Evaluating the impact of variable harvest intensity on fishing-related mortalities for Fraser River Chinook (*Oncorhynchus tshawytscha*)

by

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Declaration of Committee

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Abstract

Fish released after capture or those escaping from fishing gear face a risk of fishing-related incidental mortality (FRIM), which introduces uncertainty in total mortality estimates due to limited knowledge of specific in-river fisheries' impacts. I incorporated pre-season target harvest, release rate, and post-release survival rate into a simulation model to estimate total mortality of Chinook salmon (Oncorhynchus tshawytscha) in-river fisheries for three Fraser River Chinook populations: Chilko, Quesnel, and Lower South Thompson. Using an existing spatially explicit, individual-based salmon migration model, parameterized with Chinook salmon run reconstruction data, I examined how in-river fishery releases could affect management performance under varying pre-season harvest targets, release rates, and post-release survival rates. Across scenarios, FRIM increased with target harvest, release rate, and post-release mortality, with FRIM outputs being most sensitive to changes in release rate. This study enhances understanding of how mandatory release regulations impact fishing mortality rates for at-risk salmon populations.

Keywords: Fraser River; Chinook salmon; fishing-related incidental mortality; pre-season harvest targets; release rate; post-release survival

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Table of Contents

List of Tables

List of Figures

1. Introduction

Chinook salmon (*Oncorhynchus tshawytscha*) populations have drastically declined across much of their southern range in North America (Miller et al., 2019). To conserve declining populations, management agencies have imposed substantial restrictions on fisheries. In many instances, regional Chinook salmon fisheries have been closed to control incidental mortality of Chinook salmon in commercial and recreational fisheries that target other salmon species (Dobson et al., 2020). Reducing harvest by less drastic means primarily includes restricting harvesting times and areas (National Marine Fisheries Service, 2001; DFO, 2005). Incidental mortality is particularly problematic in mixed-stock fisheries, such as those in the Fraser River, British Columbia where multiple co-migrating stocks and species are harvested simultaneously in the same areas and times. In mixed-stock fisheries, target stock or species are retained, while fish from the non-target stocks or species are released, usually by regulation. It is poorly understood how release factors such as release rate and gear effects contribute to the mortality of released fish. A better understanding of factors contributing to mortality of fish released at-risk Chinook stocks during their freshwater migration could provide Fraser River fishery managers with valuable information to manage fisheries more effectively.

Salmon fisheries management cycle begins with the establishment of spawner escapement goals, which are typically either the number of successful spawners required for replacement (minimum goal) or spawners required for maximum sustainable yield (maximum goal) (Mace and Sissenwine, 1993). Salmon fisheries on the Fraser River are predominantly managed as mixed-stock fisheries because current data collection methods are not sophisticated enough to manage individual stocks separately (Hawkshaw & Walters, 2015). Instead, surplus returns above spawner escapement goals are managed in spatial aggregates, geographic areas where stocks coexist. The stocks comprising a mixed-stock fishery can differ in spawning location, timing, productivity, and conservation status (Hilborn, 1985; Ricker, 1973). In-river mixed-stock fisheries often experience high incidental captures because multiple co-migrating stocks and species are harvested simultaneously in the same fishery (Pinkerton, 1994). Achieving spawner escapement goals in these fisheries is challenging in part due to mortality from incidental encounters in mixed-stock fisheries. The high uncertainty in estimating total mortality makes it difficult to accurately predict the realized escapement, complicating effective management.

Considering the total mortality of a stock during its freshwater migration is crucial when setting escapement goals. Total mortality has several components, each identifiable by the cause of death during migration and before spawning. Natural en route mortality accounts for deaths resulting from adverse conditions such as extreme temperatures and discharge experienced during migration. Captured fish also contribute to total mortality as they are removed from the return before spawning. The final component is the mortality resulting from encounters with fishing gear, leading to death, known as fishing-related incidental mortality (FRIM) (Patterson et al., 2017a). Estimating FRIM is challenging as it is not directly observed like mortality in captured fish. In most cases, FRIM is delayed and occurs beyond the period of observability. For an accurate estimation of FRIM, managers must consider a range of possible values for a given stock. This range of FRIM values introduces uncertainty in total mortality estimates and can result in escapement goals that either over- or underestimate the actual number of spawners needed for replacement.

Mortality from fishing encounters, or FRIM, can be induced in several ways (Figure 1). The energy expenditure required to avoid fishing gear can cause a severe decline in physiological condition and increase susceptibility to predation (Patterson et al.

2017a). Avoidance can also increase susceptibility to physiological decline in extreme river conditions. Fish entangled in fishing gear must expend considerable energy to free themselves and can be left with debilitating and lethal injuries, which can also lead to depredation. The two FRIM pathways mentioned above are collectively described as drop-off mortality, that is, fishing-induced mortality that occurs before a fish a captured (i.e. under complete control of the fisher). The absence of observing mortality numbers makes it very difficult to generate robust estimations of drop-off mortality; instead, an extensive range of values are considered to estimate sustainable escapements for all populations.

Observation of captured fish brought aboard a vessel or ashore and then retained or released allows quantification of fish mortality from fishing encounters. Retained catch and onboard mortality and observed death of non-target fish upon landing are distinct values that account for total mortality (Patterson et al. 2017a). The final FRIM component, post-release mortality, is critical in determining the impact of FRIM because estimates of can be large and variable (Patterson et al. 2017a) Two factors crucial to understanding the impact of post-release mortality are the number of fish released, or the release rate, and the post-release survival rate (Patterson et al. 2017b). The former is linked to management processes and the latter to fishing methods and environmental conditions. The release numbers are known through the number estimated via creek surveys, but the research concerning the post-release survival from different fishing gear is still uncertain (Patterson et al. 2017a). With continued research, more refined rates of post-release survival may be determined.

Post-Release Mortality of Fraser River Chinook

Fraser River Chinook salmon returns vary in abundance, timing, and stock composition between years. Annual returns to the Fraser River are among North

America's largest (Teel et al., 2000). Fraser River Chinook are managed in five Management Units (MUs): Spring 5_2, Spring 4_2, Summer 5_2, Summer 4_1, and Fall 4_1. The season of the MU denotes the run-timing, and the numbers denote the predominate life history variant of either Stream-type, 5_2 and 4_2, or Ocean-type, 4_1 (DFO, 2021a). The five MUs are aggregations of geographically distinct spawning populations with similar return migration timing into the Fraser River (Dobson et al., 2020). Genetic stock ID sampling of fish during test fisheries in marine approaches and freshwater entry coupled with lower river hydroacoustic estimates help Fisheries and Oceans Canada (DFO) infer the MU arrival timing and abundance (Dobson et al., 2020). These accounting methods allow for active management of individual run-timing groups in-season to account for inter-annual variability in abundance (DFO 2009, 2011; Beacham et al., 2019).

The diversity of harvest locations, gear types, and objectives of the various fish harvesting groups complicates the management of Fraser River chinook. It makes curtailment of unaccountable fishery-specific FRIM complex. Fraser River commercial fisheries are extremely limited as they are restricted to increasingly infrequent lower river gill net fisheries (Dobson et al., 2020). Indigenous groups harvest Fraser River Chinook in commercial economic opportunities fisheries and in food, social, and ceremonial (FSC) fisheries (Atlas et al., 2021). Indigenous harvesters employ seines, gillnets, hook and line, beach seines, fish-wheels, dip-nets, or weirs from marine to terminal spawning tributaries (Dobson et al., 2020). Rod and reel recreational fisheries target Fraser chinook harvest in the marine approach areas, estuary, and throughout the lower Fraser River, as well as some specific near-terminal locations (Dobson et al., 2020).

An individual stock-based management approach is used for Fraser River Chinook. Each year, the Joint Chinook Technical Committee (CTC) under the Pacific Salmon Treaty (PST) provides an annual Exploitation Rate Analysis (ERA) for Chinook throughout the entire PST area. The CTC, a division of the Pacific Salmon Commission (PSC), reports stock assessment information to the Chinook Technical Working Group (CTW), a division related to DFO, to determine management decisions on British Columbia bound stocks (DFO, 2007). Harvest rates are assessed for individual Canadian and American stocks using coded wire tags data and the CTC coast-wide model to estimate exploitation rates (DFO, 2007). In response to conservation concerns in both countries, reductions in calendar-year exploitation rates of up to 12.5 percent were assigned from 2009 to 2015 for indicator populations (Dobson et al., 2020). Conservation concerns have resulted in harvest reductions across all fishery types (First Nation, recreational, and commercial fisheries).

Pre-season target harvest rates for interior Fraser River salmon are estimated based on stock assessment in fisheries and stock-recruitment estimates from historical escapement (Dobson et al., 2020). Since 2008, DFO has enforced fishery closures and limitations to safeguard Fraser Spring 4_2 Chinook Salmon stocks, with expansion in 2010 and 2012 to include additional protection for Fraser River Spring 5_2 and Sumer 5_2 Chinook Salmon stocks. To assess recent patterns in spawner abundance, biological properties, and annual exploitation rates for Fraser River Spring 4_2, Spring 5_2, and Summer 5_2 Chinook stock management units, the CTW used the available data to create a run reconstruction model. Results from the run reconstruction suggest that the overall reduction targets for Spring and Summer 5_2 Chinook exploitation rates may have been met. However, uncertainties in data and model assumptions prevent a definitive conclusion. Notably, assumptions about fishing-related incidental mortality (FRIM) rates used in this analysis are likely a major source of uncertainty in overall estimates of total mortality (Dobson et al., 2020).

Upon returning to the Fraser River, Chinook encounter several pressures that, in combination, may exacerbate FRIM. The lower Fraser River is among the most densely populated of all large eastern Pacific watersheds, leading to intense exploitation. Intensive fishing activities increase the possibility of incidental mortality as more fish are captured and released during fishing operations (Carr-Harris et al., 2018). The Fraser River has returns of five Pacific salmon species, including Chinook, sockeye (*Oncorhynchus nerka*), pink (*Oncorhynchus gorbuscha*), coho (*Oncorhynchus kisutch*), and chum (*Oncorhynchus keta*). Fraser River Chinook alone has 80 Conservation Units (CU), distinct aggregates defined by common natal spawning areas (DFO, 2016). Stock-specific impacts such as habitat degradation, diversity in species, and stock productivity have led to the simultaneous migration of at-risk and not-at-risk stocks and subsequent harvest in mixed-stock fisheries. Increased frequency of mixed-stock fisheries increases the chances of incidental catch and mortality of non-target species and stocks. The Fraser River also presents significant environmental challenges, including high water temperatures and variable flow conditions, which can exacerbate trauma incurred during a fishing encounter (Jeffries et al., 2016). Additionally, the frequency of extreme river conditions will likely increase under climate change putting adding stress on Chinook salmon (Van Wert et al., 2023). The pressures in the Fraser River are cumulative in their impact on FRIM, as increased fishing pressure increases FRIM individually, and the trauma induced by a fishing encounter will increase when fish are released into a warmer environment (Hinch et al., 2021).

Chinook salmon can have higher fishing-related incidental mortality levels compared to other Pacific salmon due to several intrinsic and extrinsic factors. Chinook salmon are often larger and more prized by commercial and recreational fishers, leading to more intensive fishing pressure and higher capture and release rates. In Fraser River

Chinook fisheries, harvest intensity, defined as the proportion of the fish population removed by fishing activities, is directly linked to fishing pressure, which encompasses the cumulative impact of fishing efforts on the fish population (Dobson et al., 2020; Walters & Martell, 2004). Chinook salmon captured in recreational fisheries also have the most extended retrieval times of the Pacific salmon species due to behavioral responses and larger, stronger body size (Gale et al., 2011). The capture and release process induces significant physiological stress in Chinook salmon, including elevated cortisol levels, which can impair immune function and increase vulnerability to disease, leading to delayed mortality after the fish is released (Donaldson et al., 2013; Patterson et al., 2017a). These factors underscore the need for species-specific management strategies to mitigate the higher potential vulnerability of Chinook salmon to incidental fishing-related mortality and ensure the sustainability of their populations.

In this study, I used a simulation approach to examine the relationship between in-river harvest intensity in the Fraser River basin and FRIM for Chinook salmon during their upstream migration. I used the Fraser River Salmon Management Model (FRSMM) (Carter, 2014; Straight, 2021) to simulate 1) the impact of increasing harvest intensity on total fishing mortality, and 2) the impact of post-release mortality factors release rate and survival rate of interior Fraser River Chinook on overall FRIM. I used the FRSMM simulations to complete a sensitivity analysis of post-release mortality factors release rate and post-release survival rate. Simulation modelling allows for the analysis of complex biological systems and evaluates the potential outcomes of various management strategies under different scenarios, which can help in understanding the impact of different harvest rates, environmental conditions, and policy decisions (Hilborn et al., 1995; Maunder & Punt, 2004).

The FRSMM is a spatially explicit simulation model with discrete time steps, employing individual-based modeling (IBM) to simulate the directional migration of salmon stocks through river systems. An IBM accommodates individuals and their environmental experiences (DeAngelis & Grimm, 2014). Within FRSMM, the IBM design enables multiple fish within each stock to encounter varying temperatures and fisheries along their migration routes based on individual factors such as migration path, entry timing, and speed. The acute and cumulative effects of environmental conditions on population survival and movement are monitored using BOTS (**B**OTS are **O**bjects for **T**racking **S**tates). BOTS determine acute and latent temperature-related mortality (i.e., natural mortality during migration). This is done through a species-specific logistic, short-term temperature-aerobic scope model, and a long-term accumulated temperature degree days model. A random draw from a multinomial distribution manages movement across discrete timesteps from one spatial increment to the next. Due to the considerable variability in temperature-dependent mortality and capture risk across time and space, IBM surpasses traditional models for assessing mixed-stock fisheries targeting migrating species.

I used the FRSMM to simulate increasing harvest intensity of in-river Fraser River Chinook fisheries using combinations of pre-season target harvest quota, post-release survival, and release rate. I hypothesized that the sensitivity of fishing mortalities to harvest intensity would vary due to stock-level differences in migration attributes such as duration, arrival timing, and return numbers that lead to variation in exposure to fisheries. I set the harvest plan to follow the conservative trend assigned by DFO in 2012 for the interior Fraser River Chinook. I tested how total fishing mortality is impacted by management actions under multiple catch-release harvest scenarios and provide a prediction model to estimate the stock-specific total fishing mortality (i.e., including FRIM) at a given harvest intensity. This analysis could help managers better understand how mortalities after release from fishing encounters in mixed-stock stocks affect their ability to meet harvest and escapement goals.

2. Methods

I used a spatially explicit individual-based model, FRSMM, to simulate post-release fishing mortality of migrating adult Chinook salmon as a function of varied exposure to in-river fisheries. For my analysis, I calibrated FRSMM for three co-migrating Chinook salmon stocks based on arrival timing, abundance, and migration rate estimates from the DFO Chinook run reconstruction model (Dobson et al., 2020). In FRSMM, each "group" of salmon travels through a prespecified sequence of Fraser River areas, known as reaches, from a starting area to their final spawning destination. Fisheries are designated by 10 km reach length, and harvest rate matrix controls harvest in fisheries. The harvest rate matrix controls each fishery-specific opening duration and seasonal timing, and the opening-specific harvest rate over an entire migration season. The FRSMM model uses a harvest rate matrix to simulate a large range of outcomes of total seasonal fishing-related deaths, expressed as total catch, given harvest conditions.

Model Inputs

Migration rate data, total run size data, spawning ground arrival timing data, and spatially explicit weekly fishery harvest rate data for all three stocks were provided by DFO Fraser River Stock Assessment group in their Chinook Run Reconstruction Model (L. Weir, personal communications, October 7, 2022). This analysis simulated a single Chinook salmon run in 2012 for the Chilko, Quesnel, and Lower South Thompson River stocks. Chilko and Quesnel stocks are part of the Summer 5_2 stock-management unit (SMU), while the Lower South Thompson River stock is part of the Summer 4_1 SMU. The DFO Environmental Watch Program provided mean daily temperature from thirteen stations along the Fraser River (See Patterson et al. 2007; Hague et al. 2007 for site descriptions and methods for temperature). The three stocks were selected based on conservation status: Chilko and Quesnel are assessed as threatened with low harvest potential; the Lower South Thompson River stock is the largest return to the Fraser River interior and could accommodate higher intensity harvest.

FRSMM structure

Natural mortality and movement sub-models in FRSMM are described in detail by Carter et al., 2014. I used FRSMM to simulate the variable impact on fishing-related deaths over a range of variable pre-season target harvest intensities through variation of the harvest rate matrix. The harvest rate matrix sets the harvest level for each fishery by defining each fishery for open/closed status, opened (“1”) or closed (“0”); harvest rate; the proportion of fish harvested over the length of a fishery opening (values range from 0 to 1); and the seasonal timing and duration of a fishery, the timing in timesteps from the start of the migration season to the end, and duration was expressed as start and end timestep values within the migration season. This simulation approach comprehensively assesses how different pre-season target harvest intensities can influence the overall fishing mortality rates within a given season.

The FRSMM can simulate a range of fishing-related mortality outcomes through alterations to the harvest rate matrix. In this study, fisheries opening duration, seasonal timing and iterations imitated the 2012 season, with a harvest rate that varied consistently across all fisheries openings. The harvest rate for each simulation was constant across every fishery to account for uncertainty in fishery-specific impacts on individual stocks. The constant harvest rate is the elemental harvest rate (EHR) and is the proportion of fish captured in each reach and timestep (Figure 2). For instance, an EHR of 0.01 in the harvest matrix would harvest 1% of the fish in a fishery (reach) for the duration of that fishery opening. In the harvest rate matrix, the EHR is the harvest rate for each fishery opening (seasonal timing and duration). The EHR value cannot exceed one as this would indicate there were more fishing encounters in a reach and timestep than fish present. The FRSMM is run with an EHR, resulting in an associated total catch.

Harvest Scenarios

In my analysis, simulated harvest is impacted by pre-season target harvest, harvest timing and harvest location. Harvest location and timing have been controlled by others using FRSMM (Straight, 2021); however, in my analysis, the harvest timing and location have been fixed. I selected harvest location and timing data derived from the 2012 run reconstruction model because this year had complete harvest data, and it occurred before additional conservation measures were introduced to reduce the impacts of in-river fisheries on the survival of interior Chinook (Dobson et al., 2020; DFO, 2016).

I defined a total fishing-induced mortality index, u_{FRIM}, for each stock as the proportion of the total return that contributes to in-river catch. Total FRSMM catch for each u_{FRIM} value is the total fishing-related mortalities and includes the proportion of fish captured and handled, u_F,

$$u_F = u_T \,/\, (1 - R)$$

Equation 1

$$u_{FRIM} = u_F\big(1 - R + R(1 - S)\big)$$

Equation 2

Where u_T is the pre-season target harvest rate (the target catch as a proportion of the return that only considers observed catch), *R* is the release rate or proportion of fish that were released after capture in fisheries, and *S* is the post-release survival rate (Figure 2).

A range of pre-season target harvest values were selected to consider how fishing mortality would impact stocks across a spectrum of harvest intensities: (1) aggressive (u_T=0.45), (2) moderate (u_T=0.3), and (3) conservative (u_T=0.15). The probability of Chinook surviving after release from fisheries can vary extensively because mortality depends on an individual's physiological response to capture and the impact of distinct fishing techniques (B. M. Connors et al., 2022). As such, the analysis considered multiple survival probabilities, including 0%, 25%, 50%, 75%, and 100%. In-river Fraser River fisheries employ a variety of harvest tactics based on objectives to target or conserve fish by size and species. Accordingly, release rates were varied using the following values: 0%, 25%, 50%, 75%, and 100%.

Simulations in FRSMM with varied EHR were run to determine the EHR in a certain reach timestep to achieve a target u_{FRIM}. The EHR will vary depending on the stock-specific exposure to fisheries. Stocks that migrate longer in the river will have more exposure.

Sensitivity Analysis

I performed sensitivity analyses to evaluate how pre-season target harvest, release and survival rate can affect simulated end-of-season total fishing mortalities.

In this study, the EHR, the proportion of fish captured per return, and the proportion of fishing-related mortalities per return were initially considered at the reach-timestep level. I used the movement and harvest models in FRSMM to simulate the effects of a fishing encounter on released Chinook over the entire spawning migration. In FRSMM, the simulated total catch as a proportion of the return is the cumulative post-release mortality across all fishing areas and time steps (i.e., FRSMM catch/return = u_{FRIM}).

The total catch outputs in the FRSMM simulations were considered in two parts: 1) mortalities in retained captures (i.e., observed catch/mortalities) and 2) mortalities occurring between release from fisheries and migration completion (i.e., unobserved post-release mortalities). The fishery-induced mortalities for u_{FRIM} scenarios depend on factors u_T, R, and S. At each level of u_T, there is an associated base fishing mortality that occurs at $S = 1$. There is no unobserved catch-release mortality in a fishery if migration survival is guaranteed (i.e., $S = 1$). As such, the difference in catch of a u_{FRIM} scenario ($\mathrm{C}_{u_T,R,S}^{\mathrm{FRSMM}}$) from the catch in the base fishing mortality ($\mathrm{C}_{u_T,S=1}^{\mathrm{FRSMM}}$) gives the post-release mortalities for a u_{FRIM} at the corresponding EHR (Equation 3).

$$PRFIM_{u_T,R,S} = \mathrm{C}_{u_T,R,S}^{\mathrm{FRSMM}} - \mathrm{C}_{u_T,S=1}^{\mathrm{FRSMM}}$$

Equation 3

Prediction Model

Simulated harvest scenarios examined how different harvest rates (i.e. EHR) impacted fishing mortality for each stock, providing insights into the stock-specific fishing mortality at various levels of harvest intensity. All stock-specific relationships were best fit by a cubic-hermit spline, as it allowed variability in slopes between data points and smooth interpolation. With a model to describe the harvest rate-fishing mortality relationship, the cubic-hermit spline model could predict the fishing mortality rate for a pre-season target harvest rate.

3. Results

Simulated post-release mortalities were most sensitive to release rates and moderately sensitive to post-release survival (Figures 3, 4, and 5). With pre-season target harvest and survival held constant, increasing the release rate from 25% to 75% incurred an 800% increase in FRIM (Tables 1, 2, and 3). Post-release survival was the next most sensitive parameter, with a 300% increase in FRIM as survival increased from 0% to 75%. The target harvest rate had the lowest overall sensitivity as FRIM only increased 200%, while the harvest increased from 15% to 30% to 45%. The smallest incremental increase was observed when S was decreased from 25% to zero, leading to a 33% increase in FRIM. The largest incremental increase occurs when R is increased, as every increase in R resulted in a 200% increase in FRIM (Tables 1, 2, and 3).

The total fishing-induced mortality index combined with the FRSMM model created a framework for a prediction model used to estimate the FRIM rate for fisheries encountered by the Chinook stocks: Chilko, Quesnel, and Lower South Thompson. The Lower South Thompson stock, the largest stock at 47,196 returns, required the highest elemental harvest rate to obtain FRIM harvest rate values (u_{FRIM})(Figure 6). EHR values ranged from 0.0543 for u_T = 15% base fishing mortality scenario (i.e., S = 1) to 0.9551 for u_{FRIM}= 80% (Table **3**). The Chilko stock had a moderate return at 6085 but, interestingly, had the lowest EHR values (Table **1**). EHR values ranged from 0.0046 for u_T = 15% base fishing mortality scenario (i.e., S = 1) to 0.1171 for u_{FRIM} = 97.5%. The Quesnel stock had a moderate-low return at 2456 and fell between Chilko and Lower South Thompson CUs. EHR values ranged from 0.0093 for u_T = 15% base fishing mortality scenario (i.e., S = 1) to 0.2946 for u_{FRIM} = 97.5% (Table **2**). The largest return required larger EHR values to meet the conditions of the u_{FRIM} scenarios, however, smaller returns did not support the lowest EHR values.

Stocks with smaller return sizes were more sensitive in relation to FRIM rates when altering the EHR. Smaller stocks will experience a greater change in FRIM compared to larger stocks over the same harvest intensity range (Figure 6). Altering the harvest rate at low harvest intensity will result in a disproportionate alteration to the FRIM rate, indicating that small stocks are more FRIM sensitive to alterations in harvest intensity. The change in FRIM over harvest intensity in the larger stock (Lower South Thompson) is relatively more proportional, although the shape of decreasing change in FRIM with increased harvest intensity is still observable (Figure 6).

4. Discussion

In this paper, I quantified the relationship between pre-season target harvest rates and their corresponding realized total mortalities after release from a fishing encounter. I focused on a select group of Fraser River Chinook stocks. I determined the total mortality (i.e., the number of dead Chinook) resulting from pre-season target harvests for each stock by integrating multiple fishing-related mortality factors that could lead to death during migration. Simulating in FRSMM allowed mortality factors to be considered over an entire migration season, as salmon groups would experience varying mortality components depending on migration timing. The results of this study demonstrate how the relationship between FRIM factors, pre-season target harvest rate, release rate, post-release survival, and realized total mortality varies according to each stock's unique exposure to fisheries based on the stock-specific migration route and timing. These findings could be helpful for managers of mixed-stock fisheries, as pre-season target harvest rates applied over an entire migration season will have varying impacts on the total realized stock-specific mortality, leading to inconsistencies in the realization of conservation and harvest objectives.

My simulations of in-river fisheries revealed that stock-specific exposure to fisheries, represented by return size and migration timing and length, influences the relationship between post-season target harvest and realized total mortality. This indicates that salmon stocks of different sizes and migration behaviors are differentially vulnerable to harvest in mixed-stock fisheries depending on harvest targets, which include total catch, release, and estimated survival after release. The hypothesized trend was observed that smaller stocks that experience higher fishing exposure are more sensitive to mortality after a fishing encounter with varying target harvest (Figure 7).

Increases in the target harvest in the smallest stock (i.e. Quesnel) resulted in a slower increase in mortalities compared to the next smallest stock (i.e. Chilko).

In the FRSMM, the Quesnel and Chilko stock have nearly identical migration timing, behavior, and exposure to fisheries, except for the final reaches, Chilcotin tributaries. The Chilko stock migration included ten additional time steps (5 days) to simulate the longer migration distance. Fisheries in the Chilcotin tributaries were open for the 2012 season, leading to five additional days of exposure to fisheries for the Chilko stock compared to the Quesnel stock. Increased fishing exposure in the Chilko stock resulted in fishing-related mortalities accruing quicker if harvest rates were increased compared to the Quesnel stock. This result demonstrates the sensitivity of small stock to changes in harvest, as a change of five or fewer days may result in a quicker accruement of fishing-related mortalities per return. Effective management of mixed-stock fisheries considers the sensitivity of all stocks to harvest targets because a minor change in harvest may impact large stocks minimally, but the same change could impact a smaller population substantially and decline returns below the spawners required for recruitment.

Understanding the sensitivity of fishing-related mortality parameters gives fisheries managers the knowledge to make informed decisions on harvest regulations. My analysis of fishing-related mortality factors shows that mortality is more sensitive to changes in the release rate than to variations in post-release survival. This suggests that changing the proportion of fish released after capture in fisheries will have a greater impact on fishing-related mortalities than changing the post-release survivability. Fisheries managers could consider the relative impact of these fishing-related mortality factors to improve end-of-season mortality accounting. By quantifying more of the total mortality beyond capture-related mortalities, estimates of total mortality and escapement goals will be more rigorous.

Limitations and assumptions

My analysis focused on only three specific Chinook salmon stocks. It used a simplified representation of a fixed in-river target harvest rate by simulating a constant harvest rate over the entire fishing season. A limitation of this study design is that it does not allow for differential harvest rates across fishing areas, which is common for migration-associated fisheries. Management of Fraser River harvest rates currently employs a varied approach, with more intense but shorter harvest periods in the lower river due to higher fishing pressure, while upper river fisheries experience lower harvest rates but remain open for longer periods (DFO, 2021b). Fraser River salmon fisheries are structured as such to mitigate the risk of over-exploitation and ensure escapement goals are met (Walsh et al., 2020). Shorter, intense fisheries in the lower river can be timed for periods when at-risk stocks are likely not migrating, and less intense, longer fisheries in the upper river can target tributaries of abundant stocks.

Further research into the stock-specific effects of FRIM due to harvest intensity should include incorporating additional stocks. My research demonstrates a trend of increasing fishing mortality with increased exploitation. Understanding the result, however, was difficult to discern initially as fishing mortality appeared to have an inflection point between 2,456 returns (Quesnel) and 6,085 returns (Chilko), where smaller returns are more sensitive to fishing mortality with increases to harvest (Figure 7). However, a closer look at the harvest matrix indicated increased fisheries exposure in the Chilko stock, leading to decreased fishing mortality sensitivity in relation to harvest. Note that the difference between the largest run size and the next largest run size was

41,111 fish, over seven times as many returns. Accordingly, it would be prudent to include a range of return sizes with similar fisheries exposure to determine if there is a predictable increase in fishing mortality with increased fishing exposure.

Future research could incorporate additional FRSMM sub-models to further consider the functional impact of release of fish after capture. The harvest matrix used in FRSMM considers retainment only for in-river fisheries along the migration route of Fraser River salmon. Fish migrating in groups through a fishing area are harvested and recorded in total catch at a given harvest rate. The post-release mortality index was created to consider how post-release mortalities would increase as a function of total mortalities (total catch). Release mortality factors, release rate, and post-release survivability are considered as they relate to variations in harvest intensity. For example, release-after-capture scenarios with higher release rates and lower post-release survival rates have a greater harvest rate and, therefore, greater post-release mortalities. In my analysis, parameters release rate and post-release survival are not independently considered in the FRSMM; they are always associated with a harvest rate. To consider release rate and post-release survival rate independently, consider the functionality of FRSMM and sub-models to remove fish (e.g., temperature and harvest) and how sub-models to add fish back (e.g., release after capture) may be created and incorporated.

The FRSMM is highly configurable and can accommodate additional functions to simulate conditions and features that salmon may encounter during their in-river migration. For instance, the harvest matrix function removes fish at harvest areas during openings; a release function could add captured fish back to the model where they were captured. Functionality further increases if released fish are added back at varying levels of health (i.e., survivability) depending on the fishing technique encountered. Studies on Fraser River sockeye salmon suggest various fishing techniques will have varying levels of migration impairment after release (Bass et al., 2018; Robinson et al., 2013, 2015). A study examining the impact of catch and release angling and beach seining on survivorship in natal spawning grounds used telemetry data to compare the proportion of fish that survived after release from each technique (Donaldson et al., 2013). The study found a significant reduction in survivability (15.9% lower) in angling compared to seine netting. With the addition of the release matrix and survivability functionality, fishery-specific survivability rates could be considered in the model, which would refine estimates of total realized mortality.

The approach used in this project does not consider many other potential causes of mortality facing Fraser River Chinook on their natal spawning migration, such as by-catch of Chinook salmon in non-target fisheries, stock-specific vulnerability to harvest and prolonged exposure to extreme environmental factors. Previous applications of the FRSMM have investigated the en-route mortality of sockeye salmon through the application of variable temperature and migration scenarios (Straight, 2021) or through consideration of stock-specific differences in temperature-related mortality risk (Carter, 2014). Future examination of Fraser River Chinook en-route mortality is problematic because research into temperature-related impacts on migration is limited and primarily on US systems (Goniea et al., 2006). If further research examined the effects of temperature on migration of Fraser River Chinook, applying these parameters in FRSMM could reveal the sensitivity of Chinook salmon to temperature extremes. This information would be essential to consider in recognition of the increased frequency of temperature extremes due to climate change.

Management implications

Mixed-stock fisheries face the challenge of balancing conservation and fishing opportunities for each stock depending on their status relative to biological limits (Kell et al., 2004). My research suggests that fisheries managers with objectives to reduce fishing mortalities should consider reducing the release rate as an initial modification to fishing practices. A simple way to reduce the release rate includes limiting fishing opportunities by reducing fisheries openings by location, duration, and seasonal iterations. Reducing the time gear is allowed to fish directly reduces the fish available for release, as fewer fish are landed. The issue with limiting openings, and why a fisheries manager may not choose this method to reduce fishing mortality, is that it reduces fishing opportunities, leading to declines in local fisheries that many communities rely on economically and culturally.

Alternatively, managers may reduce fishing mortality using more complex methods, such as implementing selective fishing practices and using gear and techniques that target specific sizes or species of salmon while allowing non-target fish to be released with minimal harm (Raby et al., 2014). Setting quotas and limits on the number of salmon that can be harvested, including daily or seasonal bag limits, can reduce the total allowable catch, ensuring more fish are released back into the wild (Walters et al., 2019). Adjusting fishing seasons to protect salmon during critical life stages, such as spawning migrations, ensures that more fish are released and able to reproduce (Carlson et al., 2011). Slot limits allow salmon to be harvested within a specific size range while requiring the release of fish outside that range, which would also protect larger, more fecund individuals and smaller, younger fish (Hard et al., 2009). Implementing gear regulations in fisheries can enable managers to limit the use of non-selective mass capture methods, such as netting, which frequently lead to the unintended capture of non-target species or stocks. By imposing restrictions on these methods, fisheries management can prioritize more selective individual capture techniques like angling and dip netting. These methods are less likely to capture non-target species, which reduces the number of fishing encounters and the potential for FRIM (Baker & Schindler, 2009; Connors et al., 2019). The complexity of these methods can be attributed to the extensive coordination and communication needed to implement them effectively.

The primary objectives of a salmon fisheries manager are to ensure the sustainable harvest of salmon populations while conserving the species and their habitats and balancing ecological health with economic health. Fisheries managers must coordinate among numerous fisheries to appropriately apportion the total catch and the allowable mortality by fisheries opening (Sainsbury, 2000). Fisheries managers will communicate approved fishing gear for fisheries openings through online and physical resources: notices, pamphlets, and brochures (O'Keefe et al., 2014). My research can assist managers in determining the appropriate adjustments for reducing fishing mortality: reducing the release rate would be appropriate if a larger reduction to fishing mortality is needed, compared to increasing the post-release survivability, which would be appropriate for a smaller reduction in fishing mortality. Incorporating these strategies into management plans will enable fisheries managers to balance between ecological sustainability and economic viability while minimizing incidental mortalities and ensuring the long-term health of salmon populations (DFO, 2021b).

Managers of Fraser River salmon must balance the regularly opposing objectives of conserving imperiled stocks that may be exploited in mixed-stock fisheries while providing fishing opportunities to First Nation FSC fisheries that target abundant stocks (Dobson et al., 2020). In response, many interior First Nations have suggested incorporating terminal harvest strategies (Atlas et al., 2021). Relocating fisheries to tributaries will allow managers to effectively target productive stocks that can tolerate elevated fishing mortality. My findings on stock-specific fishing mortality, and with the incorporation of further stocks, can assist in determining stock sensitivity to harvest, and fisheries could be established at tributary locations with consistently high returns.

Stock dynamics in many marine fisheries have been profoundly influenced by extended periods of exploitation combined with intense selectivity (Charbonneau et al., 2022). Continued selectivity can lead to inequal exploitation of populations and limit species resilience as select stocks may have relative improved adaptability to altered environments under climate change (Sadovy De Mitcheson et al., 2013). Developing an understanding of how post-release mortality factors contributes to FRIM in a marine environment can help further reduce the total FRIM of a return. Marine salmon fisheries of the northeast Pacific cover vast geographical areas leading to the exploitation of stocks returning to several different watersheds. Many commercial marine fisheries deploy nets to mass capture fish, which are conducive to high incidental capture and release of non-target species (Cook et al. 2019). My research indicates that fishing mortality is highly sensitive to release rate and a solution to reducing high fishing mortality is to reduce the release rate. Given the precarious status of some salmon stocks and managers obligations to conserve and rebuild wild stocks (DFO, 2021b), it is imperative that managers understand how to reduce fishing mortality for mixed-stock fisheries that overlap with the run timing of at-risk Chinook stocks.

Furthering our understanding of how post-release survivability factors impact fishing-related mortalities in salmon fisheries is essential for developing more accurate and effective management strategies. Post-release mortality can significantly contribute to total fishing-related mortality, yet it is often underappreciated in management decisions (Brownscombe et al., 2017). Factors such as handling time, air exposure, hook type, and water temperature can all influence the likelihood of a fish surviving after release, and failing to account for these can lead to an overestimation of fishing pressure needed to meet conservation goals (Cooke & Suski, 2005). By refining our knowledge in this area, fisheries managers can make more informed decisions that balance conservation needs with economic and recreational fishing opportunities, potentially reducing unnecessary restrictions while protecting vulnerable salmon populations (Donaldson et al., 2008).

Conclusion

Understanding the impact of fishing mortality on Chinook salmon migration survival is increasingly crucial for conservation and management. Effects leading to declines can accumulate, especially with factors like climate change projected to intensify. Recent harvest objectives for the Fraser River Chinook are conservation focused, aiming to lower harvest targets across all fisheries to mitigate decline. Comprehensively decreasing harvest without examining the impact of post-release mortality factors will limit our understanding of how alterations to fishing regulations impact total fishing mortality and overestimate the reduction in fishing opportunity required to reverse rising fishing mortality.

This study highlights the significance of release rate in the context of mixed-stock fisheries for Fraser River Chinook salmon. The results emphasize the need for an improved understanding of the impact of the factors that account for fishery-specific post-release mortality. This work provides fisheries managers with information that can help them consider fishing mortality factors release and post-release survivability when making decisions to ensure the conservation of at-risk Chinook stocks while maintaining sustainable fisheries. This research contributes to our understanding of how release dynamics and post-capture in fisheries impact the fishing mortality outcomes in mixed-stock fisheries and provides valuable insights for practical fisheries management in the Fraser River watershed.

5. Tables

Table 1. Range of simulated release mortality (RM) estimates for the Chilko stock, for the 2012 model year for scenarios varying three parameters: preseason target harvest rate ($\boldsymbol{u_T}$), release rate (R), and post-release survival (S). Values of elemental harvest rate (EHR), unobserved total harvest rate ($\boldsymbol{u_F}$), total fishery related induced mortality ($\boldsymbol{u_{FRIM}}$) and total fishing-related induced mortalities (FRIM) are also listed for each scenario.

u_T	**R**	**S**	u_F	u_{FRIM}	**EHR†**	**FRIM (# of fish)**	**RM* (# of fish)**
0.15	0.25	1	0.2	0.15	0.0046	912	0
0.15	0.25	0.75	0.2	0.1625	0.0050	988	76
0.15	0.25	0.5	0.2	0.175	0.0055	1064	152
0.15	0.25	0.25	0.2	0.1875	0.0059	1140	228
0.15	0.25	0	0.2	0.2	0.0063	1217	305
0.15	0.5	0.75	0.3	0.1875	0.0059	1140	228
0.15	0.5	0.5	0.3	0.225	0.0072	1369	457
0.15	0.5	0.25	0.3	0.2625	0.0087	1597	685
0.15	0.5	0	0.3	0.3	0.0102	1825	913
0.15	0.75	0.75	0.6	0.2625	0.0087	1597	685
0.15	0.75	0.5	0.6	0.375	0.0135	2281	1369
0.15	0.75	0.25	0.6	0.4875	0.0191	2966	2054
0.15	0.75	0	0.6	0.6	0.0265	3651	2739
0.3	0.25	1	0.4	0.3	0.0102	1825	0
0.3	0.25	0.75	0.4	0.325	0.0113	1977	152
0.3	0.25	0.5	0.4	0.35	0.0124	2129	304
0.3	0.25	0.25	0.4	0.375	0.0135	2281	456
0.3	0.25	0	0.4	0.4	0.0146	2434	609
0.3	0.5	0.75	0.6	0.375	0.0135	2281	456
0.3	0.5	0.5	0.6	0.45	0.0170	2738	913
0.3	0.5	0.25	0.6	0.525	0.0213	3194	1369
0.3	0.5	0	0.6	0.6	0.0265	3651	1826
0.3	0.75	0.75	1.2	0.525	0.0213	3194	1369
0.3	0.75	0.5	1.2	0.75	0.0405	4563	2738
0.3	0.75	0.25	1.2	0.975	0.1171	5932	4107
0.45	0.25	1	0.6	0.45	0.0170	2738	0
0.45	0.25	0.75	0.6	0.4875	0.0191	2966	228
0.45	0.25	0.5	0.6	0.525	0.0213	3194	456
0.45	0.25	0.25	0.6	0.5625	0.0238	3422	684
0.45	0.25	0	0.6	0.6	0.0265	3651	913
0.45	0.5	0.75	0.9	0.5625	0.0238	3422	684
0.45	0.5	0.5	0.9	0.675	0.0327	4107	1369
0.45	0.5	0.25	0.9	0.7875	0.0454	4791	2053
0.45	0.5	0	0.9	0.9	0.0689	5476	2738
0.45	0.75	0.75	1.8	0.7875	0.0454	4791	2053

**For all scenarios where S = 0 and/or R = 0, cumulative effects are zero. Scenarios fulfilling the previous conditions for R and S were displayed in the table once for each value of u_T, and scenarios repeating the resulting cumulative effects value were not displayed in the table.*

†All scenarios requiring a EHR > 1 for the u_{FRIM} were removed from the analysis due to the impossibility of EHR > 1. The maximum EHR value is one, and EHR = 1 indicates every fish was captured at a given reach-timestep.

Table 2. Range of simulated release mortality (RM) estimates for the Quesnel stock, for the 2012 model year for scenarios varying three parameters: preseason target harvest rate (u_T), release rate (R), and post-release survival (S). Values of elemental harvest rate (EHR), unobserved total harvest rate (u_F), total fishery related induced mortalities (u_{FRIM}) and total fishing-related induced mortality (FRIM) are also listed for each scenario.

u_T	R	S	u_F	u_{FRIM}	EHR†	FRIM (# of fish)	RM* (# of fish)
0.15	0.25	1	0.25	0.15	0.0093	368	0
0.15	0.25	0.75	0.2	0.1625	0.0103	399	31
0.15	0.25	0.5	0.2	0.175	0.0112	429	61
0.15	0.25	0.25	0.2	0.1875	0.0121	460	92
0.15	0.5	0.75	0.3	0.1875	0.0121	460	92
0.15	0.25	0	0.2	0.2	0.0131	491	123
0.15	0.5	0.5	0.3	0.225	0.0149	552	184
0.15	0.5	0.25	0.3	0.2625	0.0178	644	276
0.15	0.75	0.75	0.6	0.2625	0.0178	644	276
0.15	0.5	0	0.3	0.3	0.0209	736	368
0.15	0.75	0.5	0.6	0.375	0.0277	921	553
0.15	0.75	0.25	0.6	0.4875	0.0400	1197	829
0.15	0.75	0	0.6	0.6	0.0560	1473	1105
0.3	0.25	1	0.6	0.3	0.0209	736	0
0.3	0.25	0.75	0.4	0.325	0.0231	798	62
0.3	0.25	0.5	0.4	0.35	0.0254	859	123
0.3	0.25	0.25	0.4	0.375	0.0277	920	184
0.3	0.5	0.75	0.6	0.375	0.0277	921	185
0.3	0.25	0	0.4	0.4	0.0301	982	246
0.3	0.5	0.5	0.6	0.45	0.0356	1105	369
0.3	0.5	0.25	0.6	0.525	0.0447	1289	553
0.3	0.75	0.75	1.2	0.525	0.0447	1289	553
0.3	0.5	0	0.6	0.6	0.0560	1473	737
0.3	0.75	0.5	1.2	0.75	0.0865	1842	1106
0.3	0.75	0.25	1.2	0.975	0.2946	2394	1658
0.45	0.25	1	0.6	0.45	0.0356	1105	0
0.45	0.25	0.75	0.6	0.4875	0.0400	1197	92
0.45	0.25	0.5	0.6	0.525	0.0447	1289	184
0.45	0.25	0.25	0.6	0.5625	0.0499	1381	276
0.45	0.5	0.75	0.9	0.5625	0.0499	1381	276
0.45	0.25	0	0.6	0.6	0.0560	1473	368
0.45	0.5	0.5	0.9	0.675	0.0693	1657	552
0.45	0.5	0.25	0.9	0.7875	0.0976	1934	829
0.45	0.75	0.75	1.8	0.7875	0.0976	1934	829
0.45	0.5	0	0.9	0.9	0.1552	2210	1105

**For all scenarios where S = 0 and/or R = 0, cumulative effects are zero. Scenarios fulfilling the previous conditions for R and S were displayed in the table once for each value of u_T, and scenarios repeating the resulting cumulative effects value were not displayed in the table.*

†All scenarios requiring a EHR > 1 for the u_{FRIM} were removed from the analysis due to the impossibility of EHR > 1. The maximum EHR value is one, and EHR = 1 indicates every fish was captured at a given reach-timestep.

Table 3. Range of simulated release mortality (RM) estimates for the Lower South Thompson River stock, for the 2012 model year for scenarios varying three parameters: preseason target harvest rate ($\boldsymbol{u_T}$), release rate (R), and post-release survival (S). Values of elemental harvest rate (EHR), unobserved total harvest rate ($\boldsymbol{u_F}$), total fishery related induced mortalities ($\boldsymbol{u_{FRIM}}$) and total fishing-related induced mortality (FRIM) are also listed for each scenario.

u_T	**R**	**S**	u_F	u_{FRIM}	**EHR†**	**FRIM (# of fish)**	**RM* (# of fish)**
0.15	0.25	1	0.2	0.15	0.0543	7079	0
0.15	0.25	0.75	0.2	0.1625	0.0603	7669	590
0.15	0.25	0.5	0.2	0.175	0.0663	8259	1180
0.15	0.25	0.25	0.2	0.1875	0.0722	8849	1770
0.15	0.5	0.75	0.3	0.1875	0.0722	8849	1770
0.15	0.25	0	0.2	0.2	0.0780	9439	2360
0.15	0.5	0.5	0.3	0.225	0.0896	10619	3540
0.15	0.5	0.25	0.3	0.2625	0.1080	12388	5309
0.15	0.75	0.75	0.6	0.2625	0.1080	12388	5309
0.15	0.5	0	0.3	0.3	0.1292	14158	7079
0.15	0.75	0.5	0.6	0.375	0.1765	17698	10619
0.15	0.75	0.25	0.6	0.4875	0.2688	23008	15929
0.15	0.75	0	0.6	0.6	0.4005	28317	21238
0.3	0.25	1	0.4	0.3	0.1292	14158	0
0.3	0.25	0.75	0.4	0.325	0.1441	15338	1180
0.3	0.25	0.5	0.4	0.35	0.1599	16518	2360
0.3	0.25	0.25	0.4	0.375	0.1765	17698	3540
0.3	0.5	0.75	0.6	0.375	0.1765	17698	3540
0.3	0.25	0	0.4	0.4	0.1944	18878	4720
0.3	0.5	0.5	0.6	0.45	0.2355	21238	7080
0.3	0.5	0.25	0.6	0.525	0.3042	24777	10619
0.3	0.75	0.75	1.2	0.525	0.3042	24777	10619
0.3	0.5	0	0.6	0.6	0.4005	28317	14159
0.3	0.75	0.5	1.2	0.75	0.7291	35397	21239
0.45	0.25	1	0.6	0.45	0.2355	21238	0
0.45	0.25	0.75	0.6	0.4875	0.2688	23008	1770
0.45	0.25	0.5	0.6	0.525	0.3042	24777	3539
0.45	0.5	0.75	0.9	0.5625	0.3464	26547	5309
0.45	0.25	0.25	0.6	0.5625	0.3464	26547	5309
0.45	0.25	0	0.6	0.6	0.4005	28317	7079
0.45	0.5	0.5	0.9	0.675	0.5327	31857	10619
0.45	0.5	0.25	0.9	0.7875	0.8955	37166	15928
0.45	0.75	0.75	1.8	0.7875	0.8955	37166	15928

**For all scenarios where S = 0 and/or R = 0, cumulative effects are zero. Scenarios fulfilling the previous conditions for R and S were displayed in the table once for each value of u_T, and scenarios repeating the resulting cumulative effects value were not displayed in the table.*

†All scenarios requiring a EHR > 1 for the u_{FRIM} were removed from the analysis due to the impossibility of EHR > 1. The maximum EHR value is one, and EHR = 1 indicates every fish was captured at a given reach-timestep.

6. Figures

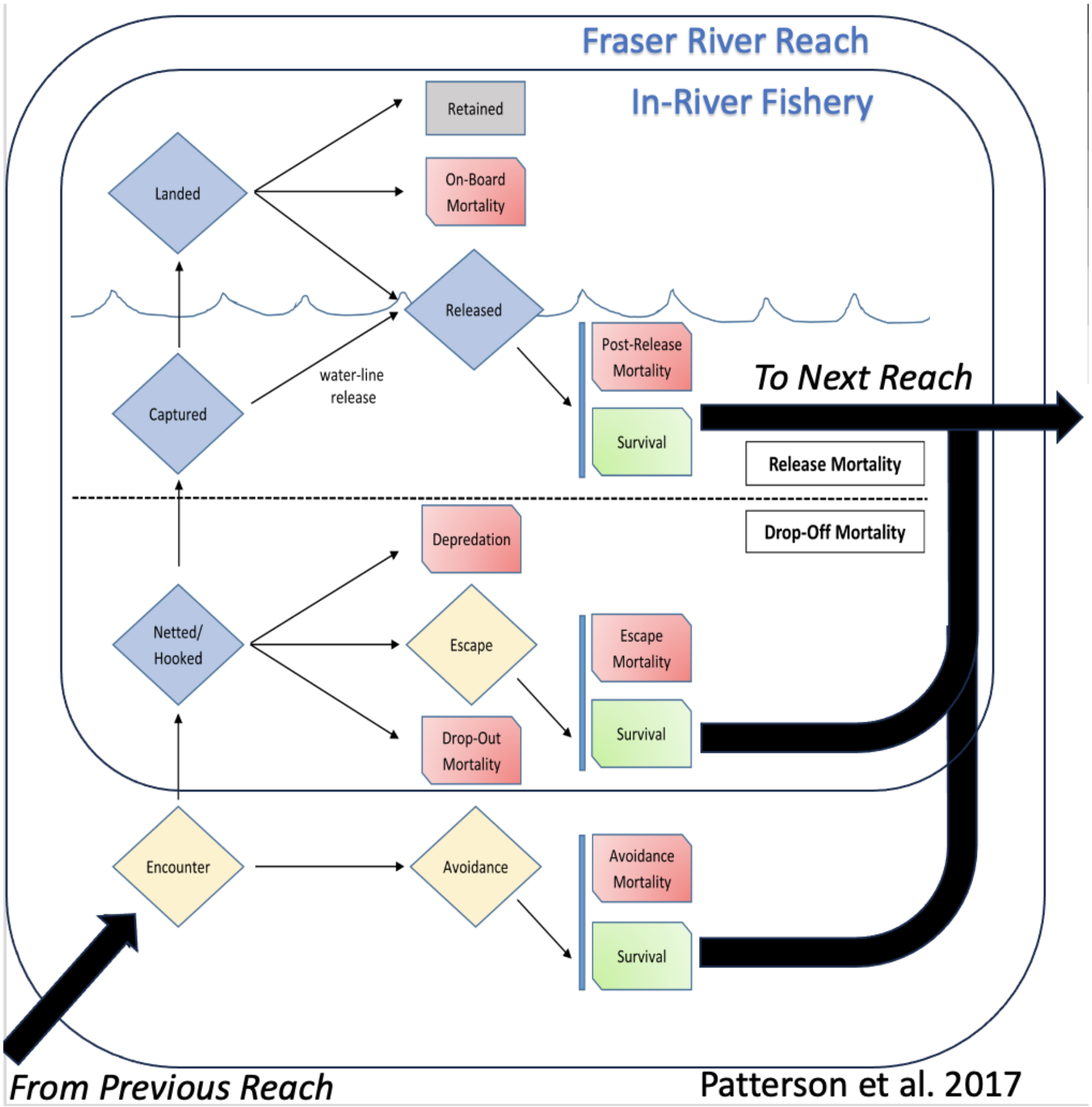

Figure 1. This diagram presents common Fishing Related Incidental Mortality terms and has been adapted from Patterson et al., 2017. This diagram highlights the types of fate (all rectangles represent mortality or survival) resulting from a general fishing event. The diamonds depict the general progression of fishing activities (blue) and fish experience (yellow). The components of fishing-related incidental mortality (FRIM) are depicted by the red rectangles. The escape, avoidance and post-release mortality rectangles include acute and latent mortality (e.g., predation, infection). Note that the post-release mortality rectangle represents both shortterm (i.e., < 24 hours) and delayed (i.e., > 24 hours) mortality components, for a total of seven FRIM components. The black dashed line partitions these seven components into two general mortality risk categories – release and drop-off mortality – for potential use in management. Survival (green rectangles) can also include sub-lethal effects.

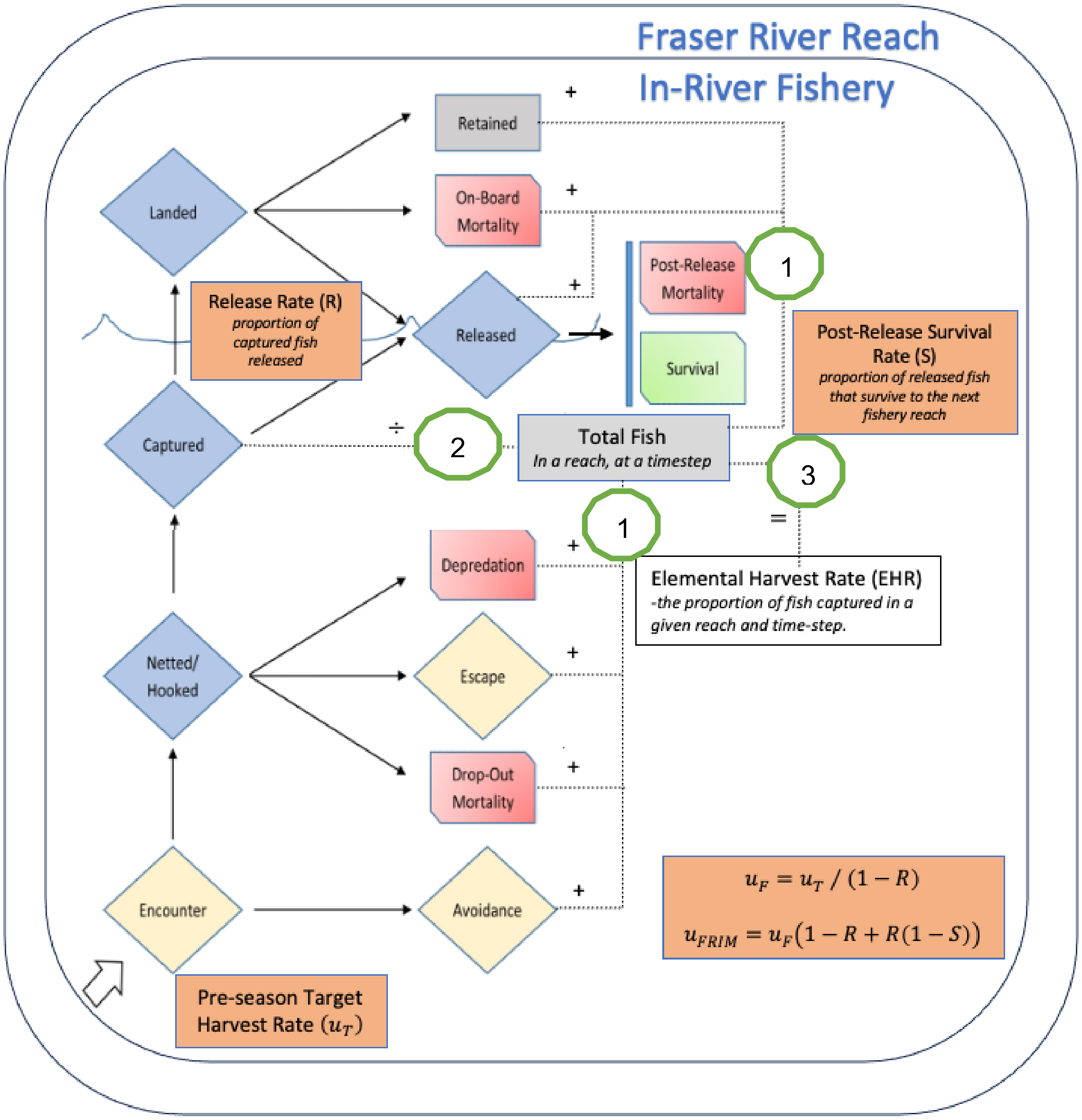

Figure 2. This diagram describes how to calculate the Elemental Harvest Rate (EHR) for an in-river fishery: 1) sum all fish in a reach timestep, 2) divide all capture fish in a reach timestep by the total fish in a reach timestep, and 3) the result is the EHR. The orange rectangles depict the parameters required to calculate the total fishing induced mortality, u_{FRIM}.

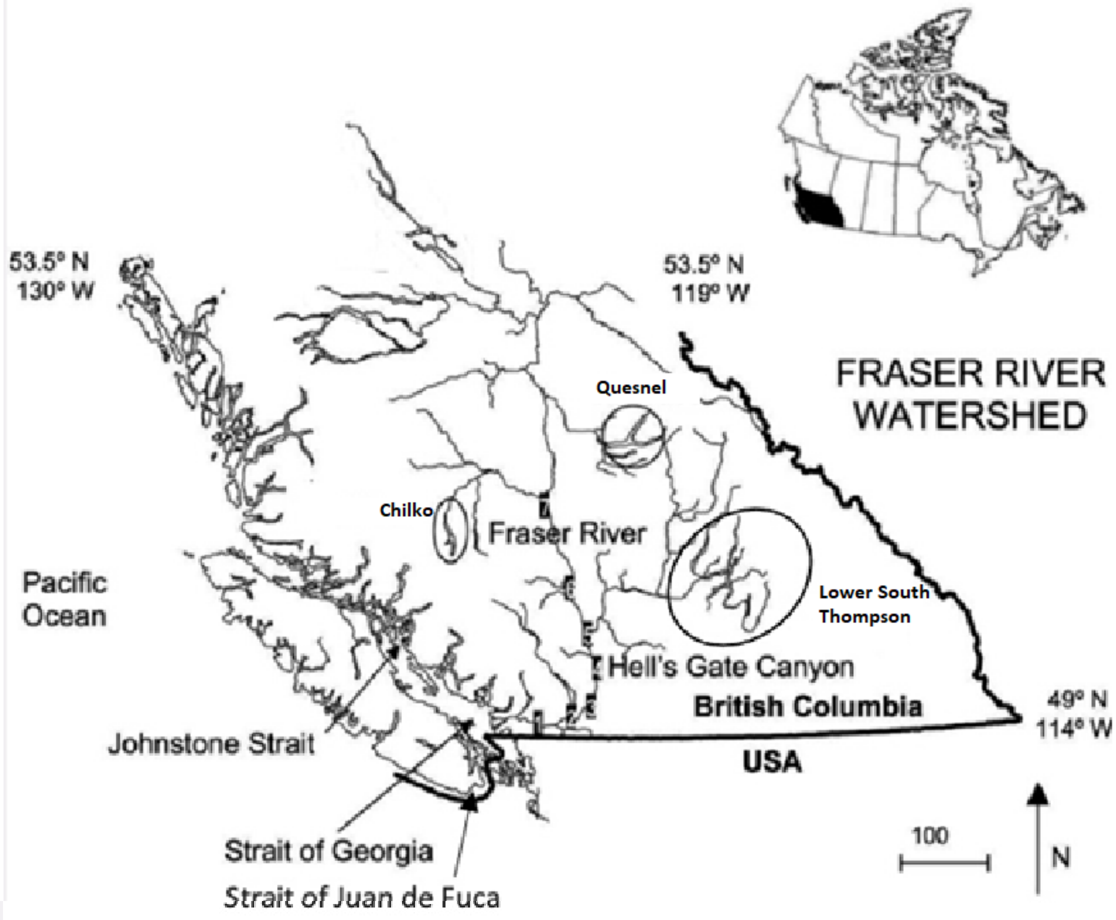

Figure 3. Fraser River Watershed –Lower in-river Fraser River fisheries occur predominantly from the mouth to Hope, the approximate location of “3”. Circles denote the natal spawning locations and freshwater rearing locations of the three chosen stocks: Chilko, Quesnel, and Lower South Thompson. Source: Hanson et al. 2008**.**

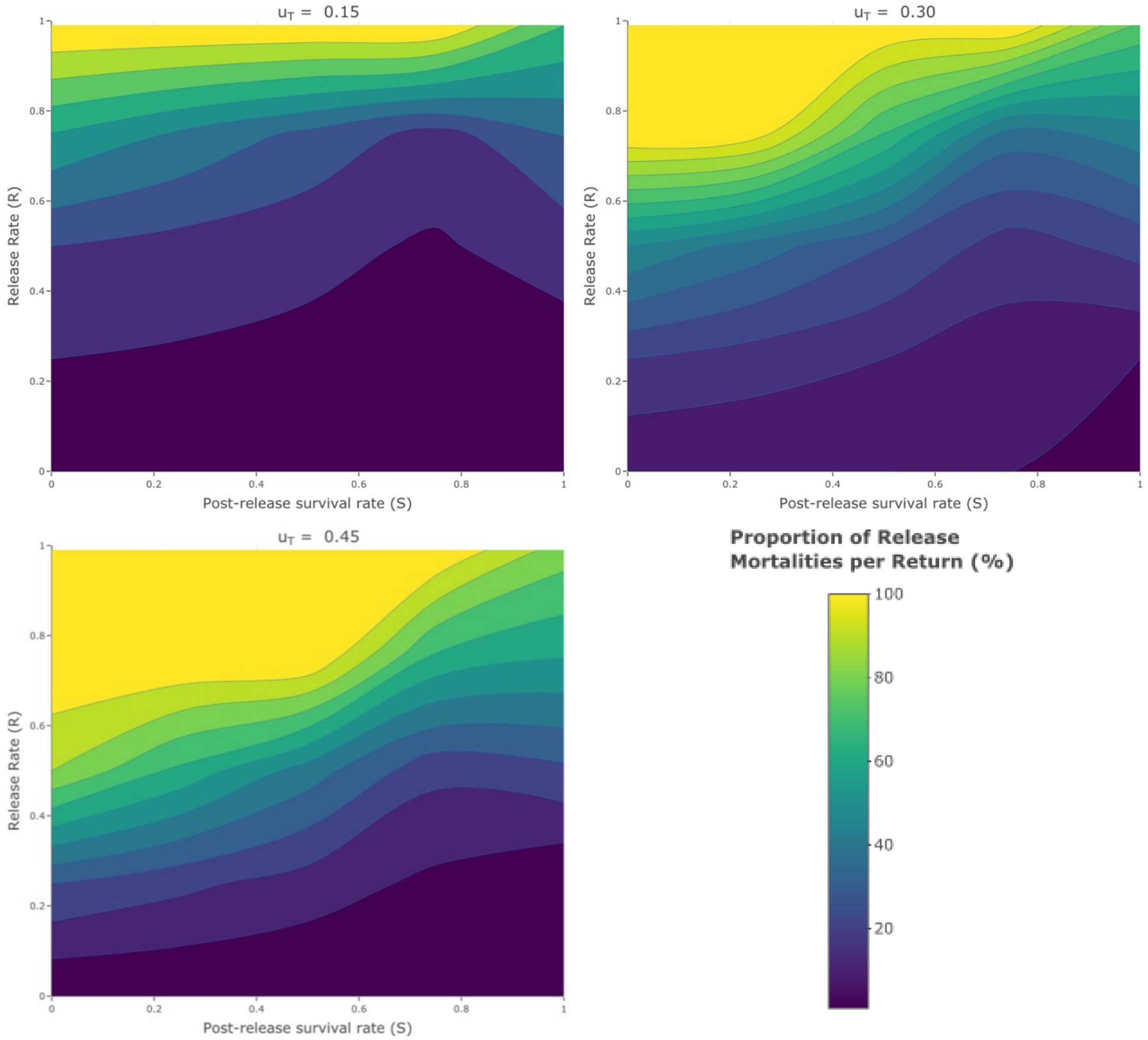

Figure 4. Contour plots showing the proportion of release mortalities per return at three different pre-season target harvest rates U_T = 0.15, 0.30, and 0.45 by release rate and post-release survival rate for the Chilko Chinook Conservation Unit, based on the 2012 migration year.

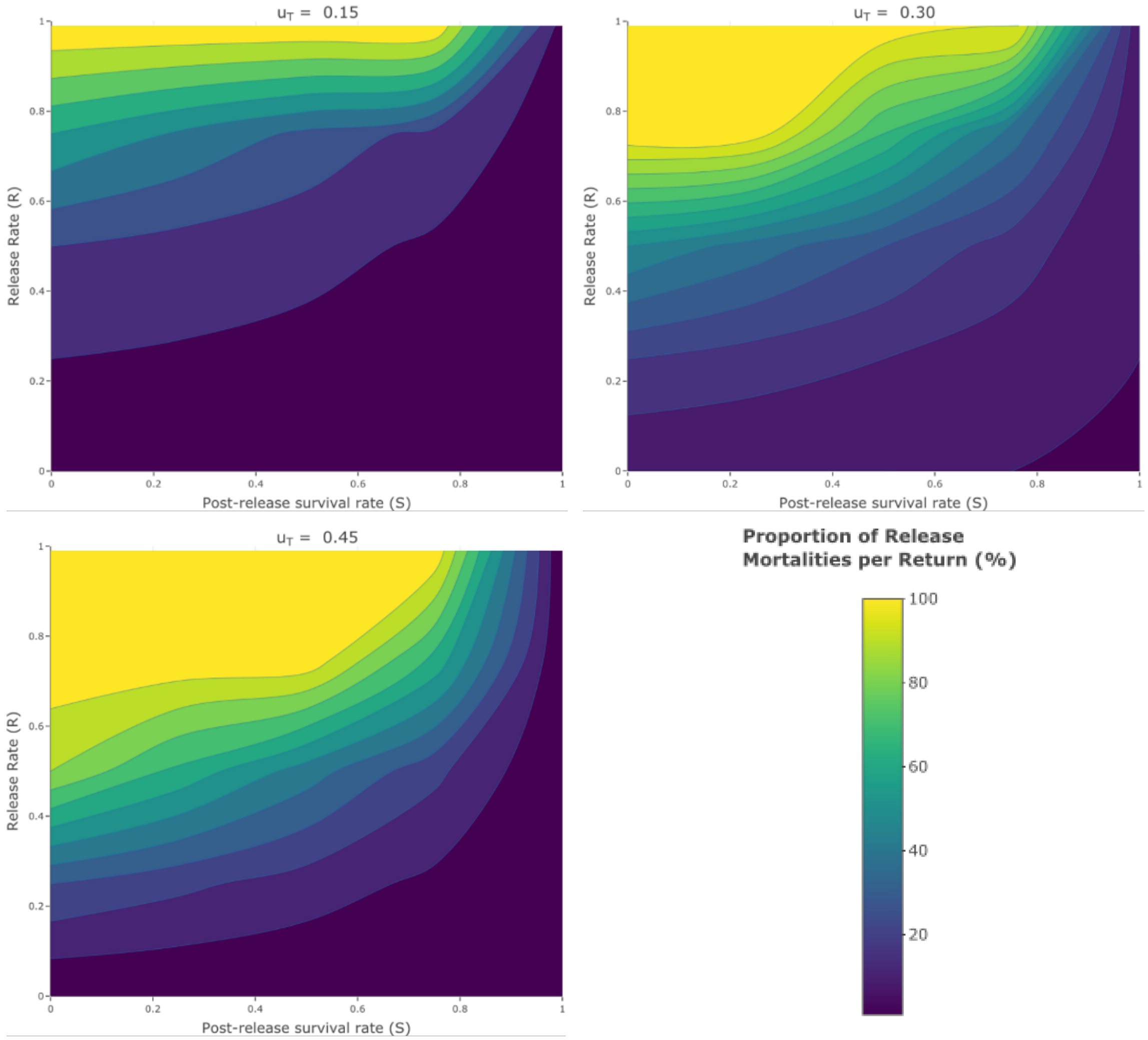

Figure 5. Contour plots showing the proportion of release mortalities per return at three different pre-season target harvest rates $U_T = 0.15$, 0.30, and 0.45 by release rate and post-release survival rate for the Quesnel Chinook Conservation Unit, based on the 2012 migration year.

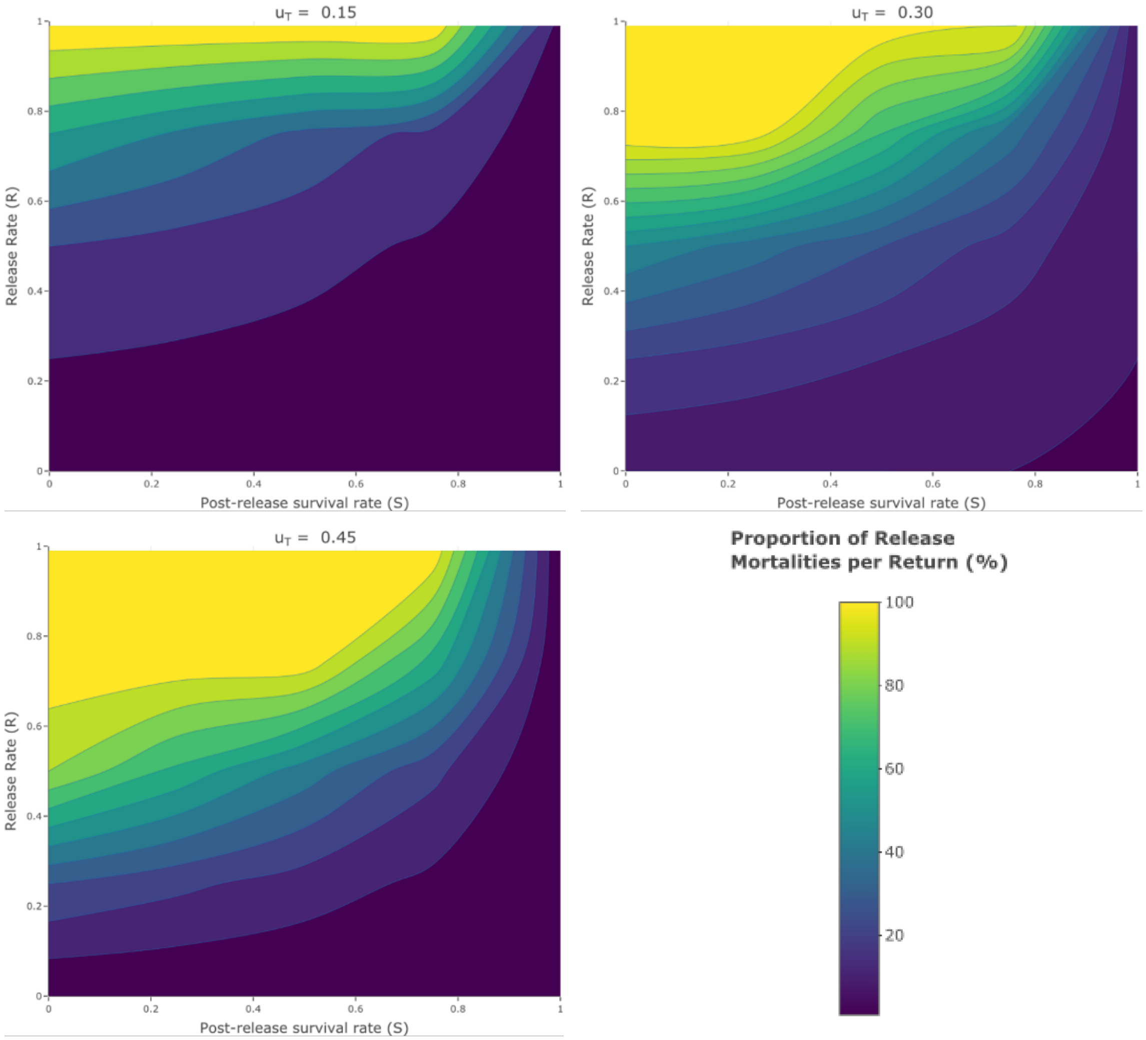

Figure 6. Contour plots showing the proportion of release mortalities per return at three different pre-season target harvest rates $U_T = 0.15$, 0.30, and 0.45 by release rate and post-release survival rate for the Lower South Thompson Chinook Conservation Unit, based on the 2012 migration year.

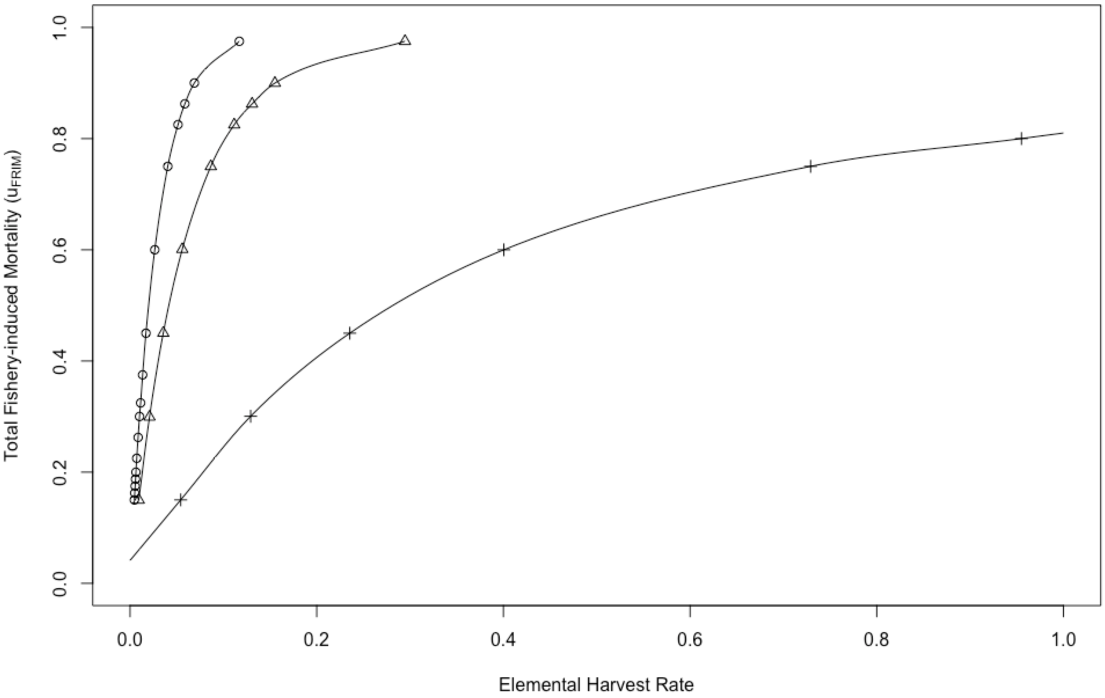

Figure 7. The relationship between total fishery-induced mortality of the three stocks (Circle: Chilko, Triangle: Quesnel, and Cross: Lower South Thompson) elemental harvest rate – a standardized harvest rate that is consistent across all fishing areas and associated openings. For each stock, a cubic hermit spline has been fit to the data.

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