YEAR 6 REPORT

UNDERSTANDING THE IMPACT OF ANTHROPOGENIC AND ENVIRONMENTAL CONDITIONS ON ADULT CHINOOK SALMON TERMINAL SURVIVAL FROM 2017-2023

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PACIFIC SALMON FOUNDATION

KWA'MUTSUN QWUM'YIQUN' XWULQW'SELU SAMUNU LHUMLHUMULUTS' XINUPSUM TL'ULPALUS

BRITISH COLUMBIA CONSERVATION FOUNDATION

ABSTRACT

Estuaries in the Northeast Pacific Ocean are vital for Pacific salmon (*Oncorhynchus* spp.) populations. Estuaries serve as crucial juvenile feeding habitats and returning adult staging areas, as they allow for gradual osmoregulatory adjustments during migrations between fresh- and saltwater environments. Habitat destruction from anthropogenic activities can substantially influence the movements, migrations, and survival of migratory salmonids. The forestry industry uses many estuaries along the west coast of North America to store logs. These logs are stored in booms in marine and estuarine habitats; associated activities (*e.g.,* dredging, grounding, noise pollution) can cause severe, negative impacts on ecosystems. Additionally, many pinniped species, such as the Pacific harbour seals (*Phoca vitulina*), have been documented to utilize anthropogenic structures (*i.e.,* locks, bridges, log booms, docks, breakwaters) as haulouts, to benefit foraging success. While studies have documented the impacts of enhancement of predation from bridges, locks, and dams, no studies have assessed the impacts of pinnipeds foraging from log booms located in key estuarine migration corridors on the terminal survival of adult Pacific salmon.

The Cowichan River on the east coast of Vancouver Island, British Columbia, Canada, has a fall run of Chinook salmon (*Oncorhynchus tshawytscha*), and the Cowichan estuary has logs stored year around, providing haulouts for pinnipeds. Adult Chinook salmon migrations were tracked over six years between 2017 and 2023 to understand the potential survival impacts due to log presence in the Cowichan estuary. Fish were captured and tagged in Cowichan Bay and tracked through the estuarine environment and into the Cowichan River using Passive Integrated Transponder (PIT) telemetry. Log booms were present in the estuary for five out of the six years, providing one control year. The average survival across all years was 48 (± 7)%. Generalized linear models representing survival and migration duration were used to determine which factors were most important for survival and migration timing. Log boom presence was found to significantly impact survival, decreasing the terminal survival of Cowichan River Chinook salmon.

River discharge was determined to be a significant factor for migration survival, with higher discharge associated with increased survival and decreased migration duration. Increased river discharge allows Chinook salmon to enter the river quickly, reducing migration duration and predation pressure in the log boom areas. While river discharge plays a critical role in the survival and speed of Cowichan River Chinook salmon spawning migrations, climate change models suggest an increase in the frequency of long summer drought periods, making the preservation of adequate flows and reducing log boom use in the Cowichan River and estuary essential in preserving this salmon stock into the future.

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INTRODUCTION

Declines in Chinook salmon (*Oncorhynchus tshawytscha*; hereinafter, Chinook) abundance in the Northeast Pacific Ocean have been observed since the 1970s (Preikshot et al. 2013; Ruff et al. 2017; Riddell et al. 2018). For example, in the Salish Sea (waters between southern British Columbia, Canada and Washington State, United States), smolt-to-adult return rates for ocean-type Chinook declined to approximately 1% from 1970 to 2000 (Welch et al. 2021). Multiple variables might be contributing to this decline, including habitat loss/degradation (Nelson et al. 1991), increased pinniped abundance (Chasco et al. 2017), climate change (Irvine and Fukuwaka 2011), impacts from hatchery production (Nelson et al. 2019), shifts in predator-prey dynamics, and anthropogenic structures (Moore & Berejikian 2022). Understanding the individual and cumulative effects of anthropogenic and environmental variables that influence terminal survival of adult Chinook is essential for effective and sustainable management.

Anthropogenic structures in marine and estuarine environments have emerged as significant causes of habitat fragmentation for salmon populations (Jefferies & Scordino 1997; Yurk & Trites 2000; Moore & Berejikian 2021; Sabal et al. 2021; Washington State Academy of Sciences 2022). Habitat fragmentation leads to isolated habitat regions, restricting or altering the ability of migrating fish, including salmon, to access suitable spawning grounds and vital staging areas (Tamario et al. 2019). Anthropogenic structures, including locks (Jefferies & Scordino 1997), bridges (Yurk & Trites 2000; Moore & Berejikian 2022) and log storage (Farrer & Acevedo-Gutierrez 2010), have been documented to have detrimental effects on the natural flow of rivers, impeding salmon migration routes, and altering predator-prey relationships. Further, habitat fragmentation severely threatens the sustainability of many salmon populations (Sethi et al. 2022). Disruption of migratory movements reduces the suitable habitat needed for survival and reproduction, which can increase mortality at critical life stages (Sabal et al. 2021).

In addition to habitat fragmentation, anthropogenic structures can disrupt predator-prey relationships (Sabal et al. 2021) and such disruptions have been observed between salmonids and pinnipeds (Washington State Academy of Sciences 2022). Pinniped species may target prey using anthropogenic structures such as dams, bridges or docks, which provide the predators with elevated vantage points and may increase prey concentrations around the structures (Sabal et al. 2021). Numerous studies have documented the positive influence of such structures on pinniped predation rates (Yurk & Trites 2000; London 2002; Wargo Rub et al. 2019; Moore & Berejikian 2022). Keefer et al. (2012) observed an increase in the abundance of California sea lions (*Zalophus californianus*) and Steller sea lions (*Eumetopias jubatus*) around Bonneville Dam during winter and early spring, specifically targeting returning adult spring Chinook with consumption rates of 2.6%. Moreover, a study assessing the impacts of seal predation on outmigrating steelhead smolts showed that during two separate years of study, only 49% and 56% of acoustic-tagged smolts survived past the Hood Canal Bridge; data from depth and temperature sensors indicated that a large portion of the mortalities showed behaviour consistent with predation events (Moore & Berejikian 2022). Further, Chinook may be limited in their ability to respond to altered predation pressures during their terminal migration because of the energetic demands of spawning migrations and the cost of predator avoidance (Sabal et al. 2021; Washington State Academy of Western Sciences 2022).

One anthropogenic structure that has received little attention in the literature is storage of harvested logs into raft-like structures (called log booms) that float in aquatic environments and their impact on the survival of salmonids. Bays and estuaries throughout the Northeast Pacific Ocean provide ideal locations to collect and store harvested logs in booms before transport to sawmills or other processing and sorting facilities. Log booming in marine and estuarine locations and associated activities (*e.g.*, noise; Murchy et al. 2023) have been documented to cause negative impacts, such as pollution (Kussin-Bordo et al. 2024), increased compaction of sediment (Toews & Brownlee 1981), reduced vegetation (Kussin-Bordo et al. 2024) and alterations to the nearshore ecosystem through changes in invertebrate populations (Brownlee & Toews 1981; Power 1987; Kussin-Bordo et al. 2024). Pinnipeds also utilize log booms as additional haul-out areas, with the majority of use during high tides (Farrer & Acevedo-Gutiérrez 2010) when natural haul-outs are unavailable. High tide is also crucial for migrating species, such as salmon, that need to use increased tide height to access freshwater environments strategically, representing key migration corridors (*i.e.,* in sheltered bays at the mouths of rivers; White 2001). Log booms represent a conservation concern for salmonids and have already been demonstrated to displace juvenile salmon due to low oxygen (Levy et al. 1990); however, more research is required to confirm the impacts on adult survival.

A more extensive collaborative study was conducted in 2019, 2020 and 2022, which utilized acoustic tags with accelerometers and pressure sensors and a suite of receivers in *the bay* and *lower river* to understand the terminal behaviour and impacts of boat noise and the marine soundscape on Cowichan Chinook (Murchy 2024). However, this report does not discuss the data and results from this portion of the study, except for information regarding the effects of tagging-related mortality.

This study aimed to investigate the potential impacts of log booms on the terminal survival of adult Chinook. Log booms are present in many estuaries around Vancouver Island, British Columbia, Canada, and remain throughout the spawning migration period of Chinook, raising concerns that these log booms may be causing undocumented, adverse effects on Chinook survival. We hypothesized that the presence of log booms reduced the terminal survival of adult Chinook during their spawning migrations.

MATERIALS AND METHODS

Study Area

Cowichan Bay is a sheltered bay located on the southeast coast of Vancouver Island, British Columbia (48.754286° North and 123.610446° West), at the mouth of the Cowichan River. The bay is approximately 4 km long and 2 km wide, with the bay opening into an ocean area between Vancouver Island and mainland Canada known as the Salish Sea, which encompasses the straits of Georgia, Juan de Fuca, and Puget Sound in Washington (Figure. 1).

The Cowichan River flows from Cowichan Lake southeast for 47 km, then bifurcates at river kilometre 4 into two arms (North and South), which connect the estuary to the main channel (Figure. 1). Chinook typically return to Cowichan Bay as early as August and move into the Cowichan River between September and October after staging in the bay (K. Pellett. Southeast Coast Stock Assessment, Senior Biologist, Department of Fisheries and Oceans, personal communication, 2021). Cowichan River discharge is controlled by a dam located at the outlet of Cowichan Lake. The dam is managed by Paper Excellence (which manufactures pulp and paper) under its water license and in consultation with Cowichan Tribes, the Department of Fisheries and Oceans, and the Province of British Columbia.

Cowichan Bay has a high presence of anthropogenic activities, with logs stored in the estuary in floating rafts called log booms (Figure. 1, brown box). Booms transport logs into Cowichan Bay approximately one day a week and are stored in the estuary before being transported up to the mill to be processed. From 2009 to 2022, the average area covered by log booms in the bay was 48,545 m^2. Similarly to many other estuaries in the Northeast Pacific Ocean, log booms in Cowichan Bay provide additional haul-out space for pinnipeds, with at least 200 individuals present at times (Atkinson & Murchy, 2020). However, due to a strike in 2019 at the Cowichan Mill, log booms were absent in Cowichan Bay that year (August to November). The only structures present throughout the study in 2019 were “boomsticks” (long logs with holes in each end used to hold log bundles together during storage) which provided minimal (> 5 m^2)structures for pinnipeds to use as a haul-out and allowed for an evaluation of the potential link between log booms and Chinook survival.

To understand survival in different areas of Cowichan Bay and River, the areas were defined as follows: *the bay* was the area east of the log boom sort (Figure. 1, brown box); *the estuary* was the area west of the log boom sort, including the log boom sort and the intertidal portions of the north- and south arms of the Cowichan River and up to first bridges (Tzouhalem Rd on Figure.1) located on the north and south arms of the river; *the lower river* was the area between the first bridges on both arms of the river and continued until the counting fence and mainstem PIT array at river kilometre 7 (Figure. 1).

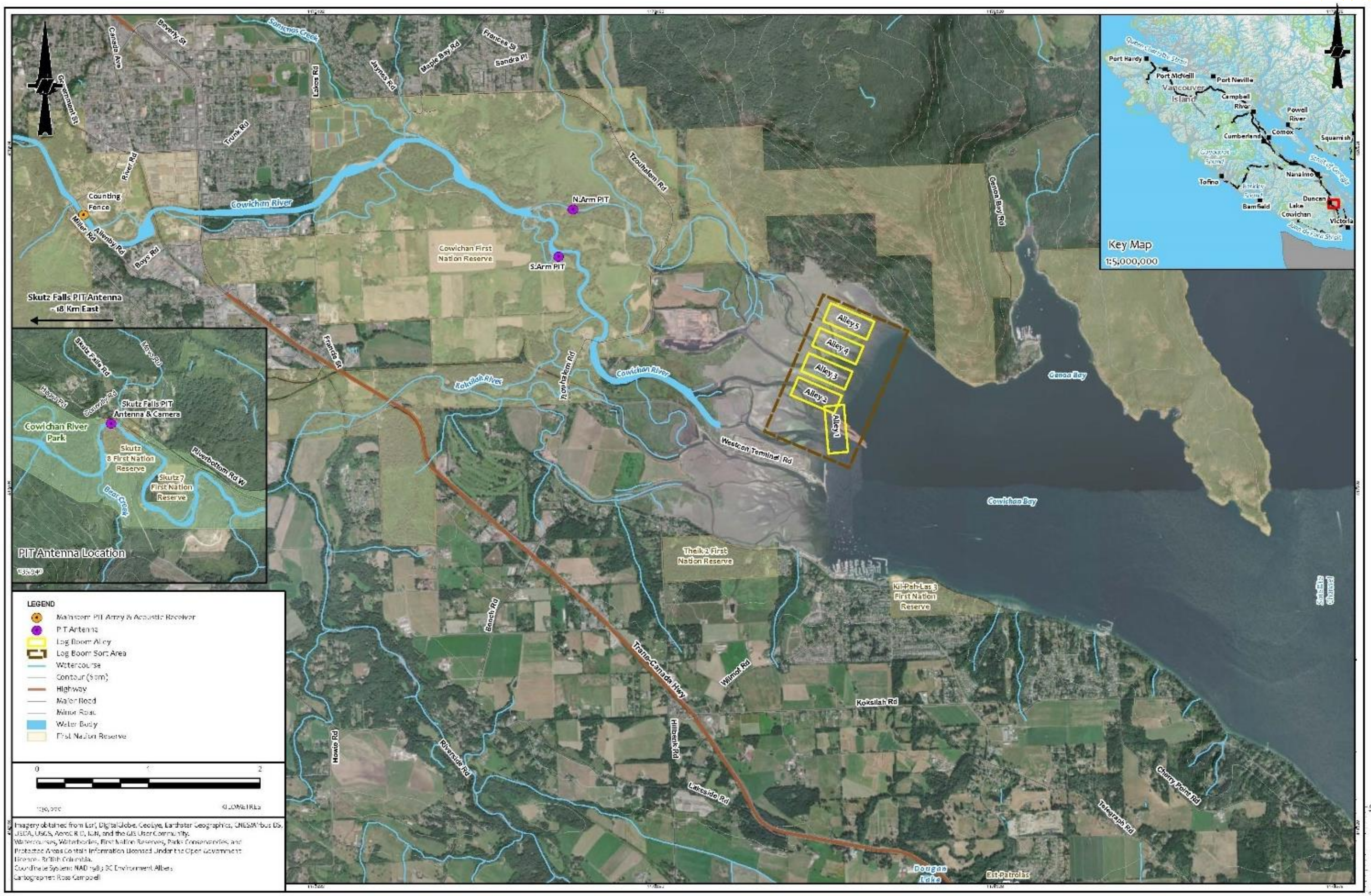

Figure 1. Map of the study area encompassing Cowichan Bay, Estuary, and Lower River. The yellow rectangles denote the current (alleys 1, 2, and 3) and historical (pre-2015 alleys 1-5) log boom leased areas. The brown rectangle highlights the entire area where log booming activities occur. The lower river PIT antennas and the Skutz Falls PIT array are marked by purple waypoints, with the Skutz Falls array location detailed in the inset. The orange waypoint indicates the mainstem PIT array and counting fence.

River Discharge and Temperature

River discharge and temperature data for all study years were obtained from The Water Survey of Canada Station (08HA011) in Duncan, BC. The mean river discharge experienced per fish was calculated individually. This was calculated using mean daily discharge values and averaged between the tagging date of a fish ('start date') and its last known detection at the mainstem PIT array ('end date'). If a fish was detected at the mainstem receiver, the first detection at this site was considered the end date for calculating the average discharge experienced. If there were no detections at the mainstem array, then the endpoint was the last detection at either the North- or South-Arm arrays. Finally, if there were no detections at any PIT antennas/arrays for a fish, the end date was considered ten days post-tagging, since that was the average migration time for tagged fish detected in the river during the study.

PIT Tagging and DNA Collection

During August and September of each study year, adult Chinook were captured using recreational angling techniques (*i.e.*, trolling and jigging) to target Cowichan River Chinook staging in Cowichan Bay and Sansum Narrows (Figure. 1). All captured Chinook had their fork length and circumference measured and were tagged intraperitoneally with Passive Integrated Transponder (PIT) tags in front of the pelvic girdle in the body cavity using a new, sterile 12-gauge needle (Biomark; Boise, ID; FDX-B 12 mm). Additionally, a fin tissue sample was collected for genetic stock identification from all fish by removing a small sliver (2-3 mm) of the caudal fin using sterilized dissecting scissors. For each fish, origin (wild or hatchery) was noted by the presence or absence of an adipose fin. Sex of each fish was then determined visually on the boat and confirmed with genetics. As part of the more extensive study, but not directly discussed in this report, a subset of Chinook was also gastrically (non-surgically) tagged with acoustic tags equipped with a triaxial accelerometer (activity level) and pressure (depth) sensors (VEMCO; Bedford, NS; V13AP-1x, 69 kHz) in 2019 (n = 17), 2020 (n = 19), and 2022 (n = 19).

The degree of bleeding was visually assessed by the colour of the trough water upon release of the fish, starting in 2019. Fish were classified based on the degree of bleeding (0, no bleeding, no redness; 1, light and redness; 2, moderate and redness; 3, significant bleeding and dark redness). Furthermore, to understand the influence bleeding may have on survival rates, fish with any degree of bleeding (1, 2, or 3) were combined into one group, and their survival rates were compared to those fish with a degree of bleeding of 0.

PIT Antenna Deployment

PIT antennas generate an electromagnetic field approximately 45 cm from the antenna. As a fish with a PIT tag moves into this field, the antenna inductively charges the PIT tag, which instantaneously transmits its unique twelve-digit number back to the antenna. This event is documented and stored with a date-time stamp. When a series of antennas are employed in succession, they are called an "array". As PIT-tagged fish pass each antenna in an array, the direction of movement can be tracked, typically upstream and downstream. In this study, all PIT antennas were built as "pass-over" systems, where the antenna is located on the riverbed and detects tagged fish as they "pass over" the antenna.

A permanent pass-over array (Biomark; Boise, ID) consisting of 12 prefabricated, individually controlled antennas was installed in the mainstem of the Cowichan River 100 m downstream of the Allenby Road Bridge (Counting Fence; river kilometre 7; Figure. 1) in August of 2016. Each antenna coil was housed in a welded 0.10 m high-density polyethylene pipe measuring 0.8 m x 6.1 m and was secured to the substrate using duckbill anchors at the end of 0.06 m stainless steel threaded rod, eight per antenna. Antennas were installed in two cross-stream transects 45 m apart, each with six antennae end-on-end. All antennas were wired into a master controller located on the north streambank and connected to a battery bank maintained by 120 v A.C. power. Additionally, a standard floating removable counting fence operated by Fisheries and Oceans Canada (DFO) was situated between the two cross-stream PIT arrays for much of the study period.

Removable PIT antennas were also installed in each of the North and South arms on August 23rd and 28th in 2019, August 24 in 2020 and August 15th and 29th in 2022 (Figure. 1). Only the south arm antenna was installed in 2021 and was installed on September 7. Antennas included housings with IS1001 reader boards (Biomark; Boise, ID) powered by four 12-volt, 80 amp-hour deep cycle batteries connected in a parallel-series configuration (24 volts; 160 amp-hours). Each rectangular antenna was held in place across the wetted channel with four 90 cm long, solid aluminum angle posts; 6 mm dynamic climbing ropes were attached to the posts and tightened using prusiks (made from 3 mm paracord). The antenna cable (12-gauge, 5 conductors, 600 Volt SJOOW Service Cord) was attached to the climbing rope with vinyl electrical tape (Temflex™). The North Arm antenna's dimensions were 3.2 x 0.60 m, while the South Arm antenna was 7.5 x 0.60 m. In 2022, a permanent 6 m pass-over antenna (Biomark; Boise, ID), identical to those used in the mainstem array, was installed in the South Arm, but the North arm remained removable being re-installed for the 2023 season on August 24, 2023.

Additionally, a PIT antenna was installed at Skutz Falls, in the fishway's main upper cell, in the fall of 2014. In 2019, the antenna had to be re-installed, and it became operational on October 2, 2019. Located at river kilometre 31, this antenna had been used to monitor Chinook migration and mainstem array efficiency. The IS1001 reader board (set to scan for FDX-B tags) was powered from the building on-site with 120 v A.C. power. The antenna had 0.60 m x 1.53 m dimensions and was constructed from 0.0254 m Schedule 80 PVC. The antenna only detected tagged fish migrating upstream via the main fishway and did not estimate numbers using the high-water bypass or main falls. On average, 15-25% of Chinook detected in the lower river are detected using the main fishway at Skutz Falls (Pearce & Pellett 2020).

Genetic Stock Identification

The probability of belonging to each of the 296 North American Chinook stocks was provided to each fish, following methods similar to those of Beacham et al. (2012). All Chinook samples were analyzed as a single mixture using the program cBayes (Neaves et al. 2005), which estimates the stock composition following Pella and Masuda (2001). Only Chinook confirmed to be of Cowichan origin through Parentage Based Tagging (PBT), or at a probability of >0.75 in GSI analysis, were utilized in survival estimates.

Data Analyses

All statistical analyses were conducted using R statistical software (R Core Team 2021). Data visualizations were completed using the ggplot package (Wickham et al. 2019).

PIT Array and Antenna Efficiencies

Detection efficiency can be calculated in several ways depending on the number of PIT antennas and the direction of tag travel. This section outlines the calculations used to determine PIT array efficiencies and survival estimates. Survival for this study was defined when an individual fish escaped into the upper river to spawn (*i.e.* was detected crossing the mainstem array at river kilometre 7).

Lower River Antenna Efficiency (LRE)

Eq. 1. $$\left(\frac{LRM}{MA}\right) * 100 = LRE$$

where LRM is the number of linked tags detected on both the lower river antennas and the mainstem array, M.A. is the number of total tags detected at the mainstem array.

Mainstem Array Efficiency (MAE)

Eq. 2. $$\left(\frac{MASK}{SKA}\right) * 100 = MAE$$

where SKA is the number of tags detected at the Skutz Falls fishway antenna, MASK is the number of tags detected at the Skutz Falls fishway, which were also detected at the mainstem array.

Survival to Lower River (L.R.)

Eq. 3. $$\left(\frac{LRT}{LRE}\right) = LR$$

where LRT is the total number of tags detected at both lower river antennas, LRE is the lower river antenna efficiency derived from Eq. 1.

Lower River to Mainstem Survival from lower river detection to mainstem array (escapement)

Eq. 4. $$\left(\frac{LRM}{LRT}\right) * 100 = LRS$$

where LRM is the number of tags detected on the lower river antennas, which were also detected on the mainstem array, LRT is the total number of tags detected on both lower river antennas.

Survival (S); from tagging to river escapement.

Eq. 5. $$\left(\frac{MA}{TS}\right) * 100 = S$$

where M.A. is the number of total tags detected at the mainstem array, T.S. is the number of total tags deployed in the marine environment.

Survival Estimates

Percent survival was calculated as *N detected (at the mainstem PIT array) / N released (in Cowichan Bay)*. Confidence intervals with a 95% coverage were calculated for survival proportions using the Clopper Pearson interval (known as the *exact* method; Clopper & Pearson 1934); this is due to the normal approximation of the binomial interval being unreliable for small sample sizes and survival proportions near 0.

Logistic and Linear Regression Analyses

A generalized linear mixed-effects model (GLMM) was used to analyze both survival and migration timing for returning adult Chinook. Survival data was binomial (0 or 1), so was fitted using a binomial family and link log, while migration timing was fit with a Gaussian family and identity link. Global models with all covariates were developed for both response variables, and a model averaging approach based on AIC selection of statistical models was used to determine which factors were associated with spawning migration survival and timing.

Both the survival and migration timing response models had the following explanatory variables, except tagging date was only included in the migration timing model: (i) origin (hatchery or wild), (ii) presence of log booms (binary variable where booms were either present or absent), (iii) fork length, (iv) sex, (v) bleeding (binary variable representing whether the fish bled during the capture and tagging process), (vi) tagging date and (vii) mean river discharge experienced (Table 1)

Table 1. Variables (fixed and random) were hypothesized to influence terminal survival and migration timing and used in both global models.

COVARIATE	HYPOTHESIZED RELATIONSHIP TO ADULT CHINOOK SURVIVAL
Year	Annual variation in biotic and abiotic factors will influence survival.
Fork Length	Smaller fish may be more susceptible to pinniped predation.
Degree of Bleeding	Higher degree of bleeding may increase predation or reduce fitness.
Origin	Hatchery fish may be more susceptible to predation.
Sex	Male fish may be more susceptible to predation and reduced survival.
Date Tagged	Fish tagged earlier may survive less due to prolonged estuary residence in drought years.
River Discharge	Lower river discharges will increase mortality due to increased staging in the bay/estuary.
River Temperature	Higher temperatures may increase mortality due to temperature stress.
Log Boom Presence	Log boom presence will increase mortality by enhancing pinnipeds' predation efficiency.

All explanatory variables were tested for correlation and multicollinearity using the *vif()* function from R package "car" (Fox & Weisburg 2011). Year was found to be an aliased coefficient in the model and removed as a fixed effect variable. After the 'Year' variable was removed, other variables were only excluded if r > 0.7 (Zuur et al. 2010) or if the variation inflation factor (VIF) exceeded 4 (O'Brien 2007). All other explanatory variables in the survival and migration duration models had VIF values < 3, so all variables were retained in the global models. We standardized all explanatory variables using the *standardize()* function of R package "arm" (Gelman & Su 2016) to allow comparisons of relative effect between explanatory variables. This function standardized continuous explanatory variables to a mean of 0 and a standard deviation of 0.5. Binary explanatory variables were scaled to a mean of 0 with a difference of 1 between the two categories.

Survival

Migration survival was determined as either the presence or absence of a fish at the mainstem PIT array located 7 km upstream from the Cowichan River estuary.

Our migration survival response model (logistic regression) was fitted with a generalized linear model (GLM; family = binomial, link = logit). Our global survival model was:

glm(formula = Survived ~ Fork length + Bleeding + Origin + Sex + Discharge*Booms,

family = binomial (link = "logit"))

The basis of logistic regression is the linear relationship between the log of the odds ratio of the probability of survival and a linear combination of independent variables.

$$Y_i \sim Binomial(p_i)$$

$$\log\frac{p_i}{1-p_i} = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_k x_{ki}$$

where p is the probability of survival to detection on the mainstem array, β_0 is the intercept, and x_i are the values of various predictor variables (Scott et al. 1991) for the *i*th fish.

Migration Duration (time)

Migration time was calculated as the length of time between tagging release and first detection at the mainstem Cowichan River PIT receiver. Migration time was calculated by the time (in days) from tagging release in the estuary to first detection at the mainstem PIT array in the Cowichan River. Our migration time model was fitted with a mixed effects linear model (Year was included as a random effect). This model also contained an interactive effect between tagging date and discharge, as a known correlation exists when higher discharge levels occur later during the tagging season.

Our migration time response model was fitted with a generalized linear mixed model (GLMM). Our global survival model was:

lmer(formula = Migration time ~ Fork length + Bleeding + Origin + Sex + Booms + Tagging date*Discharge + (1 | Year))

For both the survival and time models, all possible combinations of explanatory variables were generated and compared using the *dredge()* function from R package "MuMIn" (Barton 2016). Each model combination was ranked for comparison using AICc for small sample sizes (Burnham and Anderson 2002). For our survival logistic regression models, McFadden's pseudo-R^2 was calculated to assess the model's fit.

RESULTS

Temperature

The average temperature for the study period was similar for all years (Figure. 2). The highest monthly average temperature was recorded in August 2017 at 22.1 ± 0.05°C, while the lowest monthly average temperature was recorded in November 2023 at 11.2 ± 0.03°C. Monthly variation in temperature between years showed to be within ± 2°C, except for September, where temperature values were highly variable with average monthly temperatures of 19.3 ± 0.07, 17.4 ± 0.07, 20.1 ± 0.04, 16.9 ± 0.05, 18.2 ± 0.04, and 16.9 ± 0.05 °C for study years 2017, 2019, 2020, 2021, 2022, and 2023, respectively.

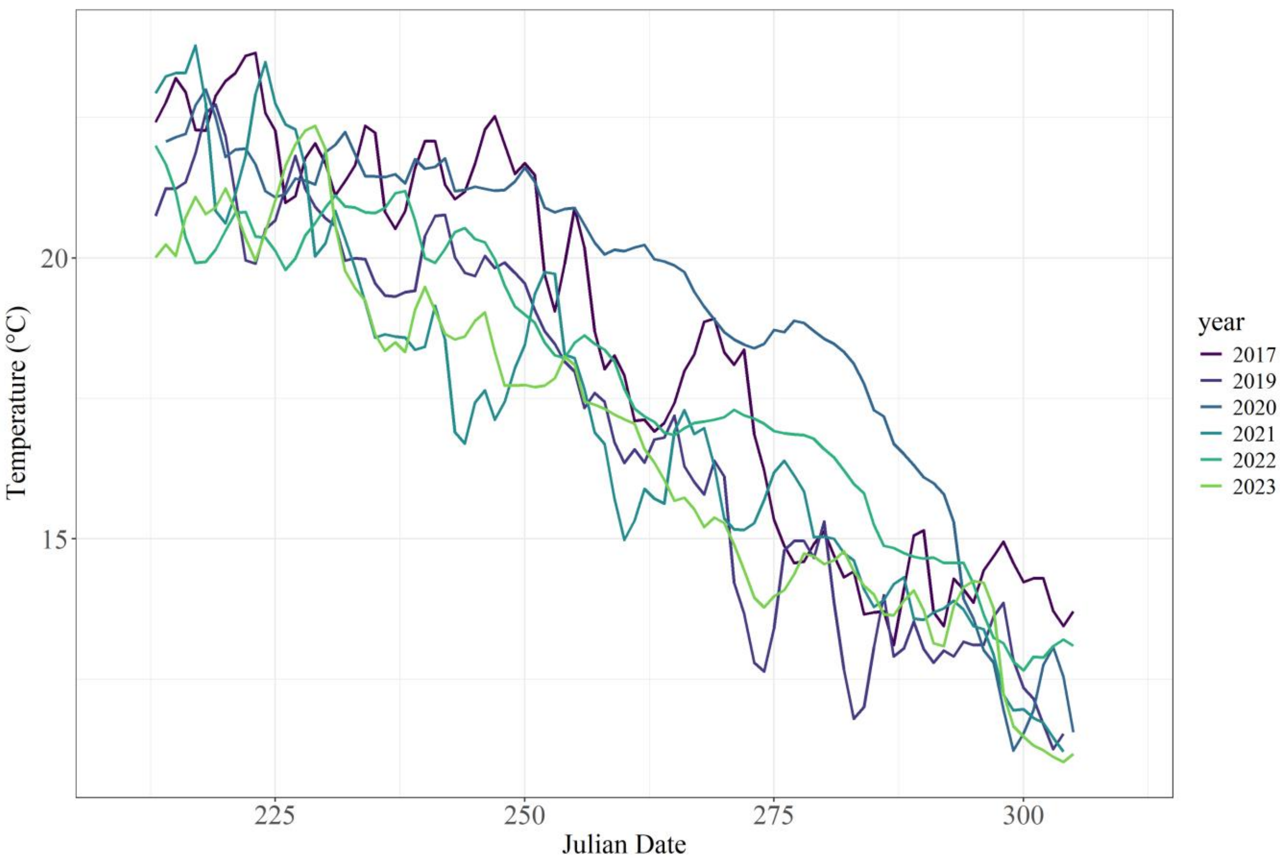

Figure 2. Cowichan River temperatures from August 1 to November 1 for each study year. The temperature was taken from the Water Survey of Canada Hydrometric Station (08HA011).

River Discharge

River discharge was highly variable between all study years (Figure. 3). Mean average discharge for the study period of August 1 to November 1 was the highest in 2021 (27.6 ± 0.2 m^3/s), while 2022 had the lowest mean average discharge (6.2 ± 0.02 m^3/s). Study years 2017, 2019, 2020, and 2023 had mean average discharges of 12.0 ± 0.1, 11.6 ± 0.1, 20.6 ± 0.1 m^3/s, and 7.8 ± 0.05 m^3/s, respectively. Paper Excellence conducted river flow pulses in the 2022 study year to assist in river migrations of returning adult Chinook. A flow pulse of 10 m^3/s occurred from September 16 to October 4, 2022 (Figure. 3).

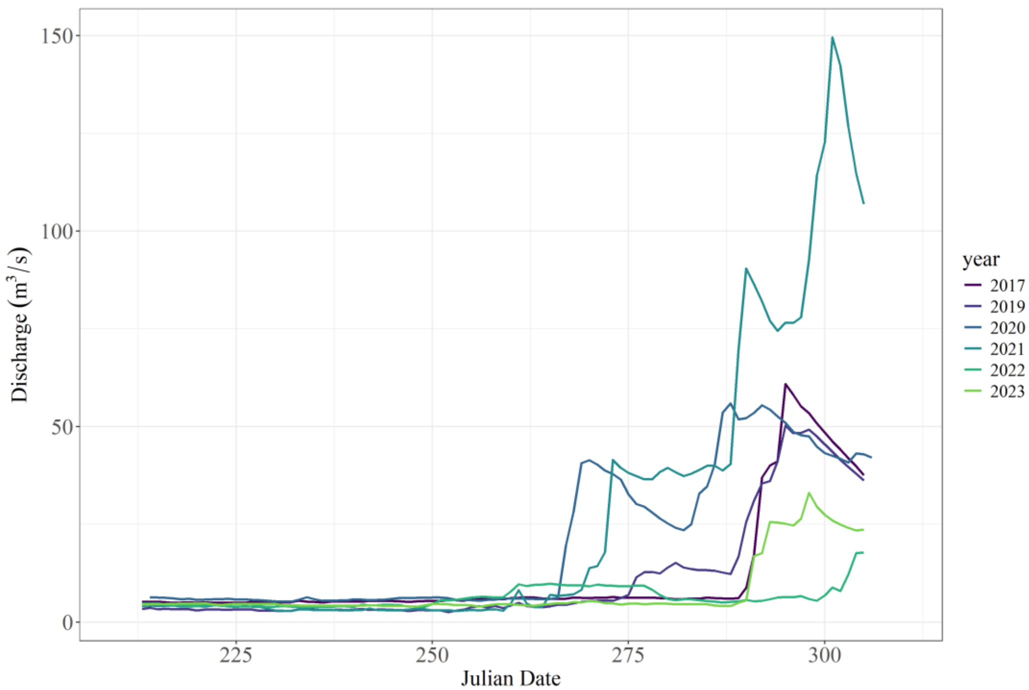

Figure 3. For all study years, Cowichan River Discharge (m^3/s) from August 1 to November 1. River discharge was taken from the Water Survey of Canada Hydrometric Station (08HA011).

Fish Data and Genetic Stock Identification

A total of 408 Chinook were captured and PIT-tagged across six years (2017, 2019-2023) in the Cowichan Bay area (Figure. 1). Of these fish, 258 were found to be of Cowichan River origin as determined by genetic stock identification (GSI) or Parental Based Tag (PBT) identification (Figure. 5). fish determined to be of non-Cowichan origin with a probability of ≤ 0.75 were omitted from survival and migration rate analyses (n = 150). The percentage of captured and tagged Chinook that were designated as Cowichan Chinook varied from 82.7% in 2020 to 58.3% in 2019; these values are for any Chinook deemed to be of Cowichan origin without applying a probability threshold (Figure. 5).

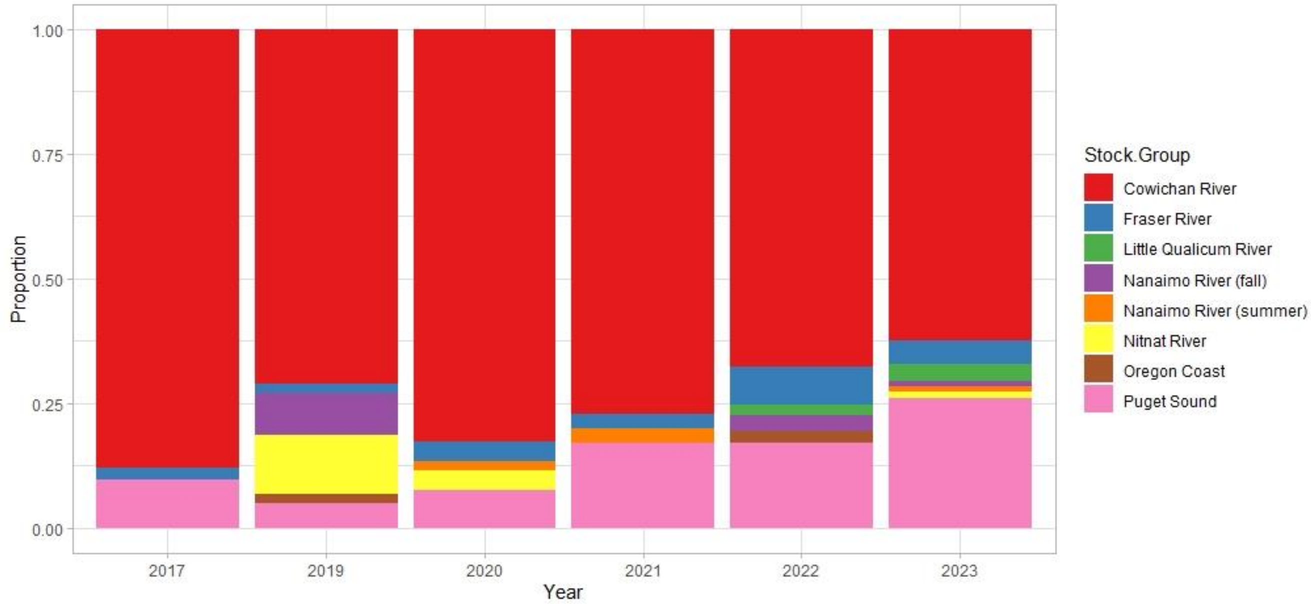

Figure 4. The proportion of individual Chinook stocks captured and PIT-tagged during each study year in Cowichan Bay and Sansum Narrows.

PIT Tag In-river Detections

Efficiency and Survival Detection Calculations

Based on detections at the Skutz Falls antenna, the Mainstem array efficiency (Eq. 2) has been ~100% since 2017 (K. Pellett. Southeast Coast Stock Assessment, Senior Biologist, Department of Fisheries and Oceans, personal communication, 2023). Annual survival (Eq. 5) to river kilometre 7 varied for each year of the study; the highest survival was found in 2021, where 65% (49-82% CI) of tagged fish survived to river kilometre 7 (Table 2). The lowest survival was documented in 2023, where only 24% (0-47% CI) survived to river kilometre 7. Year 2017 also had lower survival rates of 32% (2-63% CI), but years 2019, 2020, and 2022 were all similar for survival, with survival to river kilometre 7 being 56% (33-80% CI), 58% (41-75% CI), and 49% (34-65% CI), respectively.

Table 2. Calculated survival estimates from tagging in Cowichan Bay to detection at the Mainstem Array, located at river kilometre 7.

YEAR	DEPLOYED (N =)	DETECTED MAINSTEM RIVER (N =)	SURVIVAL TO MAINSTEM	CI LOW	CI HIGH
2017	31	10	0.32	0.19	0.51
2019	41	23	0.56	0.42	0.72
2020	43	25	0.58	0.44	0.73
2021	26	17	0.65	0.48	0.83
2022	63	31	0.49	0.38	0.62
2023	54	12	0.24	0.13	0.36

Survival model

The results of the global logistic regression model revealed significant associations between the response variable (survival) and four covariates (Table 3; Figure. 5). Firstly, a statistically significant positive relationship was observed between survival and River Discharge (estimate = 14.41, S.E. = 6.33, $z = 2.28$, $p = 0.02$); this indicates that, on average, an increase in river discharge is associated with higher survival. The variable “Booms” showed a negative, statistically significant association with survival (estimate = –3.99, S.E. = 1.98, $z = -2.02$, $p = 0.04$); when booms are present, Chinook have lower survival. Additionally, the interaction term “Discharge: Booms” showed a statistically significant association with Chinook survival (estimate = –13.53, S.E. = 6.33, $z = -2.14$, $p = 0.03$), suggesting that the relationship between discharge and the survival varies depending on boom presence in the estuary. For example, when booms are not present, discharge has a positive effect on survival, but when booms are present, the positive effect of discharge is not as strong (Figure. 6). Overall, these findings highlight the importance of considering discharge, booms and their interaction when examining the factors influencing Chinook terminal survival.

Table 3. Results of the Global Logistic Regression Model for survival of Chinook.

PARAMETER	ESTIMATE	STANDARD ERROR	Z VALUE	P VALUE
Intercept	3.53	2.05	1.72	0.08
Fork length	0.49	0.54	0.92	0.36
Sex (M)	-0.37	0.55	-0.66	0.51
Origin (W)	0.81	0.51	1.59	0.11
Discharge	14.41	6.33	2.28	0.02
Booms (1)	-3.99	1.98	-2.02	0.04
Discharge:Booms	-13.53	6.33	-2.14	0.03

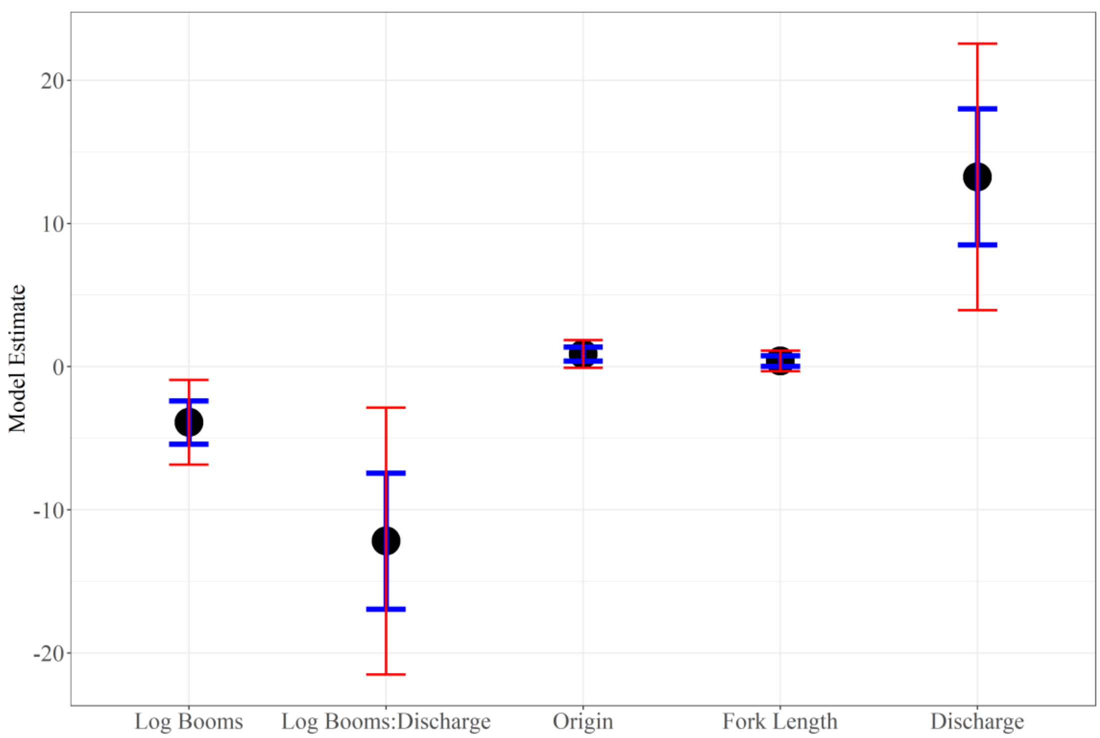

Figure 5. Model-averaged, standardized coefficients from generalized logistic regression models of migration survival. Red vertical lines represent the extent of the 95% confidence intervals for each explanatory variable. Blue vertical lines represent the extent of the adjusted standard error for each explanatory variable. Coefficients are standardized so that the effect sizes are comparable among variables.

Following model selection, the top two models' AIC values were less than 2 and were competitive for the top model (Table 4). Additionally, these two models had high weights (0.6 and 0.3) and low AICc values (325.3 and 326.8), indicating a high likelihood of accurately explaining the survival outcomes present in the data. These models both included boom presence, discharge, interactive discharge: boom, and origin as explanatory covariates, demonstrating the importance of boom presence and discharge for migration survival of Cowichan River Chinook.

The top four survival models included mean discharge experienced and boom presence as an interacting effect. Models with and without the interaction term were compared with a likelihood ratio test to validate the inclusion of discharge and boom presence as an interacting effect, which returned a significant p-value < 0.001, meaning the model that includes the interaction term is improved. Further validation for including an interactive effect between discharge and boom presence is shown by an improved McFadden's pseudo-R^2 value comparing a model including this interacting effect compared with the model without the interacting effect.

Table 4. Results of model selection for the terminal survival model. Model selection table showing the top five survival models as ranked by AICc model selection.

	(INT)	BOOM PRES.	ORIGIN	FORK LENGTH	DISCHARGE	DISCHARGE: BOOMS	ADJR2	LOGLIK	AICC	DELTA	WEIGHT
1	2.828	-3.853	0.9403	0.5542	13.4	-12.3	0.2057	-156.487	325.3	0	0.604
2	2.875	-4.046	1.081		13.12	-12.06	0.1899	-158.276	326.8	1.48	0.288
3	3.471	-3.695		0.6959	13.1	-12.08	0.1798	-159.406	329	3.74	0.093
4	3.649	-3.91			12.67	-11.73	0.1523	-162.446	333	7.74	0.013
5	-0.2641	-0.6137	0.7661	0.5009	1.263		0.1329	-164.537	339.3	14	0.001

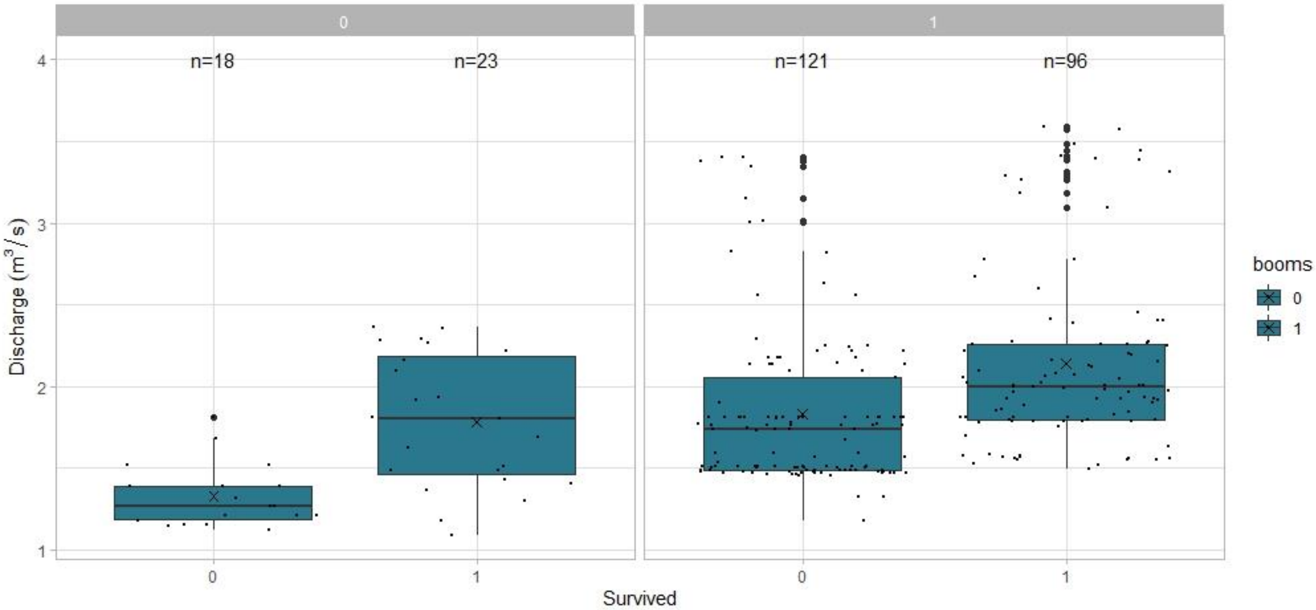

Figure 6. Side-by-side boxplots showing survival in relation to averaged discharge experienced when booms are present (booms = 1) vs absent (booms = 0) from the Cowichan Bay area. For each boxplot, the thicker black line indicates the median, the upper and lower box limits represent the first and third quartiles, the whiskers represent 1.5 times the interquartile range, and the points represent outliers. A cross indicates the mean.

Migration duration (time) model

Overall, migration time between tagging in Cowichan Bay to river kilometre 7 ranged from 2 – 57 days and had a mean of 22.2 ± 1.1 days. Migration time was fastest in 2020 at a mean of 13.8 ± 1.1 days, while longest in 2023 at a mean of 29.5 ± 3.1 days. Other years were varied with means of 29.1 ± 3.9 days in 2017, 21.9 ± 2.05 days in 2019, 17.2 ± 1.7 days in 2021, and 26.7 ± 2.8 days in 2022.

The results of the global linear regression model revealed significant associations between the response variable (migration time) and three covariates (Table 5; Figure. 7). A statistically significant positive relationship was observed between migration time and river "Discharge" (estimate = 13.79, S.E. = 2.65, t = 5.21, p = <0.001), indicating that an increase in river discharge results in a faster (*i.e.* decreased) migration time. "Tagging date" also had a statistically significant association (estimate = -16.35, S.E. = 2.02, t = -8.01, p = <0.001), but was negative, demonstrating that fish tagged later in the season migrated at a faster rate. The interaction term "Tagging date: Discharge" also showed a statistically significant negative association with migration time (estimate = -6.74, S.E. = 3.09, t= -2.2, p = 0.03), which suggests that the relationship between discharge and migration time varies. For example, fish tagged earlier will migrate faster with increased discharge. The top model for migration time included the explanatory variables boom presence, origin, fork length, discharge, tagging date, and their interacting effect (Figure 7; Table 6). The top two models had AIC values <2 and thus should be considered competitive for the top model.

Table 5. Results of the global linear regression model for migration duration (time) of Cowichan River Chinook from tagging to detection at river kilometre 7.

PARAMETER	ESTIMATE	STANDARD ERROR	T VALUE	P VALUE
Intercept	16.22	3.11	5.21	0.12
Fork length	-0.59	20.6	-0.29	0.78
Bleeding (0)	1.21	1.5	0.81	0.42
Origin (W)	-3.81	2.03	-1.88	0.07
Sex (F)	-0.04	2.07	-0.02	0.99
Tagging date	-16.35	2.02	-8.01	<0.001
Discharge	13.79	2.65	5.21	<0.001
Booms (1)	-11.18	6.35	-1.76	0.32
Tagging date: Discharge	-6.74	3.09	-2.2	0.03

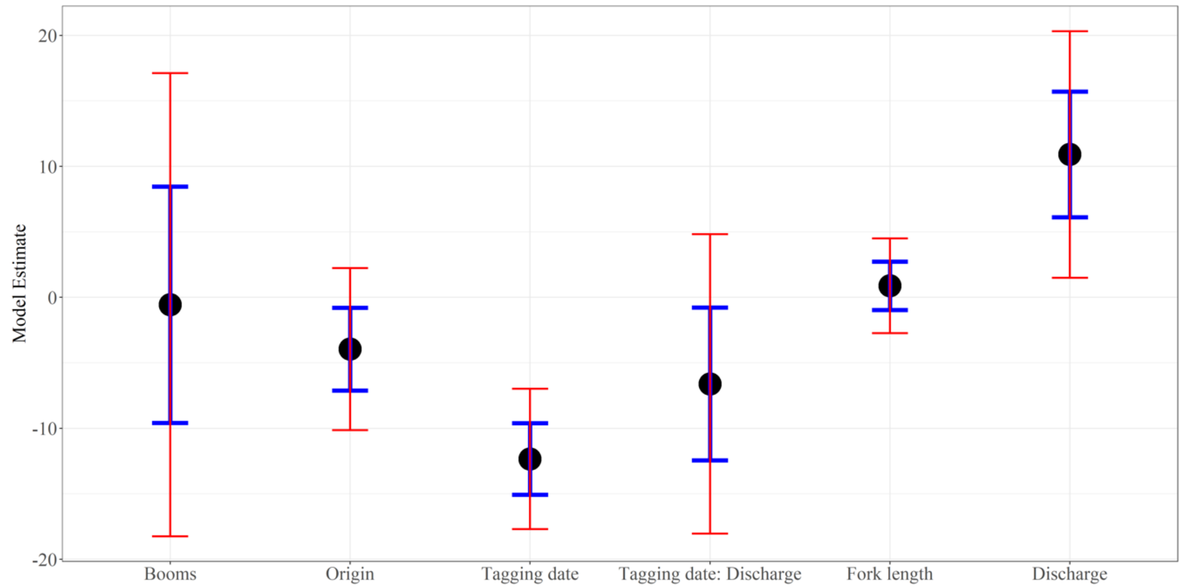

Figure 7. Model-averaged, standardized coefficients from mixed effects linear regression models of migration time. Red vertical lines represent the extent of the 95% confidence intervals for each explanatory variable. Blue vertical lines represent the extent of the adjusted standard error for each explanatory variable. Coefficients are standardized so that the effect sizes are comparable among variables.

Table 6. Results of model selection for the migration duration model. The migration speed model selection table showing the top 5 models ranked by AICc model selection.

	(INT)	BOOM PRES.	ORIGIN	TAGGING DATE	FORK LENGTH	DISCHARGE	DATE: DISCHARGE	ADJR2	LOGLIK	AICC	DELTA	WEIGHT
1	23.59	-0.4973	-4.521	-12.4	1.384	11.39	-7.216	0.2714	-433.05	885.8	0	0.467
2	23.59	-0.9774	-4.256	-12.69		11.17	-7.058	0.2687	-434.927	887.2	1.41	0.23
3	23.51		-4.532	-12.28	1.37	11.01	-7.01	0.2734	-436.17	889.6	3.9	0.066
4	23.85	-0.9376		-12.61	0.9477	12.39	-8.43	0.2562	-436.218	889.7	3.99	0.063
5	22.49	0.1214	-5.051	-10.72	1.268	6.454		0.262	-436.508	890.3	4.57	0.047

DISCUSSION

The results of this study indicate that the presence of log booms and fluctuations in river flow plays a crucial role in the terminal survival and migration time of Chinook in Cowichan Bay. Importantly, river discharge was found to have a positive association with survival and migration time, indicating that higher river flows increase survival rates and shorten migration time. The presence of log booms also significantly impacted survival, but this impact was negative, with the presence of booms decreasing the survival of adult migrating Chinook; however, booms did not influence migration time. This study demonstrates the importance of environmental and anthropogenic factors on the survival and conservation of Chinook.

The presence of log booms was found to have a negative association with survival, representing the first documentation of the impact booms have on adult Chinook. Previous research has demonstrated that log booms can alter the distribution of juvenile sockeye salmon (*Oncorhynchus nerka*) in an area due to hypoxic conditions and increased bacteria (Levy et al. 1990). Additionally, log booms and storage areas can reduce zooplankton, decreasing food consumption by juvenile sockeye salmon (Power & Northcote 1991). This demonstrates both direct and indirect effects on juvenile salmon. Additionally, an interactive effect term between boom presence and river discharge was documented to have a significant negative relationship with survival. We suspect that during periods of low river discharge, Chinook cannot enter the Cowichan River and thus stage in the estuary where log booms are present. This increased time in the presence of log booms likely leaves Chinook more vulnerable to the negative effects of the booms, and therefore, we see a further reduction in survival.

The significant negative effect on Chinook survival from log booms observed in this study are suspected to be due to log booms altering the predator-prey relationship between Harbour seals and Chinook, similar to previous observations in other species and studies (Sabal et al. 2021; Washington State Academy of Sciences 2022). The negative influence of artificial structures on predation rates of salmon by pinnipeds is well documented (Jefferies & Scordino 1997; Fraker & Mate 1999; Yurk & Trites 2000; London 2006; Wright et al. 2007; Stansell et al. 2014; Moore & Berejikian 2022), and the results of our study align with this previous research. However, because our study did not generate pinniped abundance numbers, we cannot completely rule out other potential causes of decreased survival due to log booms, such as the potential for other marine predators (sharks, piscivorous fish) to utilize them to their benefit. Toxic leachate may be another mechanism impacting survival. Toxic chemicals released from bark leachates include fulvic acids, phenols, resin acid, benzoic acid, benzyl alcohol, and terpenes (G3 Consulting ltd 2003; WSDE 2013). These toxins have higher leaching rates in saltwater compared to freshwater and are known to harm Pacific salmon roe and fry, even in small concentrations; however, the impacts on adult salmon are unknown (Breems and Goodman 2009; Sedell et al. 1991).

While log booms likely negatively affect Chinook survival by exacerbating pinniped predation, pinniped numbers could not be quantified during the study years. Abundance surveys for Harbour Seals utilizing the log booms are challenging due to seals' behaviour patterns. For example, preliminary shore-based surveys from 2019 showed that the localized abundance of Harbour Seals fluctuated by 83 individuals in 3 hours, and observers noted drastic changes from 0 to 161 individuals over 24 hours (Atkinson & Murchy 2020). Further, boat-based abundance estimates are challenging and likely to produce unreliable estimates (Andrew Trites, Marine Mammal Research Unit, UBC, personal communication, 2020). Aerial surveys for pinniped abundance estimates conducted by DFO occur only during low tides and once every few years, and as such, these data are not useful for inclusion in this study (Fisheries and Oceans Canada 2010). Additionally, low tide surveys do not accurately reflect the relationship pinnipeds have with log booms in Cowichan Bay due to the grounding of the booms during low tides. Future work should evaluate the abundance of pinnipeds on log booms over an extended period to account for daily, monthly, and yearly fine-scale abundance estimates, after which further assessments can be made to understand the potential changes to the predator-prey dynamic between Harbour seals and Chinook. We, therefore, emphasize that the exact mechanism explaining decreased Chinook survival when log booms are present cannot be fully determined by this study.

Managing river flows has been demonstrated to be important for the movement and survival of migrating fish (Taylor & Cooke 2012), and in the Cowichan system, increasing river flows during late summer and early fall during high drought conditions are critical to spawner success (Damborg et al. 2020). A previous study conducted on cutthroat trout (*Oncorhynchus clarkii clarkii*) found survival was low during periods of low stream discharge, especially during the autumn (Berger & Gresswell 2009), similar to what was observed in the current study. So, any delays in migration past the mainstem array/counting fence from anthropogenic factors like sediment accumulation, low river discharge, high-water temperatures and log boom presence would further stress Chinook and prolong their staging times in the intertidal portion of the river and estuary, resulting in increased mortality. For the Cowichan River, flows are regulated by a dam located at the outlet of Cowichan Lake and managed by Paper Excellence in conjunction with all levels of government (Cowichan Tribes, Municipal, Federal, and Provincial), allowing for controlled late-summer river pulses if rain events do not increase river discharge to aid in Chinook migrations upriver. The Cowichan River was at drought level (flows: ~4.5 m3/s) during all study years by August. These low flows inhibited the ability of Chinook to migrate upstream and prolonged their residence time in the estuary and bay. In 2022, a significant fall drought occurred until the beginning of November. This prolonged drought period could have resulted in a significant terminal mortality event. However, Cowichan Tribes, DFO and the B.C. province initiated a prolonged pulse to increase river discharge on September 10, allowing Chinook staging in the estuary to migrate into the river above the intertidal portion. Based on the preliminary analysis, the action resulted in increased overall survival and decreased migration timing for early arrival Chinook (Atkinson in prep).

Peak migration for Chinook in this study was correlated with increased river discharge via instantaneous pulses or substantial rain events, aligning with previous research (Tesch 1977; Vollestad et al. 1986; Jonsson 1991). Chinook tagged later in the season typically had shorter migration times, but this was dependent on river discharge. While river discharge positively influenced migration time in this study, there is an expected upper discharge limit where the positive relationship may be reversed. Additionally, with the projected impacts of climate change on summer drought levels and early fall rains, developing a more holistic understanding of these influences on the terminal survival of Chinook is critical. Thus, more information on the relationships between Cowichan Chinook survival and Cowichan River flows, particularly at higher flow rates, is needed before we can make more conclusive predictions to explain the relationship between discharge and migration time we found in this study.

Capture and tagging effects can substantially impact adult salmon survival (Candy et al. 1996; Bendock & Alexandersdottir 1993). While understanding rates of tagging mortality on tagged salmon, in this study, was not possible using PIT tags, Chinook acoustically tagged in 2019, 2020, and 2022 allow for an understanding of tag-related mortality for the current study (Murchy 2024). Acoustic-tagged Chinook were monitored for 24 hours after tagging, and tagging mortality was estimated at ~5% (Murchy 2024). Additionally, in the previous year of this project, a few acoustically tagged Cowichan-origin Chinook left the bay and never returned (~10% of acoustic fish; Murchy 2024), potentially skewing tagging-related mortality rates. Overall, tagging mortality was low (~5%) and aligned with previous research on the topic (Candy et al. 1996; Bendock & Alexandersdottir 1993).

CONCLUSIONS

The decline in Chinook populations in the Salish Sea since the 1970s has been well-documented through various studies (Ruff et al. 2017; Riddell et al. 2013). Previous research has primarily attributed this decline to high mortality during the early marine phase and consistent annual mortality as the fish ages (Beamish & Mahnken 2001). However, this study suggests that terminal mortality for adult Chinook can also be substantial and is highly influenced by river flows and the presence of anthropogenic structures in migration corridors (Moore & Berejikian 2021; Damborg et al. 2020). This study aimed to assess the potential impacts of log booms in critical migration corridors on returning adult Chinook survival. The results revealed that late-summer low flow rates and log boom presence negatively affected the ability of adult Chinook to enter the lower river and successfully migrate past the mainstem PIT array. These challenges are expected to worsen due to global climate trends. This study provides evidence of the negative influence of anthropogenic structures (log booms) and reduced river flows on the terminal survival and migration duration of Cowichan Chinook. Examining factors impacting Chinook survival underscores the necessity of accounting for the dynamic interplay between river discharge and the presence of log booms or other human-made structures. Furthermore, the findings highlight the need to further our knowledge of the repercussions that anthropogenic structures might impose as a result of habitat fragmentation and modifications to predator-prey dynamics. These insights hold profound implications for managing and preserving Chinook populations in the Northeast Pacific Ocean, particularly within evolving climatic conditions. Continued research is warranted to further explore the ramifications of anthropogenic structures within critical migration corridors, specifically those associated with habitat fragmentation, as well as the intricate interplay between predators, humans, and climate change, and their combined effects on salmon populations in the region.

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