Bessette Creek Coho Enumeration Using a Resistivity Counter (Year 3 of 3)

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Executive Summary

Bessette Creek supports Coho Salmon (kisúʔ; *Oncorhynchus kisutch*) belonging to the South Thompson conservation unit and the Threatened Interior Fraser Coho Management Unit (COSEWIC 2016). Enumeration of Bessette Coho is currently conducted using streamwalks and the area-under-the-curve (AUC) method. Due to the cryptic behaviour of Coho and their propensity to travel at night, Coho detection during streamwalks can be difficult and may lead to underestimation of escapement. Resistivity counters may eliminate these biases because they continuously detect fish throughout the entire Coho migration period. A resistivity counter was operated concurrently with Coho walks for three years in Bessette Creek to test the counter as a method of enumeration.

Coho escapements estimated using the resistivity counter and streamwalk AUC methods produced the results summarized in the table below.

Year	Streamwalk AUC	Resistivity Counter
2017	323	348
2018	318	318
2019	597	837

Escapements were very similar between the two methods for 2017 and 2018. In 2019, the streamwalk AUC method provided a lower estimate by 240 fish. This result is likely attributed to the reduced streamwalk effort in 2019 that missed the early portion of Coho migration. We place higher confidence in the resistivity-based results because it captured the entire Coho migration and extensive video validation of the counter data was done.

The escapement calculation using counter data requires extrapolation of false negatives (a fish passage that was undetected by the counter) over periods of time that were not validated by video, which generates a small degree of uncertainty. A novel analysis method was developed by Instream Fisheries Research to quantify uncertainty related to extrapolation, although the application of this method to smaller populations (<500) is still under development. Analysis using this novel method produced an escapement of 679 (95% credibility interval 560-817) in 2019, which is closer to the streamwalk estimate. We expect the resistivity counter program to improve in the future by refining analysis methods and applying lessons learned in the past three years.

While the higher cost of operating a resistivity counter is an important consideration for future enumeration efforts, we expect cost to decrease with increased efficiency over time. Furthermore, extensive video validation of the counter data increases the reliability of estimates. We recommend that the counter and streamwalks be continued concurrently for three to five more years to allow for counter operations to improve and thereby enabling a more informed comparison between the two methods. Additional data would also lead to a better understanding of the calibration relationship between the two methods, particularly for high return years.

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nsyilxcn – English Translations

Okanagan Species Names (nsyilxcn – English Translation)	
kəkni or kəkn ̓i	Kokanee Salmon
kisúʔ	Coho Salmon
ntityix	Spring Chinook Salmon
sćwin	Sockeye Salmon
xʷuminaʔ	Rainbow Trout
miməlt	Whitefish

Acronyms and Abbreviations

Acronym	Description
AUC	Area-under-the-curve
CU	Conservation Unit
FN	False negative
FP	False positive
IFC	Interior Fraser Coho
IFCMU	Interior Fraser Coho Management Unit
IFR	Instream Fisheries Research
PSS	Peak signal size
TP	True positive

1.0 INTRODUCTION

1.1 Project Background

Bessette Creek is a tributary of the Middle Shuswap River and is located in Lumby, BC. The mainstem of Bessette and its three tributaries, Harris, Duteau, and Creighton creeks, provide spawning and rearing habitat for several salmonid species, including Coho Salmon (kisúʔ; *Oncorhynchus kisutch*). Bessette Creek Coho are part of the South Thompson conservation unit (CU) and the Interior Fraser Coho Management Unit (IFCMU), which was assessed as “Threatened” by COSEWIC (2016). With an average of 1076 spawners, Bessette Creek Coho comprises around 18% of the South Thompson CU and 4% of the IFCMU.

Escapement estimates enable resource managers to assess the status of threatened populations and administer recovery programs. In Bessette Creek, Coho escapements are currently estimated using streamwalks in conjunction with the Area-Under-the-Curve (AUC) method. However, visual enumerations of Coho may be prone to underestimation due to their propensity to move at night, cryptic behaviour and multimodal migration patterns that extend over several months. Visual counting conditions in Bessette Creek are frequently poor due to high flows, and turbid and dark water conditions (tannins). Fisheries managers identified resistivity counters as a potential method to address these challenges. If installed in the stream properly, resistivity counters can continuously detect fish movements throughout the entire migration period. This eliminates the biases created by reduced detection ability during streamwalks.

From 2017 to 2019, a resistivity counter was operated in Bessette Creek during the Coho escapement period to test this method of enumeration against streamwalk surveys. This report summarizes results from three years of operation and compares the two methods of enumeration.

1.2 Project Objectives

The goal of this project was to determine the feasibility of using a resistivity counter to provide accurate escapement estimates of Coho Salmon in the Bessette Creek system.

Specific objectives were to:

1. operate a resistivity counter concurrently with streamwalk surveys for three years during the Coho spawning season,
2. validate the resistivity counter data with video footage,
3. compare data quality, logistics, and cost between the two methods,
4. examine the relationship between the two escapement estimate methods, and
5. make recommendations for future enumeration efforts.

2.0 METHODS

2.1 Study Area

The Bessette Creek watershed is 795 km^2 in area and includes three main tributaries: Harris, Duteau and Creighton creeks (Figure 1). The three tributaries join at the town of Lumby, BC, and Bessette Creek flows northeast for 12 km before emptying into the Middle Shuswap River. In addition to Coho Salmon, the Bessette watershed provides habitat for other fish species, such as Chinook Salmon (ntityix; *Oncorhynchus tshawytscha*), kokanee salmon (kəkni; *Oncorhynchus nerka*), Rainbow Trout (xʷuminaʔ; *Oncorhynchus mykiss*), and Mountain Whitefish (miməlt; *Prosopium williamsoni*). On rare occasions, particularly during peak years, Sockeye Salmon (sćwin; *Oncorhynchus nerka*) from the Middle Shuswap venture up into the Bessette system.

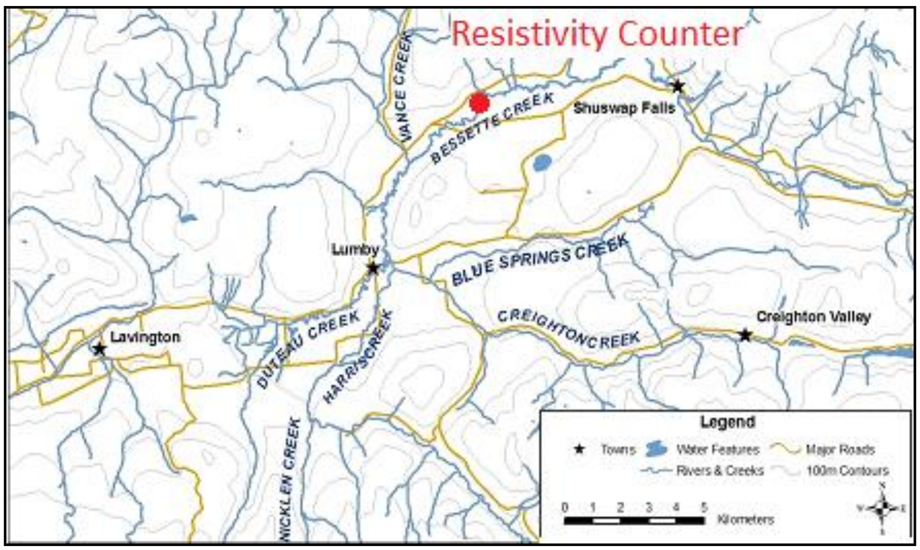

Figure 1. Location of resistivity counter on Bessette Creek.

2.2 Project Location

A resistivity counter was installed in Bessette Creek approximately 6 km northeast of Lumby, BC (Figure 1). The location of the counter is downstream of the majority of Coho spawning areas, though low numbers may spawn downstream near the confluence with the Middle Shuswap River. Following trial operation of the counter using batteries in 2015, power was installed to the site in 2017 to reduce the likelihood of power outages. The site initially chosen in 2017 was a wide and shallow glide with a width of 12 m and mean depth of 0.3 m (Figure 2a). However, channel changes during the 2018 freshet caused deepening over the most trafficked panel, which was undesirable because panel sensitivity decreases as fish travel higher in the water column. In 2018, the majority of fish migrated over this particular panel, which performed poorly in detecting downstream migrating fish. In 2019, the counter was moved approximately 15 m upstream of the original location to the tail end of a riffle with relatively uniform depths (Figure 2b).

Figure 2. Location of resistivity counter in Bessette Creek in 2017 and 2018 (A), and in 2019 (B).

2.3 Resistivity Counter Setup and Operation

The Logie 2100C resistivity counter setup consists of two components: an electronic unit (a computer containing an algorithm) that is deployed onshore, and flat pad sensors which are deployed in the stream (Figure 3). Three electrodes along the flat pad sensors continuously measure the bulk resistance of the water column above (Figure 3). When an object passes over the electrodes, the resulting change in resistance is detected. If the change in resistance exceeds a user-defined threshold, the counter's algorithm then classifies the movement as either an upstream moving fish, a downstream moving fish, or an event (vegetation, mammals, etc.). Movement direction is determined by the order in which the fish passes the negative and positive electrodes.

Figure 3. Electronic unit of the resistivity counter deployed onshore (left) and a flat pad sensor deployed in the stream (right).

For each event, the counter records the date, time, direction of movement, channel[1] number, and peak signal size (PSS; i.e. peak change in resistance). In addition, graphical trace data are stored for each event, which is later used to verify counter events and correct for algorithm errors (Section 2.4.1).

In Bessette Creek, four flat pad sensors were installed in series to span approximately 10 m of the stream. Channel 1 was installed on the right bank and channel 4 on the left bank. The remaining stream margins were blocked for fish passage using fencing and sandbags (Figure 2). A video camera with infrared lighting was mounted above each panel and recorded the panels continuously. Lights were installed to illuminate the stream and reduce the glare of the infrared lights in the video footage. In 2018, white plastic strips were installed beneath the flat pad sensors to increase image contrast and fish visibility (Figure 4). These strips remained in place in 2019.

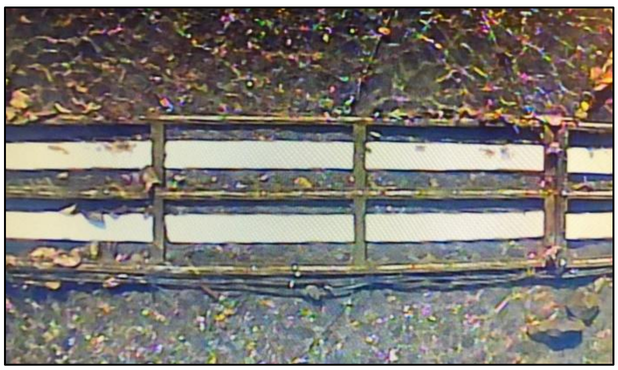

Figure 4. Flat pad sensors with white plastic stripping installed underneath to aid in fish detection during video review.

The resistivity counter was in operation from late September to late November or early December each year. Once installed, the counter was visited at least weekly but typically, biweekly, to check the integrity of the system, clean the resistivity pads, check the fencing, download counter data and video, and clear video storage space. Unscheduled visits were required on occasion to restart the computer system following power outages.

2.4 Validation

All counter records were validated through the following process:

1. **Graphics review**: each graphical trace is reviewed and classified as up, down, or event, correcting for counter algorithm errors if needed,
2. **Targeted video validation**: all up and down records are reviewed on video and classified as either a true positive (TP), or false positive (FP), and
3. **Random video validation**: a subset of randomly-selected video segments is reviewed. Fish movements observed on video that were undetected by the counter were classified as false negative (FN).

[1] Channel number is the ID assigned to each panel. In Bessette Creek, 4 panels were installed, and therefore the channels were numbered from 1 to 4.

2.4.1 Graphical Trace Data

We reviewed graphical trace data for all records to correct for errors in counter algorithm assignment (Figure 5). The graphics-corrected data were then used as the new counter raw data moving forward[2].

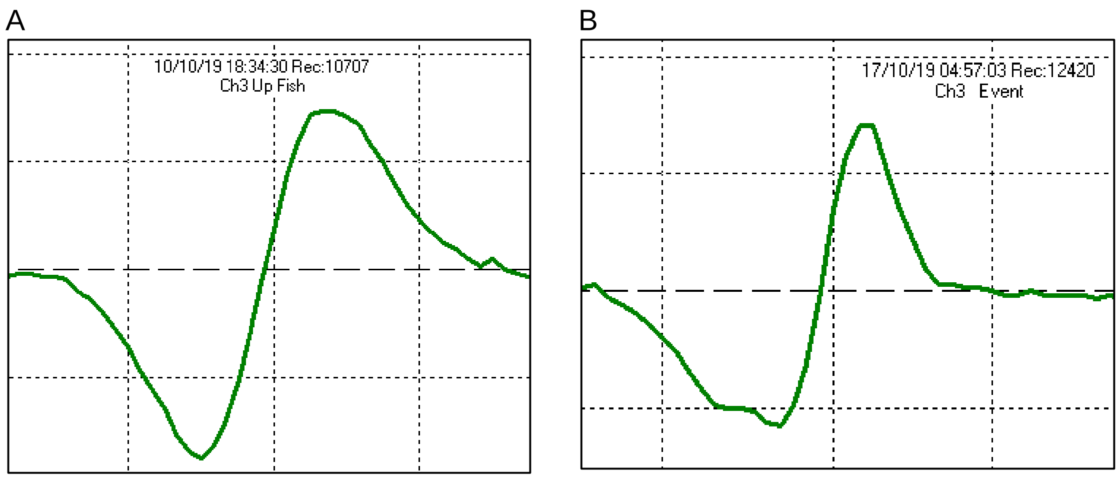

Figure 5. Graphical trace data for the Bessette Creek resistivity counter: A) correct algorithm assignment of an upstream fish movement, and B) incorrect algorithm assignment of an upstream fish movement as an event.

2.4.2 Video Validation

Due to an overlap in run timing between the end of the Chinook run and the start of the Coho run, data collected prior to the first appearance of Coho on video (generally early to mid-October) were not reviewed or analyzed. At times, power outages and insufficient video storage resulted in interruptions in the video footage. Table 1 summarizes the analysis periods, video interruptions, and the percent of video reviewed for each year.

Table 1. Video validation analysis periods for Bessette Creek Coho enumeration from 2017 to 2019, along with periods of video interruptions and percentages of total video reviewed.

Year	Analysis period	Video interruptions	Percent video reviewed
2017	Oct. 15 – Nov. 30	Oct. 15 – 19 Oct. 29 – Nov. 1	10.06%
2018	Oct. 9 – Dec. 4	Nov. 2 – 5 Nov. 21 – 23	10.03%
2019	Oct. 9 – Nov. 25	Oct. 20 – 22 Oct. 25 – 28	10.59%

[2] All mentions of counter records from this point forward refer to graphics-corrected counter data.

We conducted targeted validation by video-validating all counter records of fish movement within the analysis period for each year. On occasion, unclassified events were video-reviewed if the graphics data were unclear. All records were classified as true positive (TP; the counter recorded a movement and fish was observed during validation), or false positive (FP; the counter recorded a movement but no fish were observed during validation).

We then conducted random validation by randomly reviewing a subset of video totalling 10% of the total video record to quantify false negatives (FN; the counter did not record a movement, but a fish was observed during validation). In 2017 and 2018, random validation was conducted evenly across the entire counter period. In 2019, we increased the proportion of night time random validation to 74% and decreased day time random validation to 26% because most Coho movements in the previous years occurred at night (Figure 6). The stratified sampling approach resulted in a larger sample size of Coho movements and therefore should result in a more accurate measure of counter performance. Counter performance is expected to be the same during the day and night.

A trained analyst recorded the movement direction of all fish observed during validation and determined the species using guidelines provided in Appendix A. Fish length was also calculated using the known panel width and the proportion of onscreen fish length and onscreen panel width. Counter records that could not be validated due to no video or poor video quality were given a classification of NA. These records were incorporated into the final escapement estimate, but were not included in counter performance estimates.

All non-Coho and non-Chinook records were removed from the dataset prior to further analysis.

2.5 Extrapolation of False Negatives

Because we only sampled for FN counts in 10% of the video record, we extrapolated the FN counts to the entire unwatched video period in order to estimate how many fish went undetected throughout the entire study period. Extrapolations were stratified based on panel, day, and time of day:

Equation 1

$$FN_{e_d} = \sum_{i=1}^{I} \left(\sum_{n=1}^{\mathrm{N}} \left[\frac{FN_{d,i,n,t}}{\mathrm{W}_{i,n,t}} \right] \right)$$

where FN_{e_d} is the extrapolated false negative count for direction *d*. $FN_{d,i,n,t}$ is the false negative count for direction *d*, channel *i*, day *n*, and time of day *t* (nighttime or daytime). $W_{i,n,t}$ is the proportion of video watched for channel *i*, day *n*, and time of day *t*. Extrapolations were completed for both Coho and Chinook data. The Coho extrapolated

FN count was used in the escapement estimate, while the combined extrapolated FN count was used to calculate counter performance.

2.6 Counter Performance

We evaluated counter performance by calculating recall, precision, and accuracy. Recall and precision were later used to correct counter data that could not be validated by video. Recall evaluates the ability of the counter to detect fish movements by determining the proportion of true fish movements that were correctly recorded by the counter (i.e., how often the counter recorded an up or down when a fish moved past):

Equation 2

$$Recall = \frac{\sum TruePositives}{\sum ConditionPositive}$$

Equation 3

$$Recall = \frac{TP}{TP + FN_e}$$

Precision evaluates the proportion of movements recorded by the counter that correspond to true fish movements (i.e., how often a fish actually moved past when the counter detected a movement):

Equation 4

$$Precision = \frac{\sum TruePositives}{\sum PredictedConditionPositive}$$

Equation 5

$$Precision = \frac{TP}{TP + FP}$$

Accuracy describes the proportion of true results over all results, whether positive or negative (i.e., what is the ability of the counter to make a correct assignment overall):

Equation 6

$$Accuracy = \frac{TP}{TP + FP + FN_e}$$

We calculated separate recall, precision, and accuracy for each channel and direction. We combined Chinook and Coho data assuming the counter performs similarly for species with similar size distributions. Combining species data also ensured the sample size was adequate to calculate direction-specific performance. Performance indicators were calculated for the entire counter season to further increase sample size, assuming that counter performance was uniform across the season.

2.7 Calculating Species Ratios

Daily species ratios using combined up and down counts were calculated for Coho, which was used to correct raw counter data that could not be video-validated. For days with no species data, we applied the average Coho ratio of the days immediately before and after the missing data until the last day that a Chinook was observed, after which we assumed all fish were Coho.

2.8 Counter Data with No Corresponding Video

For counter data that could not be validated by video, we can reasonably assume that not all fish were Coho and that counter errors were made. We corrected this dataset for species and counter performance using the equation:

Equation 7

$$CC_d = \sum_{i=1}^{I} \left(\sum_{n=1}^{\mathrm{N}} \left[(RC_{d,i,n} * Sp_n) * P_{d_i} * \frac{1}{R_{d_i}} \right] \right)$$

where CC_d is the corrected count for direction *d*. $RC_{d,i,n}$ is the raw counter counts for direction *d*, channel *i* on day *n*. R_{d_i} and P_{d_i} are the recall and precision for direction *d* and channel *i*. Sp_n is the species ratio for up and down movements (combined) of the target species on day *n*.

2.9 Estimating Coho Escapement

We estimated total Coho escapement by combining true positives from validation, the extrapolated false negatives, and the corrected counts from periods without video using the equation:

Equation 8

$$Escapement = \left(TP_u + FN_{e_u} + CC_u\right) - (TP_d + FN_{e_d} + CC_d)$$

where TP_u and TP_d are the true positive up and down counts, FN_{e_u} and FN_{e_d} are the extrapolated false negative up and down counts, and CC_u and CC_d are the corrected up and down counts for periods with no video.

3.0 RESULTS

3.1 Coho Migration Timing

In all years, the Coho Salmon migration in Bessette Creek began in early to mid October, and lasted until the end of November (Figure 6). There was overlap with the end of the Bessette Chinook run, which extended into mid October. In 2019, Chinook (possibly from the Middle Shuswap population) were observed at the counter as late as November 2.

Peak Coho migration in 2017 occurred between November 11 to 16. In 2018, peak migration was earlier, between October 24 and November 3. In 2019, peak migration was even earlier, between October 13 and 28, although a second pulse was detected between November 2 and 6. Fish returning in multiple pulses was observed across the three years.

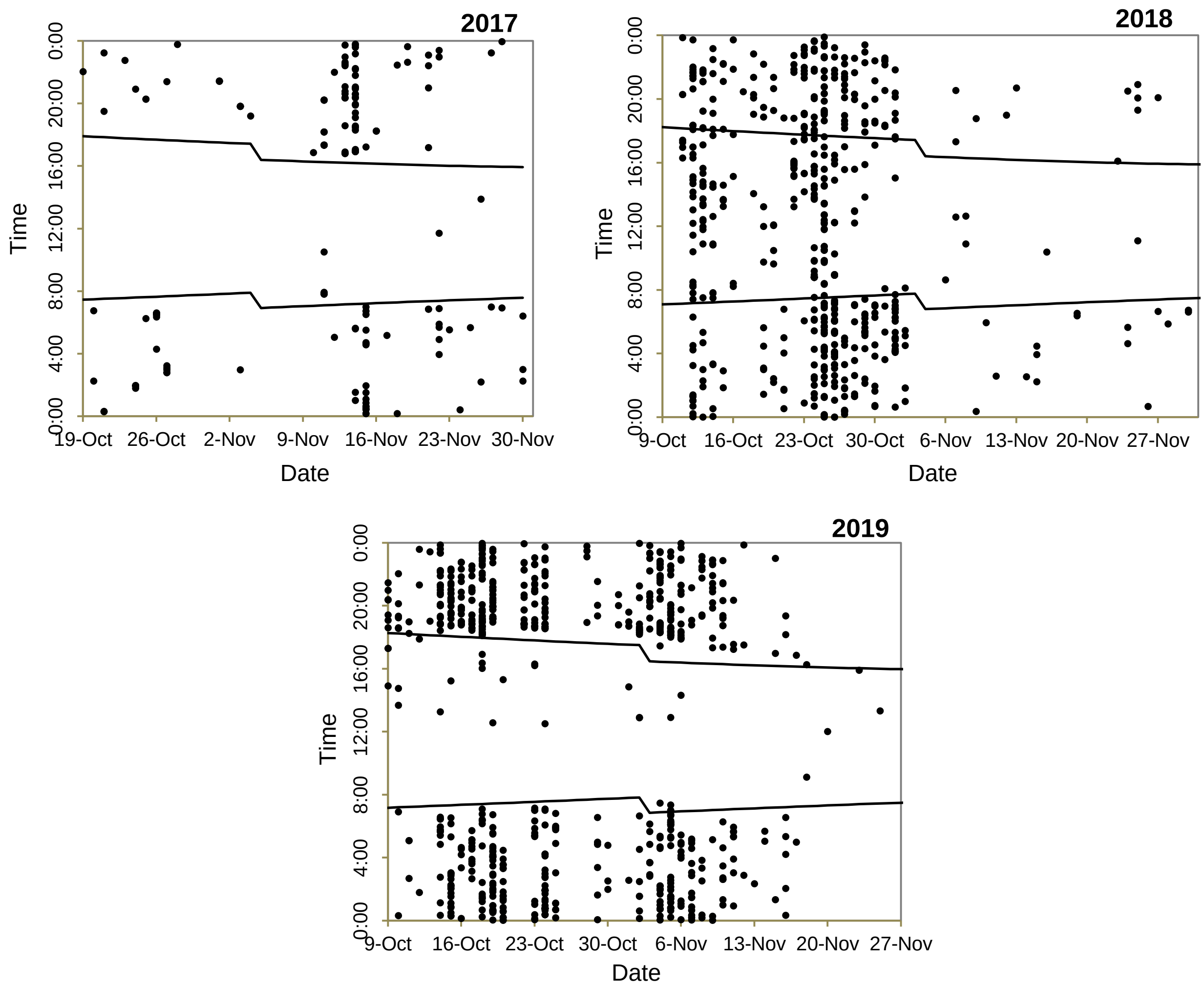

Figure 6. Video-validated Coho movements detected by the counter by date and time from 2017 to 2019. Daily sunrise and sunset are indicated by black horizontal lines (the one hour shift in early November indicates daylight savings).

In all three years, the majority of Coho fish movements occurred between sunset and sunrise (Figure 6).

3.2 Counter Performance

Counter performance measures are presented in Table 2. Counter precision was generally high for 2017 but varied considerably in recall. It is important to note that channels 1 through 3 had very small sample sizes and was prone to large changes in performance in response to even small changes in TP, FP, and FN counts. Channel 4 was the most trafficked panel and had low recall for both up and down movements.

In 2018, precision was high for all channels and both directions (Table 2). Recall was overall good, with the exception of channels 3 and 4 in the down direction, which had low recall. As with 2017, channel 4 experienced the highest amount of traffic, possibly as a result of deepening of the channel on the left bank.

In 2019, precision was overall good but lower in comparison to 2018 (Table 2). Recall was higher for upstream movements than downstream movements. Recall for channel 1 and 4 were particularly low for the downstream direction. This year, channel 1 spanned over the deepest part of the channel and saw the most traffic.

Table 2. Precision (P), recall (R), and accuracy (A) of the Bessette Creek resistivity counter in 2017, 2018, and 2019 using combined Coho and Chinook data. N is the combined sample size of true positives, false positives, and false negatives used in the calculations.

	2017				2018				2019			
Up Performance												
Channel	**P**	**R**	**A**	**N**	**P**	**R**	**A**	**N**	**P**	**R**	**A**	**N**
1	1.00	1.00	1.00	1	1.00	0.77	0.77	60	0.93	0.68	0.65	593
2	1.00	0.19	0.19	3	0.99	0.72	0.72	95	0.86	0.54	0.50	139
3	0.69	0.77	0.58	43	0.98	0.85	0.83	103	0.90	0.84	0.76	123
4	0.90	0.29	0.28	121	0.99	0.80	0.79	296	0.92	0.65	0.62	69
mean	**0.90**	**0.56**	**0.51**		**0.99**	**0.79**	**0.78**		**0.90**	**0.68**	**0.63**	
Down Performance												
Channel	**P**	**R**	**A**	**N**	**P**	**R**	**A**	**N**	**P**	**R**	**A**	**N**
1	1.00	1.00	1.00	1	1.00	0.78	0.78	28	0.52	0.17	0.14	63
2	1.00*	1.00*	1.00*	0	0.90	0.73	0.68	30	0.82	0.54	0.49	85
3	0.33	0.11	0.09	4	0.95	0.45	0.44	43	0.85	0.40	0.37	53
4	0.81	0.15	0.14	23	0.94	0.34	0.33	112	0.84	0.27	0.26	38
mean	**0.79**	**0.57**	**0.56**		**0.95**	**0.58**	**0.56**		**0.76**	**0.35**	**0.32**	

*assumed; no data

Of the three years, the counter performed the best in 2018. Counter accuracies for all panels were relatively high (>72%) for upstream movements in that year, indicating that the counter was able to reliably detect fish passage. In 2019, decreased counter accuracy could be attributed to a pair of Chinook that built a redd on top of the counter, which partially covered the electrodes on channels 1 and 2. Overall, downstream recall was lower in panels with high traffic, although channel 4 remained problematic in 2019 despite having lower traffic.

3.3 Peak Signal Size

We examined the relationship between PSS and fish length to evaluate whether PSS could be used as a species identification tool. We found essentially no relationship between PSS and fish length in this study (Figure 7). There was also significant overlap in PSS between Chinook and Coho (Figure 8).

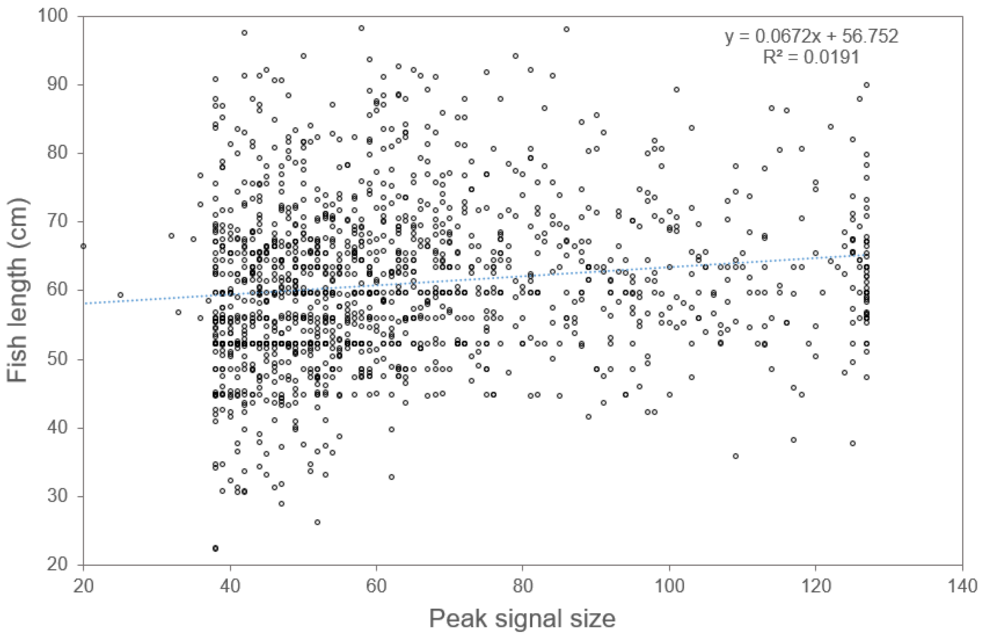

Figure 7. Regression analysis of peak signal size and measured fish length using combined data from the 2017 to 2019 study years.

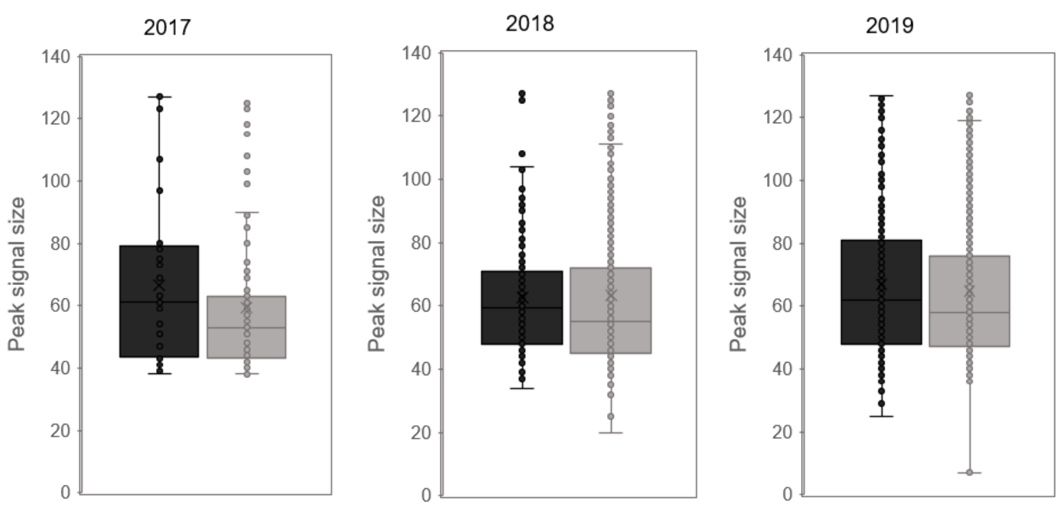

Figure 8. Distributions of Chinook (black) and Coho (grey) peak signal sizes in 2017, 2018, and 2019.

3.4 Species Ratios

Figure 9 depicts the calculated daily species ratios of Coho and Chinook in all three study years. Coho-Chinook ratios exhibited a similar pattern for 2018 and 2019. There was only one day of Chinook data in 2017, which was used to backfill a video blackout period from October 15 to 19.

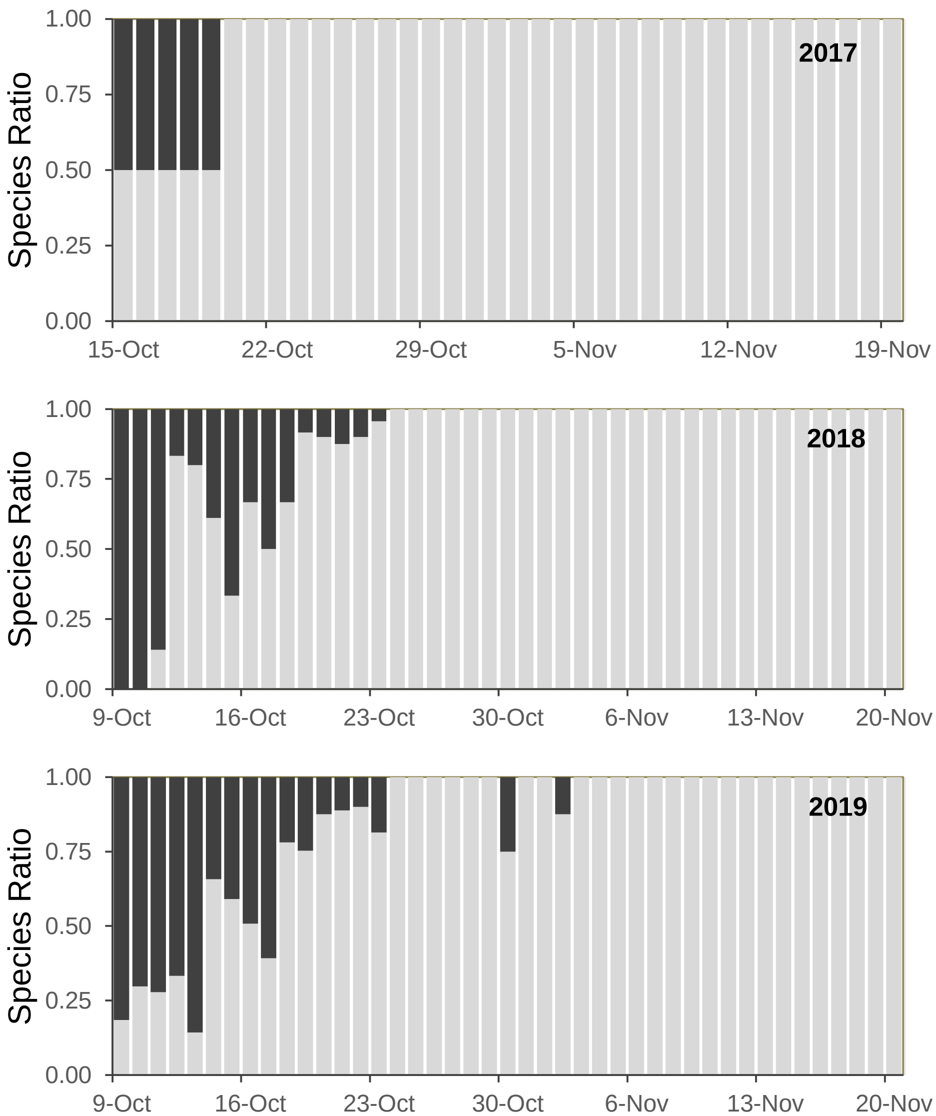

Figure 9. Coho (grey) and Chinook (black) daily species ratios observed at the Bessette Creek resistivity counter in 2017, 2018, and 2019.

3.5 Coho Escapement

In 2017, an estimated net number of 348 Coho moved upstream past the resistivity counter. Fish overwhelmingly preferred to travel over channel 4 on the left bank, while very few traveled over channels 1 and 2 on the right bank (Figure 10). Daily net upstream counts show that migration peaked on November 1 and 14 (Figure 11). The November 1 peak was initially not captured by the counter due to a large number of extrapolated FNs calculated for that day.

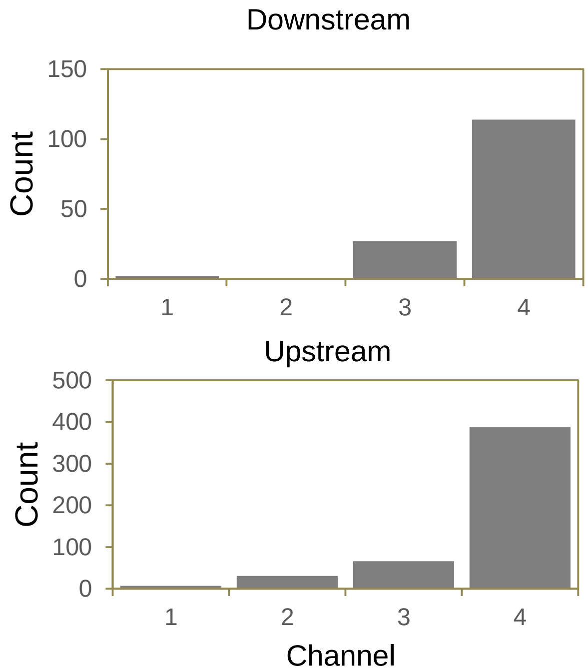

Figure 10. Species- and performance-corrected Coho counts by channel and direction at the Bessette Creek resistivity counter in 2017.

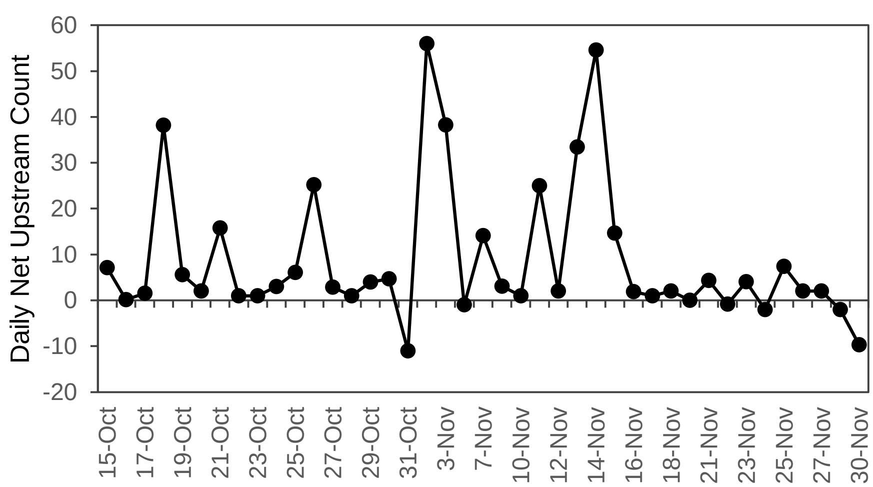

Figure 11. Daily net upstream Coho migration past the Bessette Creek resistivity counter in 2017.

In 2018, an estimated net number of 318 Coho moved upstream past the resistivity counter. Fish still strongly preferred to travel over channel 4 over the other channels (Figure 12). Daily net upstream counts show that migration peaked on October 24 and November 1 (Figure 13).

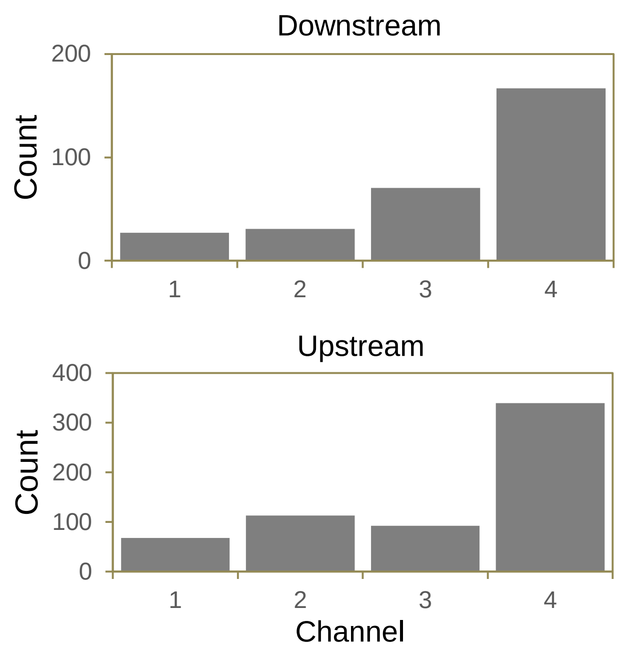

Figure 12. Species- and performance-corrected Coho counts by channel and direction at the Bessette Creek resistivity counter in 2018.

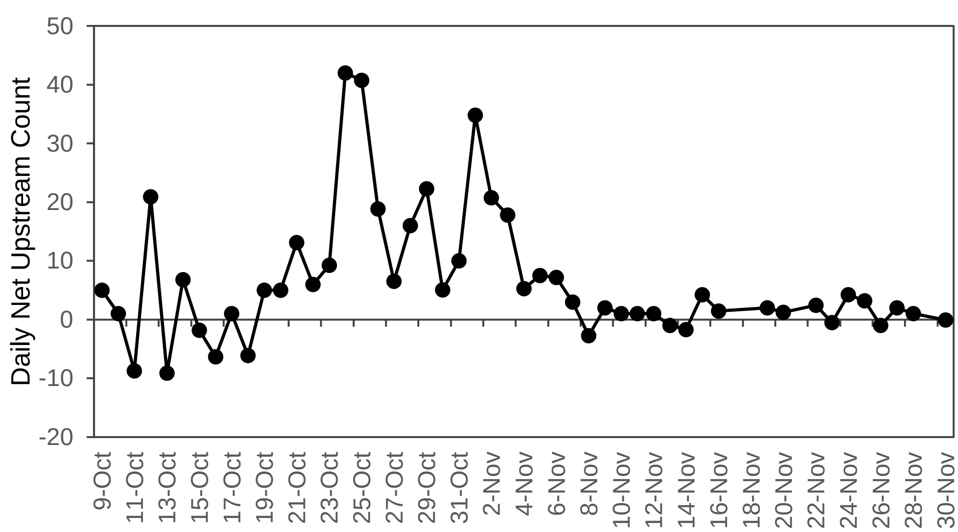

Figure 13. Daily net upstream Coho migration past the Bessette Creek resistivity counter in 2018.

In 2019, an estimated net number of 837 Coho moved upstream past the resistivity counter. The counter was moved approximately 15 m upstream in this year, and Coho migrated primarily over channel 1 (Figure 14). Daily net upstream counts show that migration peaked on October 18 and November 5 (Figure 15). A detailed breakdown of true positives, false positives, extrapolated false negatives, and corrected no-video counts are provided in Table 3.

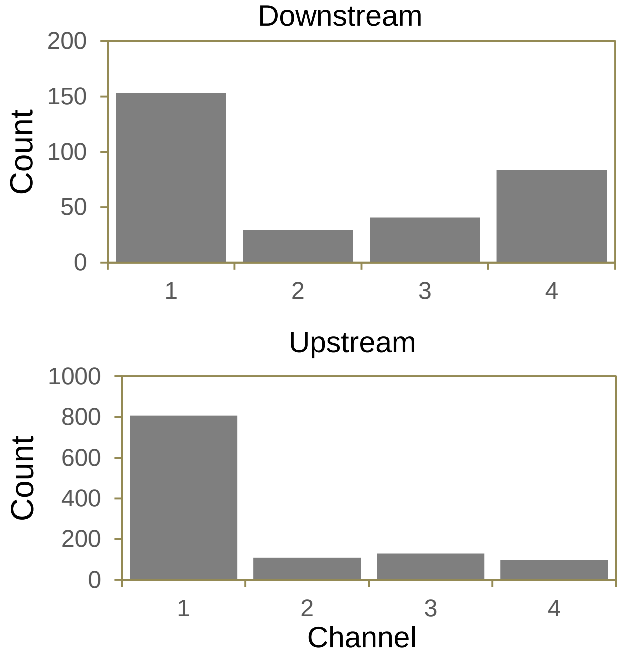

Figure 14. Species- and performance-corrected Coho counts by channel and direction at the Bessette Creek resistivity counter in 2019.

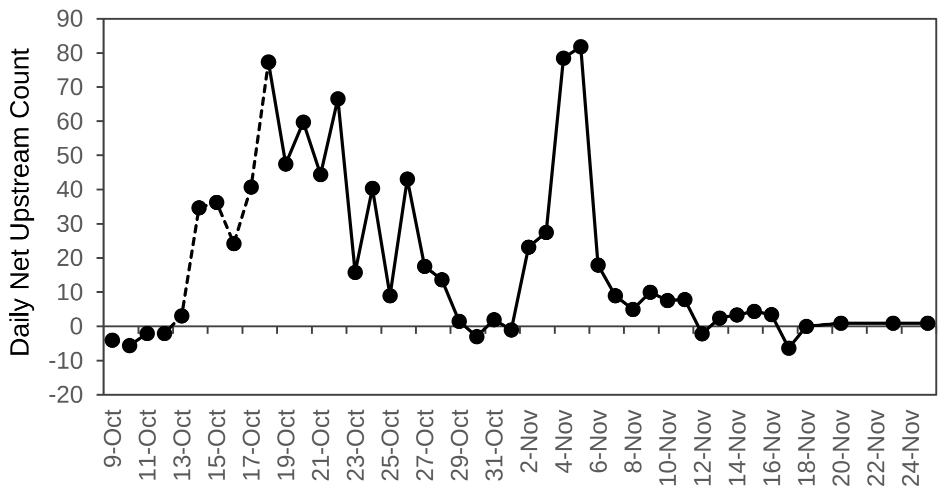

Figure 15. Daily net upstream Coho migration past the Bessette Creek resistivity counter in 2019. This year, there were a number of FN counts between October 9 and 18 that were not dated. The extrapolation of these FN counts were based on pooled watch efforts in that time frame. The daily FN numbers were assigned based on the daily proportions of TP counts, and therefore represents an estimate (shown by dotted line).

Table 3. Net counts of true positives, false positives, extrapolated false negatives, and corrected no-video counts for Bessette Creek Coho Salmon in 2019.

Panel	Net True Positives	Net False Positives	Net Extrapolated False Negatives	Net Corrected No-Video Counts
1	443	6	92	119
2	51	1	8	20
3	54	1	0	35
4	27	0	-22	10
TOTAL	**575**	**8**	**78**	**184**

4.0 DISCUSSION AND RECOMMENDATIONS

4.1 Comparison of Resistivity Counter and Streamwalk AUC Methods

Coho escapements estimated using the resistivity counter and streamwalk AUC methods were very similar for 2017 and 2018 (Table 4). In 2019, a higher return year, the streamwalk AUC method resulted in a lower estimate by 240 fish. This could be due to a reduced number of streamwalks (4 weekly surveys instead of the previous 6 weekly surveys) during this year, which started in late October and missed the beginning of the Coho run in mid-October. Differences in observer competence and survey period during streamwalks can have large effects on population estimates if not properly accounted for.

Table 4. Coho escapement estimates using the streamwalk AUC method and resistivity counter method in 2017, 2018, and 2019.

Year	Streamwalk AUC	Resistivity Counter
2017	323	348
2018	318	318
2019	597	837

The resistivity counter's high performance metrics in 2018 suggest that it can be a reliable tool for enumeration. It is also important to note that low counter performance does not necessarily result in an inaccurate estimate. Counter performance solely indicates how effectively it detected fish, and should not be used to judge the success of the program. Our current analysis method validates 100% of the counter records, and the only uncertainty lies within the false negative count, which has been accounted for largely through extrapolation. While the counter performance was moderate in 2017 and 2019, we are confident in the estimates produced due to the extensive validation that was performed.

Operating a resistivity counter, however, does come with its own set of challenges. The system itself is technical and complex, and operating it requires a considerable amount of training. During analysis, some uncertainty comes from the extrapolation of false negatives over the unwatched video period. Video validation is very time consuming, and only 10% of video was reviewed each year (instead of the recommended 15%). This leaves a large proportion of the study period unsampled for false negatives. Extrapolation over such a large proportion of the timeframe generates uncertainty, although the amount is unknown using current methods.

In an effort to quantify the uncertainty related to extrapolation, a new method for analysis was developed by Instream Fisheries Research (IFR). In this new method, true positives, false positives, and false negatives are equally sampled by video validation over a proportion of the study period (a random sub-sample of approximately 10% in this case). Counter performance is then calculated without any extrapolation, and applied to raw counter data. IFR conducted the analysis for Bessette Coho in 2019 using their new method, and the results are provided in Appendix B. The escapement estimate using this method was 679 (95% credibility interval 560-817), which is closer to the streamwalk estimate. It is interesting to note that both the streamwalk and old counter estimates both roughly fall within the credibility interval range. While this method is only suitable for larger populations (>500) at this moment to achieve sufficient sample size, IFR is working on ways to increase its applicability to smaller populations (or smaller run years). It is important to note that this method eliminates the need for targeted validation, greatly reducing cost of analysis. The approach validates 10% of video overall rather than validating all counter detections as was done for our analysis.

Moving forward, there are several factors to consider when making a recommendation for a preferred enumeration method. While the resistivity counter eliminates the sampling bias of the streamwalks and presumably has higher accuracy, it is more costly to run. Table 5 describes some other advantages and disadvantages of both methods.

Table 5. Pros and cons of streamwalk AUC and resistivity counter methods for Coho enumeration in Bessette Creek.

Method	Advantages	Disadvantages
Streamwalk AUC	• Lower cost • Not much training or equipment required • Can conduct biosampling, gathering genetic and physiological data • Gathers information on spawner distribution and habitat conditions	• Potentially lower Coho detection ability • May not cover entire spawning period when migration timing varies • May miss night time movements • Requires consistent effort each year • Higher risk of injuries
Resistivity Counter	• Operational throughout entire migration period with reduced risk of missing fish when migration timing varies • Can estimate escapement of other species (e.g., Chinook) by extending monitoring period • Captures all information needed to calculate true escapement using graphics data and video	• Higher cost • Greater technical expertise required • Vulnerable to power outages and mechanical/technical problems

Based on similarities in escapement estimates between the two methods in 2017 and 2018, the extra cost and effort to run the resistivity counter may not be justified. However, the discrepancy in the 2019 estimates suggest that there are differences between the methods. We place higher confidence in the resistivity-based escapement in 2019 due to the extensive validation and high sample sizes achieved this year, which increases accuracy and reduces uncertainty in the final escapement estimate. Meanwhile, streamwalks missed a number of Coho migrating into the system in earlier October. In all three years, the majority of Coho fish movements occurred between sunset and sunrise (Figure 6). This supports the notion that Coho may be underestimated by daytime streamwalks. Further years of analysis may show that the two methods continue to provide different estimates, depending on various factors and river conditions. We recommend that the counter and streamwalks run concurrently for three to five more years to better understand the relationship between the two methods, particularly in high return years. Further, this is necessary to develop a calibration relationship.

4.2 Peak Signal Size

The PSS between Chinook and Coho overlapped significantly, and we found no relationship between PSS and fish length. We recognize that PSS-length relationships change with different water depths over each panel, and thus a stronger relationship may be found if we examined PSS-length relationships by panel. However, water depths within a panel varies over the season due to rain events, and the significant overlap between Chinook and Coho PSS would lead to too much uncertainty in species identification. Not only do Chinook and Coho in Bessette Creek exhibit natural overlap in their length distributions, fish can travel at different depths in the water column, causing PSS to vary at different depths (McDubbing et al. 2000). We tried to minimize this effect in 2019 by moving the counter to a more uniform and shallow section of the creek. However, PSS between the two species still overlapped significantly due to similar body sizes. Future species identification would have to be completed by video validation or by using historical daily species ratios if they remain fairly constant from year to year. However, this does not constitute additional effort as video validation will be conducted annually to determine escapement estimates.

4.3 Future Improvements to Counter Operation

Over the past three years, we have learned that proper setup and maintenance of the counter can greatly increase its success. We installed a backup power supply to keep the counter operational during brief power outages, although a larger battery is recommended for longer blackout periods typical of this site in the fall. Treating the cameras with insecticide also greatly reduced instances where camera view was obscured by insects.

We found that panels generally had low recall in the downstream direction, particularly if heavily trafficked. Lower recall for down movements is typical of flat pad counter systems. Fish are more likely to be missed travelling downstream because they move higher in the water column above the counter sensors. Luckily, downstream counts are generally far outnumbered by upstream counts, and therefore the impact of low downstream recall on escapement estimates is reduced. Although the new 2019 location exhibited better channel conditions, counter performance remained low for the most trafficked panel (which switched from panel 4 to 1). This could be due to sensor interference from a metal fish fence that was installed next to panel 1. In future years, a bigger gap should be left between the fish fence and the sensor, while ensuring the gap is blocked off with sufficient sandbags to prevent fish from migrating through. Alternatively, an additional sensor pad and video camera could be installed to cover the entire stream width, eliminating the need for a fish fence.

In 2019, a pair of Chinook built a redd over the flat pad sensors, partially covering panels 1 and 2 with its tail end. The electrodes were routinely cleared of gravel but counter performance could have been reduced during periods when gravel accumulated on the electrodes. The gravel also covered the white contrast strips on the pads, making video validation more difficult. The proximity of the redd resulted in a big surge of Chinook traffic from the spawning pair swimming back and forth around the sensors. One fish also hovered over the panel for long periods of time. During this timeframe, the counter assigned many false positives by either detecting a fish movement when the fish did not completely cross the panel or by assigning the wrong direction completely. Incorrect direction assignment of this scale was not observed in previous years. We also observed a lot of noise over channel 3 in 2019 where a large number of unclassified events would be recorded every few seconds for hours at a time. The reason for this is unknown. Channel 4 also continued to perform poorly for downstream movements despite lower traffic. We recommend continued monitoring of these two sensor pads.

In the future, we recommend the flat pad sensors be installed in the same location due to favourable channel conditions. The 2019 location is suitable for counter setup because it is a uniform glide, free of significant sediment buildup, and relatively fast moving to discourage gathering of fish around the panels. We also recommend budgeting enough time to review 15% of the video record to reduce uncertainty of the extrapolated counts.

4.4 Final Recommendation

Over the three project years, the resistivity counter was able to detect a large number of fish movements with good performance measures. This, combined with a rigorous validation protocol, led to high confidence in the Coho escapement estimates produced by the resistivity counter program. Counter and streamwalk escapement estimates were very similar during 2017 and 2018. However, in 2019, a higher return year, the counter provided a higher estimate, potentially as a result of reduced streamwalk efforts that missed an early surge of migrating Coho. The differences between the two enumeration methods should be further explored in future years. The resistivity counter is still a relatively new method of enumeration and is constantly undergoing improvements. We recommend that both enumeration methods be continued concurrently for three to five more years to allow for counter operations to improve and thereby enabling us to make a more informed comparison. Additional data would also lead to a better understanding of the calibration relationship between the two methods, particularly for high return years.

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Appendix A

Guidelines for species identification

Table A1. Guidelines for species identification during video validation of the Bessette Resistivity Counter data.

Species	Timing	Size	Colour	Decay	Behaviour
Coho	• Early-mid October to end of project • Mostly nighttime travellers	• >50-60 cm • Fatter bodies	Dark grey/blue	None to rare, more likely at end of November	More cryptic behaviour (faster swimmers, does not hover)
Chinook	• Start of project until mid-October • Mostly daytime travellers	• >60 cm • Slender bodies with large heads	Red/black	White decay marks present in patches or along top of body	Less cryptic behaviour (slow swimming, hovers over panel)
Sockeye	• Entire project period, although rare • Night and day travellers	• Similar to Coho, slightly smaller	Bright red	None to rare	-
Whitefish	• Entire project period • Night and day travellers	• 20-40 cm	Dark	None to rare	-

Appendix B

Bessette Creek Coho Enumeration 2019 using a New Resistivity Counter Analysis Method

April 27, 2020
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Methods

Validation:

We validated counter records from October 9 to November 25 using video validation data collected continuously for each counter channel. Our goal was to randomly validate 10% of the total video record, which we did in 5-minute validation selections. The amount of validation was equal between the four counter channels.

A trained analyst recorded the movement direction of all fish observed during validation, which was then compared to the direction recorded by the counter. All records were classified as true positive (TP; the counter recorded a movement and fish was observed during validation), false positive (FP; the counter recorded a movement but no fish were observed during validation), or false negative (FN; the counter did not record a movement, but a fish was observed during validation). The analyst also determined species for each movement record and measured the total length of all fish.

Calculating Sensor Performance:

We estimated counter performance for the validation subset by calculating recall and precision, which are standard descriptors in confusion matrix analyses (Fawcett 2006). Recall evaluates the ability of the counter to detect fish movements by determining the proportion of true fish movements that were correctly recorded by the counter (i.e., how often the counter recorded an up or down when a fish moved passed):

Equation 2

$$Recall = \frac{\sum TruePositives}{\sum ConditionPositive}$$

Equation 3

$$Recall = \frac{TP}{TP + FN}$$

Precision evaluates the proportion of movements recorded by the counter that correspond to true fish movements (i.e., how often the counter was correct when it detected a movement).

Equation 4

$$Precision = \frac{\sum TruePositives}{\sum PredictedConditionPositive}$$

Equation 5

$$Precision = \frac{TP}{TP + FP}$$

Combined, recall and precision describe the ability of the counter to correctly detect fish movements; however, it is important to note that precision and recall as calculated above describe the counter during the validation time period. We use the validation recall and precision to represent precision and recall for the full counter dataset, assuming that these values are representative because video validation data are random.

We calculated separate recall and precision values for each of the four channels and for up and down movements. We did not calculate species-specific performance because the size distributions of Chinook and Coho overlapped considerably, indicating that counter performance should be relatively similar.

Calculating Species Ratios:

Species ratios must be determined for the Bessette counter because both Coho and Chinook are present during the Coho migration period. We used a binary classification system, where Coho were given a value of one and Chinook were given a value of zero. Pooling data from all channels, we then calculated daily species ratios for Coho, and applied these ratios to the raw daily counter counts. For days with no species data, we applied the average species ratio until the last day Chinook were observed, after which we assumed all records were Coho.

Estimating Total Abundance:

We used channel-specific precision, recall, and daily species ratios calculated for the validation data to estimate Coho abundance using the equation

Equation 6

$$Abundance = \sum_{i=1}^{I} \left(\sum_{n=1}^{\mathrm{N}} \left[(U_{i,n} * Sp_n) * P_{u_i} * \frac{1}{R_{u_i}} \right] - \left[(D_{i,n} * Sp_n) * P_{d_i} * \frac{1}{R_{d_i}} \right] \right)$$

where $U_{i,n}$ and $D_{i,n}$ are raw counter up and down estimates, respectively, for channel *i* on day *n*. R_{u_i}, R_{d_i}, P_{u_i}, and P_{d_i} are the recall (*R*) and precision (*P*) for channel *i*, and Sp_n is the species ratio for up and down movements (combined) of the target species on day *n*. We used a Bayesian application of the confusion matrix (Caelen 2017) to incorporate measurement error into abundance estimates and obtain 95% credibility intervals. Our method assumes the values in the confusion matrix (TP, FP, and FN) are drawn from a multinomial distribution:

Equation 7

$$V \backsim Mult(N_T, \theta)$$

where *V* is a vector of TP, FP, and FN, N_T is the total number of events, and θ is a vector of multinomial probabilities ($\theta = (\theta_{TP}, \theta_{FP}, \theta_{FN})$). In the Bayesian model, the θ values are modeled by a Dirichlet distribution, which is the conjugate distribution of the multinomial distribution:

Equation 8

$$\theta \backsim Dir(\alpha) = Dir(\alpha_{TP}, \alpha_{FP}, \alpha_{FN})$$

where the vector α is the paramters for the Dirichlet distribution. We use uninformative priors for θ ($\alpha = (1,1,1)$) and generate posterior distributions of precision and recall for each channel and movement direction using posterior distributions of TP, FP, and FN from the vector *V*. The model generates a final posterior distribution of abundance by applying posterior distributions of precision and recall and species ratios to the raw counter estimate using
Equation 8.

All analyses were performed in the open-source R Project Software (R Core Team 2019) and RStudio (RStudio Team 2015). We used the R packages lubridate (Spinu, Grolemund, and Wickham 2018) and dplyr (Wickham, François, et al. 2019) during data preparation, ggplot2 (Wickham, Chang, et al. 2019) to produce visuals, and rjags (Plummer 2018) for Bayesian modelling.

Results

<u>Validation:</u>

Video validation data were collected between October 9 and November 25, 2019, with two small periods of missing data from October 20 to 22 and from October 25 to 28. We validated 10.25% of the total video record (~25,000 minutes) by watching randomly selected 5-minute video segments (the same segments were watched on all four channels).

Sensor Performance:

We estimated channel- and direction-specific counter performance (recall and precision) for the validation dataset using
Equation and Equation . We combined Coho and Chinook records when estimating performance because their size distributions overlapped substantially (Figure B1), and we would therefore expect the counter to perform similarly for both species. Combining species data also ensured the sample size of down movements was adequate to calculate direction-specific performance.

Precision was generally high for both up and down movements on all channels (Table B1). This indicates that a very high proportion of movements recorded by the counter were true fish movements observed during validation. Except for channel 4, recall was high for up movements on all channels, suggesting the counter detected a large portion of fish that moved upstream (Table B1). Channel 4 had a lower recall, indicating fish were missed more frequently on this channel. Recall was lower for down movements, which is typical of flat-pad counter systems. Fish are more likely to be missed as they move downstream because they may move higher in the water column above the counter sensors.

Table B1. Precision and recall (Chinook and Coho combined) for the Bessette resistivity counter in 2019.

Channel	Precision	Recall
Up Performance		
1	0.99	0.93
2	1.00	0.92
3	1.00	1.00
4	1.00	0.60
Down Performance		
1	0.75	0.43
2	1.00	0.65
3	1.00	0.80
4	1.00	0.45

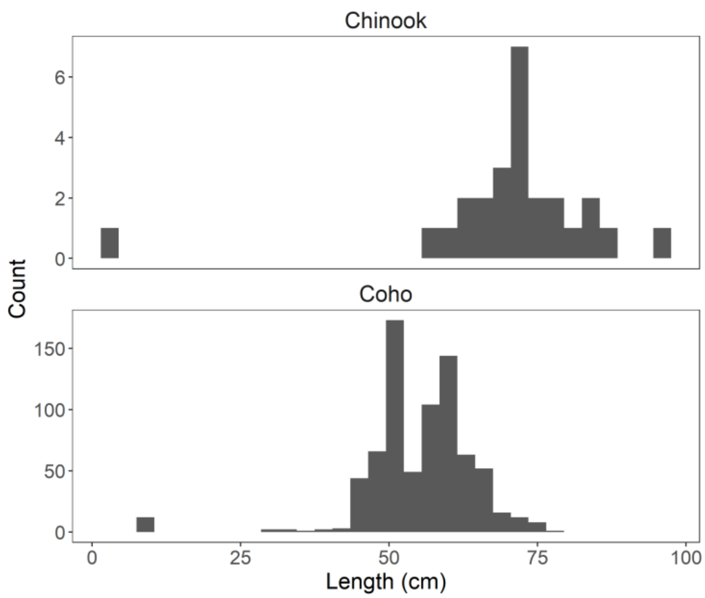

Figure B1. Chinook and Coho total length (cm) distributions at the Bessette resistivity counter in 2019.

<u>Species Ratios:</u>

We estimated daily species ratios for Coho and Chinook (Figure B2). To avoid small sample sizes biasing our species ratios, we combined daily up and down movements on all channels. There were eleven days with no species data; we applied the average Coho ratio (0.80) to missing data up to November 2 (the last day Chinook were observed during validation), after which we assumed all movements were Coho.

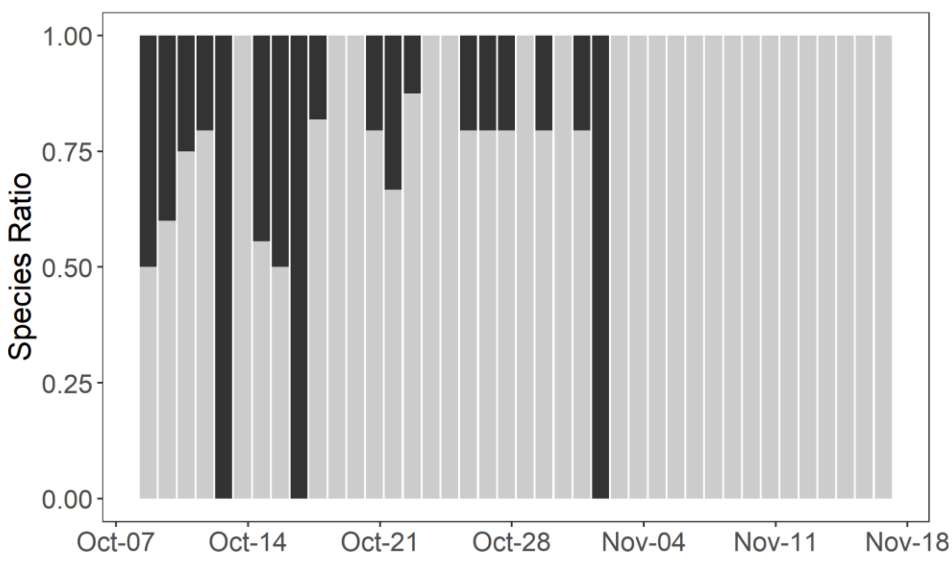

Figure B2. Coho (grey) and Chinook (black) species ratios (up and down movements and all channels combined) for the Bessette resistivity counter in 2019.

Estimated Abundance:

We applied daily species ratios and channel- and direction-specific precision and recall to raw counter data from October 9 to November 25. Corrected Coho counts in Figure B3 show that most upstream movements occurred on channel 1, while downstream movements were more evenly distributed across the four channels. Daily corrected counts (Figure B4) show a somewhat bimodal migration distribution, with Coho upstream movements peaking around October 20 and November 4.

Using a Bayesian application of
Equation 8, we estimated that 679 (95% credibility interval 560-817) Coho moved upstream passed the Bessette resistivity counter during the 2019 migration.

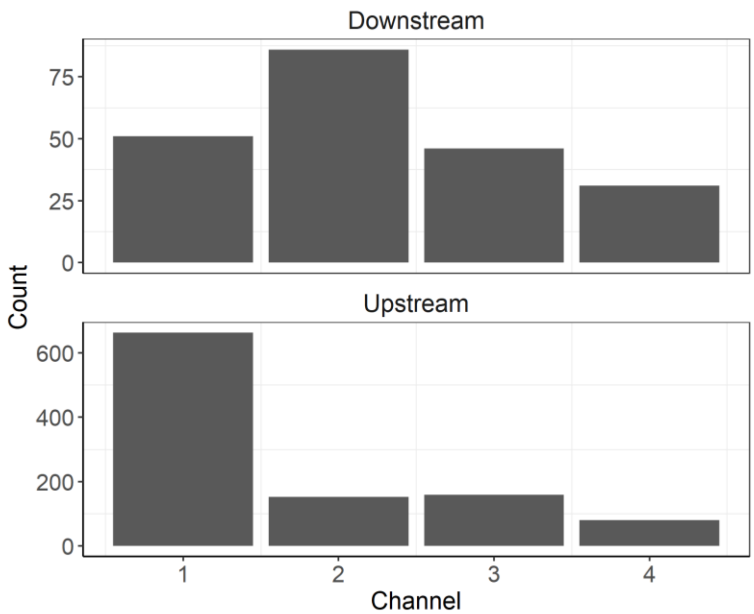

Figure B3. Species- and performance-corrected Coho counts by channel and direction at the Bessette resistivity counter in 2019.

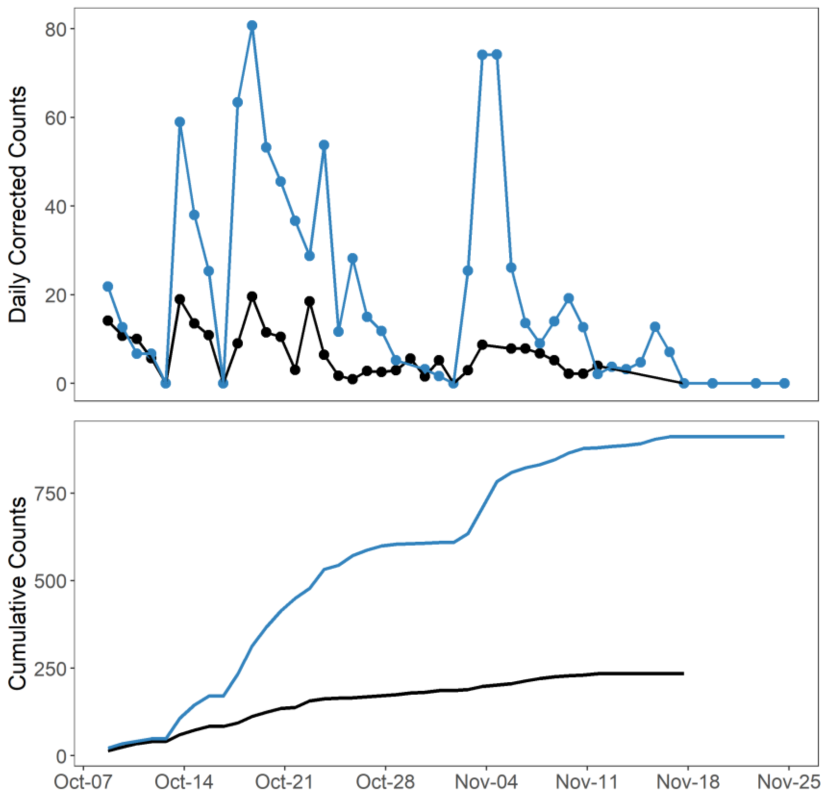

Figure B4. Daily corrected Coho counts and cumulative corrected Coho counts for up (blue) and down (black) movements at the Bessette resistivity counter in 2019.

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