	1,819	196	196	0.104	1,888	318	325	0.333	975
Coho Salmon	Fry 0+	550	1,011	0.167	6,042	17	17	0.135	126	743	760	0.091	8,339
	Smolt 0+	112	208	0.239	871	58	63	0.135	461	90	99	0.333	296
	Smolt 1+	2	4	0.239	18	0	0	0.135	0	4	4	0.333	13
Steelhead/ Rainbow Trout	Fry 0+	5	9	0.167	53	3	4	0.135	28	1	1	0.091	11
	Parr 1+	13	24	0.167	145	9	10	0.135	72	5	5	0.333	16
	Parr 2+	75	140	0.167	835	10	10	0.135	74	31	33	0.333	100
	Smolt 3+	0	0	0.167	0	7	7	0.135	54	27	30	0.333	89
Chum Salmon	Fry 0+	20,201	36,735	0.135	271,301	2,784	2,788	0.133	20,997	13,274	13,619	0.091	149,399
Pink Salmon	Fry 0+	141	274	0.324	846	2	2	0.135	15	315	320	0.091	3,512
Sockeye Salmon	Fry 0+	82	148	0.167	884	18	18	0.135	133	8	9	0.091	93

ECOFISH RESEARCH

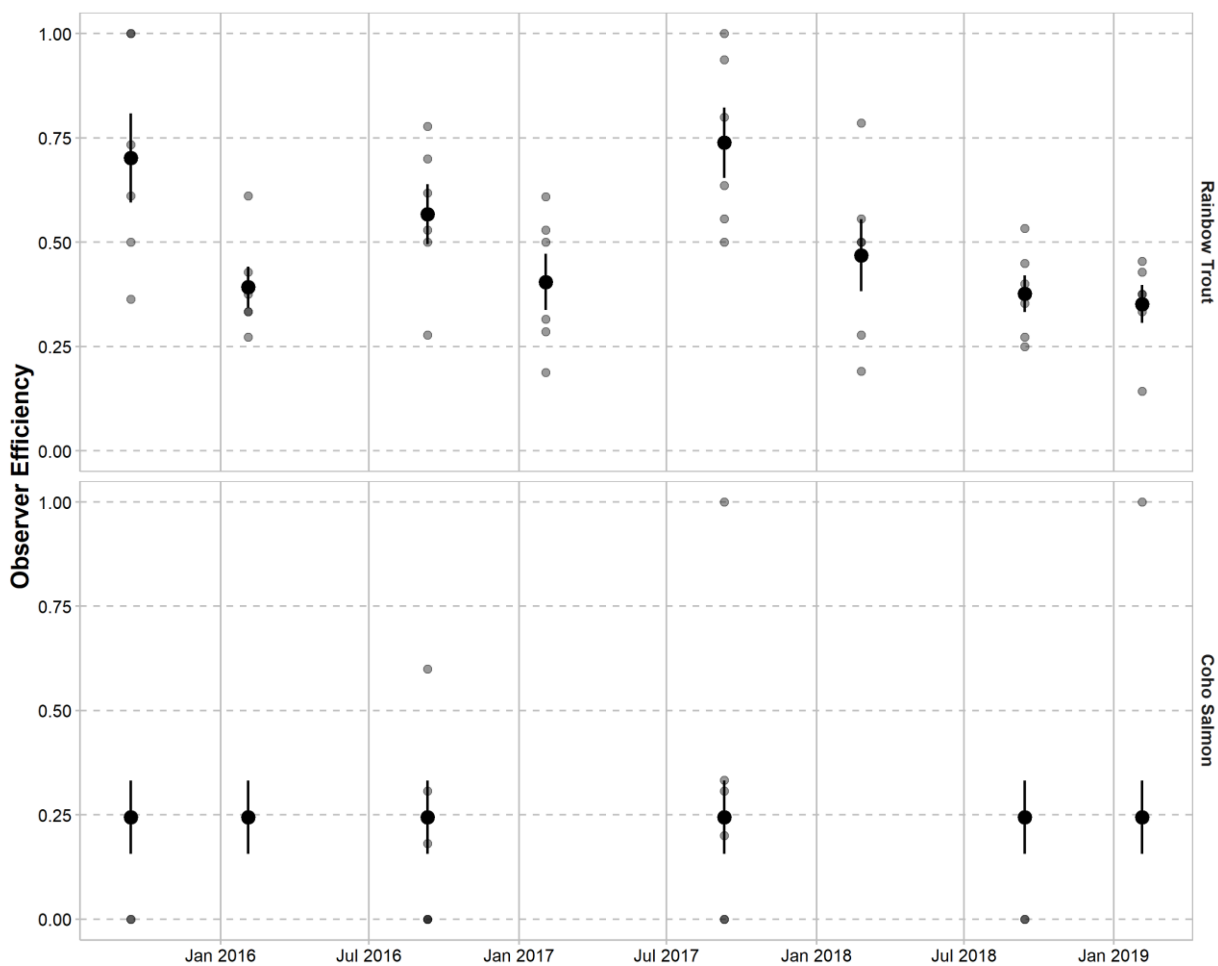
3.2. Overwintering Assessment

3.2.1. Observer Efficiencies

Sufficient re-sights of Rainbow Trout were obtained to estimate observer efficiencies for each of the eight mark-re-sights experiments, whereas enough re-sights of Coho Salmon were obtained only in two mark-re-sights experiments (fall 2016 and fall 2017, Figure 15). Thus, overall mean observer efficiency was used to estimate fish density for Coho Salmon.

Steelhead/Rainbow Trout parr densities estimated using the observer efficiency and Peterson methods were very similar in all cases (Figure 16). Given the similar patterns in the estimates of Rainbow Trout densities obtained using the observer efficiency and Peterson methods, we tested $H_0$2 using observer efficiency density estimates only.

Figure 15. Observer efficiencies of Rainbow Trout ages 1+ to 3+ and Coho Salmon ages 0+ to 1+ for mark-resight experiments carried out during fall and spring 2015-2019. Gray points are the observer efficiency estimates, black points represent the means, and vertical bars represent ± standard error (SE).



3.2.2. Test of H_02

Steelhead/Rainbow Trout parr density was similar between fall (September) and early spring (February) sampling seasons in Elk Canyon during the four years of monitoring (2016-2019) (Figure 16, Figure 17). Steelhead/Rainbow Trout density was higher during the early spring than during the fall in two of the paired samples (fall 2016-spring 2017 (red dots in Figure 16), and fall 2017-spring 2018 (green dots in Figure 16)), whereas the opposite was true for the remaining two paired samples. There was considerable inter site variation in the estimates of Steelhead/Rainbow Trout density, ranging from around 2 to 32 fish/100 m^2, whereas there was less variability in the mean densities by survey, ranging from around 6 to 14 fish/100 m^2.

Across all four years of overwintering assessment data collection, the effect of season on the density of Steelhead/Rainbow Trout was not significant, i.e., the 95% credible intervals of the mean posterior estimate of the parameter encompasses zero (Figure 16). The mean posterior estimate of the change in area density due to season was -0.6 (95% CI: -4.2 to 3). Average Steelhead/Rainbow Trout density was 10.8 fish/100m^2 (SE: 1.4 fish/100m^2) in the fall and 10.2 fish/100m^2 (SE: 1.2 fish/100m^2) in the early spring prior to outmigration. Therefore, across all four years of the overwintering assessment we conclude that Steelhead/Rainbow Trout overwinter in Elk Canyon and that the number of rearing residents deemed likely to smolt the following spring, as measured during September, is not significantly different from the abundance estimate obtained in February prior to the onset of their outmigration.

Coho Salmon juveniles were observed during fall surveys in all four years of the monitoring program. Across all sites, estimates of Coho Salmon density in the fall ranged from 0 to 57.4 fish/100 m^2. Mean Coho Salmon density was 11.6 fish/100 m^2 (SE: 4.35 fish/100 m^2) during fall 2015, 24.7 fish/100 m^2 (SE: 6.62 fish/100 m^2) during fall 2016 and 16.9 fish/100 m^2 (SE: 2.15 fish/100 m^2) during fall 2017 (Figure 18). Mean Coho density could not be calculated for fall 2018 as only one fish was observed during the re-sight swim. In comparison, in the spring, three Coho Salmon were observed during the 2016 spring survey (these were observed during the re-sight swim and thus fish density could not be estimated), 0 were observed in 2017 and 2018, and five were observed during the 2019 spring survey. The low abundance of Coho Salmon parr in the spring surveys of 2016 and 2019 coupled with their absence in 2017 and 2018 indicate that very few Coho Salmon overwinter in Elk Canyon. We therefore reject H_02 for Coho Salmon parr.

Figure 16. Rainbow Trout ages 1+ to 3+ area density estimates for the four years of monitoring. Translucent points are the area density estimates, and solid points with vertical bars represent the means ± standard error (SE). Circles represent estimates obtained using observer efficiency estimates, and triangles represent estimates obtained using the Peterson estimator with Chapman modification. Colours indicate paired surveys by monitoring year.

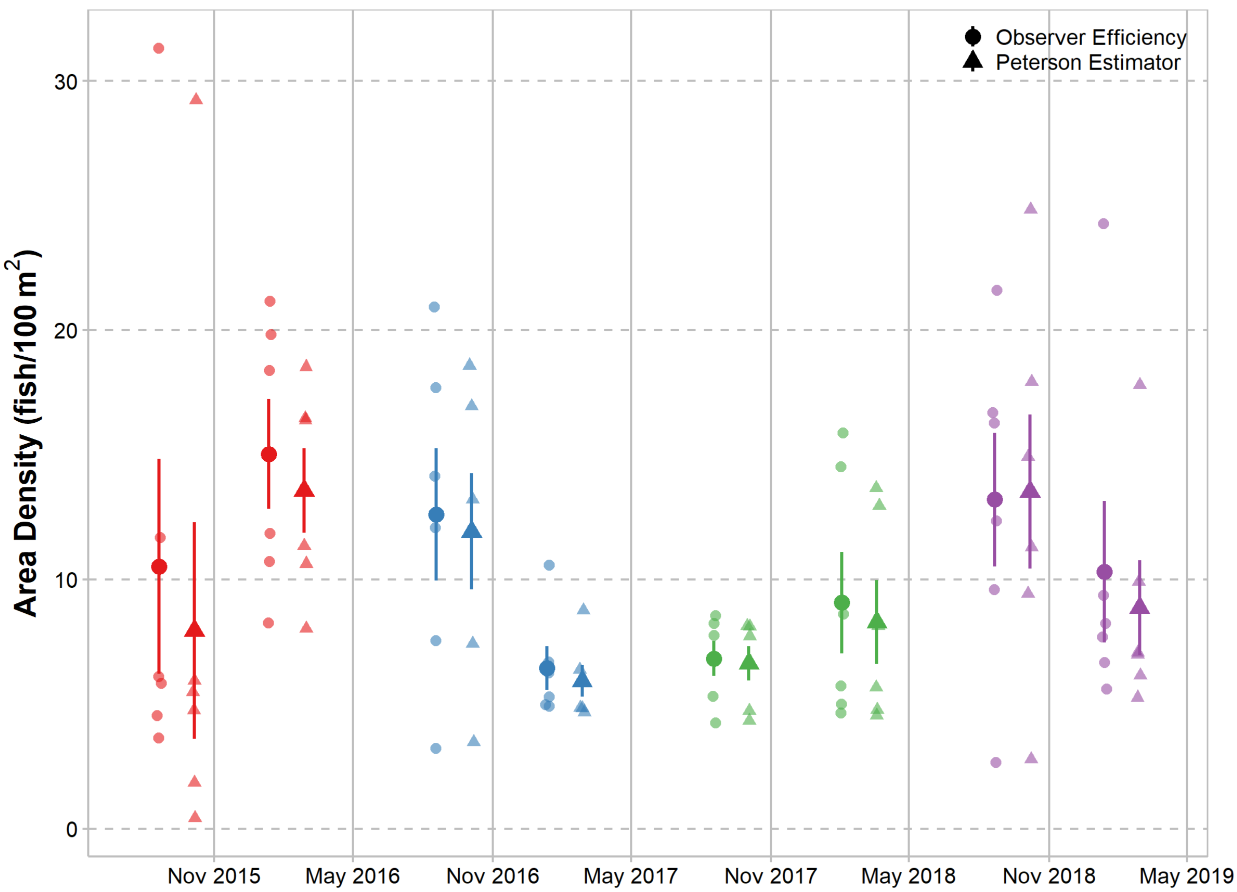


Figure 17. Test of H_02. A) Rainbow Trout ages 1+ to 3+ area density estimates obtained using observer efficiency for the four years of monitoring. Translucent points are the area density estimates, and solid points with vertical bars represent the means ± standard error (SE). Colours indicate paired surveys by monitoring year. B) Posterior mean and 95% credible interval of the parameter for the effect of season on the density of fish. Overlap of the 95% credible interval with zero indicates that the likelihood that Rainbow Trout density differs by season is small.

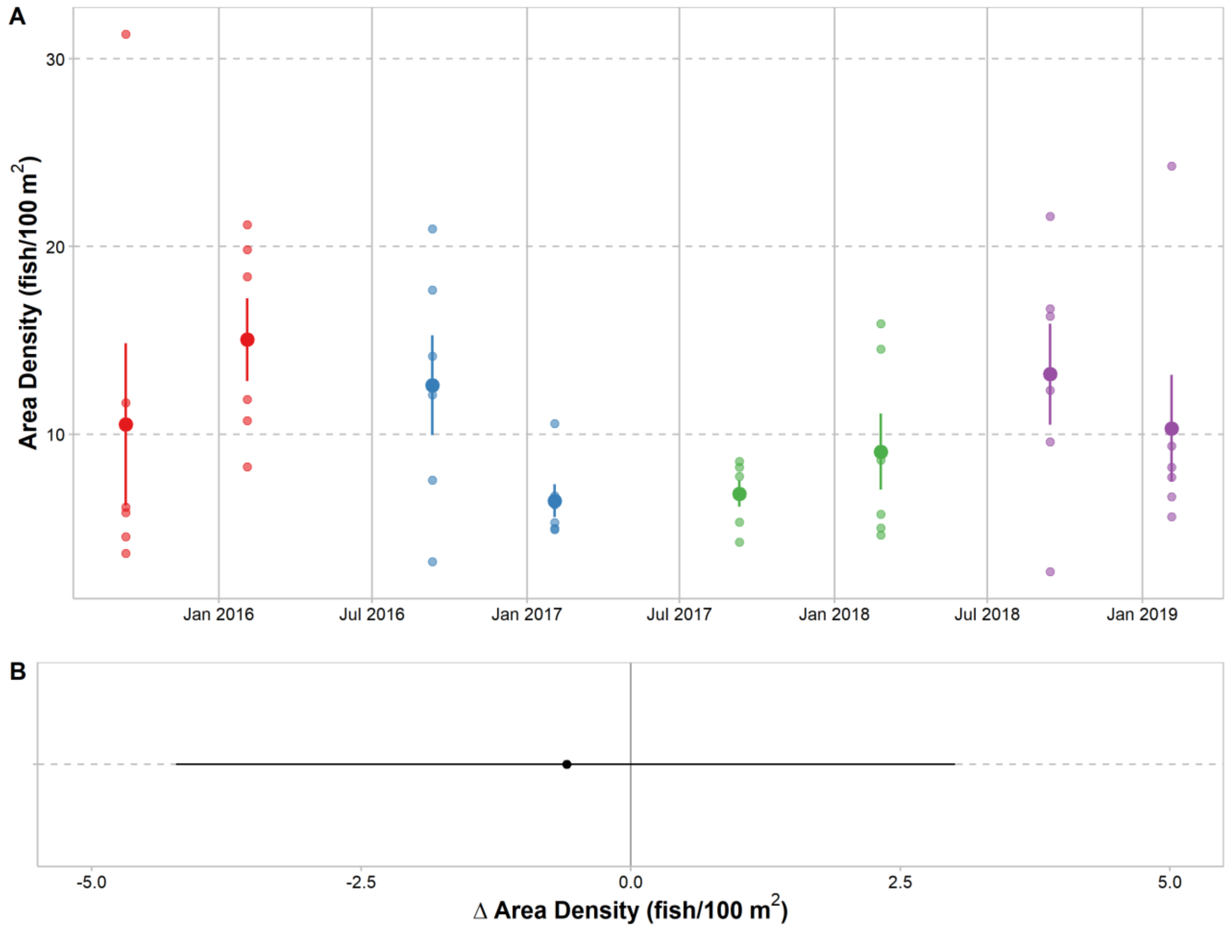
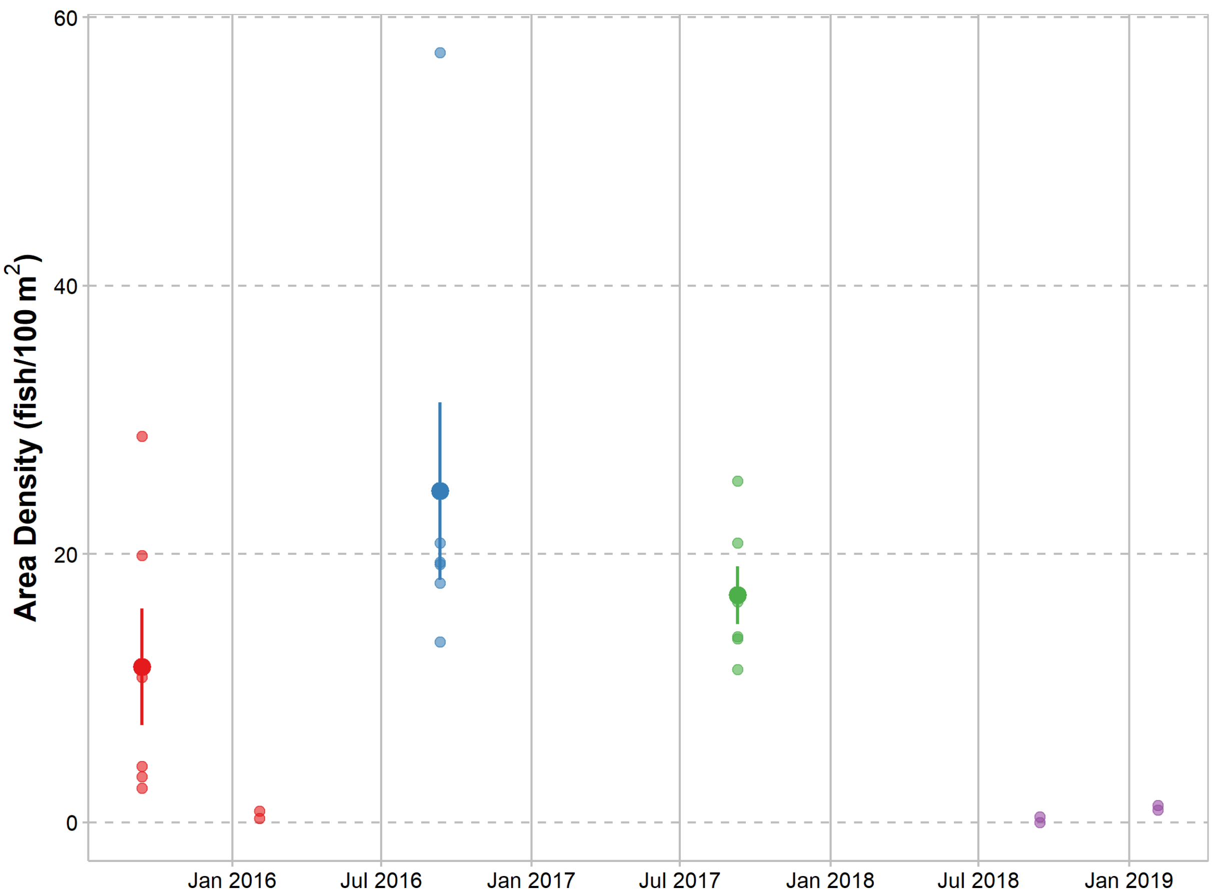


Figure 18. Coho Salmon ages 0+ to 1+ area density estimates obtained using observer efficiency for the four years of monitoring. Translucent points are the area density estimates, and solid points with vertical bars represent the means ± standard error (SE). Colours indicate paired surveys by monitoring year.



3.3. Pulse Flow Assessment

3.3.1. Fall Pulse Flow Assessment

3.3.1.1. Summary of Salmon Counts

Across all three years of fall pulse flow assessment data collection (2015, 2016, and 2018), the counts of Chinook Salmon peaked in mid-October, two weeks earlier than Coho and Chum Salmon, which both peaked in late October (Figure 19). No distinct peak in abundance was observed for Steelhead.

Surveys of adult salmon and Steelhead were paired pre and post pulse Salmon counts in the paired surveys both pre-pulse and post-pulse were similar across all three years (Figure 19). These were higher during the post-pulse surveys in only a few of the paired observations: two observations for Chinook Salmon in each of 2015 and 2016, none in 2018; two observations for Coho Salmon in 2015, three in 2016 and two in 2018; three observation for Steelhead in 2015 and 2016, and two in 2018; one observation for Chum Salmon in 2015, three in 2016, and one in 2018 (Figure 19).

3.3.1.2. Test of H_05

The abundance of Coho Salmon, Chinook Salmon, Chum Salmon, and Steelhead in Elk Canyon did not differ the day after the 2-day 7 m^3/s fall pulse release compared to the day prior to the pulse release. Therefore, the null hypothesis of H_05 of no difference in the number of spawning salmonids following pulse flow release compared to just prior to the release was not rejected.

Patterns of variation in the counts of Pacific Salmon in Elk Canyon were well described by the generalized additive mixed models (Figure 20A, Figure 21A, Figure 22A). Given the high inter-survey variability observed in Steelhead abundance, the effect of day of the year on the counts was estimated as constant (Figure 23A). The mean effects of pulse flow release operation on the counts of Chinook Salmon was -0.8 fish (95% confidence interval: -13.6 fish – 11.9 fish, Figure 20B), on the counts of Coho Salmon was 3.4 fish (95% confidence interval: -21.5 fish – 28.4 fish, Figure 21B), on the counts of Chum Salmon was -4.7 fish (95% confidence interval: -51.7 fish – 42.4 fish, Figure 22B), and on the counts of Steelhead was -0.04 fish (95% credible interval: -1.14 fish – 1.07 fish, Figure 23B), i.e., mean counts were higher prior to the pulse release than following the pulse for all species considered except for Coho Salmon. However, none of these effects were statistically significant (i.e., the 95% confidence (or credible) intervals for the parameters encompass zero).

The abundance of early spawners Coho Salmon, Chinook Salmon, and Chum Salmon in Elk Canyon did not differ the day after the 2-day 7 m^3/s fall pulse release compared to the day prior to the pulse release. Therefore, the hypothesis of no difference in the number of early spawning salmonids following pulse flow release compared to just prior to the release was not rejected.

The mean effects of pulse flow release operation on the counts of Chinook Salmon was -3 fish (95% confidence interval: -22.5 fish – 16.3 fish, Figure 23A), on the counts of Coho Salmon was 7.1 fish (95% confidence interval: -18.9 fish – 33.3 fish, Figure 23B), and on the counts of Chum Salmon was -10.8 fish (95% confidence interval: -37.6 fish – 59.4 fish, Figure 23B). None of these effects were statistically significant (i.e., the 95% confidence (or credible) intervals for the parameters encompass zero).

Figure 19. Fall salmon count in Elk Canyon pre and post the 2-day 7 m^3/s pulse releases. Target species include A) Chinook Salmon, B) Coho Salmon, C) Chum Salmon, and D) Steelhead.

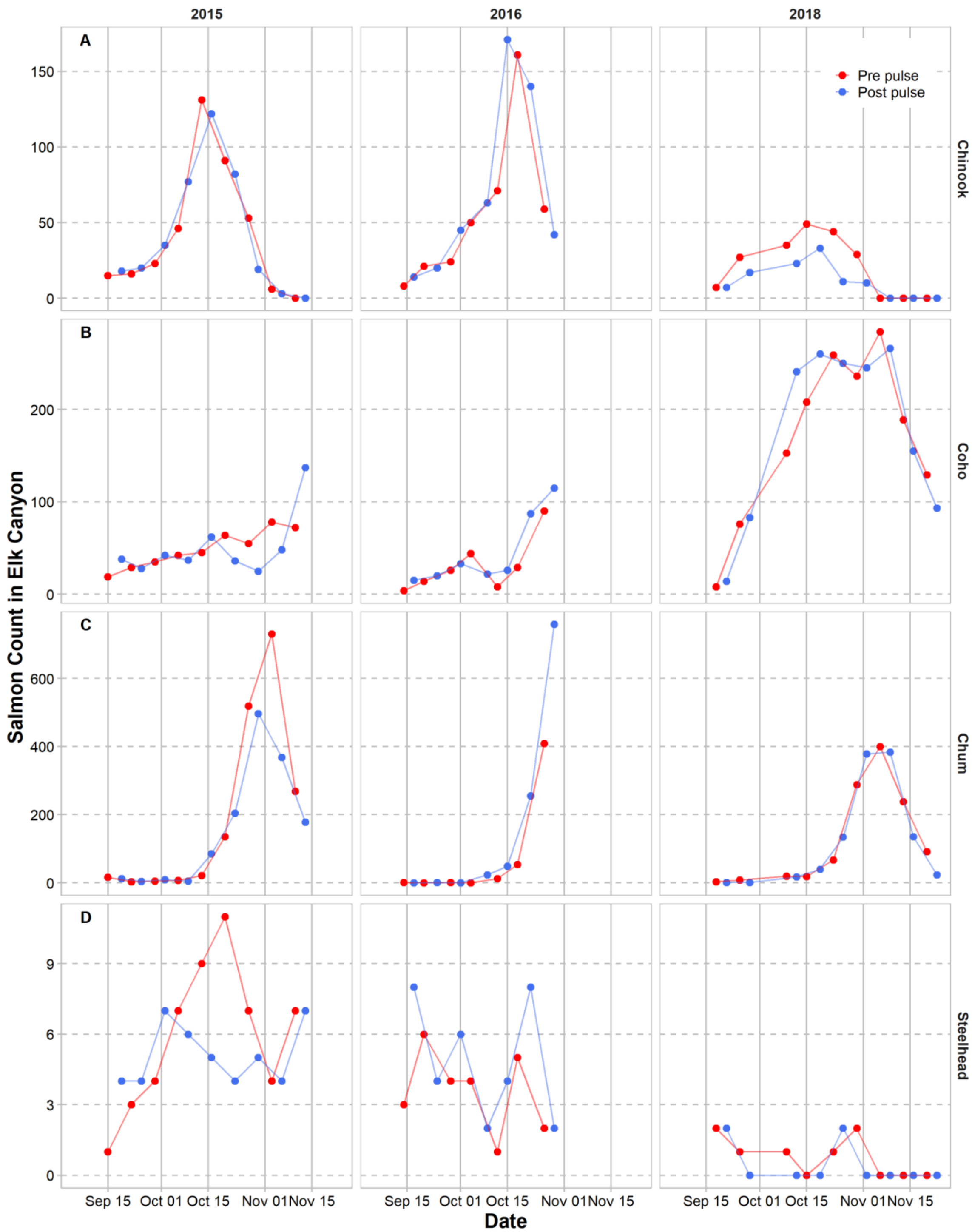


Figure 20. A) Fit of the General Additive Mixed Model to describe the number of Chinook Salmon in Elk Canyon as a function of day of year and pulse flow release operation. B) Point estimate and 95% credible interval of the parameter for the effect of pulse flow release operation on the number of Chinook Salmon in Elk Canyon. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.

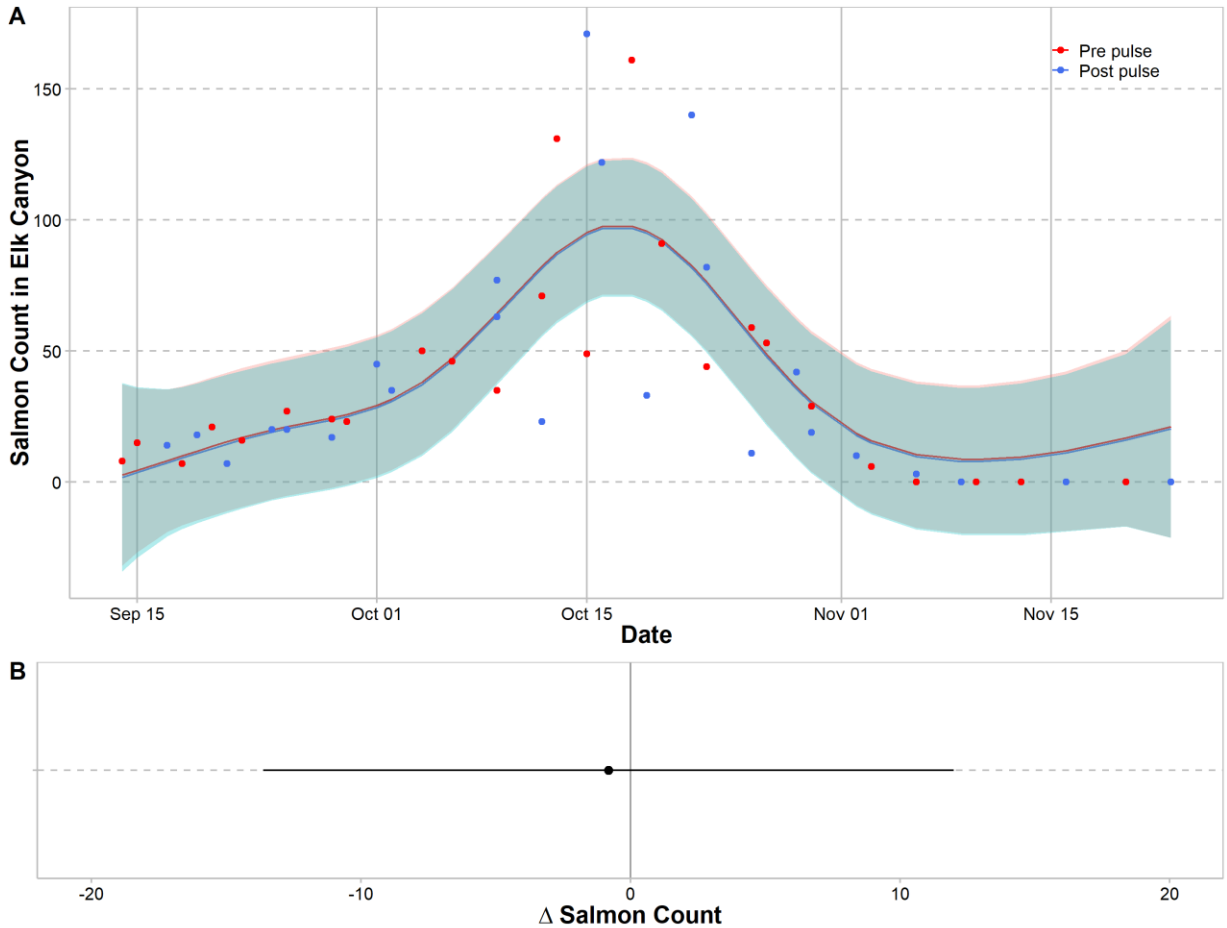


Figure 21. A) Fit of the General Additive Mixed Model to describe the number of Coho Salmon in Elk Canyon as a function of day of year and pulse flow release operation. B) Point estimate and 95% credible interval of the parameter for the effect of pulse flow release operation on the number of Coho Salmon in Elk Canyon. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.

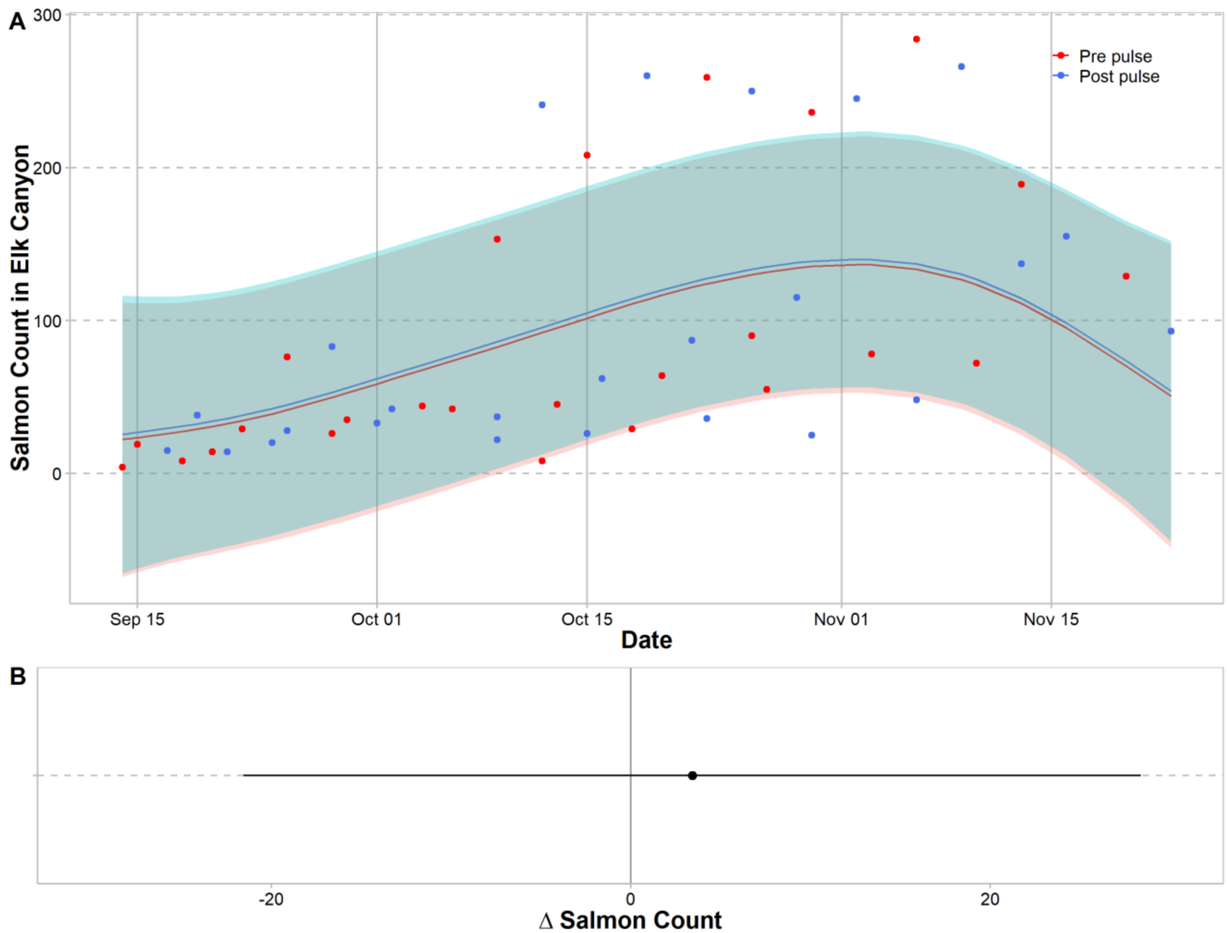


Figure 22. A) Fit of the General Additive Mixed Model to describe the number of Chum Salmon in Elk Canyon as a function of day of year and pulse flow release operation. B) Point estimate and 95% credible interval of the parameter for the effect of pulse flow release operation on the number of Chum Salmon in Elk Canyon. Overlap of the 95% confidence interval with zero indicates that the likelihood of an effect is small.

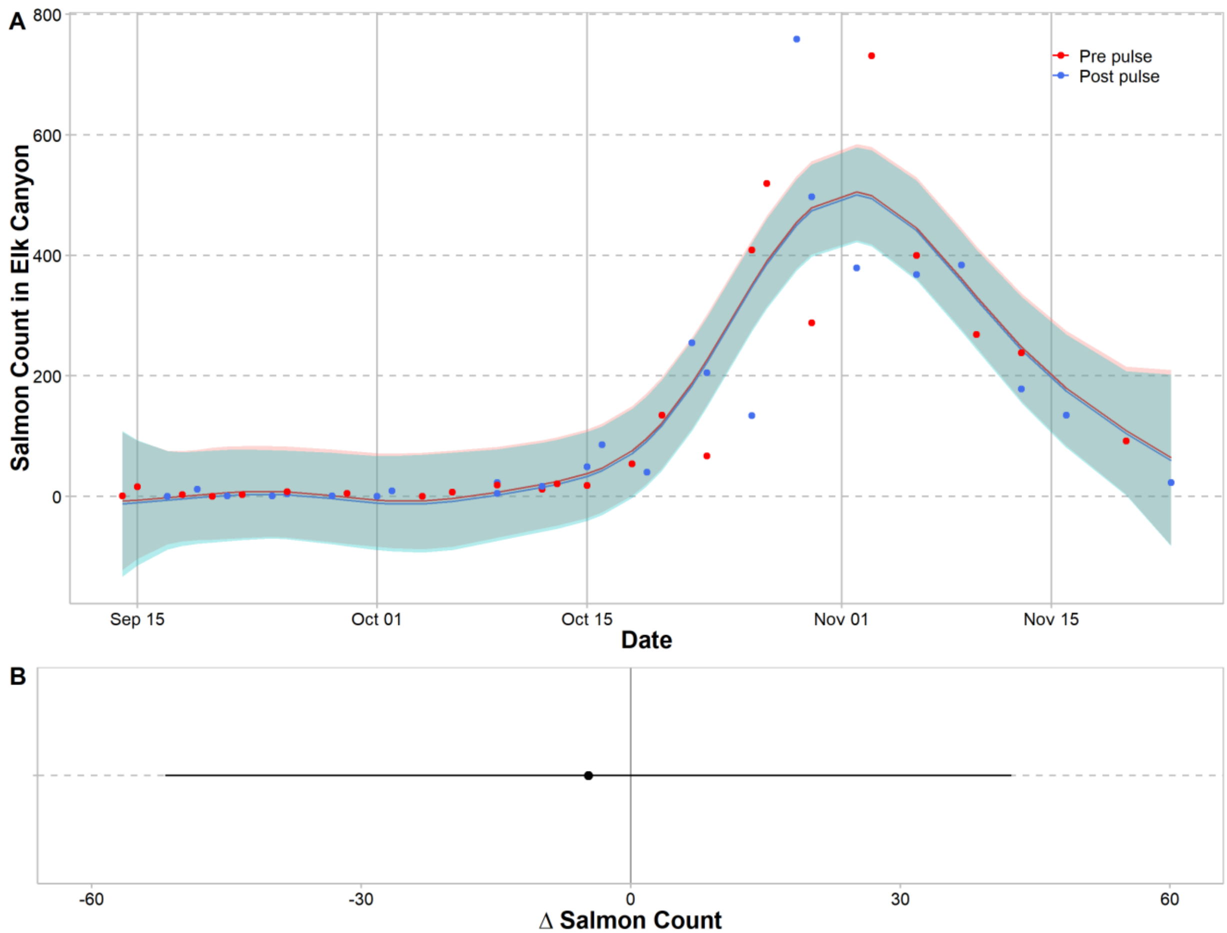


Figure 23. A) Fit of the General Additive Mixed Model model to describe the number of Steelhead in Elk Canyon as a function of day of year and pulse flow release operation. B) Posterior mean and 95% credible interval of the parameter for the effect of pulse flow release operation on the number of Steelhead in Elk Canyon. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.

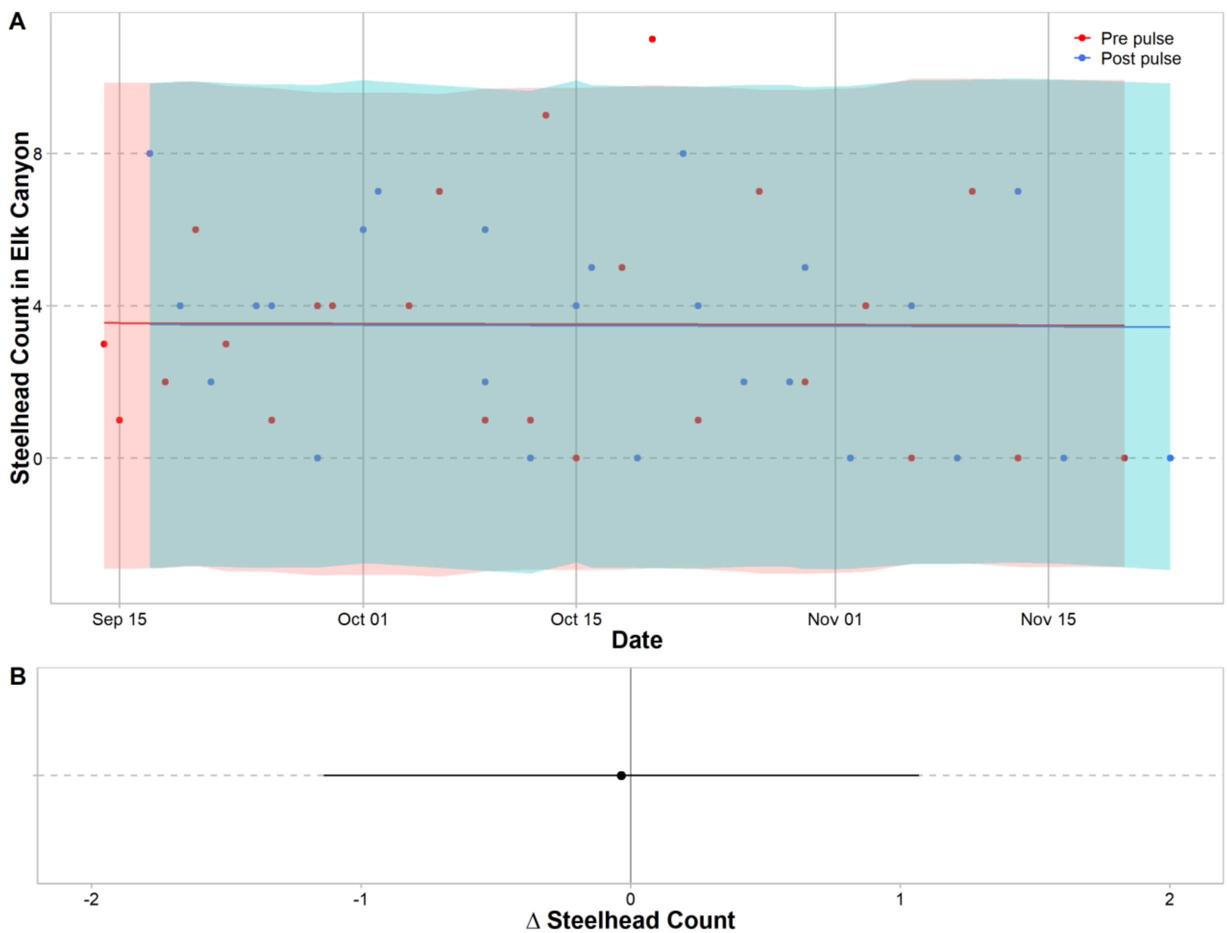
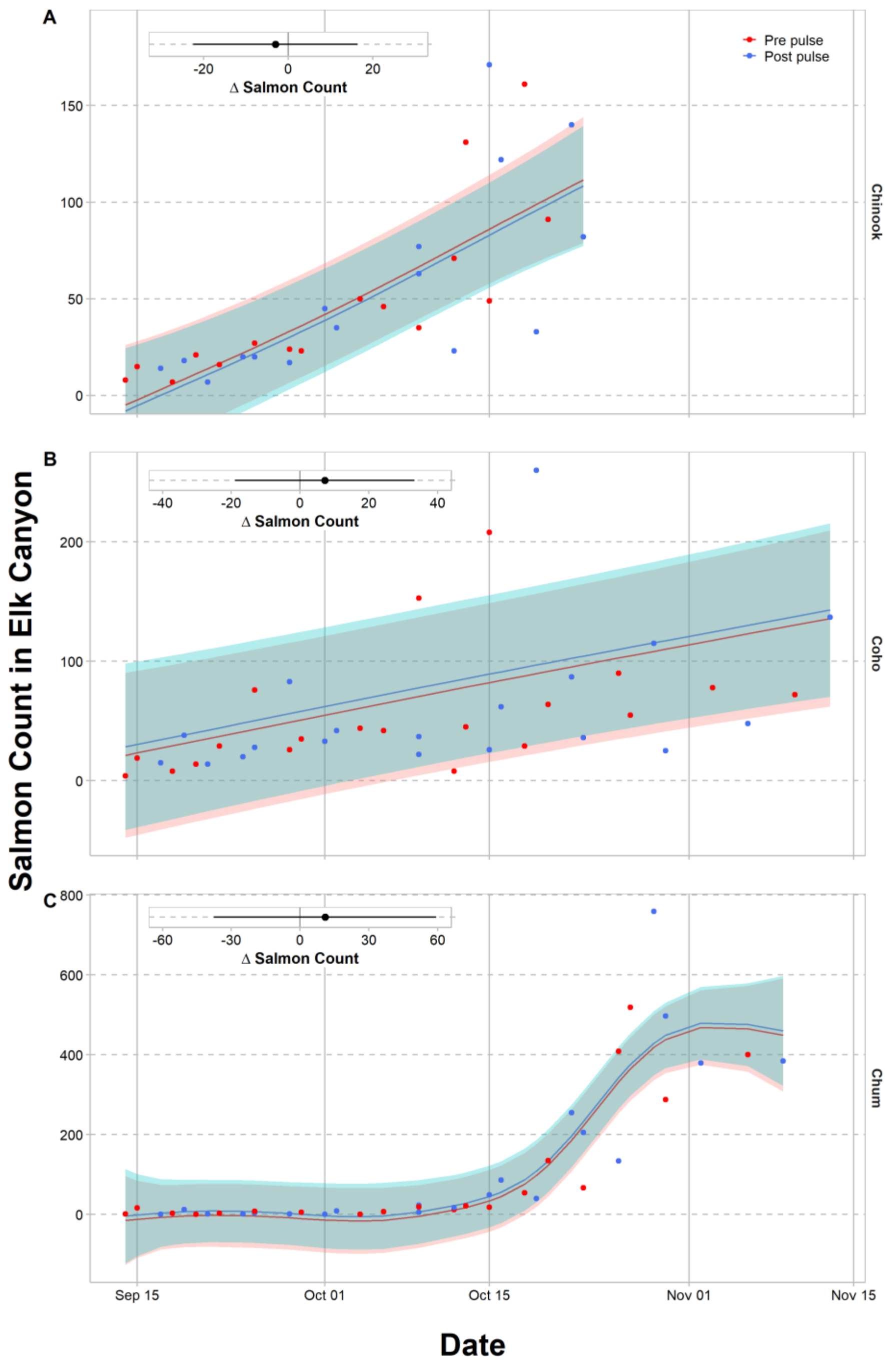


Figure 24. Fit of the General Additive Mixed Models to describe the number of A) Chinook Salmon, B) Coho Salmon, and C) Chum Salmon in Elk Canyon as a function of day of year and pulse flow release operation, using counts up to the peak count was recorded in each year. Insets show posterior means and 95% credible intervals of the parameters for the effect of pulse flow release operation on the number of Pacific Salmon in Elk Canyon. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.



3.3.1.3. Test of $H_0 3$

The rate of spawning salmonid in-migration per day did not differ markedly between periods of pulse flows ($\Delta salmon/day_{pulse\ flow}$) and periods of base flows ($\Delta salmon/day_{base\ flow}$) for Coho Salmon, Chinook Salmon, Chum Salmon, and Steelhead. The average rate of salmon in-migration per day of these species was near zero and was similar to the average rate of salmon in-migration per day during base flows, which act as the control. Therefore, the null hypothesis of $H_0 3$ of no difference in the rate of spawning salmonid in-migration (No./day) during the 2-day pulse flow release operation compared to during base flow operation was not rejected.

The rate of spawning Chinook salmon in-migration ranged from -20.2 fish/day to 33.3 fish/day, mean in-migration rates were -0.2 fish/day (SE: 2.1 fish/day) during base flow and -0.2 fish/day (SE: 1.9 fish/day) during pulse flow in 2015, -2.4 fish/day (SE: 3.1 fish/day) during base flow and 4.8 fish/day (SE: 5 fish/day) during pulse flow in 2016, and 2.3 fish/day (SE: 1.1 fish/day) during base flow and -3.2 fish/day (SE: 1.3 fish/day) during pulse flow in 2018 (Figure 25A).

The rate of spawning Coho salmon in-migration ranged from -19.2 fish/day to 29.3 fish/day, mean in-migration rates were 3 fish/day (SE: 1.5 fish/day) during base flow and 0.3 fish/day (SE: 3.4 fish/day) during pulse flow in 2015, 0.3 fish/day (SE: 1 fish/day) during base flow and 4.6 fish/day (SE: 2.2 fish/day) during pulse flow in 2016, and -0.9 fish/day (SE: 3.6 fish/day) during base flow and 1.9 fish/day (SE: 4.3 fish/day) during pulse flow in 2018 (Figure 25B).

The rate of spawning Chum salmon in-migration ranged from -121 fish/day to 117 fish/day, mean in-migration rates were 13.9 fish/day (SE: 11 fish/day) during base flow and -12.6 fish/day (SE: 14.5 fish/day) during pulse flow in 2015, 5.2 fish/day (SE: 5.6 fish/day) during base flow and 26.2 fish/day (SE: 16.5 fish/day) during pulse flow in 2016, and 0.8 fish/day (SE: 6.5 fish/day) during base flow and -0.9 fish/day (SE: 6.7 fish/day) during pulse flow in 2018 (Figure 25C).

The rate of spawning Steelhead in-migration ranged from -2.3 fish/day to 1.7 fish/day, mean in-migration rates were 0.3 fish/day (SE: 0.2 fish/day) during base flow and -0.3 fish/day (SE: 0.3 fish/day) during pulse flow in 2015, -0.5 fish/day (SE: 0.2 fish/day) during base flow and 0.5 fish/day (SE: 0.3 fish/day) during pulse flow in 2016, and -0.1 fish/day (SE: 0.1 fish/day) during base flow and -0.1 fish/day (SE: 0.1 fish/day) during pulse flow in 2018 (Figure 25D).

The mean effects of pulse flow release operation on the in-migration rate of Chinook Salmon was 0.04 fish/day (95% credible interval: -4.2 fish/day – 4.2 fish/day, Figure 26A), on the in-migration rate of Coho Salmon was 1.2 fish/day (95% credible interval: -3.7 fish/day – 6.2 fish/day, Figure 26B), on the in-migration rate of Chum Salmon was -4.3 fish/day (95% credible interval: -22.7 fish/day – 14 fish/day, Figure 26C), and on the in-migration rate of Steelhead was -0.03 fish/day (95% credible interval: -0.4 fish/day – 0.4 fish/day, Figure 26D), i.e., mean in-migration rates were higher during base flows than during pulse flows for all species considered except for Coho Salmon. However, none of these effects were statistically significant (i.e., the 95% credible intervals for the parameters encompass zero).

Figure 25. Rate of salmon in-migration per day during the pulse flow release and during base flows for A) Chinook Salmon, B) Coho Salmon, C) Chum Salmon, and D) Steelhead. Translucent points are the estimates of in-migration rate; boxplots represent the median (solid line), the interquartile range (IQR) (box), and values extending to ± 1.5 IQR (whiskers). Closed circles represent the means, and vertical bars represent ± standard error (SE).

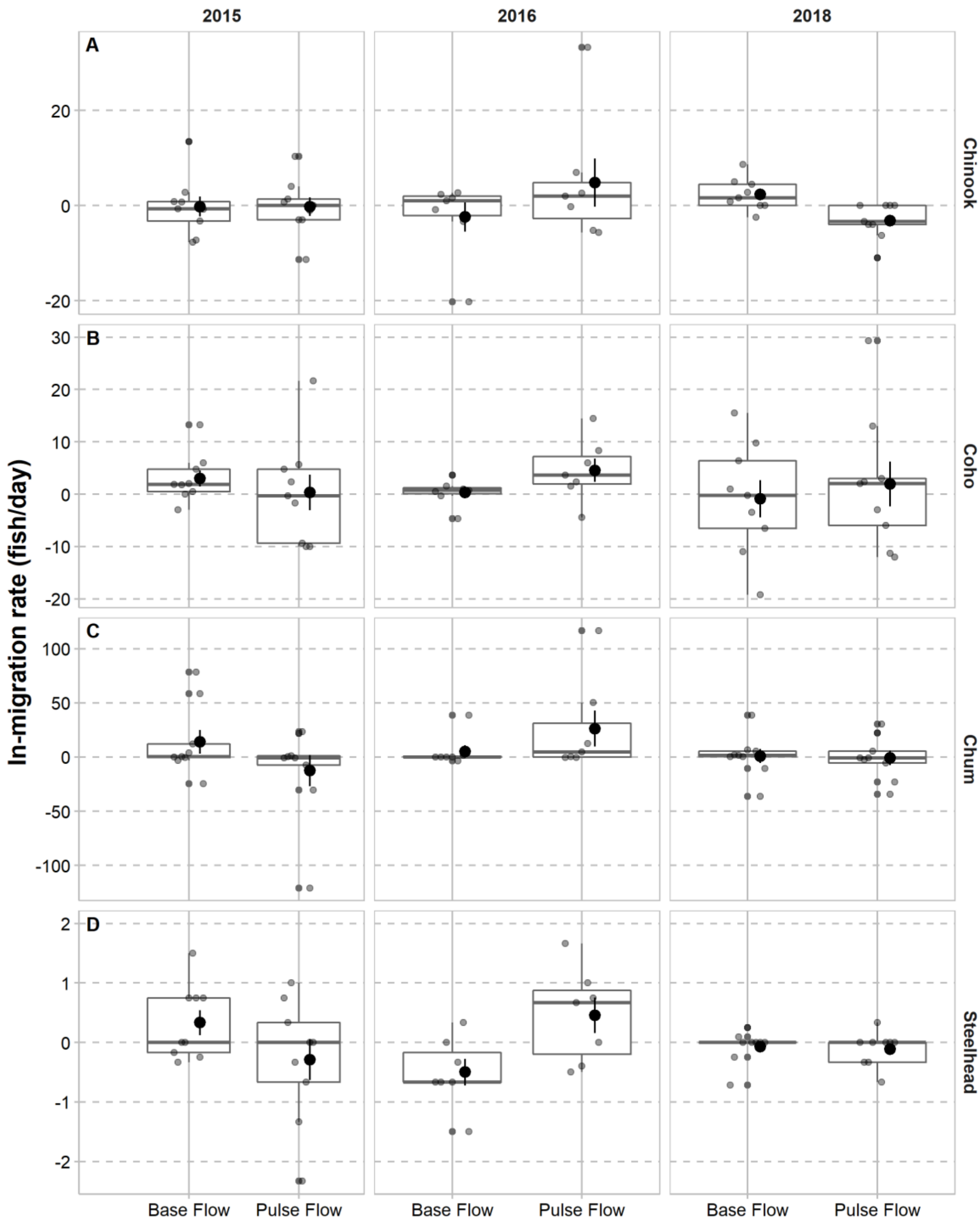
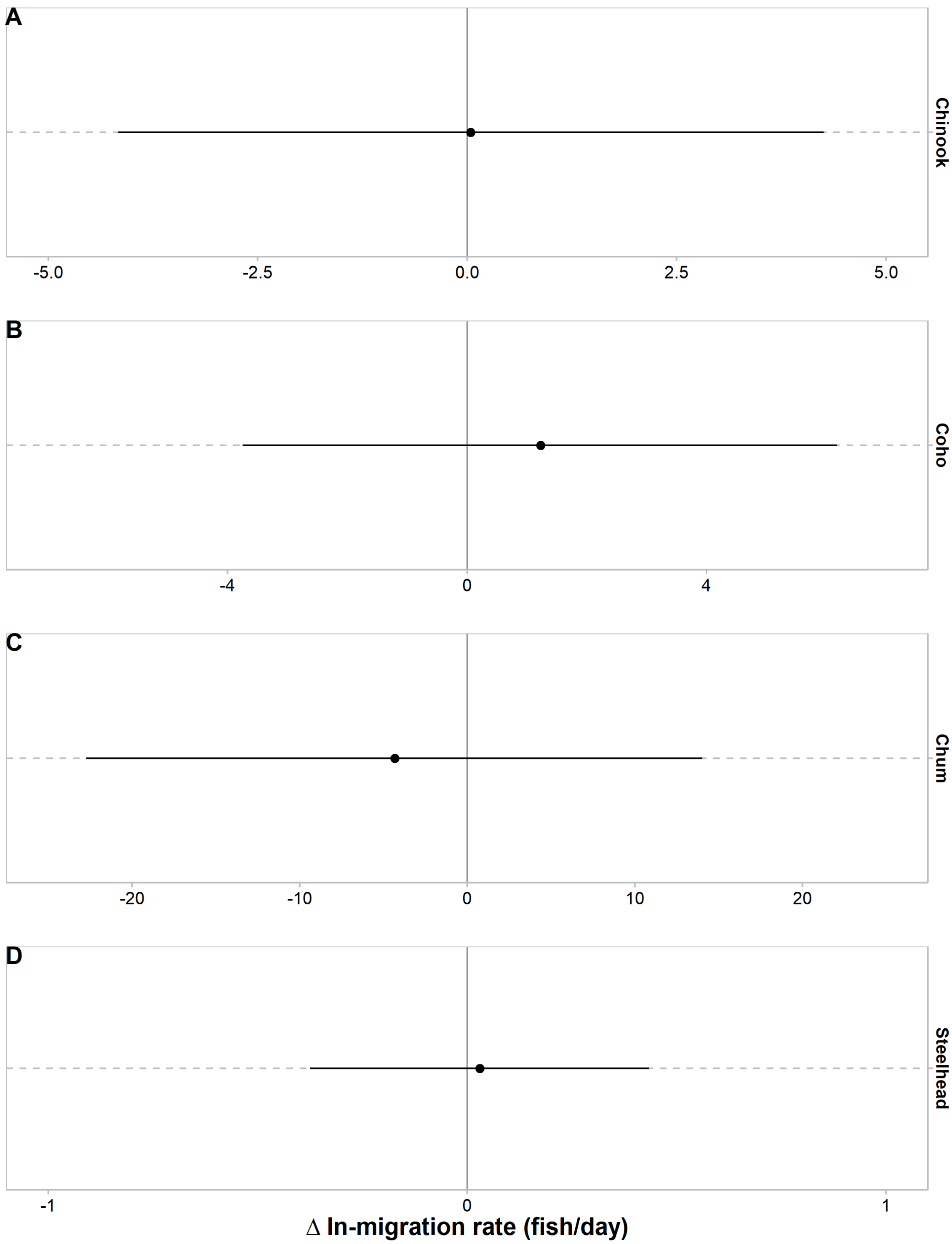


Figure 26. Posterior means and 95% credible intervals of the parameter for the effect of pulse flow release operation on in-migration rate of salmonids. A) Chinook Salmon, B) Coho Salmon, C) Chum Salmon, and D) Steelhead. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.



The rate of early spawning salmonid in-migration per day did not differ markedly between periods of pulse flows (Δsalmon/day$_{\text{pulse flow}}$) and periods of base flows (Δsalmon/day$_{\text{base flow}}$) for Coho Salmon, Chinook Salmon, and Chum Salmon. The average rate of salmon in-migration per day of these species was near zero and was similar to the average rate of salmon in-migration per day during base flows, which act as the control. Therefore, the null hypothesis of no difference in the rate of spawning salmonid in-migration (No./day) during the 2-day pulse flow release operation compared to during base flow operation was not rejected.

The rate of spawning Chinook salmon early in-migration ranged from -7.75 fish/day to 33.3 fish/day, mean in-migration rates were 1.6 fish/day (SE: 2.8 fish/day) during base flow and 1.7 fish/day (SE: 2.0 fish/day) during pulse flow in 2015, 0.6 fish/day (SE: 0.9 fish/day) during base flow and 6.6 fish/day (SE: 5.6 fish/day) during pulse flow in 2016, and 3.8 fish/day (SE: 1.4 fish/day) during base flow and -2.8 fish/day (SE: 1.0 fish/day) during pulse flow in 2018 (Figure 24A).

The rate of spawning Coho salmon early in-migration ranged from -11 fish/day to 29.3 fish/day, mean in-migration rates were 3 fish/day (SE: 1.5 fish/day) during base flow and 0.3 fish/day (SE: 3.4 fish/day) during pulse flow in 2015, 0.3 fish/day (SE: 1 fish/day) during base flow and 4.6 fish/day (SE: 2.2 fish/day) during pulse flow in 2016, and 3.0 fish/day (SE: 5.5 fish/day) during base flow and 11.7 fish/day (SE: 6.4 fish/day) during pulse flow in 2018 (Figure 24B).

The rate of spawning Chum salmon early in-migration ranged from -7.33 fish/day to 117 fish/day, mean in-migration rates were 13 fish/day (SE: 11.1 fish/day) during base flow and 5.4 fish/day (SE: 4.5 fish/day) during pulse flow in 2015, 5.2 fish/day (SE: 5.6 fish/day) during base flow and 26.2 fish/day (SE: 16.5 fish/day) during pulse flow in 2016, and 7.8 fish/day (SE: 5.2 fish/day) during base flow and 7.0 fish/day (SE: 5.2 fish/day) during pulse flow in 2018 (Figure 24C).

The mean effects of pulse flow release operation on the early in-migration rate of Chinook Salmon was 0.5 fish/day (95% credible interval: -4.7 fish/day – 5.7 fish/day, Figure 28A), on the early in-migration rate of Coho Salmon was 2 fish/day (95% credible interval: -3.2 fish/day – 7.2 fish/day, Figure 28B), and on the early in-migration rate of Chum Salmon was -4.1 fish/day (95% credible interval: -10.9 fish/day – 19 fish/day, Figure 28C), i.e., mean early in-migration rates were higher during pulse flows than during base flows for all Pacific Salmon species. These differences were driven mostly by higher early in-migration rates during pulse flows in 2016. However, none of these effects were statistically significant (i.e., the 95% credible intervals for the parameters encompass zero).

Figure 27. Rate of salmon early in-migration per day during the pulse flow release and during base flows for A) Chinook Salmon, B) Coho Salmon, and C) Chum Salmon. Translucent points are the estimates of in-migration rate; boxplots represent the median (solid line), the interquartile range (IQR) (box), and values extending to ± 1.5 IQR (whiskers). Closed circles represent the means, and vertical bars represent ± standard error (SE).

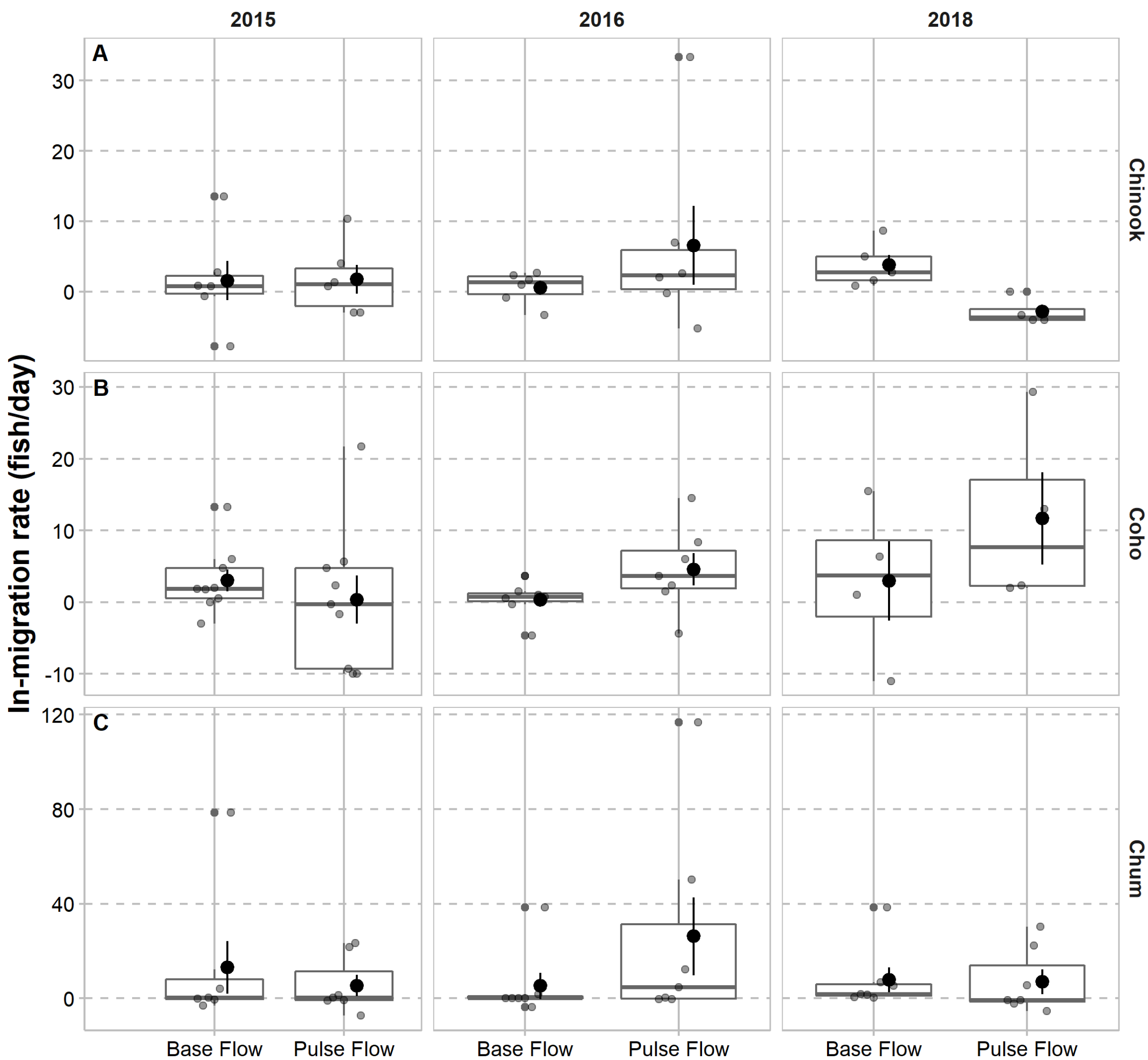
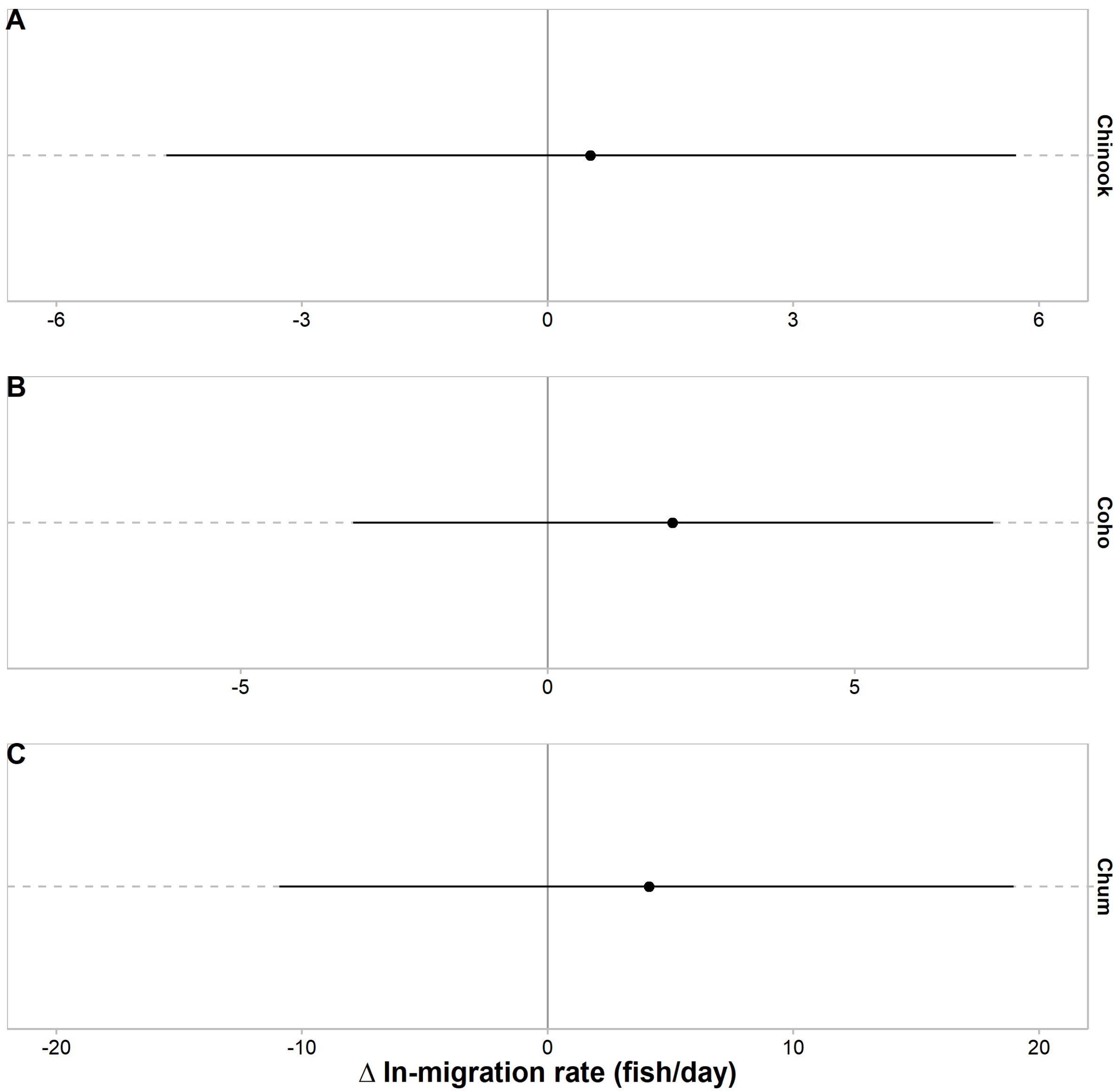


Figure 28. Posterior means and 95% credible intervals of the parameter for the effect of pulse flow release operation on early in-migration rate of salmonids. A) Chinook Salmon, B) Coho Salmon, and C) Chum Salmon. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.



3.3.2. Spring Pulse Flow Assessment

3.3.2.1. Test of $H_0 5$

The counts of Steelhead in Elk Canyon did not differ the day after the 2-day 10 m^3/s spring pulse release compared to the day prior to the pulse release. Therefore, the null hypothesis of $H_0 5$ of no difference in the number of Steelhead following pulse flow release compared to just prior to the release was not rejected.

The counts of Steelhead during spring were highly variable, with no distinct peak in abundance. In most paired surveys (pre-pulse and post-pulse) Steelhead counts were higher during the pre-pulse survey, except for one count in March 2017, and two counts in spring 2018 (first and last counts in the season) (Figure 29). Given the high weekly variability observed in Steelhead abundance, the effect of day of the year on the counts was estimated as constant (Figure 30A). The mean effects of pulse flow release operation on the counts of Steelhead were -0.8 fish (95% credible interval: -2.3 fish – 0.5 fish, Figure 30B), i.e., mean counts were higher prior to the pulse release than following the pulse. However, this effect was not statistically significant (i.e., the 95% credible interval for the parameter encompasses zero).

3.3.2.2. Test of $H_0 3$

The rate of spawning Steelhead spring in-migration per day was statistically significantly higher during periods of base flows (Δsalmon/day$_{\text{base flow}}$) than during periods of pulse flows (Δsalmon/day$_{\text{pulse flow}}$). Therefore, the null hypothesis of $H_0 3$ of no difference in the rate of spawning Steelhead spring in-migration (No./day) during the 2-day pulse flow release operation compared to during base flow operation was rejected. The effect of the pulse was, however, contrary to the expected effect as the in-migration rate was higher during base flows than during pulse flows. However, the magnitude of the difference was very small (0.4 fish/day higher during base flows), and therefore not likely to bear biological relevance.

The rate of spawning Steelhead spring in-migration ranged from -1 fish/day to 1 fish/day, mean in-migration rates were -0.15 fish/day (SE: 0.35 fish/day) during base flow and -0.5 fish/day (SE: 0.17 fish/day) during pulse flow in 2015, 0.2 fish/day (SE: 0.08 fish/day) during base flow and -0.42 fish/day (SE: 0.2 fish/day) during pulse flow in 2016, and 0.3 fish/day (SE: 0.25 fish/day) during base flow and 0.12 fish/day (SE: 0.26 fish/day) during pulse flow in 2018 (Figure 31A). The mean effect of pulse flow release operation on the in-migration rate of Steelhead was -0.4 fish/day (95% credible interval: -0.8 fish/day – -0.01 fish/day, Figure 31B), i.e., mean in-migration rates were higher during base flows than during pulse flows and, although small, this effect was statistically significant (i.e., the 95% credible interval for the parameter does not encompass zero).

Figure 29. Spring Steelhead count pre and post the 2-day 10 m^3/s spring pulse releases in Elk Canyon.

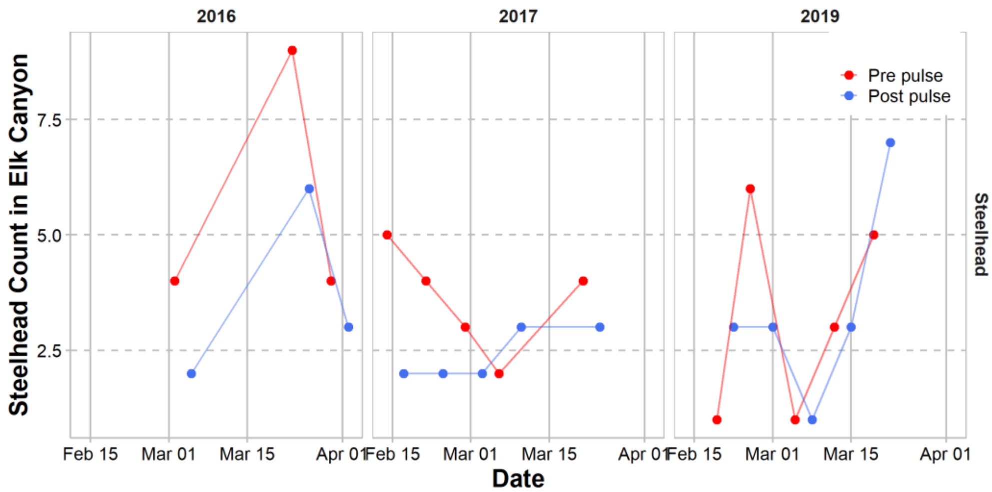


Figure 30. A) Fit of the GLMM model to describe the number of Steelhead in Elk Canyon as a function of day of year and pulse flow release operation. B) Posterior mean and 95% credible interval of the parameter for the effect of pulse flow release operation on the number of Steelhead in Elk Canyon. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.

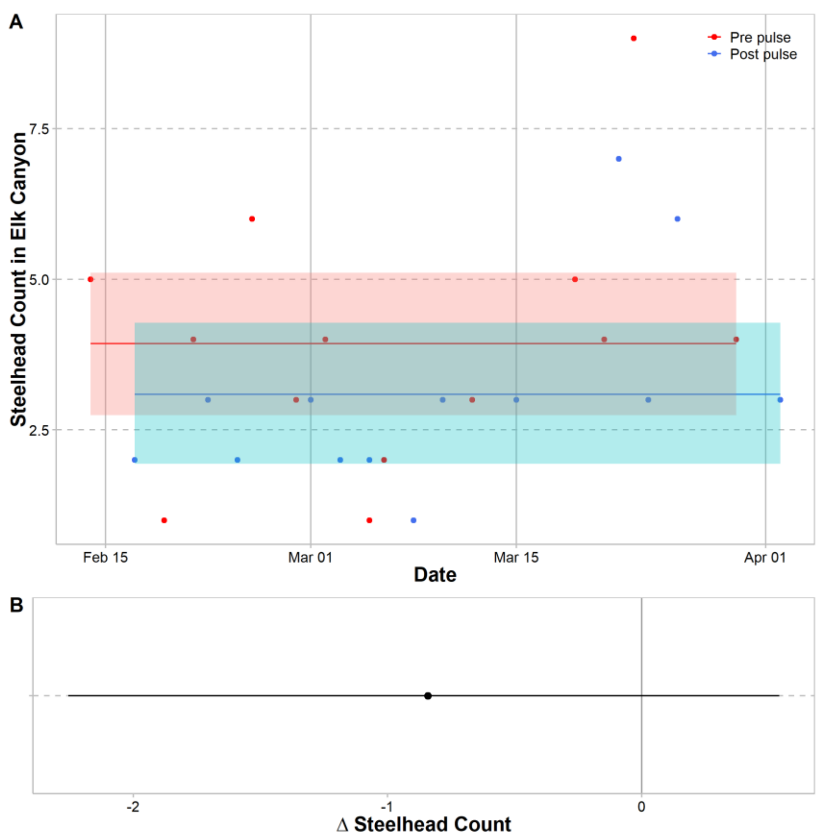
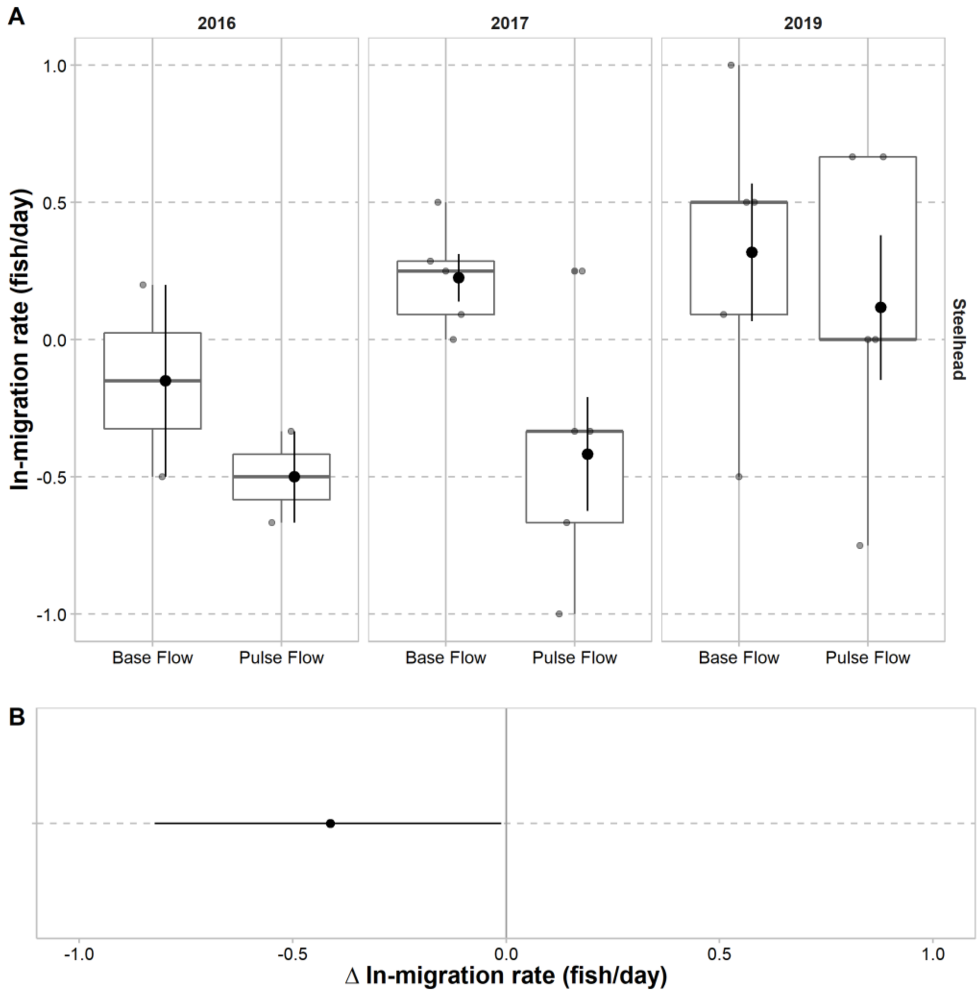


Figure 31. **A) Rate of Steelhead in-migration per day during the pulse flow release and during base flows. Translucent points are the estimates of in-migration rate; boxplots represent the median (solid line), the interquartile range (IQR) (box), and values extending to ± 1.5 IQR (whiskers). Closed circles represent the means, and vertical bars represent SE. B) Posterior mean and 95% credible interval of the parameter for the effect of pulse flow release operation on Steelhead in-migration rate.**

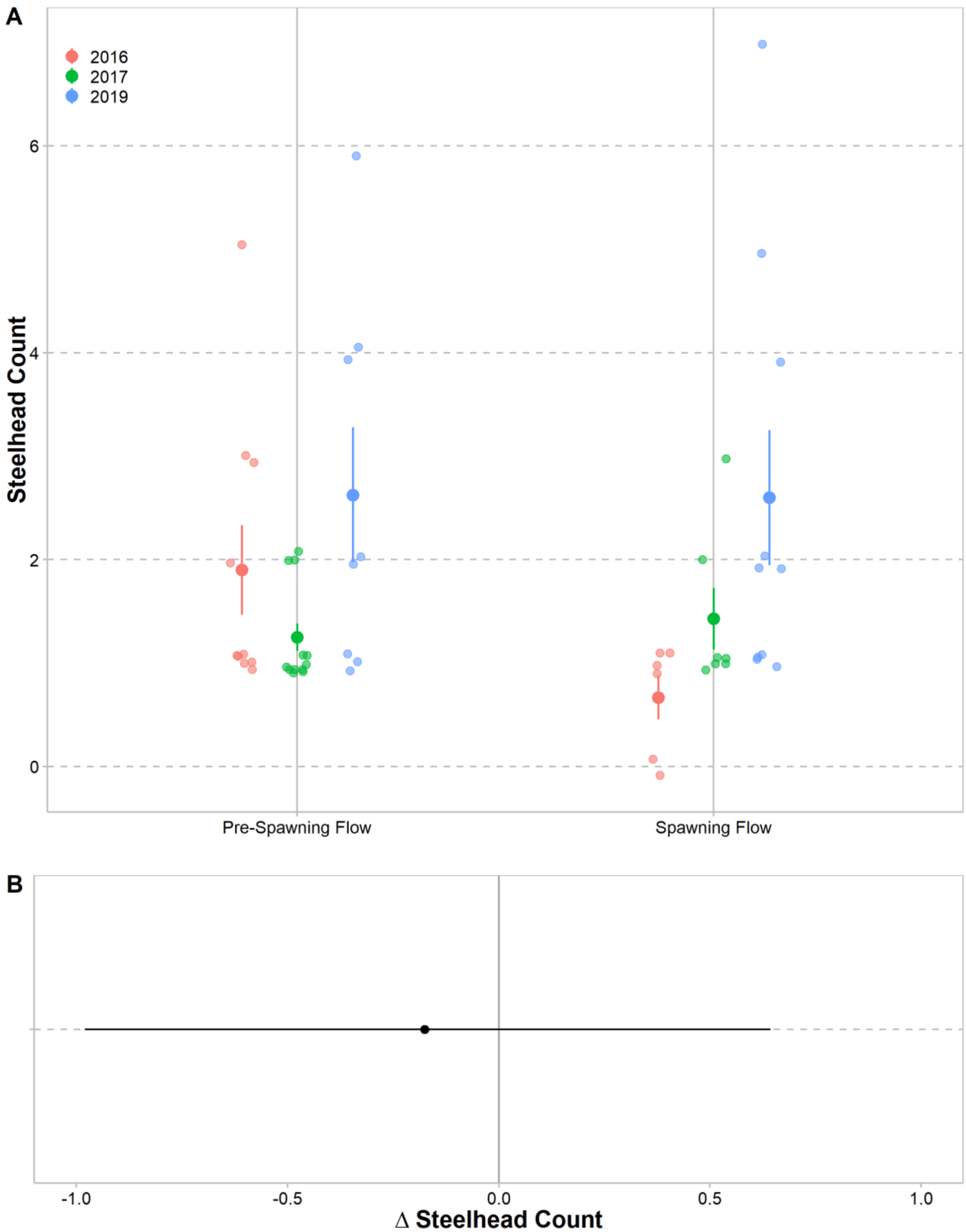


3.4. Steelhead Spawning Flow Assessment

The counts of Steelhead in Elk Canyon during the 2-week 7 m^3/s spawning release period did not differ from those estimated prior to the release period. Therefore, the null hypothesis of H_06 of no difference in the number of Steelhead following spawning release compared to just prior to the release was not rejected.

Steelhead counts in Elk Canyon ranged from 0 to 7 fish during the three years analyzed (Figure 29A). Mean counts were 1.9 fish (SE: 0.4 fish) during pre-spawning flow, and 0.7 fish (SE: 0.2 fish) during spawning flows in 2016, 1.25 fish (SE: 0.13 fish) during pre-spawning flow, and 1.43 fish (SE: 0.3 fish) during spawning flows in 2017, and 2.6 fish (SE: 0.65 fish) during both pre-spawning and spawning flows in 2019 (Figure 29A). The mean effect of spawning flow release operation on Steelhead abundance -0.17 fish (95% credible interval: -0.98 fish – 0.64 fish, Figure 29B, i.e., mean Steelhead abundance) was higher during pre-spawning flows than during spawning flows, although this effect was small and statistically not significant (i.e., the 95% credible interval for the parameter encompasses zero).

Figure 32. A) Adult Steelhead Abundance prior to and during 7 m^3/s spawning flow releases. Translucent points are the observer efficiency estimates, and solid points with vertical bars represent the means ± standard error (SE). B) Posterior mean and 95% credible interval of the parameter for the effect of spawning flow release operation on Steelhead abundance. Overlap of the 95% credible interval with zero indicates that the likelihood of an effect is small.



3.5. Fall and Spring Spawner Enumeration

3.5.1. Fall Spawners

Chinook and Coho Salmon adult abundance in fall 2018 were estimated to be 103 and 1,083 individuals respectively using the area under the curve method (Table 14). Pink Salmon had the highest estimated abundance of 1,432 individuals. A population of 672 Chum Salmon and 273 Sockeye Salmon were also estimated in 2018 (Table 14). Few Steelhead were observed in fall with a peak observed abundance of only seven individuals.

As in previous years, the peak spawning time was variable across salmon species. Chinook counts in 2018 were the lowest observed since 2014 (Figure 33). Chinook observations peaked in mid-October and showed a similar spawning periodicity to other years. In contrast to Chinook observations, Coho counts in 2018 were the highest observed since 2014 (Figure 34). Coho Salmon had the latest peak spawn, occurring in late October/early November similar to all previous years. 2017 and 2018 had a notably longer peak run timing than other years. Peak Chum counts in 2018 were comparable to observations in 2015 and 2017 but much higher than 2014 (Figure 35). Chum spawn timing was similar to all other years with peak counts occurring in late October and early November. Pink Salmon counts in 2018 were similar to those observed in 2016 and 2017, but much lower than peak counts observed in 2014 and 2015 (Figure 36). Pink Salmon had the earliest peak similar to previous years, with observed spawner counts peaking in late September. Sockeye observations in 2018 were comparable to 2017, lower than 2015, but higher than peak counts observed in 2014 and 2016 (Figure 37). Similar to other years, Sockeye were not observed after early November with the exception of 2015 when Sockeye were still observed on the final survey in late November. A maximum of seven Steelhead were observed in mid-September similar to previous years with observations scattered throughout the fall surveys (Figure 38).

Not all observed adults spawned in Elk Canyon. The number of redds was also recorded during the fall spawner surveys. The maximum number of redds observed varied considerably among species (Table 15). Chum, followed by Sockeye Salmon had the highest numbers of redds at 42 and 30 redds, respectively, while a maximum of 10 Chinook Salmon redds, 20 Pink Salmon redds, and 12 Coho Salmon redds were observed during fall snorkels. Similar to spawner counts, redd counts peaked for Pink, Sockeye and Chinook Salmon in September and October, with Pink and Sockeye Salmon redd counts peaking the earliest, followed by counts of Chinook. Chum Salmon redd counts peaked in early November while Coho Salmon redd counts peaked in late November.

3.5.1.1. Productivity of Fall Salmon Spawners

Salmon fry and smolt production from Elk Canyon was estimated based on the fall 2018 redd counts and fecundity, egg-to-fry and egg-to-smolt survival values from the literature (Bradford 1995, Quinn 2005). These estimates were compared to the 2019 outmigration predicted from RST catch (Section 3.1.4). Based on the mean fecundity by salmon species and the maximum number of redds observed for each species, Chum Salmon had the greatest number of estimated eggs produced with 134,000, followed by Sockeye, Chinook, Pink and Coho Salmon (Table 16).

Pink Salmon and Coho Salmon predictions for production based on redd counts were similar to outmigration estimates from the RST, while Chum Salmon, Chinook Salmon and Sockeye Salmon estimates diverged. For Pink Salmon, 3,456 fry were estimated from RST catch compared to 4,140 individuals predicted from the redds observed. Coho Salmon estimates were also similar with 8,151 Coho Salmon 0+ fry estimated from the RST compared to 9,108 individuals predicted from the redds observed.

In contrast, 145,614 Chum Salmon fry were estimated from the RST catch, although only 17,338 individuals were predicted from the Chum redds observed. For Chinook Salmon, 31,385 Chinook Salmon 0+ fry and smolts were estimated from the RST compared to 16,340 individuals predicted from the Chinook redds observed. For Sockeye Salmon, only 88 Sockeye fry were estimated from the RST compared to 13,335 individuals predicted from the Sockeye redds observed.

These differences in production estimates derived from redd surveys and RST catch could be attributed to multiple factors, including our course estimates of fecundity and survival by species from the literature, and redd superimposition, where redds constructed from early spawners such as Pink and Sockeye Salmon are superimposed by later spawners. For Chum Salmon and Chinook Salmon however, the results suggest that redd counts may have been underestimated, or, alternatively, that egg-to-fry survival was high. It can be difficult to distinguish redds from different species when multiple species are in the system at a given time. Nevertheless, even if redd counts for Chum Salmon have been underestimated by a half, the production of Chum Salmon fry from the RST suggests that egg-to-fry survival for Chum Salmon was high (>25%) in 2018-2019.

Table 14. Fall salmon spawner counts by species and estimates of abundance.

Date	Count of Adult Fish Observed[1]					
	ST	CH	CM	CO	PK	SK
5-Sep-18	3	0	0	0	3	26
11-Sep-18	7	1	0	1	3	48
18-Sep-18	2	7	3	8	1,045	57
21-Sep-18	2	7	1	14	1,226	74
25-Sep-18	1	27	8	76	1,432	119
28-Sep-18	0	17	1	83	1,001	103
9-Oct-18	1	35	19	153	207	115
12-Oct-18	0	23	17	241	13	48
15-Oct-18	0	49	18	208	2	46
19-Oct-18	0	33	40	260	0	38
23-Oct-18	1	44	67	259	0	14
26-Oct-18	2	11	134	250	0	13
30-Oct-18	2	29	288	236	0	17
2-Nov-18	0	10	379	245	0	6
6-Nov-18	0	0	400	284	0	0
9-Nov-18	0	0	384	266	0	0
13-Nov-18	0	0	238	189	0	0
16-Nov-18	0	0	135	155	0	0
20-Nov-18	0	0	92	129	0	0
23-Nov-18	0	0	23	93	0	0
29-Nov-18	0	0	1	53	0	0
Abundance Estimate[2]	**7**	**103**	**672**	**1,083**	**1,432**	**273**

[1] ST = Steelhead Trout, CH = Chinook Salmon, CM = Chum Salmon, CO = Coho Salmon, PK = Pink Salmon, and SK = Sockeye Salmon.

[2] Abundance estimate of salmon species are based on an area under the curve analysis while the abundance estimate of Steelhead Trout are based on maximum observed fish.

Figure 33. Adult Chinook Salmon counts in Elk Canyon by date and year.

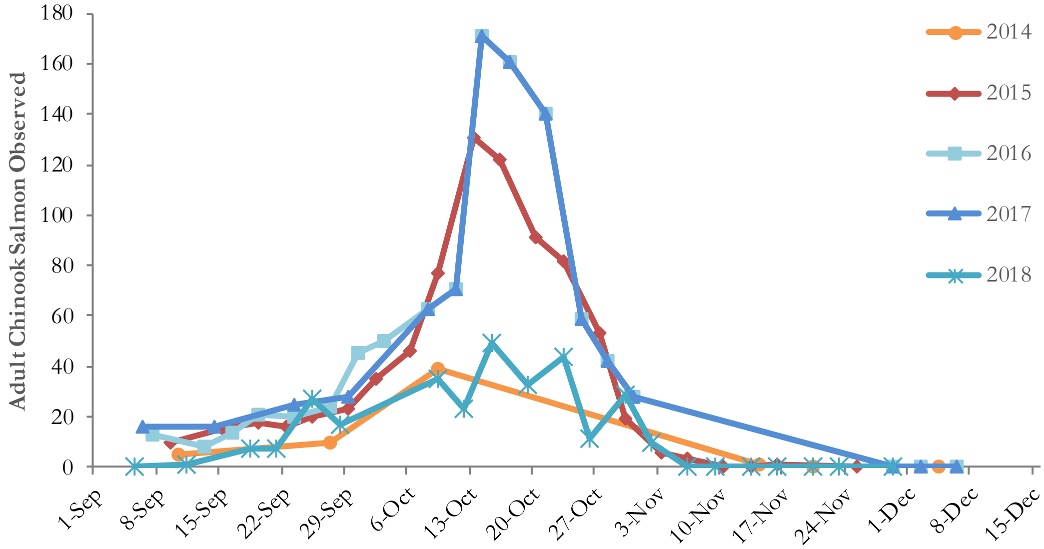


Figure 34. Adult Coho Salmon counts in Elk Canyon by date and year.

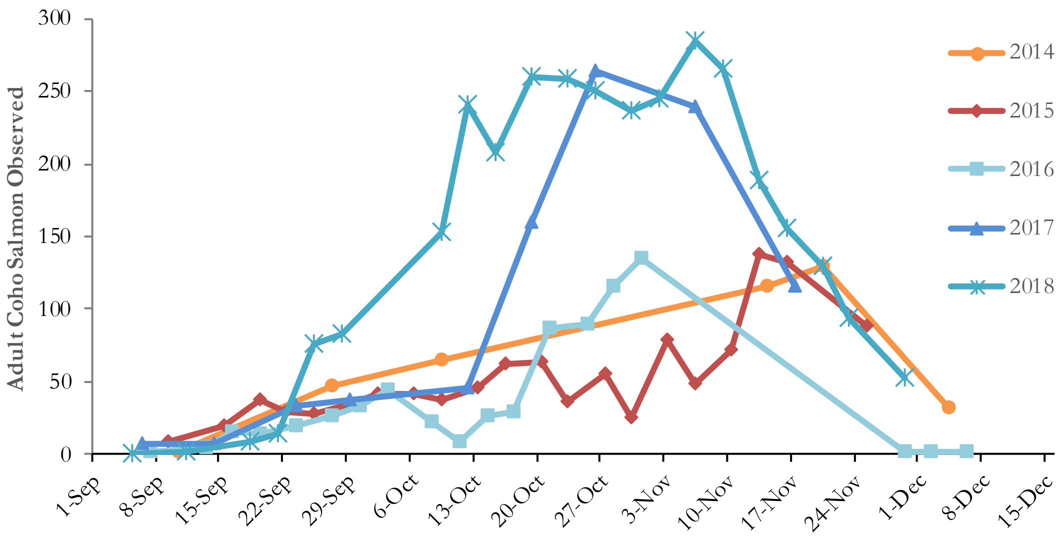


Figure 35. Adult Chum Salmon counts in Elk Canyon by date and year.

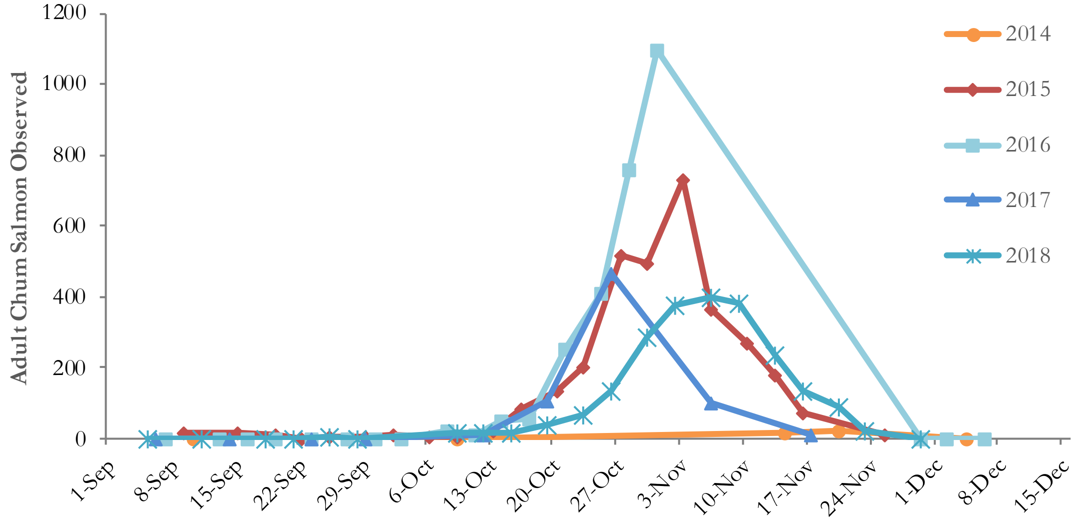


Figure 36. Adult Pink Salmon counts in Elk Canyon by date and year.

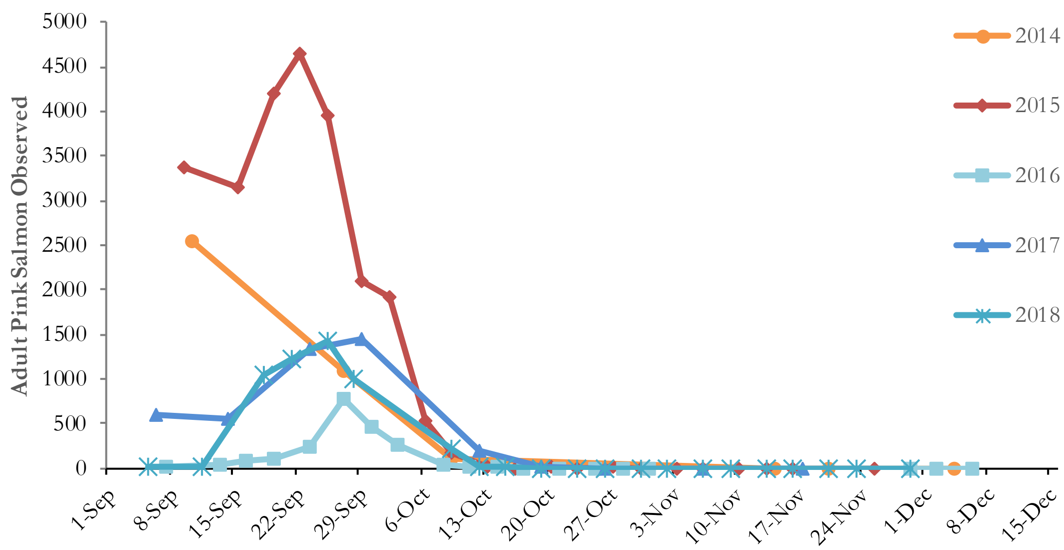


Figure 37. Adult Sockeye Salmon counts in Elk Canyon by date and year.

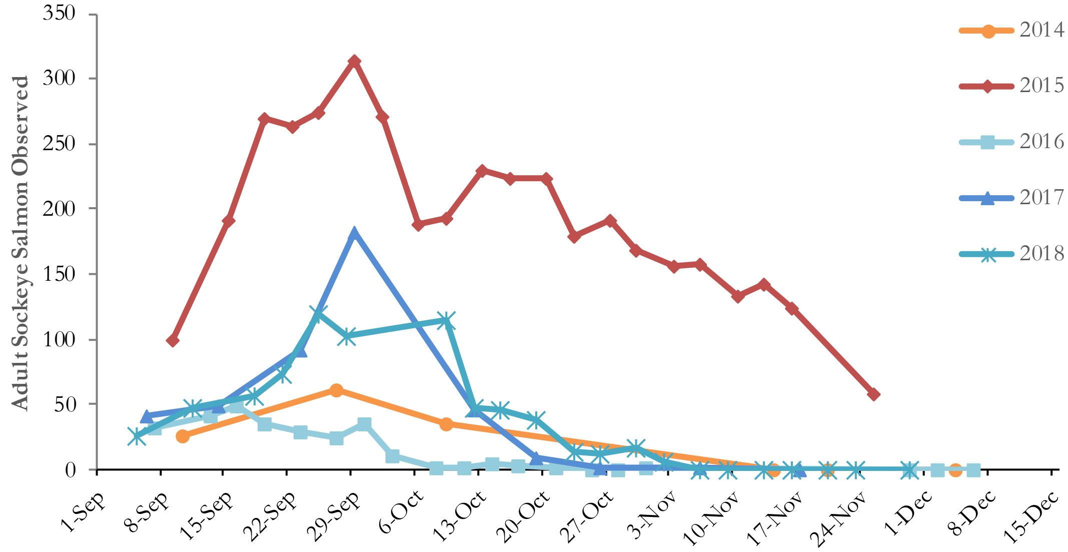


Figure 38. Adult Steelhead counts in Elk Canyon by date and year.

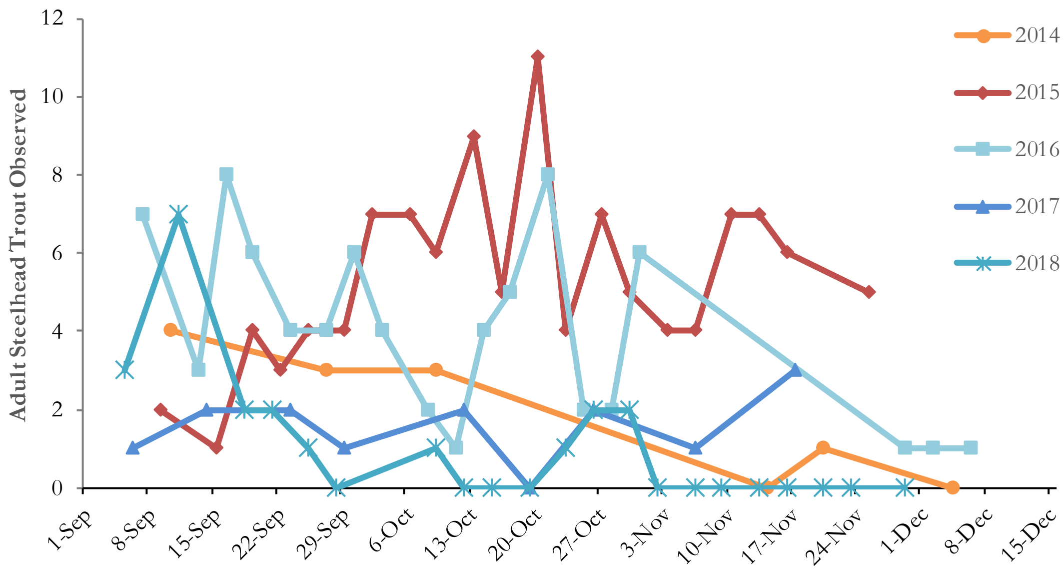


Table 15. Fall counts of salmon redds by species.

Date	Count of Trout/Salmon Redds[1]					
	ST	CH	CM	CO	PK	SK
5-Sep-18	0	0	0	0	0	0
11-Sep-18	0	0	0	0	0	0
18-Sep-18	0	0	0	0	0	8
21-Sep-18	0	0	0	0	4	25
25-Sep-18	0	0	0	0	20	30
28-Sep-18	0	0	0	0	15	10
9-Oct-18	0	1	0	0	10	12
12-Oct-18	0	1	0	0	0	6
15-Oct-18	0	2	0	0	0	20
19-Oct-18	0	8	0	0	0	20
23-Oct-18	0	10	0	0	0	10
26-Oct-18	0	10	1	2	0	10
30-Oct-18	0	6	8	1	0	3
2-Nov-18	0	4	38	3	0	1
6-Nov-18	0	0	39	6	0	0
9-Nov-18	0	0	42	6	0	0
13-Nov-18	0	0	20	6	0	0
16-Nov-18	0	0	31	5	0	0
20-Nov-18	0	0	23	6	0	0
23-Nov-18	0	0	30	6	0	0
29-Nov-18	0	0	0	12	0	0
Max Observed	**0**	**10**	**42**	**12**	**20**	**30**

[1] ST = Steelhead Trout, CH = Chinook Salmon, CM = Chum Salmon, CO = Coho Salmon, PK = Pink Salmon, and SK = Sockeye Salmon.

Table 16. Comparisons of estimated juvenile production by salmon species from Elk Canyon derived from redd counts and RST catch.

Species	Mean Fecundity[1]	Max Redds Observed	Total Estimated Eggs	Survival[2]		Estimated Redd Production[3]		Estimated Outmigration[4]	
				Egg-Fry	Egg-Smolt	Fry	Smolt	Fry[5]	Smolt[6]
Pink	1,800	20	36,000	0.115	n/a	4,140	n/a	3,456	n/a
Chum	3,200	42	134,400	0.129	n/a	17,338	n/a	145,614	n/a
Sockeye	3,500	30	105,000	0.127	n/a	13,335	n/a	88	n/a
Coho	3,000	12	36,000	0.253	0.17	9,108	5,940	8,151	282
Chinook	4,300	10	43,000	0.38	0.10	16,340	4,343	31,385	954

[1] Information from Bradford (1995).

[2] Information from Quinn (2005).

[3] Estimated redd production based on the total estimated eggs and literature survival rates.

[4] Estimated outmigration of fish based on the RST sampling results.

[5] Sockeye Salmon fry RST outmigration estimates are based on overall Capture efficiency of all species combined as no Sockeye Salmon fry were recaptured.

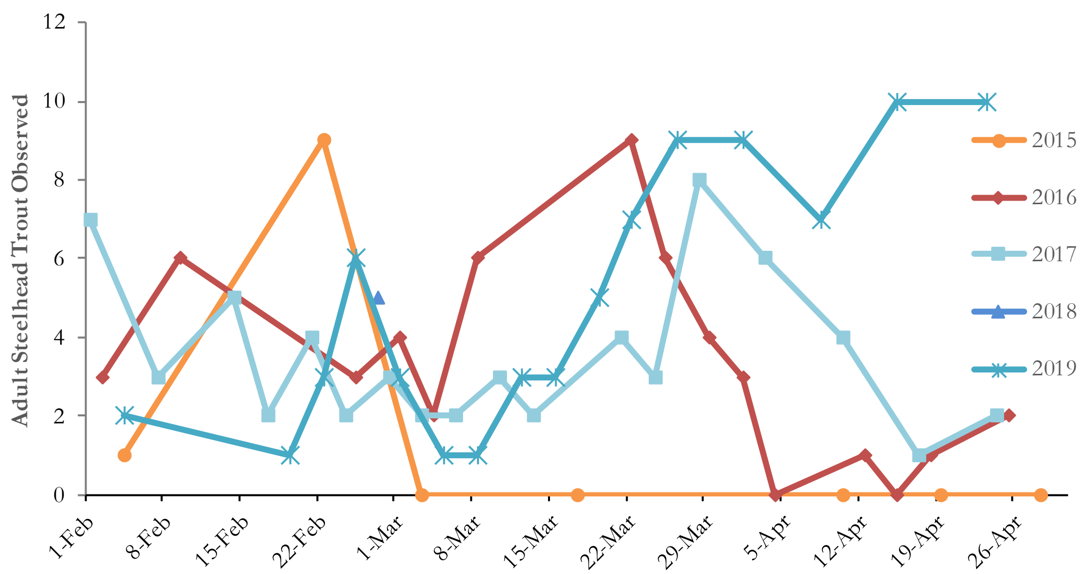
[6] Coho smolt RST outmigration estimates are based on the sum of the 0+ and 1+ smolt outmigration estimates.

3.5.2. Spring Spawners

Steelhead abundance in Elk Canyon peaked at a maximum count of ten individuals in late April 2019 (Figure 39). This was the highest count of Steelhead in all years of spring surveys to date. Steelhead counts ranged from 1 to 10 fish throughout the period of surveys, which overall was similar to counts in previous years.

Five Steelhead redds were observed on April 1 on the first day of 7 m^3/s spawning flow in the Elk Canyon pool near the tailout. No additional Steelhead redds were observed during the remaining snorkel surveys. All five redds remained wetted when flows returned to 4 m^3/s.

Figure 39. Steelhead counts during the spring spawner surveys by Year.



4. CONCLUSIONS

4.1. Overview

All BC coast salmonid species were observed using Elk Canyon for spawning and/or rearing during the Year 5 of sampling of the JHTMON-15 program. Although many of these species occur in low abundance, this nevertheless indicates that habitats in Elk Canyon are used by a diversity of salmon and trout. The following sections highlight the main conclusions for each component of the study conducted in Year 5.

4.2. Smolt Enumeration

The smolt enumeration component of JHTMON-15 uses an RST to monitor fry and smolt outmigration from Elk Canyon to assess if the carrying capacity of Elk Canyon is affected by the magnitude of base flows (e.g., 4 m^3/s) provided in the flow prescription (hypothesis H_01):

$H_0$1: Carrying capacity of the Elk Canyon reach, as measured by annual smolt out-migrant counts, does not vary as a function of discharge.

Smolt enumeration is to be undertaken each year of JHTMON-15 with synthesis analyses planned for Year 6 and Year 10 to address $H_0$1.

In Year 5, the RST operated for a total effort of approximately 130 days or 3,110 hours between March 1, 2019 to July 11, 2019. In total, 18,167 fish were captured in the RST in 2019. Similar to previous years, catches in 2019 were primarily composed of Chum Salmon (73.1%), Chinook Salmon (17.5%), and Coho Salmon (4.6%). Steelhead/Rainbow Trout and Sockeye Salmon represented 0.4% and 0.04% of the catch, respectively. The combined catch of all salmonids (17,690 fish) accounted for 97.4% of the total catch while the catch of the key target species of Chinook Salmon, Coho Salmon, and Steelhead/Rainbow Trout (4,081 fish) accounted for 22.5% of the total catch.

Total salmonid outmigration by species was estimated by standardizing the RST catch by the capture efficiency of the RST, which was determined from mark recapture experiments. As in Year 2 and 3, Chum Salmon outmigration was the highest of all salmonid species, with an estimated total outmigration of 149,399 fry. Coho Salmon total outmigration was estimated to be 8,339 fry and 296 age 0+ smolts, and 13 age 1+ smolts. Chinook Salmon total outmigration was estimated to be 32,031 fry and 975 age 0+ smolts. Steelhead/Rainbow Trout outmigration was estimated to be 11 age 0+ fry, 16 age 1+ parr, 100 age 2+ parr, and 89 3+ smolts. Pink Salmon and Sockeye Salmon total outmigration was estimated at 3,512 and 93 fry, respectively. Overall, outmigration estimates in 2019 were similar to 2016 values but generally higher than 2017. It is likely that the low outmigration estimates in 2017 result from the large spill event between November 4 and 24, 2016, which may have scoured out many of the redds within Elk Canyon.

Outmigration timing information by life stage is evident within and across species from the RST data. Similar to previous years, all of the Chinook Salmon that were caught in the RST are likely to be 0+ fish based on scale age analysis. This indicates that they are exclusively 'ocean type', meaning that they rear for only a few months in freshwater and then migrate to the estuary to continue rearing. Two peaks in Chinook outmigration were observed, an early peak in March of Chinook fry that may rear downstream in the Campbell River system, and a later peak in June of larger individuals that have reared for a few months in Elk Canyon. A small number of these larger fish may have originated from the Quinsam Hatchery similar to what was observed in Year 3 (~3%).

Two primary Coho Salmon life stages were observed including an early migration of Coho fry in March and April, and a later migration of larger 0+ Coho smolts from May through July. In addition, three 1+ Coho Salmon smolts and one 2+ smolt were observed in Year 5 compared to zero ≥1+ observed in Year 3.

Five age classes of Steelhead/Rainbow Trout were identified in the RST catch, including 0+, 1+, 2+, 3+, and >3+ fish. The majority of captured Steelhead/Rainbow Trout were 2+ (~48%) (148-199 mm) and 3+ (~42%) (200-256 mm), which were captured between April and June and peaked between early May and early June. Steelhead/Rainbow Trout 0+ (≤80 mm), 1+ (85-146 mm) and adult >3+ individuals (>257 mm) made up small proportions of RST captures (~2%, ~8% and ~1% respectively). Steelhead/Rainbow Trout 0+ and 1+ did not have a clear peak in outmigration timing, suggesting that catches of these age classes represented more localized movements rather than outmigration.

4.3. Overwintering Assessment

The overwintering assessment component of JHTMON-15 is designed to test if juvenile fish rear for their entire life history in Elk Canyon or if a portion of the population consists of immigrant juveniles ($H_0$2):

> $H_0$2: The number of rearing residents deemed likely to smolt the following spring, as measured during late summer, is not significantly different from the abundance estimate obtained in late winter just prior to the onset of their out-migration.

This was the final year of overwintering assessment data collection. Night snorkeling mark/re-sight methods were used to estimate Steelhead/Rainbow Trout and Coho Salmon parr densities in fall and in early spring, which were then compared to determine the extent of parr overwintering in Elk Canyon. A synthesis analyses was also completed across all four years of data collection (Year 2, 3, 4, and 5) to address Management Question #1 and $H_0$2 of the TOR as no further overwintering assessment fieldwork is planned in future years.

Across all four years of overwintering assessment data collection, the effect of season on the density of Steelhead/Rainbow Trout was not significant, i.e., the 95% credible intervals of the mean posterior estimate of the parameter encompasses zero. Average Steelhead/Rainbow Trout density was 10.8 fish/100m^2 (SE: 1.4 fish/100m^2) in the fall and 10.2 fish/100m^2 (SE: 1.2 fish/100m^2) in the early spring prior to outmigration. Therefore, we conclude that Steelhead/Rainbow Trout overwinter in Elk Canyon and that the number of rearing residents deemed likely to smolt the following spring, as measured during September, is not significantly different from the abundance estimate obtained in February prior to the onset of their outmigration (retain $H_0$2 for Steelhead/Rainbow Trout parr).

Coho Salmon juveniles were observed during fall surveys in all four years of the monitoring program. Across all sites, estimates of Coho Salmon density in the fall ranged from 3 to 45 fish/100 m^2. Mean Coho Salmon density was 23.6 fish/100 m^2 during fall 2016 and 11 fish/100 m^2 during fall 2017. Coho density could not be calculated for fall 2015 or 2018 as no marked fish were observed during the re-sight swim. In comparison, in the spring, three Coho Salmon were observed during the 2016 spring survey (these were observed during the re-sight swim and thus fish density could not be estimated), 0 were observed in 2017 and 2018, and five were observed during the 2019 spring survey. The low abundance of Coho Salmon parr in the spring surveys of 2016 and 2019 coupled with their absence in 2017 and 2018 indicate that very few Coho Salmon overwinter in Elk Canyon. We therefore reject $H_0$2 for Coho Salmon parr.

4.4. Fall and Spring Pulse Flow Assessment

Part of the flow prescription for Elk Canyon is to provide 2-day pulse flows of 7 m^3/s every week in the fall (September 15 to November 15) and 2-day pulse flows of 10 m^3/s every two weeks in the spring (February 15 to March 15) as an attraction flow primarily for spawning salmonids. Hypotheses H_03, H_04, and H_05 were developed to test the effectiveness of these pulse flows in attracting spawning salmonids and attracting and retaining Steelhead in Elk Canyon. Hypothesis H_04 is not testable using the current sampling method of snorkel surveys immediately prior to and after the pulse flows. Year 5 is the final year of pulse flow assessment surveys to address H_03 and H_05:

> H_03: The rate of spawning salmonid in-migration (No./day) during the 2-day pulse flow release operation is not significantly different from that during the base flow operation.
>
> H_05: The estimated number of spawning salmonids following pulse flow release operation is not significantly different from that just prior to the release.

No strong evidence was found to indicate that the fall or spring pulse flows are attracting salmon into Elk Canyon across all three years of data collection (2015, 2016, and 2018 for fall spawners; spring 2016, 2017, and 2019 for Steelhead). The abundance of all fall spawners in Elk Canyon measured using snorkel surveys pre- and post pulses, did not differ the day after the 2-day 7 m^3/s fall pulse release compared to the day prior the pulse release. This means that the null hypothesis H_05 is retained for all fall spawning species including Coho Salmon, Chinook Salmon and Chum Salmon. The rate of fall spawning salmonid in-migration per day also did not differ between periods of pulse flows and periods of base flows for all fall spawners, which retains H_03 for Coho Salmon, Chinook Salmon and Chum Salmon. These results were confirmed in a supplemental analysis where only counts during the buildup to peak abundance were considered.

The count of Steelhead in Elk Canyon in the spring was similar the day after the 2-day 10 m^3/s spring pulse releases compared to the day prior to the pulse releases, which retains H_05 for Steelhead. The rate of Steelhead in-migration per day was significantly higher during the base flow than during the pulse flow, which is a rejection of H_03 for Steelhead but is opposite to the hypothesized effect direction. The magnitude of this increase in Steelhead during base flows was small (0.4 fish/day higher during base flows).

Overall, we conclude that there is no current evidence to suggest that pulse flows are attracting key salmonids into Elk Canyon, including Coho Salmon, Chinook Salmon, Chum Salmon and Steelhead.

4.5. Steelhead Spawning Flow Assessment

The flow prescription for Elk Canyon also includes a two-week 7 m^3/s spring spawning flow (April 1-15) aimed at increasing available spawning habitat for Steelhead. Hypotheses H_06, H_07, and

$H_0 8$ were developed to test the effectiveness of the spawning flow at increasing the numbers of spring spawners, as well as available Steelhead spawning habitat:

$H_0 6$: The estimated number of spawning Steelhead during the two-week, 7 m^3/s spawning release period in spring is not significantly different from that observed just prior to the operation.

$H_0 7$: The number of redds found above the base flow water level (minus a nominal depth to take into account that Steelhead will not spawn in very shallow water, e.g., 10 cm) following the two-week spawning release is not considered significantly different when compared to the total number of redds in the reach.

$H_0 8$: Following resumption of base flow operations, the number of Steelhead redds found above the water line and therefore, at risk of egg mortality from stranding, is not considered significant compared to the total number of redds in the reach.

Using snorkel survey methodology, the abundance of Steelhead in Elk Canyon was found to be not significantly different prior to the two-week spawning flow release than during the release across all three years of data collection (2016, 2017, 2019), which retains null hypothesis $H_0 6$. In contrast, habitat modeling from the IFS predicts that more Steelhead spawning habitat is available at 7 m^3/s (96-97% of maximum) compared to 4 m^3/s (69-71% of maximum) (Healey *et al.* 2018). These combined results suggest that another factor (such as marine conditions) may be limiting Steelhead populations in Elk Canyon than spawning habitat.

A total of 5 Steelhead redds were observed during 2019 spring surveys, while none were observed in 2016 or 2017. Redds were first observed during the 7 m^3/s spawning flows and all redds remained wetted when flows returned to base flows (4 m^3/s). The IFS results highlight that at 7 m^3/s, 96-97% of the available Steelhead spawning habitat is predicted to be present, and that 97-99% of that habitat is predicted to remain wetted once flows return to base flows at 4 m^3/s (Healey *et al.* 2018).

Overall, we conclude that few Steelhead spawn in Elk Canyon and that current data suggest that Steelhead abundance is not affected by 7 m^3/s spawning flows in Elk Canyon, which retains the null hypothesis $H_0 6$. Observational and habitat modeling results also suggest that the majority of redds (97-99%) will remain wetted at 4 m^3/s, which retains the null hypotheses of $H_0 7$ and $H_0 8$.

4.6. Fall and Spring Spawner Enumeration

Spawner counts in both fall and spring are to be conducted annually for the full JHTMON-15 program. Area under the curve (AUC) estimates of abundance are calculated each year to determine spawner abundance in Elk Canyon. Redd counts are also performed and compared to annual outputs of fry and smolts estimated from RST catch. After 10 years of data collection estimates of spawner abundance are compared to smolt enumeration data to test if the annual abundance of 'resident' smolts is correlated with spawner abundance ($H_0 9$):

$H_0 9$: Annual abundance of 'resident' smolts is not correlated with an index of Steelhead spawner abundance.

This is a final check to make sure that the assumption of 'full seeding' needed to test Hypothesis H_01 is satisfied.

Snorkel surveys and area under the curve methods were used to estimate the abundance of Chinook, Coho, Pink, Chum, and Sockeye Salmon fall spawners in Elk Canyon in fall 2018. Chinook and Coho Salmon adult abundance were estimated to be 103 and 1,083 individuals, respectively. Pink Salmon had the highest estimated abundance of 1,432 individuals. A population of 672 Chum Salmon and 273 Sockeye Salmon were also estimated. Few Steelhead were observed in fall with a peak observed abundance of only seven individuals.

As in previous years, the peak spawning time was variable across salmon species. Pink and Sockeye Salmon had the earliest peaks, with observed spawner counts peaking in late September and late September and early October respectively. The peak was not as clear for Sockeye Salmon as other species. Chinook Salmon had a peak in mid-October. Chum and Coho Salmon had the latest peak in spawning in late October/early November. A maximum of seven Steelhead were observed in mid-September.

Chinook, Chum, Coho, Pink and Sockeye Salmon redds were counted during fall spawning surveys, and the estimated fry and smolt production from these redds was compared to the estimated outmigration from the RST data. Chum, followed by Sockeye Salmon had the highest numbers of redds at 42 and 30 redds, respectively, while a maximum of 10 Chinook Salmon redds, 20 Pink Salmon redds, and 12 Coho Salmon redds were observed. Pink and Coho Salmon predictions for juvenile production based on redd counts were similar to outmigration estimates from the RST, while Chum, Chinook and Sockeye Salmon estimates diverged. These differences could be attributed to multiple factors, including redd superimposition, where redds constructed from early spawners such as Sockeye Salmon are superimposed by later spawners. For Chum Salmon and Chinook Salmon, the results suggest that redd counts may have been underestimated, and/or that egg-to-fry survival was high. For example, even if redd counts for Chum Salmon have been underestimated by a half, the production of Chum Salmon fry from the RST suggests that egg-to-fry survival for Chum Salmon was high (>25%) in winter 2018-2019.

5. CONSIDERATIONS FOR YEAR 6

The following represents a summary of considerations for Year 6.

<u>Smolt enumeration component</u>:

1. The RST is an effective method to inventory juvenile salmonids (fry and smolts) that are migrating out of Elk Canyon and provides valuable life history information. In Year 5, the mark-recapture experiments included wild Chinook and Chum fry in addition to Quinsam hatchery Chinook fry and smolts. These experiments with wild fry will continue if sufficient catches are observed in Year 6.

2. In the mark-recapture experiments, most wild fry releases were marked with Bismarck Brown. All hatchery Chinook fish used were clearly marked with a unique fin clip to help distinguish them from wild fish. This is recommended to continue in Year 6.
3. Based on the catch results of the target fish species, it remains appropriate for the RST sampling period to remain open until the end of July to ensure that the Coho and Chinook Salmon outmigration periods are captured.

Overwintering assessment component:

4. Year 5 was the fourth and final year that overwintering assessments were conducted. Night snorkeling mark/resight methods worked well again in Year 5 and were successful in addressing $H_0 2$ of the TOR for Steelhead/Rainbow Trout and Coho Salmon. A summary analysis was completed which showed that average Steelhead/Rainbow Trout parr abundance is not significantly different both fall and early spring seasons. This suggests that the majority of the population of Steelhead/Rainbow Trout is resident in the canyon during the winter months with little immigration or emigration during this period. Coho Salmon were observed during the fall in Elk Canyon, with only a few observed during the spring mark/resight swims. These low numbers of observed Coho Salmon parr match the observations from the RST, in which only three 1+ Coho Salmon smolts were captured from Elk Canyon in spring 2019. Overwintering assessments will not be completed in subsequent years.

Pulse flow assessment component:

5. Year 5 was the third and final year that pulse flow assessments were conducted. Snorkel surveys were successful in addressing $H_0 3$ and $H_0 5$ of the TOR, and results were similar to those in Years 2 and 3. A synthesis analysis across years was conducted which showed the pulses did not affect the counts or migration rates of any of the species considered (Steelhead, Chinook, Coho, Chum). There is no evidence to indicate that the pulses are effective at attracting fish.

Steelhead spawning flow component:

6. Year 5 was the third year that spawning flow assessments were conducted. Snorkel surveys were successful in testing $H_0 6$, $H_0 7$, and $H_0 8$ of the TOR. A total of 5 Steelhead redds were observed in 2019 during the 7 m^3/s spawning flow that remained wetted at 4 m^3/s. Redds were not deposited in the additional habitat created by the increase in water level/flow. Mean Steelhead abundance was higher during pre-spawning flows than during spawning flows, although this effect was small and statistically not significant. There is no evidence to suggest that maintaining spring spawning flows attract Steelhead into Elk Canyon.

Spawner enumeration component:

7. Adult Steelhead and Chinook, Chum, Coho, Pink and Sockeye Salmon and were all observed in Elk Canyon; Chinook, Chum, Coho, Pink and Sockeye redds were also counted. Year 5 was

the third year when estimates of production derived from RST catches were compared to estimates of production predicted from redd counts by species. This was a useful component of the analysis, which showed that egg-to-fry survival for Chum and Chinook Salmon was high in 2018-2019.

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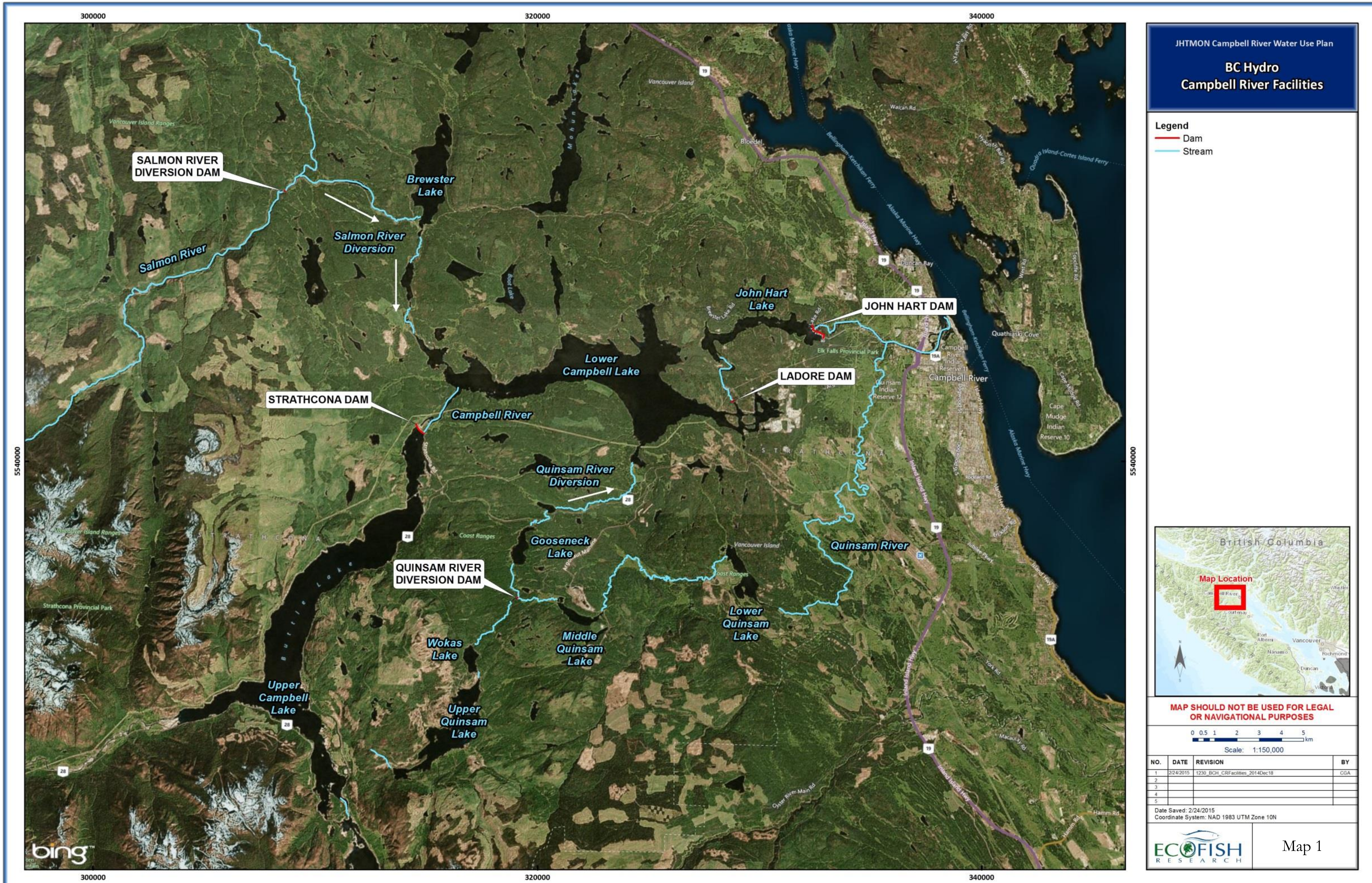
PROJECT MAPS



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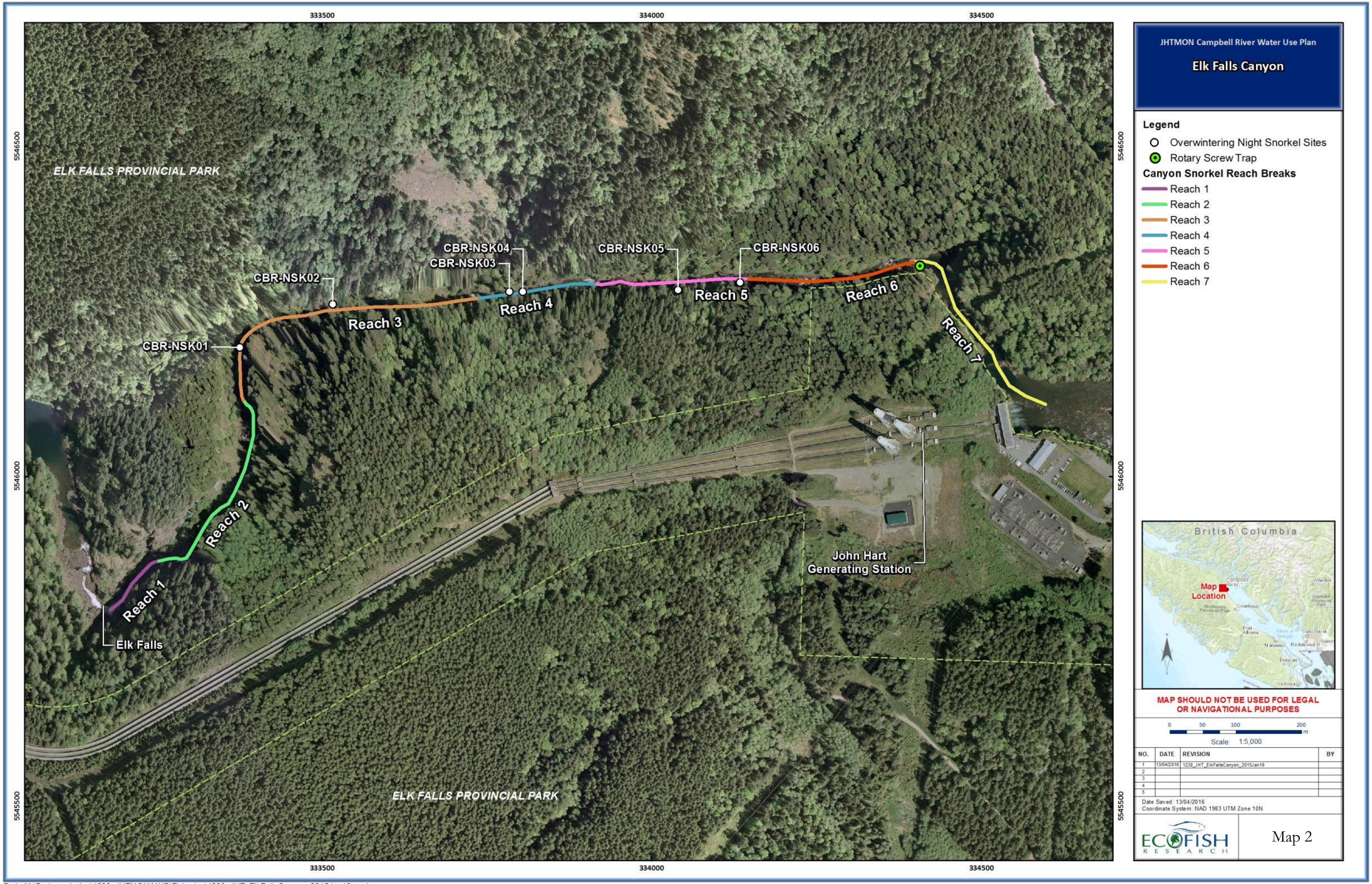

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