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Guidance to Derive and Update Fishing-Related Incidental Mortality Rates for Pacific Salmon

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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ABSTRACT

This paper provides guidance towards deriving and updating estimates of fishing-related incidental mortality (FRIM) for Pacific salmon (*Oncorhynchus* spp.) captured in salmon-directed fisheries. We recommend condensing the multiple mortality components of FRIM into drop-off (i.e., avoidance, escape, depredation, and drop-out mortality), capture (i.e., on-board mortality) and post-release (i.e., short-term and delayed mortality) mortality to assist in the practical information needs of fisheries management and stock assessment. However, for the purposes of assessing the risk of mortality, capture mortality and post-release mortality are combined into a single release mortality risk value. A risk assessment approach was designed to provide relative values of mortality risk across all major salmon-directed fisheries (i.e., various species, sectors, gears, and locations). An objective process to characterize salmon fisheries in a manner that reflects their potential to cause FRIM is proposed. A procedure for generating the overall mortality risk values for both drop-off and release mortality combine the separate mortality risks associated with different levels of impact for key risk factors that drive FRIM, namely capture, handling, injury, water temperature, and predators. The cumulative impact of multiple risk factors for a given fishery is presented as a range of mortality risk values using multiplicative, dominance, and synergistic interactions among these factors. The risk assessment tool was validated with a set of experimental telemetry projects for which we had detailed information on the risk factors and estimates of release mortality. Next, we provide advice on anchoring the relative mortality risk values to a range of mortality estimates from FRIM studies whose purpose was to directly assess components of FRIM in a real fishery. Recommendations on sourcing and selecting the most appropriate studies to inform the risk assessment and anchoring process are provided. In addition, the major considerations in interpreting the reliability and relevance of previous FRIM research are highlighted to emphasize the potential problems inherent in selecting only a few studies. Major limitations of most FRIM research include the lack of true controls, the study realism (i.e., resemblance to the real fishery), and the mortality response time (e.g., immediate versus delayed). The guidance provided herein is designed to be repeatable, transparent, and scientifically-defensible. Areas with important knowledge gaps include sub-lethal effects, cumulative impacts, disease, and scoring of the relative mortality risk associated with different risk factors. Recommendations include the use of alternative survival analyses and the incorporation of the risk assessment process as part of a larger risk analysis plan.

Orientation pour calculer et mettre à jour les taux de mortalité accidentelle du saumon du Pacifique liée à la pêche

RÉSUMÉ

Le présent document fournit une orientation pour calculer et mettre à jour les estimations de la mortalité accidentelle liée à la pêche pour le saumon du Pacifique (*Oncorhynchus* spp.) capturé lors de la pêche dirigée au saumon. Nous vous recommandons de résumer les divers éléments de mortalité accidentelle liée à la pêche en trois catégories : la mortalité après rejet (p. ex., évitement, évasion, déprédation, décrochage), la mortalité par capture (p. ex., mortalité à bord) et la mortalité après remise à l'eau (p. ex., mortalité à court terme ou différée) afin de répondre aux besoins en matière de renseignements pratiques de la gestion des pêches et de l'évaluation d'un stock. Toutefois, aux fins de l'évaluation du risque de mortalité, la mortalité par capture et la mortalité après remise à l'eau sont combinées en une seule valeur de risque de mortalité liée à la remise à l'eau. Une approche d'évaluation des risques a été conçue pour fournir les valeurs relatives de risque de mortalité dans l'ensemble des principales pêches dirigées au saumon (c.-à-d. différentes espèces, secteurs, engins et emplacements). Un processus objectif, lequel vise à caractériser les pêches du saumon de manière à refléter leur potentiel d'entraîner la mortalité accidentelle liée à la pêche, est proposé. La procédure pour produire les valeurs globales de risque de mortalité pour la mortalité après rejet et la mortalité liée à la remise à l'eau combine les risques de mortalité distincts associés aux différents niveaux de répercussions pour les principaux facteurs de risque qui entraînent la mortalité accidentelle liée à la pêche, à savoir la capture, la manipulation, les blessures, la température de l'eau et les prédateurs. Les répercussions cumulatives de plusieurs facteurs de risque pour une pêche donnée sont présentées sous la forme d'une gamme de valeurs de risque de mortalité utilisant des interactions multiplicatives, de dominance et synergiques parmi ces facteurs. L'outil d'évaluation des risques a été validé à l'aide d'un ensemble de projets de télémesure expérimentaux pour lesquels nous avions des renseignements détaillés sur les facteurs de risque et des estimations de la mortalité liée à la remise à l'eau. Ensuite, nous offrons des conseils sur l'ancrage des valeurs relatives de risque de mortalité à un éventail d'estimations de la mortalité, lesquelles sont tirées d'études sur la mortalité accidentelle liée à la pêche dont l'objectif était d'évaluer directement les éléments de la mortalité accidentelle liée à pêche dans le cadre d’une vraie pêche. Des recommandations pour trouver et choisir les meilleures études pour guider l'évaluation des risques et le processus d'ancrage sont fournies. En outre, les principaux éléments à prendre en compte dans l'interprétation de la fiabilité et de la pertinence des recherches précédentes sur la mortalité accidentelle liée à la pêche sont soulignés afin de mettre l'accent sur les éventuels problèmes inhérents à la sélection de quelques études seulement. Les principales contraintes de la plupart des recherches sur la mortalité accidentelle liée à la pêche comprennent le manque de contrôles réels, le réalisme de l'étude (c.-à-d. la ressemblance avec la vraie pêche) et le délai de mortalité (p. ex., la mortalité immédiate par rapport à la mortalité différée). L'orientation fournie dans le présent document est conçue pour être reproductible, transparente défendable sur le plan scientifique. Les domaines présentant d'importantes lacunes en matière de connaissances comprennent les effets sublétaux, les effets cumulatifs, la maladie et la cotation du risque relatif de mortalité associé à différents facteurs de risque. Les recommandations comprennent l'utilisation d'autres analyses de la survie et l'intégration du processus d'évaluation des risques dans le cadre d'un vaste plan d'analyse des risques.

1 INTRODUCTION

Stock assessment methods for Pacific salmon (*Oncorhynchus* spp.) require estimates of total mortality to obtain accurate exploitation rate and stock size estimates. Total mortality includes natural and fishing-related causes. The latter is composed of retained catch, plus any incidental mortalities associated with fishing activities. It is possible to estimate this fishing-related incidental mortality (FRIM) by accounting for mortality that occurs prior to capture (e.g., depredation and drop-out mortality), during handling (i.e., on-board mortality), and after release (i.e., post-release mortality). However, several issues have been raised with respect to the information currently used to generate estimates of different types of FRIM, including the variability in the time course for monitoring mortality after a fishery encounter, the lack of fishery-specific information, and the need for an efficient process to incorporate new research as it becomes available. This research document is the second of two documents written in response to these knowledge gaps. The first research document (Patterson et al. 2017) reviewed and discussed the available literature pertaining to factors relevant to FRIM, compiled an evidence catalogue of FRIM estimates for anadromous salmonids, and generated key risk factor scoring tables that can be used to assess FRIM across different fisheries. This second research document uses the scientific information from Patterson et al. (2017) to provide guidance and recommendations on a process to derive and/or update current estimates of FRIM rates for use in the assessment and management of Pacific salmon fisheries.

This document provides an application of the information presented in Patterson et al. (2017), addressing the following objectives outlined in the overall project Terms of Reference:

1. Provide guidance with respect to a process to derive (or update existing) fishing-related incidental mortality rates (or range of rates) for Pacific salmon by species, gear type, location, and/or other factors deemed relevant to various fisheries (where possible and appropriate).
2. Provide guidance with respect to the future incorporation of new information and research on fishing-related incidental mortality for Pacific salmon.

The following outputs are designed in response to the above objectives:

- Guidance for standardizing the language and use of different components of FRIM across species for fisheries assessments
- Guidance on characterizing a fishery in a manner that describes the extent to which key risk factors can influence FRIM in that fishery
- Guidance in creating an adaptable risk assessment approach that uses the latest research on FRIM to assign relative mortality risk values for Pacific salmon fisheries
- Guidance on using an anchoring method to convert mortality risk values to numerical estimates of mortality
- Recommendations on updating the risk assessment approach with new research and for sourcing information on mortality estimates for Pacific salmon

We have tried to match examples herein to fisheries that are relevant to Interior Fraser River coho salmon (*O. kisutch*; IFC). This was done to satisfy two upcoming Canadian Science Advisory Secretariat (CSAS) processes that could benefit from updated FRIM estimates for IFC. It is expected that this document can then be used as a guide for the application of this approach to other Pacific salmon species and relevant fisheries.

2 METHOD TO DERIVE MORTALITY RATE ESTIMATES

2.1 METHODS BACKGROUND

Efforts to estimate mortality rates associated with different aspects of a fishery encounter are challenged with estimating natural mortality (Ricker 1976), selecting relevant factors that drive FRIM (Davis 2002), and trying to emulate realistic fishery conditions (Cooke et al. 2013). The most common means of addressing the latter is to conduct studies during real fisheries to generate directly-relevant estimates of mortality. These mortality estimates can be obtained through observational studies of on-board mortality (e.g., landed, immediate mortality), holding studies to assess short-term post-release mortality (e.g., 24 hour holding), and tagging studies to track long-term (i.e., delayed) post-release mortality. However, there are limitations to applying these methods to real fisheries; these methods are non-random without controls, and as such the results typically apply only to a specific fishery. Further, they are not designed for a mechanistic understanding of the factors that drive mortality. This is not meant to diminish the value of the information collected, but rather to speak to the limitations of applying fishery-specific mortality studies beyond their intended scope. Holding studies enable researchers to control various aspects of the fish experience, but also remove potential mortality drivers, such as predators. In addition, holding studies can be stressful, particularly for migrating salmon (Patterson et al. 2004; Donaldson et al. 2011), and thereby can confound the interpretation of the mortality estimates that are derived from them.

Attempts at establishing a broader understanding of FRIM have focused on examining different aspects of the fish response to develop predictors of mortality (Cooke et al. 2013). These approaches include the evaluation of physiological stress and vitality metrics, such as assessments of injury and/or reflex responses. For example, vitality metrics that evaluate reflex impairment have been used with the aim of predicting survival for each released fish (e.g., Davis 2007, 2010; Raby et al. 2012, 2013). There have been several attempts to marry different combinations of fish condition with direct estimates of mortality from real fisheries (see review by Raby et al. 2015).

These methods are still challenged with separating fishing-related mortality from natural mortality. One approach involves using fish that are perceived to be in excellent condition as a surrogate control to allow for an estimate of mortality for poor condition fish through time (e.g., Hueter et al. 2006; Raby et al. 2014). Martins et al. (2011) used a similar approach in which they estimated capture, handling and tagging effects on sockeye salmon (*O. nerka*) that were tagged in fresh water by using marine-tagged fish that survived to reach the freshwater tag site as a surrogate control for subsequent mortality. However, it remains a big assumption to think that any fish that has previously experienced a fishery encounter would be representative of natural mortality.

The above methods are commonly applied to estimate mortality for specific fisheries by either directly assessing mortality or by directly assessing the condition of the fish. The real challenge comes with synthesizing this information across different fisheries and environmental conditions for which we have limited information on either mortality or fish condition. Previous efforts to deal with this problem have involved the use of expert input. Expert opinion involves gathering a select group of knowledge experts to review the general literature in the context of their personal knowledge base and provide commentary on different mortality rates across a range of fisheries. The strengths of this approach are that it is inexpensive and comparatively quick, and it takes advantage of experiential knowledge that may not be available to others outside of the review process. Further, experts can synthesize large quantities of information relevant to their particular level of knowledge. The problems with this approach include the fact that the selection of experts can be biased, the outputs are unlikely to be repeatable, and the syntheses are sometimes not conducive to updates as new information becomes available.

Upon identifying the strengths and weaknesses of the above approaches, we suggest that a combination of methods would be appropriate for developing estimates of FRIM in Pacific salmon fisheries. An approach that involves assessing the response of fish to a fishery encounter by using key risk factors (as determined by scientific review) to assess the risk of mortality will place FRIM in a broader ecological context that can allow for the inclusion of environmental variables and fishery differences. Grounding this assessment of mortality risk to numerical estimates of mortality from direct studies will provide additional guidance for landing on a defensible mortality estimate for different fisheries. Therefore, we have taken a syncretic approach where we combine the information on the factors that drive FRIM and ground them with actual estimates of mortality for Pacific salmon. More specifically, we provide a risk assessment tool that generates the cumulative mortality risk associated with FRIM for different fisheries using information on five key risk factors. This is achieved by scaling the impact of the five risk factors on mortality and combining the overall mortality risk, making assumptions about how each of the factors interact to generate a cumulative mortality risk value. To validate this approach, we selected a subset of studies to evaluate the accuracy of the fishery risk assessment tool. Actual mortality estimates from these studies were extracted and then compared against the tabulated risk values to assess for consistency. We also provide advice on methods for anchoring these risk values to generate mortality estimates for use in stock assessment or fisheries management models. The science information used in this approach is summarized in the first research document, Patterson et al. (2017). The overall project design and proposed future work is presented in Figure 1.

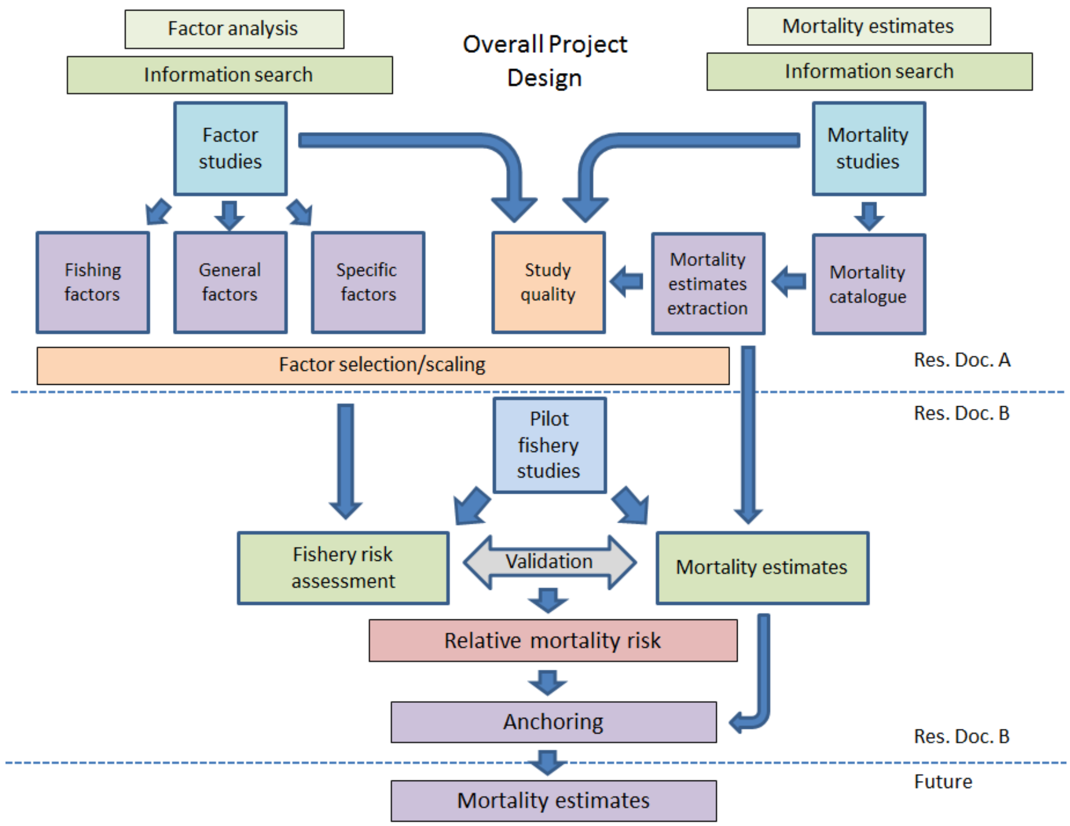

Figure 1. The overall project design that connects the two Canadian Science Advisory Secretariat (CSAS) research documents (Res. Doc. A refers to Patterson et al. 2017; Res. Doc. B. refers to this document). Future work to arrive at updated mortality estimates for use in the assessment of Pacific salmon fisheries is still required. The research documents are summarized in DFO (2016).

2.2 RISK ASSESSMENT

Risk assessment is an analytical approach for estimating risk, which in this case, is defined as the probability that a Pacific salmon not targeted for retention will die due to exposure to one or more identified factors related to fishing. Risk assessment can provide a systematic and transparent process for gathering, evaluating and synthesizing information related to the risk of harm to Pacific salmon from fishing activities and associated extrinsic and intrinsic factors. The use of the FRIM risk assessment is intended to facilitate the communication of the relative risk of mortality associated with different aspects of fishing (e.g., gear, method, location, timing, and species). Overall, the risk assessment approach provides a process to develop a relative mortality risk for different fisheries directed at salmon to help inform more realistic estimates of FRIM.

2.2.1 Use of Mortality Estimates

The first step of the risk assessment is to match the different components of FRIM to the intended application. Accurate stock assessments require estimates of total mortality, which is the combination of natural mortality and total fishing mortality. Fishing mortality can occur at different stages of the fishery encounter. We assigned total fishing mortality at these different stages into eight different mortality components, one for retained catch and seven for FRIM (Figure 2). The seven FRIM mortality components are defined in Patterson et al. (2017) and include avoidance, escape, drop-out, depredation, on-board, short-term post-release, and delayed post-release mortality. These FRIM mortality components were not designed to be directly used to generate estimates of FRIM for use in stock assessment or fisheries management. Rather, they were defined to provide a biological approach to understanding FRIM based on the fish response to different aspects of a fishery encounter across time and space.

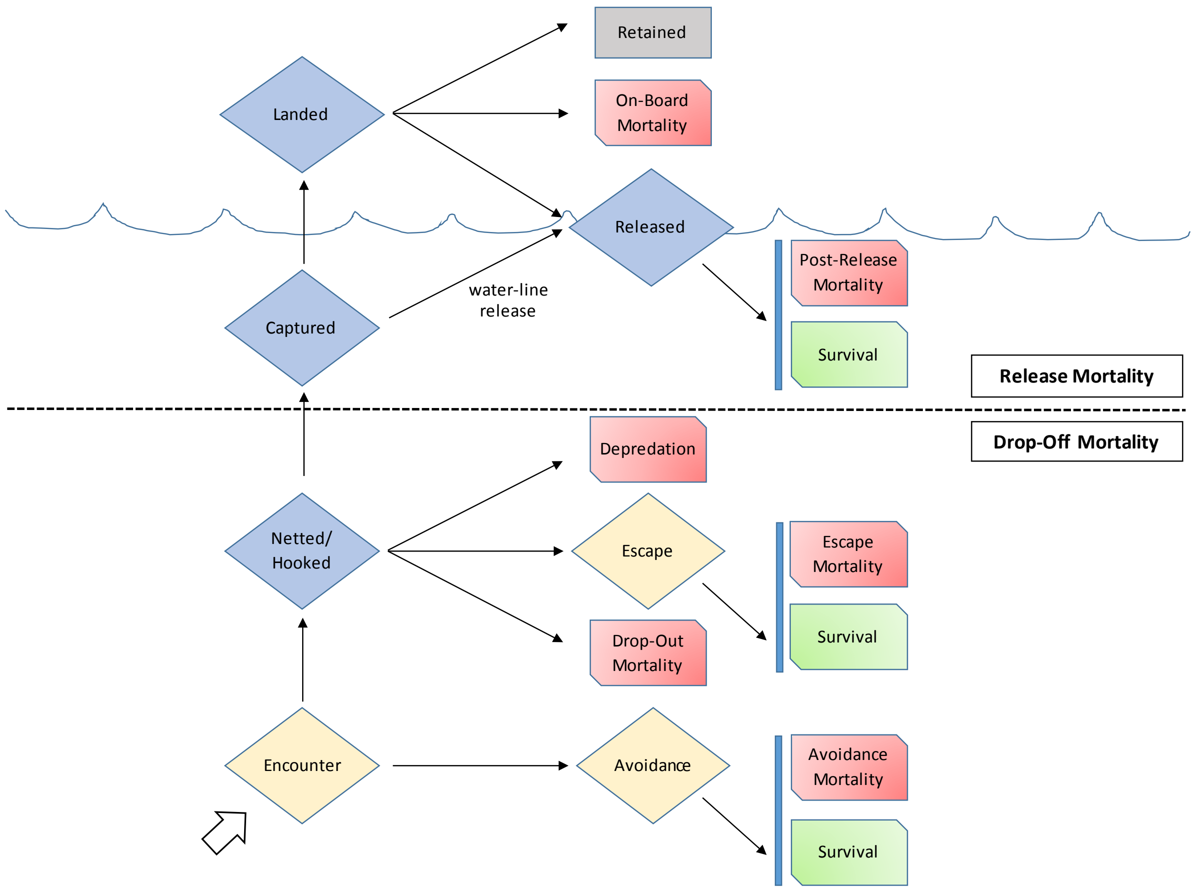

Figure 2. This diagram highlights the types of fate (all rectangles represent mortality or survival) resulting from a general fishing event. The diamonds depict the general progression of fishing activities (blue) and fish experience (yellow). The components of fishing-related incidental mortality (FRIM) 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 short-term (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.

Estimating total mortality in fisheries requires an estimate of FRIM. As shown in Figure 2, there are many pathways that can result in FRIM. Estimating fishery-specific mortality probabilities for each of the seven FRIM pathways and the total mortality resulting from those outcomes would be complicated. Indeed, we are unaware of any studies for which each of the seven forms of FRIM have been carefully estimated using rigorous scientific approaches. Conversely, it is insufficient to have a single FRIM rate to apply across fisheries. Instead, we suggest that three separate mortality rates are required to match information provided by catch monitoring programs and regulations and practices regarding retention of dead catch (see rate definitions in Table 1).

First, a *non-capture mortality* (NCM) rate is required for estimating mortalities of fish that encounter a fishery but are never captured (i.e., never brought to the boat or shore and never under complete control of the fisher). NCM applies to both fish that do not physically make contact with the gear and those that do. Therefore, the NCM rate includes avoidance, escape, depredation, and drop-out mortality components (also collectively described as drop-off mortality for the purposes of the risk assessment tool; see below). NCM should be assessed against all fish captured, both kept and released, since the NCM pathways are open to fish regardless of whether they would be retained if caught. Applying a combined FRIM rate to kept catch would overestimate NCM because the release mortality component does not apply to kept fish. Therefore, an NCM rate that is separate from release mortality rates is required.

Potentially, NCM could be separated into component rates, such as separate rates for depredation and non-depredation NCM. Such separation would improve accuracy if those rates could be applied to estimates of the number of occurrences of each type of non-capture gear encounter. For example, depredation frequency presumably varies among (and within) fisheries, and so a direct estimate of the number of depredation events in a fishery would therefore lead to improved estimates of FRIM in that fishery. However, catch monitoring programs are challenged to develop reliable estimates of released catch because of their reliance on fisher recall; relying on fishers to identify and recall the number of various types of non-landed encounters seems untenable. Moreover, many non-landed fish encounters are unobservable from the vantage point of the fisher, creating further uncertainty regarding the nature of a fish lost below the waterline (e.g., Diewert et al. 2002). Therefore, the use of a combined NCM rate is recommended at present.

Some aspects of NCM may be dependent on whether an encountered fish will be retained or not. For example, in recreational fisheries, smaller fish that will be released may be brought to the vessel more quickly than larger fish intended to be retained. Longer encounters will presumably have higher depredation rates, and possibly greater drop-off mortality. However, given the uncertainty in estimating NCM rates, we recommend applying the same rate against retained and released catch. The uncertainty associated with variation in fishing times and fish sizes can be encapsulated in the proposed mortality risk assessment.

Second, a *capture mortality* (CM) rate is required. We define CM as captured (target or non-target) fish that died during capture or during handling and that would otherwise have been intended for live release. CM is akin to on-board mortality in our list of the seven components of FRIM (Table 1 and Figure 2), and includes fish that are dead on arrival to the boat; Hargreaves and Tovey (2001) also use the term capture mortality for this quantity, but other terms have been used as well, including immediate mortality (Cox-Rogers 2004). Capture mortality needs to be treated as a separate component of release mortality for two reasons. First, much of the research into release mortality is focused on the mortality of fish alive at release (Patterson et al. 2017). Therefore, treating capture mortality as a separate component of release mortality will help ensure that this mortality is accounted for rather than overlooked by simply considering published “release mortality rates”. Second, legal requirements and fishing practices mean that in many cases, capture mortalities are retained even when the fisher would normally have released the fish had it been alive. Section 34 of Canada’s Fishery (General) Regulations prohibits “wasting” fish in commercial, food and recreational fishing; wasting fish is interpreted as discarding legally retainable fish that are dead. Thus, for example, a fisher intending to retain as many large Chinook salmon (*O. tshawytscha*) as possible (and would normally return coho salmon and small Chinook salmon to preserve capacity under the daily salmon limit) is obliged to keep any dead Chinook salmon (above sublegal size) and coho salmon (if retention is allowed) if they are dead and of legal size. To what extent fishers observe this prohibition is unclear; it likely varies widely among and within fisheries, and probably depends partly on the species in question. Recently, First Nation food fisheries in the lower Fraser River have been operating under a new coho salmon non-retention policy, allowing for the retention of coho salmon that are dead or “mortally wounded” prior to release. When fishers retain these capture mortalities, the fish are estimated as part of the kept catch; accounting for the mortality through a total release mortality rate (that includes CM) would account for CM twice. The use of separate CM and post-release mortality rates avoids this error.

A separate rate for *post-release mortality* (PRM) is the third mortality estimate required for an estimate of total FRIM. This rate refers to fish that die *after* they have been released by the fisher. PRM is the second component of release mortality, and includes short-term (often defined as ≤ 24 hour) and delayed (e.g., multiple days to weeks) post-release mortality components (Table 1 and Figure 2). PRM occurs after release due to the physiological effects of injury and/or stress, and sometimes due to a heightened risk of predation because of reduced swimming capacity and/or (usually temporary) cognitive-behavioural impairments caused by the fishing encounter.

The estimation of FRIM, using these three rates of mortality, could be accomplished using the following simple equations. First, in cases where fishers are expected to retain capture mortalities,

$$FRIM = \left(Kept\ Catch\ \times P(NCM)\right) + \left[Released\ Catch \times \left(P(NCM) + P(PRM)\right)\right] \tag{1}$$

where *Kept Catch* and *Released Catch* refer to catch estimates, P(NCM) is the NCM rate, and P(PRM) is the PRM rate. This equation would apply when the species of interest (i.e., species for which a FRIM estimate is required) is retainable and fishers are understood to be observing the prohibition against wasting. P(NCM) appears twice in the formula because the rate at which NCM occurs (i.e., the number of fish that fall under the NCM category) is a function of the total landed catch, which includes both the kept catch and the released catch; therefore, it must be applied to both the kept and released catch as provided in the formula. For example, for a given number of landed (i.e., captured) fish, a given number of fish will be estimated to have been lost through NCM (e.g., depredation).

The Pacific Salmon Commission Chinook Technical Committee calculates FRIM for Chinook salmon (in recreational fisheries, at least) in accordance with the above formula; however, it is unclear whether the release mortality rate used corresponds only to P(PRM) or also accounts for capture mortality. In cases where fishers release capture mortalities, those mortalities need to be accounted for in FRIM,

$$FRIM = \left(Kept\ Catch\ \times P(NCM)\right) + \left[Released\ Catch \times \left(P(NCM) + P(CM) + P(PRM)\right)\right] \tag{2}$$

where P(CM) is the CM rate.

Providing guidance on determining estimates of the three mortality rates defined above is the aim of this project. However, based on the previous research on FRIM (Patterson et al. 2017), it is not feasible to create and use three separate mortality risk assessments. Instead, we have derived a risk assessment for drop-off mortality (or NCM) and for release mortality (CM and PRM combined). The risk assessment for release mortality includes on-board (i.e., immediate) and post-release (short-term and delayed) mortality. The reasons for having a single risk assessment value for arriving at release mortality rates include the frequent ambiguity in the literature regarding whether immediate mortality has been included in post-release mortality values, and the fact that the risk assessment is based on the response of the fish so it should not be constrained by the vagaries of different methods used in detecting (or accounting) for immediate mortality among fisheries. For example, the ability to observe mortality is greater in seine fisheries than in other fisheries, only because fish are observable for a longer period. Observing mortality upon release is unrealistic given that salmon are negatively buoyant and will sink immediately upon death (Patterson et al. 2007b). We recommend the partitioning of release mortality back into the two components of capture mortality and post-release mortality during the anchoring process (see Section 2.4). The remainder of the risk assessment will use 'drop-off mortality' and 'release mortality' according to the following definitions:

- *Drop-off mortality* – includes depredation, drop-out mortality (i.e., fish that die and drop out of fishing gear prior to landing), and mortality caused by some aspect of avoidance or escape responses by the fish. This will be used to estimate the NCM rate for the formula above.
- *Release mortality* – includes immediate (i.e., on-board) mortality of fish that are not retained, along with short-term post-release mortality and delayed post-release mortality. This will be used in relation to both the PRM and CM rates in the formulas presented above.

Table 1. An overview designed to match the different terms used to define the fishing process and fish response with associated management terms for the three distinct fishing events (capture, handling and post-release). Each row represents a unique combination of fishing actions and the common terms that describe the encounter, the type of fish response that can occur (i.e., stress, injury, behavioural alteration and infection), the period of the response (i.e., acute or chronic), the associated fish fate (predation, latent mortality, acute mortality), the type of mortality component, the risk category, and the mortality rate use. Full definitions can be found in the glossary.

Event	Fishing Process		Fish Response			Management Terms		
	Action	Encounter	Acute	Chronic	Mortality	Mortality Component	Risk Category	Mortality Rate Use
Capture	Deploying	Avoidance	Stress	Behaviour	Predation	Avoidance	Drop-off	NCM
	Deploying	Avoidance	Stress	Behaviour	Latent	Avoidance	Drop-off	NCM
	Capturing	Escape	Stress	-	Acute	Escape	Drop-off	NCM
	Capturing	Escape	Stress	Stress	Latent	Escape	Drop-off	NCM
	Capturing	Escape	Stress	Behaviour	Predation	Escape	Drop-off	NCM
	Capturing	Escape	Injury	Behaviour	Predation	Escape	Drop-off	NCM
	Capturing	Escape	Injury	-	Acute	Escape	Drop-off	NCM
	Capturing	Escape	Stress	Infection	Latent	Escape	Drop-off	NCM
	Capturing	Escape	Injury	Infection	Latent	Escape	Drop-off	NCM
	Capturing	Depredation	Injury	-	Predation	Depredation	Drop-off	NCM
	Capturing	Drop-out	Stress	-	Acute	Drop-out	Drop-off	NCM
	Capturing	Drop-out	Injury	-	Acute	Drop-out	Drop-off	NCM
Handling	Spilling	Release	Stress	-	Acute	Short-term	Release	PRM
	Spilling	Release	Stress	Stress	Latent	Delayed	Release	PRM
	Spilling	Release	Stress	Behaviour	Predation	Short-term	Release	PRM
	Spilling	Release	Injury	Behaviour	Predation	Short-term	Release	PRM
	Spilling	Release	Injury	-	Acute	Short-term	Release	PRM
	Spilling	Release	Injury	Infection	Latent	Delayed	Release	PRM
	Spilling	Release	Stress	Infection	Latent	Delayed	Release	PRM
	Sorting	On-board	Stress	-	Acute	On-board	Release	CM
	Sorting	On-board	Injury	-	Acute	On-board	Release	CM
	Retaining	Killed	Stress	-	Acute	Retained	N/A	N/A
	Retaining	Killed	Injury	-	Acute	Retained	N/A	N/A
	Reviving	Revival	Stress	-	Acute	On-board	Release	CM
	Reviving	Revival	Injury	-	Acute	On-board	Release	CM
Post-Release	Releasing	Release	Stress	-	Acute	Short-term	Release	PRM
	Releasing	Release	Stress	Stress	Latent	Delayed	Release	PRM
	Releasing	Release	Stress	Behaviour	Predation	Short-term	Release	PRM
	Releasing	Release	Injury	Behaviour	Predation	Short-term	Release	PRM
	Releasing	Release	Injury	-	Acute	Short-term	Release	PRM
	Releasing	Release	Stress	Infection	Latent	Delayed	Release	PRM
	Releasing	Release	Injury	Infection	Latent	Delayed	Release	PRM

2.2.2 Fishery Characterization

In order to provide scientific advice on FRIM, a standardized process is required to describe or characterize a fishery in detail that is sufficient to enable a reliable assessment of mortality risk. This means recording information that allows fisheries management to identify the fishery within the catch and assessment databases (e.g., DFO Fishery Operating System [FOS]), provides sufficient spatial and temporal detail to accurately assess relevant environmental factors, and explains enough variation to accurately reflect the key features of the fishing gear and method to assess the potential impact on fish mortality (see Table 2). In Table 2, the first three columns, titled *Management Fishery Name*, *Gear Name*, and *Common Fishery Name*, provide relatable fishery categorizations for fisheries management. The first two drop-down columns represent terminology from the FOS; the third column refers to the vernacular term used to describe that fishery. The remaining columns are descriptors of the fishery; they were chosen based on their relevance to the risk assessment process. Each of these descriptors can be linked to a specific fishing factor for which there is evidence of a relationship with fish mortality (see Patterson et al. 2017). Information on the month, water body, and location of a fishery is key to assessing the impact level of risk factors relevant to mortality risk. For example, information on month and water body is sufficient to estimate water temperature relevant to the fishery encounter. The *Generic Capture Gear* column provides the common names used to describe the major types of fisheries. In the characterization process, a fishery type is a generic gear in combination with a common gear/method variant used to target Pacific salmon (see drop-down menu options in Table 2). Aspects relevant to how a fish will respond to a fishery encounter are associated with the generic gear list. The additional details associated with gear and method variants that are specific to each generic gear type are denoted in the method/gear variant columns. These descriptors are critical to characterizing a fishery; they provide the required level of detail of the gear and method variation necessary to assess the level of impact a key risk factor will have on mortality risk for that given fishery. For example, the mortality risk associated with a specific terminal tackle gear variant for rod and reel fishing could be reflected in the severity of injury. Table 2 provides a key to be used to match generic gear type to gear and method variants. Target species is included in the table because it can influence how fishing is executed and the potential duration or nature of exposure to the stressful or injurious aspects of the fishery interaction. We have not described all possible gear and method variants, but rather the ones with current support in the literature for having a consistent effect on mortality (Patterson et al. 2017). This table, along with all parts of the risk assessment, is meant to be flexible so that it can be updated as new information becomes available. The current table was designed based on the immediate requirements involved in characterizing a fishery for the purposes of estimating the impacts of FRIM on IFC.

Table 2. The information required to describe a fishery prior to generating a mortality risk assessment for FRIM (details in Section 2.2.2). The columns with text depict the drop-down menu options available during population. The first three columns represent reference information to match the fishery to existing DFO management databases (e.g., Fishery Operating System [FOS]). The next three columns represent information required to help score the environmental risk factors (i.e., water temperature, predators). The information on target species provides insight into how the fishery is executed. The next four columns represent the generic capture gear type and the associated gear/method variants of a fishery. Fishery contact information is required to document the fishery expert responsible for populating the fishery-specific information.

Management Fishery Name (FOS-based)	Gear Name (FOS-based)	Common Fishery Name	Month	Waterbody	Location	Target Species	Generic Capture Gear	Gear/Method Variant A	Gear/Method Variant B	Gear/Method Variant C	Fishery Contact
Aboriginal - Communal (FSC)	Fence, Salmon	-	-	-	-	-	Beach Seine	Set	5 to 8"	Revival	-
Aboriginal - Salmon Econ. Opport.	Fish Wheel	-	-	-	-	-	Dip Net	Drift	> 8"	Hook Type	-
Commercial - Salmon Gill Net	Fishway, Permanent	-	-	-	-	-	Fish Wheel	Tangle	< 5"	Hook Size	-
Commercial - Salmon Seine	Gaff	-	-	-	-	-	Gaff	River Troll	Bait	-	-
Commercial - Salmon Troll	Gill Net, Salmon	-	-	-	-	-	Gill Net	Bar fishing	Lure	-	-
Test Fishery - Salmon Gill Net Test	Jig, Hand	-	-	-	-	-	Purse Seine	Fly	Shallow	-	-
Test Fishery - Salmon Seine Test	Net, Dip	-	-	-	-	-	Reef Net	Bottom-bouncing	Hook type	-	-
Test Fishery - Salmon Troll Test	Net, Drift	-	-	-	-	-	Rod and Reel	Flossing	-	-	-
Recreational - Salmon	Net, Fyke	-	-	-	-	-	Trap	Ocean Troll	-	-	-
-	Net, Reef	-	-	-	-	-	Troll	Spin	-	-	-
-	Net, Set	-	-	-	-	-	Other	Brailer	-	-	-
-	Net, Tangletooth	-	-	-	-	-	-	No Brailer	-	-	-
-	Net, Trap	-	-	-	-	-	-	Bait	-	-	-
-	Rod And Reel	-	-	-	-	-	-	Lure	-	-	-
-	Seine, Beach	-	-	-	-	-	-	-	-	-	-
-	Seine, Purse, Salmon	-	-	-	-	-	-	-	-	-	-
-	Trap, Salmon	-	-	-	-	-	-	-	-	-	-
-	Troll, Dayboat, Salmon	-	-	-	-	-	-	-	-	-	-
-	Troll, Freezer, Salmon	-	-	-	-	-	-	-	-	-	-
-	Troll, Iceboat, Salmon	-	-	-	-	-	-	-	-	-	-
-	Troll, Salmon	-	-	-	-	-	-	-	-	-	-
-	Weir, Temporary	-	-	-	-	-	-	-	-	-	-

2.2.3 Key Risk Factors

The criteria used to select key risk factors to include in the assessment of mortality risk were based on recommendations provided in the scientific information gathered in Patterson et al. (2017). The following is a synopsis of the process used in Patterson et al. (2017) to generate a shortlist of key risk factors and to scale the impact of each factor on the risk of mortality for drop-off and release mortality. The first step in the process was to evaluate the evidence for all factors evaluated, this included the following steps: sufficient volume of evidence (>10 primary publications); a clear (i.e., unambiguous) and consistent (directional) impact on FRIM; and a mechanism of action on a fish response (i.e., stress, injury, behaviour, infection) that is well defined. The second step involved evaluating the utility of given factor. This involved determining whether the factor could be scaled against a risk of mortality, had a large magnitude (demonstrated) of effect on either drop-off or release mortality, and there were no major limitations to using the information. Finally, we considered the biological mechanism by which a factor was impacting a fish response and whether the mortality risk associated with certain factors could be matched to one or more surrogate (or proxy) risk factor(s) that better reflects the pathway of effect. The process generated five key risk factors, four generic factors (capture, handling, injury, and water temperature) and one context-specific factor (predators). Note that the factors selected for drop-off mortality did not include handling (because drop-off mortalities are, by definition, never handled).

The key risk factors can be relevant to all fisheries irrespective of gear, method, or target species. This is the base level of information required to assess the relative risk of mortality associated with different fisheries. In short, the factors, capture, handling, injury, water temperature, and predators, were selected to reflect different aspects of the fish response to a fisheries encounter. Capture reflects the physiological responses to gear encounter (e.g., exhaustive exercise, and confinement) and is scaled based on the duration of exposure. Similarly, handling reflects the duration of stress of directly handling of fish in air and/or in water (e.g., exhaustive exercise, hypoxia, and crowding). Injury reflects the magnitude of physical damage to fish caused by capture and handling and the associated increase in mortality risk. Water temperature reflects the incremental mortality associated with acute and chronic stress (e.g., more severe stress reaction during capture, inability to recover from exhaustive exercise) and the increased risk of infection (e.g., mortality associated with disease) with warmer temperatures. Predators reflects the direct impact that predators can have on fish mortality during capture and post-release events. For more details on factor rationale see Patterson et al. (2017) and the factor scoring tables in Appendix A.

A major criterion for risk factor selection was the ability to scale the factor at different levels against a risk of mortality. For each factor, its risk of adding to mortality was binned into 6 levels, 1 representing the best case scenario (i.e., highly unlikely that the factor will contribute to mortality; 0-5%), and 6 being the worst (i.e., high probability that the factor at this level will contribute substantially to mortality; 45-100%). Scores of 2, 3, 4, and 5 are equally distributed in 10% increments between 5% and 45%. The asymmetry in the bin size range for level 6 reflects the high uncertainty associated with the more severe impacts of these factors on mortality risk. Conversely, the small bin size for level 1 (5% range) represents high confidence that the mortality risk will be minimal. Most of the mortality risk relationships within a criteria are also non-linear, reflecting the threshold-type responses that can occur with physiological stress responses (e.g., to air exposure). The risk scoring criteria for each factor used information extracted from the factor analysis repository tool, the mortality evidence catalogue, and recent unpublished data, as well subject area experts. See Patterson et al. (2017) and Appendices A.1 to A.6 for further rationale and details on the scoring tables.

2.2.4 Cumulative Impacts

There are numerous papers that speak to the importance of accounting for the cumulative impacts of multiple factors (i.e., stressors) in determining the survival of fish (reviewed in Johnson et al. 2012). However, defining exactly how two or more factors interact is challenging given the limited information available on multivariable physiology studies in salmon (Patterson et al. 2016). We do know that all interactions can be defined under three types: additive, antagonistic, or synergistic (Côté et al. 2016). For this risk assessment, we recommend providing a range of total mortality risk values that are based on three specific variants of the three main interaction types:

- *Multiplicative* (a variant of additive) – This assumes that the cumulative impact of two or more risk factors follows a simple multiplicative risk model. Multiplicative risk is a variant of the additive interaction type that is used when the response variable (or cumulative impact) is measured with percent mortality. This implies that any two factors are independent and therefore do not interact in a synergistic or antagonistic way. Therefore, the contributions of both factors to the overall mortality risk can be simply added together with an adjustment for the fact that a fish killed by one factor cannot be killed 'again' by another. For this risk assessment, we use the following equation to estimate mortality risk, where A, B, C and D represent the percent mortality risk values for the four different generic risk factors.

  $$MR = ((((A+B)-(A \bullet B)+C)-(((A+B)-(A \bullet B))\bullet C))+D)-((((A+B)-(A \bullet B)+C)-(((A+B)-(A \bullet B))\bullet C))\bullet D)$$

- *Dominance* (a variant of antagonistic) – This will generate the lowest risk rating because it ignores the cumulative impact of multiple factors. This assumes that there is no overall increase in mortality associated with two or more stressors. This is commonly defined as a masking effect and is a type of antagonist interaction (i.e., the interaction is less than the expected sum of the factors individually). For the risk assessment, this means selecting the factor with the largest mortality risk rating to represent overall risk to either drop-off or release mortality, respectively (i.e., if $A > B, C, D$, *or* E then $MR = A$), where E represents the percent mortality risk values for a context-specific risk factor.

- *Synergistic* – This model assumes that there is a synergy between all factors, meaning that the combined effect of two or more factors is greater than the simple multiplicative risk of the risk factors. For this risk assessment, we have added the mortality risk percentages for each of the generic risk factors to a maximum of 100% (i.e., $MR = (A+B+C+D)$). This means there are positive dependent relationships between factors that amplifies the overall mortality risk.

The dominance interaction calculations are conducted using all five key risk factors. However, as noted above, the context-specific risk factor – predators – is excluded from the multiplicative and synergistic interaction calculations. Context-specific risk factors for the cumulative mortality risk calculations are the result of clear evidence that these factors can increase or decrease mortality independent of other risk factors. For predators, a context-specific risk factor that can increase mortality, the associated mortality risk is included as a masking or dominance interaction. Post-release predation is an inherent component of both the acute and latent mortality risk associated with the four generic risk factors (e.g., predators are more likely to take fish that are injured or do not recovery immediately). Therefore, including predators in the multiplicative or synergistic interaction calculations would double count the impact of predators on release mortality. However, there are certain contexts in which the impact of predators is demonstrably above the expected contribution to the cumulative risk of mortality from the four generic risk factors. In other words, only in certain circumstances (e.g., high predator densities, habituation of predators) will the predator risk factor dominate the combined generic risk factors. Future work could include other context-specific risk factors that mitigate the mortality impact of a fishery encounter, reducing the overall risk value. At present, we have not recommended using any mitigating factors, but we have included that possibility in the risk assessment tool to reflect the fact that research is on-going in this area (Katrina Cook, University of British Columbia, Vancouver, BC, personal communication, 2016).

2.2.5 Risk Tabulation

The process of applying the risk scores is straightforward. The fishery expert matches the appropriate score (1 to 6) for each of the risk factors. The information on how to score each risk factor is provided in the scoring tables (see Appendix A). The choice of fishery expert(s) assigned to characterize the fishery and, in so doing, choose the most appropriate level of each risk factor, will vary depending on the factor and fishery in question. However, we do recommend standardized training in the use of the risk assessment tool to ensure consistency of application, and the use of multiple experts to build a more robust assessment outcome.

The risk assessment tool converts each risk score into an upper and lower mortality risk value and then tabulates and presents a series of mortality risk values using the different factor interactions outlined in the cumulative impacts section (e.g., Table 3). The presentation includes an estimate of uncertainty based on individual mortality risk values. For each risk factor level (1 to 6), a range of mortality risk is presented to reflect some of the uncertainty in ascribing mortality risk to a given risk factor level (i.e., risk level 2 ranges from 5-15% mortality risk). We also provide upper and lower mortality values when tabulating the cumulative mortality risk (i.e., dominance, multiplicative, synergistic effects) for factors combined. The lower limit was determined by using the lowest mortality risk percentile associated with each score per risk factor when calculating each of the three cumulative interaction types. The upper limit was determined by using the highest mortality risk percentile associated with each score per risk factor. Our recommended ‘best estimates’ (for both upper and lower limits) of relative mortality risk for a given fishery is based on the upper and lower estimates for the multiplicative tabulation. The exception would be when the upper and lower values for the dominance tabulation are higher than the multiplicative (e.g., masking effect of context-specific factor, such as predators). We presented the upper and lower values for synergistic interactions, but do not recommend them in our best estimate calculations because previous biological reviews of cumulative impacts suggest that it is unlikely that all four factors would interact in a synergistic manner (Darling and Côté 2008; Côté et al. 2016; Jackson et al. 2016). Figure 3 provides a hypothetical example of how mortality risk values from individual risk factors are combined under different assumptions of cumulative interactions.

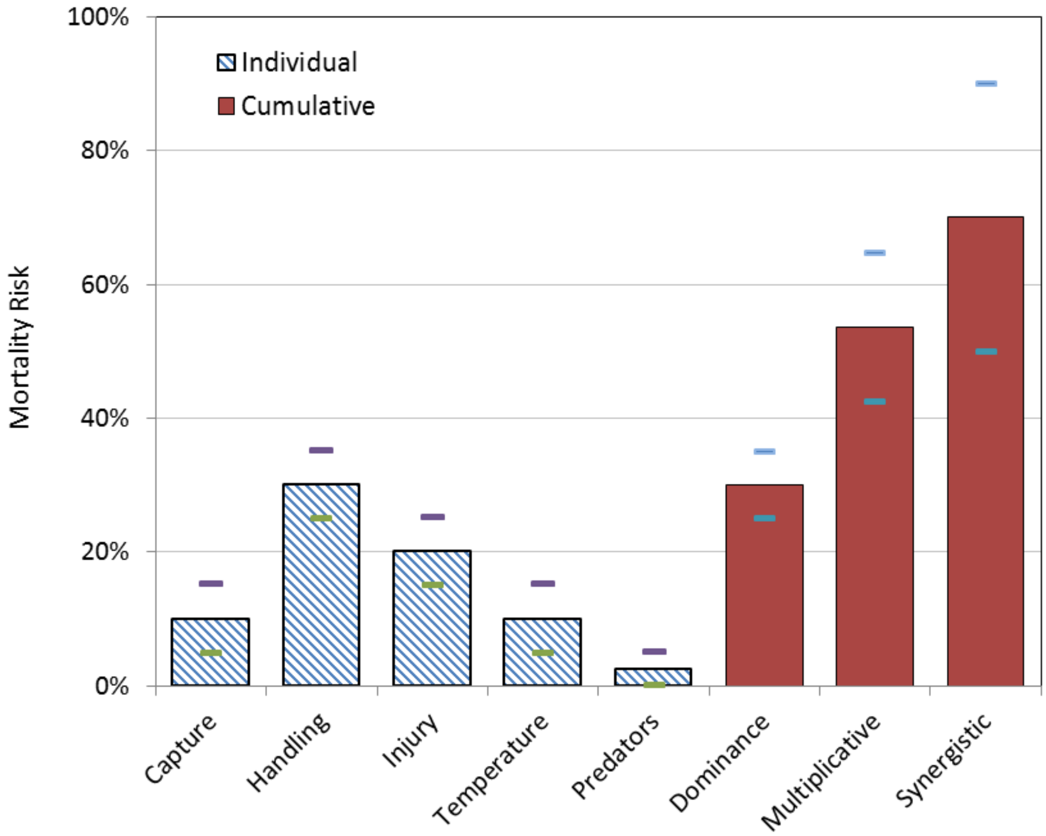

Figure 3. A hypothetical example of the range of mortality risk values from individual key risk factors (blue diagonal bars) and from calculating the cumulative impacts (red solid bars) using different assumptions regarding the type of interaction among factors (i.e., dominance, multiplicative, or synergistic). Results are based on a fishery with the following risk scores: 2 for capture, 4 for handling, 3 for injury, 2 for water temperature, and 1 for predators. The highest of the dominance and multiplicative values is recommended for current use. The dash marks represent the lower and upper mortality risk values for each risk factor and interaction type. Predators only contribute to the dominance interaction.

2.3 VALIDATION OF RELATIVE MORTALITY RISK

2.3.1 Pilot Studies

We selected twelve completed mortality studies that represent a range of mortality rates to assess the ability of the risk assessment tool to consistently rank the mortality risk of fisheries in the same order as that based on the actual mortality estimates generated by each study. The requisites for study inclusion included: sufficient information to assess the five risk factors (i.e., capture, handling, injury, water temperature, and predators); standard fishing gear that is relevant to Pacific salmon fisheries; and estimates of release mortality that include immediate, short-term (≤ 24 hours) and delayed mortality (approximately 7-21 days). The twelve selected pilot studies were recently conducted by an individual researcher, which provides a consistent and direct evaluation of the five risk factors for each study (i.e., each 'fishery'). Thus, this individual researcher is the expert for characterizing each 'fishery' for the risk assessment process. The characterizations of the pilot studies are presented in Table 3. The scoring of the risk factors for each study was completed independent of the cumulative interaction tabulations. In other words, the expert was asked to score each of the risk factors without insight into the range of cumulative mortality risk values that would be generated. This was done to avoid the potential bias or adjusting of scores based on the results; we strongly recommend this approach in the future when fishery experts are scoring fisheries using this risk assessment protocol.

The twelve individual studies were not conducted to directly evaluate a particular fishery or type off fishing; instead, they are part of a research project aimed at better understanding a variety of aspects of FRIM. The mortality values that are used herein to compare the ranks came from telemetry projects in which fish were tracked to evaluate migration success. We have not adjusted the values for tagging effects or unreported catch, in part because the researcher considered these issues to be consistent across studies (i.e., a consistently positive bias in mortality estimates). A consistent bias would therefore not affect the goal of determining a relative mortality risk value and ranking of the studies. More details on how the studies were scored for each risk factor are provided in Appendix B. The next section provides the results of the validation process.

Table 3. Summary table of the lower (L.) and upper (U.) cumulative mortality risk values calculated from the characterization of twelve pilot studies used to validate the risk assessment tool. The risk scores for the five risk factors were determined using the scoring tables in Appendix A. Detailed notes on the scoring process for these pilot studies are provided in Appendix B. The lower and upper cumulative risk values for mortality were calculated for multiplicative, synergistic and dominance interactions among the risk factors. Predators, a context-specific factor, only contributed to the dominance calculations.

Year	Target Species	Month	Location	Gear/Method Variant	Capture	Handling	Injury	Temperature	Predators	L. Multiplicative	U. Multiplicative	L. Synergistic	U. Synergistic	L. Dominance	U. Dominance
2013	Chinook	Aug.	Chilliwack R.	Gill net, simulated	3	3	2	3	1	42%	64%	50%	90%	15%	25%
2013	Chinook	Oct.	Chilliwack R.	Gill net, simulated	3	3	2	1	1	31%	55%	35%	70%	15%	25%
2014	Sockeye	Sep.	Fraser R. @ Annacis	Gill net, drift	3	2	4	2	2	43%	65%	50%	90%	25%	35%
2014	Sockeye	Sep.	Fraser R. @ Ft. Langley	Gill net, drift	3	2	4	2	2	43%	65%	50%	90%	25%	35%
2014	Sockeye	Sep.	Fraser R. @ Ft. Langley	Beach seine	4	2	2	2	2	36%	60%	40%	80%	25%	35%
2014	Sockeye	Oct.	Fraser R. @ Peters Rd.	Gill net, drift	3	2	4	1	2	40%	61%	45%	80%	25%	35%
2014	Sockeye	Oct.	Fraser R. @ Peters Rd.	Beach seine	4	2	2	1	2	32%	55%	35%	70%	25%	35%
2014	Sockeye	Oct.	Thompson R. @ Savona	Gill net, drift	2	2	2	2	1	19%	48%	20%	60%	5%	15%
2014	Sockeye	Oct.	Thompson R. @ Savona	Gill net, drift	3	2	1	2	1	23%	49%	25%	60%	15%	25%
2015	Sockeye	Aug.	Fraser R. @ Peters Rd.	Gill net, drift	3	2	5	4	2	61%	77%	80%	100%	35%	45%
2015	Sockeye	Aug.	Fraser R. @ Peters Rd.	Beach seine	4	2	3	4	2	55%	73%	70%	100%	25%	35%
2015	Sockeye	Aug.	Seton R. below Dam	Dip net - weir	2	2	1	3	1	23%	49%	25%	60%	15%	25%

2.3.2 Validation Results

The range of mortality risk values derived from the risk assessment of the twelve pilot studies (see Table 3) was contrasted against the range of actual mortality estimates provided by those studies. Studies that were ranked as having a high relative risk did, on average, have a higher ranked estimate of mortality; similarly, low risk studies had lower mortality estimates based on ranks (Figure 4). Further, the mortality risk values did correlate with the mortality estimates (R^2 = 0.66; Figure 5). The range of observed mortality estimates among the studies ranged from 10% to 90%, suggesting that the mortality risk assessment is robust to a large spread of mortality values. However, the range of mortality risk values was narrower than the range of observed mortality estimates, limiting the ability to make any direct comparisons between mortality risk values and mortality estimates. This narrow range impacts both the high and low risk fisheries. For example, the observed mortality estimates were lower than the mortality risk values for the three lower-risk studies, and conversely, the higher-risk studies had observed mortality estimates greater than the mean risk values. This suggests that further work could be done to test some of the underlying assumptions regarding factor interaction (e.g., synergistic effects of temperature and injury).

The purpose of this validation was to determine if the risk assessment tool can reflect the relative mortality risk associated with FRIM across a range of studies. To this end, we have confidence that the current risk assessment, as presented, can provide useful information to assess the risk of FRIM for release mortality. More detailed examinations of some of the deviations between risk values and mortality estimates for individual studies in the validation are tempting, but are beyond the purpose of this guidance document. Moreover, we recommend that heightened focus on any one study should be downplayed given the potential for spurious results.

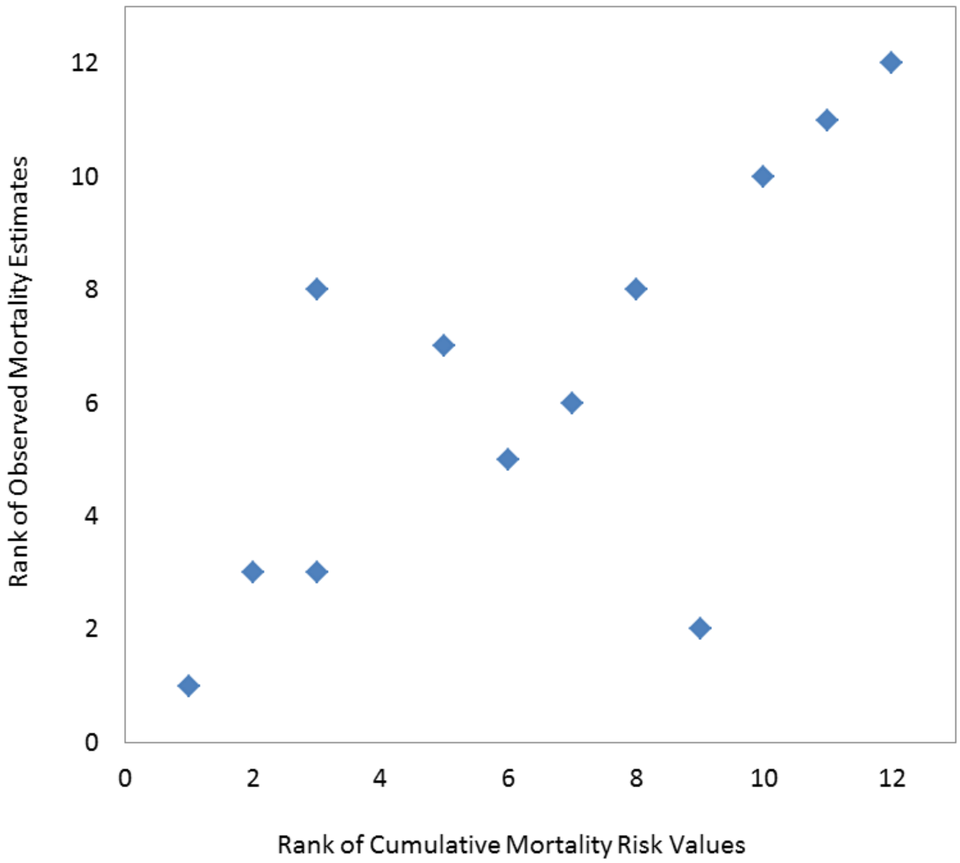

Figure 4. Comparison of the ranks between the 'best estimate' cumulative mortality risk values and observed mortality estimates from twelve pilot studies. Rank 1 represents the highest mortality risk value and the highest observed mortality estimate among the twelve studies. The few outliers likely represent areas to focus new research, such as the impact of maturity or proximity to the spawning grounds on overall resilience to capture and handling stressors.

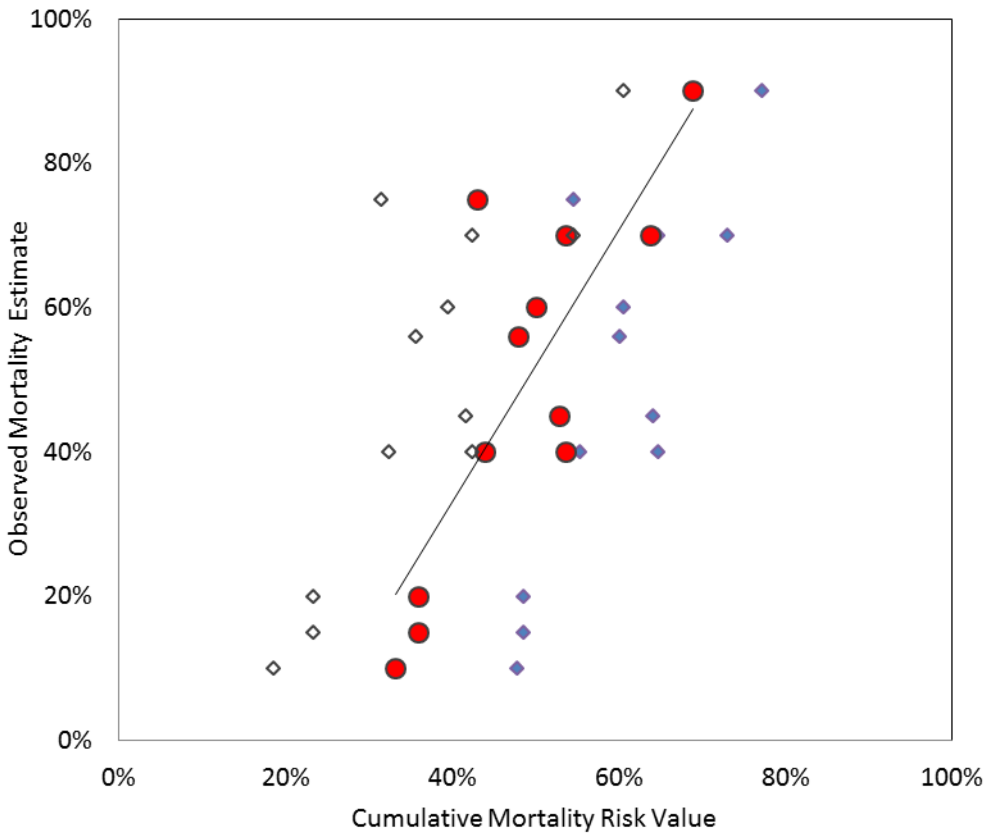

Figure 5. Comparison of the observed mortality estimates from the twelve pilot studies to the corresponding mean cumulative mortality risk values (R^2=0.66). The cumulative mortality risk values presented here are based on the multiplicative risk of capture, handling, injury, and water temperature (i.e., the suggested 'best estimate'). The diamonds represent the lower and upper cumulative risk values.

2.4 ANCHORING METHODS

The risk assessment process described herein is designed to generate a relative mortality risk value for a given fishery to determine the likely impact the fishery will have on mortality compared to other fisheries. The above comparisons of cumulative mortality risk values to direct estimates of mortality provided a simple method to evaluate the level of confidence in the risk assessment approach (see Section 2.3). However, the mortality risk values do not directly translate to a numerical estimate for release mortality rates (i.e., the points in Figure 5 do not fall along a 1:1 line). Therefore, our final advice piece for this project involves converting the relative mortality risk values into actual mortality rates that are more useful to Fisheries Management and Stock Assessment. We advise the anchoring of the relative mortality risk values against a subset of studies that have generated direct estimates of mortality from research conducted during realistic fishery conditions. The validation in Section 2.3 was completed using scientific experiments that did not replicate all aspects of a real fishery. However, for validating the risk assessment tool, we felt it was important to use studies for which we had detailed information on the characteristics of the 'fishery'. We suggest using the mortality evidence catalogue created for anadromous salmonids in Patterson et al. (2017) to select and evaluate an appropriate set of studies for the anchoring process. This catalogue presents information for assessing the reliability and relevance of each study, and should be continually updated to include new information.

The information on study quality documented in the evidence catalogue can be used as an aid in interpreting the reliability of the results and the relevance of a study. For study reliability, also referred to as study quality or internal validity, the information that we have extracted attempts to document the scientific rigor of a given study; the mortality evidence catalogue contains information on the following measures to assess a study in relation to the author's intended purpose: study type, sample size, replication, reference fish, statistical method, confounding factors (e.g., experimenter effects), and effect modifiers (e.g., FRIM factors). For study relevance, also referred to as study utility or external validity, the extracted information speaks to the generalizability of a study for interpretation given the intended purpose of extraction; thus, the mortality evidence catalogue contains information on the following measures to assess a study in relation to informing FRIM: objective(s), location, year, temporal extent, and intervention realism. Note that the intervention realism measure codes the type of intervention (i.e., fishery) study, but it does not necessarily indicate whether the intervention is reflective of realistic conditions of an actual fishery. Fishery experts conducting the risk assessments will need to evaluate whether the intervention in a study reflects a real fishery. For each study used in the risk assessment process, we recommend evaluating and reporting on the study reliability and relevance information.

The ability of any study to reflect the true range of fishing practices, environmental conditions, and biological variation of a fishery is limited given the myriad of factors that can contribute to FRIM during the entirety of the capture, handling, and release process (Raby et al. 2015; Patterson et al. 2017). Further, there are often alterations to fishing practices and/or fisher behaviour during experimental work; such alterations can include smaller catch sizes, shorter set times for net studies, better handling practices, and gear and fishing method adjustments designed to target the study species rather than the actual target species for that fishery. In addition, the degree of realism in the study environment for assessing mortality will depend on the method used to estimate the mortality response. Using direct estimates of mortality from holding studies is problematic because of the potential to bias the estimates low due to the lack of predators and the often short duration of monitoring. In addition, a positive bias (i.e., an overestimate of mortality) is likely introduced by confinement stress and poor water quality conditions within in the holding environment; these factors are considered to be important for Pacific salmon (Donaldson et al. 2011; Raby et al. 2015). Tagging studies can partially overcome these opposing directional biases, but if tagged fish are not randomly assigned (something that is rarely mentioned – see Donaldson et al. 2008) and handled in a more 'fish-friendly' manner than normal, then they are not necessarily reflective of accurate fishery conditions and practices.

Fishery experts also have to consider the role of natural mortality. Rates of natural mortality are notoriously difficult to assess, varying by species, age, and life-history stage. This makes the interpretation of mortality results from field-based tagging studies a challenge. Attempts to isolate natural mortality from tagging study results will have to also consider unreported catch and delayed tagging-related effects (separate from normal fishing capture and handling effects). Thus, the mortality estimates derived from tagging studies conducted under realistic fishing conditions likely represent the maximum mortality for that monitoring period. For example, if a study found 60% of fish survived 15 days, then the maximum mortality rate would be 40%. This mortality rate would include capture and handling mortality itself as well as natural mortality, unreported catch and any additional mortality associated with the tagging. In addition, the error associated with tag loss or failure, and detection efficiency issues can contribute to this estimate. It is reasonable to use mortality estimates from direct mortality studies as the upper limit if they are truly representative of the fishery and they monitor the full time course needed for all FRIM to manifest.

Lastly, any scientific advice provided with respect to FRIM needs to be couched in the context of the type (i.e., mortality component) and period (i.e., duration of monitoring) of the mortality response being considered. For example, the relative mortality risk for release mortality incorporates immediate (i.e., on-board), short-term (i.e., $\leq$ 24 hours), and delayed mortality (e.g., multiple days to weeks). Ideally, any study selected for the anchoring process would have a similar mortality response period. Unfortunately, there are very few papers that included all three of the above release mortality components. If immediate mortality rates are available, then they can be used to directly estimate CM. We also recommend using the immediate mortality rates to assist in the calculation of PRM rate; the total release mortality estimate applied would have to be greater than the immediate mortality estimate. The traditional assumption that most of the mortality occurs within the first 24 hours is often incorrect (Donaldson et al. 2011; Robinson et al. 2013; Patterson et al. 2017). However, we do not recommend trying to extrapolate delayed mortality from short-term studies given that there is no standard temporal pattern in mortality associated with either drop-off or release mortality. A more formal analysis of the timing pattern of mortality associated with different monitoring periods for different combination of risk scores for both holding and telemetry studies is warranted.

Similar to the validation process, we recommend evaluating the relative risk of mortality for several studies with observed mortality estimates ranging from low to high. The output from this approach would be a range of mortality risk values matched to a range of observed mortality estimates from the selected studies. A variety of approaches could be used to generate a numerical estimate of the rate of mortality for a given fishery using this relationship between the risk values and observed estimates (see Section 3.4). Landing on a rate, with an appropriate uncertainty distribution, that can then be used by Fisheries Management and Stock Assessment will require further work with those individuals who will use the FRIM estimates.

3 DISCUSSION AND RECOMMENDATIONS

The following discussion and recommendations are structured around the five main outputs of the document as stated in the introduction. These outputs have been addressed throughout this document; this section focuses on providing discussion points and future directions.

3.1 USE OF MORTALITY ESTIMATES

Guidance for standardizing the language and use of different components of FRIM across species for fisheries assessments

To appropriately account for FRIM, estimates of mortality rates for those fish that are never caught (i.e., NCM), those that die during capture (i.e., CM), and those that die after live release (i.e., PRM) are required. Finer-scale separation of NCM, although possible in theory, is not recommended at this time due to incomplete scientific knowledge. Combining NCM with release mortality (CM and PRM) into a total FRIM rate is also not appropriate since NCM must be assessed against kept catch as well as released catch, whereas release mortality only applies to released catch (see Section 2.2.1). Separate rates for CM and PRM, components of total release mortality, are required only because in some circumstances the capture mortalities of the species of interest will be retained by fishers, and the use of a total release mortality rate would over estimate FRIM. Although the risk assessment approach leads to only NCM (i.e., drop-off) and (total) release mortality estimates, the separation of release mortality into CM and PRM component rates should be conducted, where needed, in the anchoring process.

Currently, the estimation of FRIM by DFO is inconsistent, even within salmon species. Chinook salmon FRIM estimates account for NCM against kept and released catch, whereas Coho salmon FRIM estimates do not incorporate NCM at all. Further, it is unclear whether the release mortality rates used, for both species, include CM as well as PRM (note that the rates reported in the DFO Salmon Integrated Fishery Management Plan are referred to as "post-release mortality rates", with no mention of corresponding CM rates). Given how common it is for PRM rates to be referred to as "release mortality rates", it is quite possible that the rates currently used do not include CM. More clarity on the use of different types of FRIM rates across species and groups of individuals assessing FRIM would help in the development of more appropriate, fit-for-purpose scientific advice on this subject.

A primary recommendation is the standardization of terminology used to describe all aspects of total fishing mortality. The lack of consistency in the primary literature, across fishing sectors, and within management organizations creates unnecessary confusion regarding what exactly is being estimated or directly measured. We are not suggesting that the terms developed and used consistently throughout this project should be the definitive answer to this problem, but rather a starting point to reduce the ambiguity that currently exists.

3.2 FISHERY CHARACTERIZATION

Guidance on characterizing a fishery in a manner that describes the extent to which key risk factors can influence FRIM in that fishery

A detailed characterization, or description, of a fishery is essential to link the most appropriate estimate of FRIM to a fishery at a given scale (see Section 2.2.2). There are multiple uses of FRIM, therefore, the spatial and temporal scale of the fishery characterization will change depending on the use of the FRIM data. The current version was specifically designed for a case study on IFC. It is possible to broaden the characterization of a fishery to include a wider geographic scale, but the concern would be the oversimplification of the mortality risk. Alternatively, the characterization could include more gear and method variants, but the concern here would be in overstating the discriminatory ability of the tool. Currently, we have included the fishery characteristics with support in the available literature base for having a consistent effect on one or more of the risk factors, along with a few other variables that have been identified as having the potential to be modifying factors (e.g., revival) with respect to estimating mortality. The risk assessment tool, including the fishery characterization table, is meant to be adaptable to new information and applicable to other Pacific salmon species/populations.

3.3 RISK ASSESSMENT

Guidance in creating an adaptable risk assessment approach that uses the latest research on FRIM to assign relative mortality risk values for Pacific salmon fisheries

To meet both objectives of this document, the risk assessment tool was designed to assess the current risk of different fisheries with respect FRIM, as well as be proactive to future changes in fishing gear and methods, environmental conditions, and biological condition of fish. Therefore, the risk assessment tool can be updated as new research and information becomes available with respect to the mortality risk of existing and new FRIM-related factors. We recommend following the evaluation of the information methods outlined in Patterson et al. (2017) and in the following sections.

A limitation of the risk assessment tool proposed herein is the inability to validate the risk assessment approach for drop-off mortality (needed for the NCM rate). We are confident that the risk factors chosen for the assessment reflect the mortality risk, but we are more uncertain regarding the overall risk values and their translation to numerical rates of mortality, compared to release mortality. During the project development process, we have become aware of a few potentially-useful data sets on depredation rates that we suggest could be further analyzed to address this uncertainty (e.g., data from test fishing platforms).

A simple way to test some of the proposed fishery scoring systems would be to build relationships among fish mortality, fish vitality, and the scoring metrics. Fish vitality assessments have been used by DFO to characterize the vitality of fishery discards in both East Coast and West Coast fisheries (e.g., demersal species in Benoît et al. 2010; Pacific salmon in Farrell et al. 2001 and Buchanan et al. 2002). Previous assessments have typically used three or four categories that roughly comprise increasingly more severe levels of exhaustion and injury (e.g., a scale from 1-4). An alternate, and potentially more consistent approach, is to score a series of vitality metrics as present or absent; these metrics typically include reflex impairments (e.g., whether equilibrium is lost, whether the fish is ventilating) and injury assessments (e.g., whether operculum tearing took place, whether the fish is bleeding or deep-hooked). A series of presence-absence evaluations, which typically take less than 30 seconds, can then be summed into a overall vitality score for a single fish to predict fate. Averaging the vitality scores across different catches can lead to a predictive FRIM estimate for a given fishery. Each metric can also be used separately in an effort to clarify the relative effects of different fishing gears or handling practices on vitality-at-release, and/or predict post-release mortality given sufficient validation of a mortality-vitality relationship. Even in the absence of the latter and the ability to use vitality scores to generate indirect estimates of post-release mortality, vitality assessments have proven very useful for showing the relative impacts of different capture and handling practices on Pacific salmon (e.g., Donaldson et al. 2012; Raby et al. 2012, 2013; Nguyen et al. 2014; Raby et al. 2015). Thus, in the absence of (or in concert with) reliable expert input for scoring risk factors, vitality assessments could be used to improve the accuracy of the factor scoring system and its link to mortality. For instance, if an expert scores a fishery for each risk factor and the subsequent risk assessment calculations produce a range of possible FRIM rates of 25-50%, but a separately collected data set on fish vitality in the fishery shows that the condition of fish is substantially better than expected (i.e., most fish are vigorous and injury-free), then the lower end of the mortality range (i.e., 25%) could be used for management purposes (e.g., rather than the median of 37.5%).

There are limitations in the scientific information on the factors that drive FRIM; the deficiencies in the information have been well documented in Patterson et al. (2017). Most pressing for the current risk assessment is the need to reduce the uncertainty in aligning a risk factor level with the most appropriate mortality risk value (e.g., water temperature > 22°C equates to a 45-100% mortality risk; see Appendix A). This is especially true for elucidating species-specific differences in the relationship between factor level and mortality risk. For example, species differences or even population differences in thermal tolerance will likely play an increasing role in determining mortality risk for as rivers continue to warm, extreme temperatures are more likely to occur (Patterson et al. 2007a; Hague et al. 2011). Continued scientific research can reduce some of the current uncertainty with respect to this scaling of the impacts of different risk factors (see Section 4.3 in Patterson et al. 2017).

A major challenge is understanding the interactions among factors to better estimate the risk of mortality that results from multiple stressors. More applied research could be conducted using various combinations of key stressors. In addition, different analytical techniques could be used to maximize the utility of both current and future data sets. Survival data can be analyzed using generalized linear models (GLM), where the response – a binary variable denoting survival [1] and mortality [0] – is related via a link function (e.g., logit, probit, and cloglog) to a linear combination of predictors (McCullagh and Nelder 1989). The linear combination of predictors can be structured to assess whether multiple factors, presumably affecting survival, can act in an additive way (i.e., only main effects of the factors are supported) or in a synergistic/antagonistic way (i.e., two-way and higher order interactions between two or more factors are supported). Support for the type of cumulative effect (i.e., whether factors act additively, synergistically, or antagonistically) can be determined by using model selection approaches (e.g., Akaike Information Criterion) on a set of models where each one represent a different hypothesis for how multiple effects influence survival (Burnham and Anderson 2002). When data on survival are collected under conditions of imperfect detectability, such as in telemetry studies assessing the survival of tagged fish migrating past receiver stations, GLMs can still be used to estimate the effects of multiple factors. However, the model likelihood should also include a term describing the probability of individuals being detected (Amstrup et al. 2005).

An area of research that needs more attention is the confounding role that fish maturation (i.e., proximity to spawning) may play in mortality risk. Some of the risk assessment values appear to overestimate mortality risk for fisheries that take place nearer terminal areas, likely because of thickening integument (i.e., less susceptible to injury and infection) and/or a muted stress response (discussed in Raby et al. 2015). The inclusion of a context-specific risk factor to mitigate the higher mortality risk values for fisheries that occur in or near terminal areas should be considered. However, some caution is warranted in doing so as mortality risk may not always decrease for fish that have reached or are approaching spawning areas; sockeye salmon in the Harrison River system seem to consistently experience high post-release mortality (e.g., > 50%; Donaldson et al. 2012; Robinson et al. 2015) even when caught within 5 kilometers of spawning areas using relatively mild capture methods. Temporal proximity to spawning may be the more important factor to evaluate when considering maturation status given that the fish in those studies were approximately 5-8 weeks from spawning, leaving ample time for FRIM to manifest (e.g., via FRIM-induced pathogenesis). Other potential factors that may mitigate higher risk values include the use of best handling practices and revival techniques, and the consideration of species-specific differences in thermal tolerance. The challenge will be in incorporating this information into the current risk assessment approach.

To address the challenge of using this risk assessment tool across all potential fisheries in the Pacific Region, we recommend developing standard risk scores for some of the risk factors across major fishing types. For example, standard injury scores could be applied to commercial trolling, gill net, purse seine, beach seine, and rod and reel fisheries. These standard injury scores would be based on existing knowledge about the median level and type of injury caused by each gear. If, for a specific fishery, there are reasons to select a higher or lower risk score, then a clear rationale would need to be provided. The rationale for deviating from a standard fishing-type mortality risk value could include empirical information directly relevant to that fishery. Similarly, generalizations for variation in water temperature can be reflected on a broad spatio-temporal basis. However, the effectiveness of this approach to generalize mortality risk values for a group of fisheries will depend on the uses of the risk assessment outputs. For example, during the post-season accounting of FRIM impacts, the use of precise, fine-scale measurements of in-river water temperatures may be critical for accurate assessment for a given year.

There is currently no explicit incorporation of sub-lethal effects within the risk assessment tool. Reductions in growth and reproductive output associated with fishery encounters have been reported (Baker and Schindler 2009; Wilson et al. 2014). The high uncertainty in the magnitude of the effect currently precludes the ability to incorporate this information. However, this should not be a barrier to future work and we encourage researchers to include a broader suite of lethal and sub-lethal responses in their future research on FRIM.

Finally, we recommend updating the risk assessment tool in the future to focus on survival rather than on mortality. This will better reflect the existing literature on survival analysis and assist with other population dynamic models used in stock assessment. We chose to present mortality values in this approach to emphasize the connection to the first research document (Patterson et al. 2017) and to facilitate ease of communication of mortality risk.

3.4 ANCHORING METHODS

Guidance on using an anchoring method to convert mortality risk values to numerical estimates of mortality

The mortality risk values attained for different fisheries are only part of the information required to arrive at useable estimates of FRIM. The anchoring of these mortality risk values against available estimates of mortality from more realistic studies is required (see Section 2.4). The key to selecting the appropriate studies will be to use some standard repository of information on mortality estimates. We have recommended using the mortality evidence catalogue developed in Patterson et al. (2017) to both source the appropriate information and evaluate the study reliability and relevance. The use of an evidence catalogue will increase the transparency and repeatability of the process to extract information in defense of any derived estimate. Concerted effort by those requiring the information will be needed to support updates to the evidence catalogue and research on factors related to FRIM.

In addition to supporting efforts to assimilate the relevant information, exploring alternatives for analyzing the existing research results may reap large benefits. With the growing number of tagging projects and associated telemetry databases, comes the ability to do more sophisticated analysis of the survival information. For example, one option is to use the so-called "survival analysis" or more generally termed time-to-event models (Klein and Moeschberger 1997). These models are often used when information on time (or distance) until an event (e.g., mortality) occurs is recorded during the study. Because it is difficult to determine the time of death for fish in the field, this type of analysis finds more applications in laboratory studies, where the fate of fish subject to multiple effects can be constantly monitored. Analysis of time-to-event models typically follows the approach described in Section 3.3 for GLMs (i.e., one can assess the additive and interactive effects of factors under a model selection framework). One useful output of time-to-event analysis is the hazard function, which "gives the instantaneous potential per unit time for the event to occur, given that the individual has survived up to time *t*" (Kleinbaum and Klein 2005). Typically, hazard rates can be constant over time (e.g., the potential for dying after experiencing a stressor does not change over time), decreasing (e.g., the potential for dying is highest after experiencing a stressor and declines over time) or increasing (e.g., the potential for dying is lowest after experiencing a stressor and increases over time). Therefore, hazard rate functions can be used to determine, for example, if the experience of a particular factor or combination of factors has acute (decreasing hazard rate) or delayed effects (increasing hazard rate).

3.5 UPDATING RISK ASSESSMENT

Recommendations on updating the risk assessment approach with new research and for sourcing information on mortality estimates for Pacific salmon

Our recommendations for sourcing information that is relevant to FRIM estimates for Pacific salmon are based on the steps used to gather information in the partner document, Patterson et al. (2017). There were three main approaches to obtaining FRIM-related materials: the solicitation of experts, a review of the literature related to factors that may drive FRIM, and a comprehensive search for mortality estimates relevant to FRIM for anadromous salmonids. The solicitation of experts involved a formal call for information from fishery managers and affected user groups, as well as an informal request to academics in the field. This process generated a lot of information with minimal effort; however, the main challenges with using this collection type include study bias (i.e., the use of a non-systematic collection method), duplication of material, and a large amount of grey literature that needs additional vetting for study quality. To deal with these challenges we recommend: evaluating the information for confirmation bias (i.e., did certain groups only share positive information) by comparing results to the mortality evidence catalogue, providing the current inventory of information (i.e., factor analysis tool and mortality evidence catalogue) prior to future requests to reduce duplication, and conducting a gap analysis on the factor analysis and mortality evidence catalogue to prioritize areas for which there is limited information (e.g., central and north coast; pink (*O. gorbuscha*) and chum salmon (*O. keta*); purse seine fisheries) as a means to cope with the large volume of material, respectively. Both the factor analysis and the mortality evidence catalogue generated thousands of potential information sources that required large amounts of time and effort to sort through and determine relevance. We do recommend that such comprehensive collections and reviews of the available literature be conducted annually using the same search criteria, but that the searches are simply restricted to new information (e.g., since date last accessed).

We recommend a series of information storage locations to maximize the utility of the information based on type. The major types of information we propose include: information that is relevant to factors that improve our understanding of FRIM, direct empirical data on mortality of anadromous salmonids that is associated with fishing, information on different gear and method variants that will impact FRIM, and research on how any of the four generic risk factors are likely to interact (e.g., synergistic effects) in the assessment of FRIM. The following paragraphs provide guidance on where this information should be stored and how it may be used, including instances where information needs to be peer reviewed prior to adoption.

Information that is relevant to the review of FRIM-relevant factors would go into factor analysis repository. New information may contribute to the knowledge base that informs how a specific factor can modify the relationship between one of the key risk factors and the mortality risk or help determine the likelihood of a specific risk level being achieved in a given fishery (e.g., Appendix Table A3). If the impact of the new information is deemed to be major and is consistent with the information informing the current mortality risk assessment, it can be used as supporting evidence (e.g., references for scoring tables; Table A.2). However, if the information is not consistent with the current knowledge base, then this information needs to be added as counter evidence to the scoring table references. Currently, this part of the reference tables does not exist; we recommend expanding the tables to be more inclusive of the uncertainty surrounding the ability to score mortality risk. However, any major review of or modification to the risk factor synthesis, or changes to the scoring tables (e.g., Table A.1), should go through another review process (e.g., CSAS evaluation).

Information that is relevant to the collection of FRIM-related mortality estimates (i.e., passes the article screening process detailed in Section 3.3 of Patterson et al. 2017) would be added to the mortality evidence catalogue. Note that this information can overlap with the information added to the factor analysis repository. If the new information is relevant to the mortality risk scoring tables, then the information can be added to the summary reference or modifier tables (e.g., Table A.2 and A.3). Similar to the factor analysis, if the information challenges the current scoring system, this should be clearly noted in the reference table. Further, new mortality estimate information that is added to the catalogue can be used in different parts of the anchoring process, depending on the level of information provided by the authors. For example, studies that generate delayed mortality estimates using methods relevant to Pacific salmon fisheries and that have enough information to characterize at least the four generic risk factors, can be used in a mortality estimate to mortality risk relationship. However, before such a relationship can be employed, it should be peer reviewed.

Information on new fishing gear or method variants may be used in the fishery characterization process once vetted. By vetted, we mean that there must be empirical evidence that the variant would have a demonstrable effect on the scoring of mortality risk for one of more of the four generic risk factors prior to its addition to the fishery characterization drop-down menus (Table 2).

Lastly, new information that is relevant to understanding the interactions between the four generic risk factors will need to be peer reviewed as part of the risk assessment. We recommend creating a separate inventory of information relevant to understanding factor interactions. When sufficient evidence has been collected, this inventory could be part of a larger exercise to better model cumulative impacts, including the use of some of the methods outlined above and in Côté et al. (2016). This would also need to be peer reviewed.

Overall, by tracking the accumulation of information for both FRIM-relevant factors and mortality estimates, it makes it possible to evaluate how compatible the current risk assessment approach is with new information. If the information indicates that a new factor should be considered in the risk assessment, then this would trigger a peer-reviewed re-synthesis requiring an evaluation of the existing volume of evidence and utility in the risk assessment process (e.g., Tables 4 and 5 in Patterson et al. 2017). Similarly, any new information that has the potential to alter the existing mortality risk scoring system would need to be peer reviewed. The methods proposed herein for continually updating the knowledge base for understanding FRIM provides a platform for the transparent and repeatable use of scientifically-defensible information in the derivation of FRIM estimates.

4 CONCLUSIONS

A major advantage of a risk assessment approach to developing estimates of mortality rates is the clarity it provides management and fishers with respect to the information being used to evaluate a given fishery. This clarity provides transparency and facilitates mitigation. The importance of the latter point should not be underestimated given that the uncertainty in the mortality risk values is a reflection of the magnitude of the response and not the direction of the effect on FRIM. This means that any efforts to mitigate the factors (i.e., reduce the risk level of any factor) are likely to have reduce FRIM, irrespective of whether we know the absolute change in mortality associated with such efforts.

The ability to accurately characterize the conditions that exist for an actual fishery will continue to be a major limitation of this work. This concern is similar to the problem of study realism echoed repeatedly in previous efforts to directly estimate FRIM in the field or laboratory. Simply knowing the risk factors that are important and at what level they begin to affect fish is only part of the solution to estimating FRIM in real fisheries. More work needs be carried out to accurately assess and characterize Pacific salmon fisheries with respect to these key risk factors. This is a challenge to the fishery experts in Stock Assessment and Fisheries Management.

More work and feedback is required before the risk assessment tool developed herein could be considered for prescriptive use. As such, this risk assessment should be considered as just one step in a bigger overall risk analysis of FRIM (e.g., Mandrak et al. 2011). We would recommend that an overall risk analysis plan be set up to complement the factor analysis, mortality evidence catalogue, and risk assessment process through engagement with management and all interested groups.

The information collected and used in this research document and in Patterson et al. (2017) was primarily based on the literature available in scientific journals. This was deliberate, given that we are primarily interested in a rigorous and defensible scientific information base that is vetted and readily available, to provide credible scientific advice in a short time frame. However, there are lots of researchers and groups collecting information that is relevant to FRIM outside of the primary literature, our research group, and the Pacific region. We recommend that continued efforts seek a broader census of information and research related to FRIM. The guidance developed here should act as good platform from which to assess the quality and relevance of other work, as well as inform which information needs are pressing.

5 GLOSSARY

Acute mortality: Mortality of fish in direct and immediate response to a capture or handling stressor. Most likely associated with severe injuries, such as exsanguination, or mortality from severe exercise or extreme hyperactivity.

Avoidance mortality: Mortality of fish that encounter fishing gear but actively avoid the gear without direct physical contact, resulting in fatigue and stress (e.g., gear avoidance through difficult passage areas) and eventual death.

Barbless hook: A hook from which all barbs have been removed—either filed off or pinched flat against the shaft. The shaft of a hook is the straight part between the eye and the bend.

Bycatch (or by-catch): Various definitions from unintended catch (fish not sold or kept for personal use) to discarded catch plus the incidental catch. Does not refer to fish released alive in catch and release fishing.

Captured: A fish is considered captured when it is under the complete control of the fisher; when the fish brought alongside the boat or shore (related to landed). Not to be confused with hooked or tangled where the fish may escape or drop-out.

Capture time: Time from potential gear encounter to capture: e.g., deployment to bag net, gill net deployment to drum, hook time to boat/shore, periods between trap check.

CM – Catch mortality, or ‘CM’: Is captured (target or non-target) fish that died during capture or during handling and that would otherwise have been intended for live release. CM is akin to on-board mortality in our list of the seven components of FRIM.

Catch-and-release: Usually in reference to recreational angling, the act of catching a fish with the intention to release it alive.

Commercial fishing: The act of fishing with the intent to make a profit from selling the harvested fish to consumers.

Confinement stress: The stress associated with limiting the movement of fish via entrapment, but without persistent physical contact with the gear or other fish. All trap and seine net fisheries as well as holding studies elicit some level of confinement stress.

Context-specific risk factor: A risk factor that is not applicable or relevant to all fisheries, but whose impact can both dominate (e.g., predator) or mitigate (revival methods) the overall mortality response. (See Risk Factor).

Crowding stress: The stress associated with confining fish into every tighter spaces such that the fish are in repeated and direct contact with fishing gear or other fish. Corralling fish to the point of physical interaction results in increased number of fight responses and higher probability of injury associated with physical contact (e.g., scale loss).

Cryptic mortality: A mortality event that is not observed.

Delayed post-release mortality (> 24 hr): Mortality of fish that occurs more than 24 hours after released alive that can be attributed to back to the fishing event.

Depredation: Fish that die as a result of predators directly removing fish from fishing gear during the capture process; this does not include the predation of released fish.

Discard mortality: The mortality of catch that is returned to the water (non-retained), includes fish that are released alive or dead.

Discarded catch: The proportion of the total catch that is returned to the water – may be either target species or non-target species.

Drop-off mortality: Combined mortality of avoidance, escape, depredation, and drop-out mortalities (i.e., mortality of all fish that encounter gear but do not make it on-board). Also referred to as non-catch mortality (NCM).

Drop-out: Fish that die and drop out of the fishing gear prior to landing (e.g., drop-out of gill nets). Fish that fall off alive would be escapees.

Escape mortality: Mortality of fish that actively escape after contact with fishing gear prior to landing (e.g., escape from a hook or gill net).

Fishery: The activities leading to and resulting in the capturing of fish. A fishery is typically characterized by the species caught, the fishing gear used, and the area of operation.

Fishery encounter: The time and events associated with a fish perceiving and responding to the different events associated with a fishery (e.g., gear deployment, capture, handling, and release).

Fishing mortality: Death of fishes that can be directly or indirectly attributed to fishing activities, includes drop-off, retained catch, and release mortality.

Fishing-related incidental mortality (FRIM): Refers to any mortality that occurs as a result of an encounter with fishing gear that is not included in the retained catch estimates.

Generic risk factor: A mortality risk factor that is relevant to all fisheries. (See Risk Factor)

Handling time: Total time spent being handled from the point of capture to release; includes bag time for seines, removal times from gear, hand netting, and time sorting.

Hooking mortality: Death of fishes attributable to capture with standard hook and line fishing gears (baited hooks, artificial baits with various hook types, and arrays).

Immediate mortality: Immediate (or initial) mortality is defined as capture-related death that is observable immediately up capture and during the handling process. We have used this term as being synonymous with on-board mortality.

Incidental catch: Catch of non-target species. Also often called bycatch.

Landing: When a fish is brought aboard the boat or streamside, under complete control of the fisher, similar to capture for most fisheries except for seine fisheries (i.e., capture ends at crowding in water, but landing involves being on board).

Latent mortality: Latent effects of capture or handling that eventually lead to mortality (e.g., related to chronic stress).

Natural bait: Foodstuff or other natural substance (other than wood, cotton, wool, hair, fur or feathers) that is used as bait.

NCM – Non-catch mortality, or ‘NCM’: Refers to fish that die prior to being landed, this includes the mortality components of avoidance, escape, depredation, and drop-outs.

Non-target catch: Species that are captured but are not the intended or target catch.

On-board mortality: Mortality of captured fish; this observable mortality includes fish that are dead on landing or die on board prior to release (e.g., during sorting or in holding tanks) and is synonymous with immediate mortality.

Play time: total time spent on hook and line. (See capture time)

PRM – Post-release mortality or ‘PRM’: Represents death from a fishing event at some point after release by a fisher. PRM is akin to short-term and delayed post-release mortality components. It also includes mortality associated with shakers, fall-outs, or slippage.

Release mortality: Mortality of fish captured but not retained, includes immediate (i.e., on-board) mortality of fish that are not retained, along with short-term post-release mortality and delayed post-release mortality.

Risk assessment: An analytical approach for estimating risk.

Risk: In the context of FRIM, it is defined as the probability that a Pacific salmon not targeted for retention will die due to exposure to one or more identified factors related to fishing.

Risk factor: In the context of FRIM, a factor whose effect on the probability of a fish surviving a fishery encounter can be quantified across a severity of impact scale.

Set time: time from net deployed to net bagged (i.e., capture). (See capture time)

Shaker/shake-off: Fish that are captured but shaken off of the gear before being brought on board (non-target catch). These fish can be observed and associated mortalities would part of PRM.

Short-term post-release mortality (≤ 24 h): Mortality of fish that occurs up to 24 hours after released alive, that is associated with the fishery encounter.

Single barbless hook: A barbless hook with only one point. A treble hook (with three points) is not considered to be a single hook.

Slippage: Release of captured fish at water-line for seine fishing (i.e., no on-board sorting). They would be treated as a post-release but likely have lower post-release mortality rates. Also related to the spilling of fish that are captured but not landed.

Soak time: See capture time; time from first cork in to last cork out for gill nets. Represents the maximum time a fish could encounter a gill net.

Sub-lethal effects: Non-lethal injurious, physiological, behavioural, and fitness-related impacts as a result of fishing interaction that lead to reductions in future fitness via impairment to growth or reproduction. Not considered in the review.

Target catch: The species that are the primary target in a given fishery. The target catch can either be retained or released.

Terminal fishery: Fishery in a river or near the mouth of a river where returning salmon pass through or congregate near to and prior to spawning, and where stocks are relatively unmixed.

Vitality: A term to reflect the overall condition of a fish. It is meant as an integrative measure of the physiological state of a fish through the use of visual assessments of injury and reflex impairments.

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APPENDIX A: RISK FACTOR SCORING TABLES

A.1 CAPTURE

Table A.1. Mortality risk scoring table for the capture risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to capture time, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factor are provided in Table A.2. All references to section numbers are in Patterson et al. 2017.

Mortality Risk Range	Risk Score	Gill Net	Hook	Seine	Trap
0 to 5%	1	0-3min	0-3min	0-10min	0-10min
5 to 15%	2	3-10min	3-10min	10-30min	10-60min
15 to 25%	3	10-20min	10-20min	30-60min	60-120min
25 to 35%	4	20-40min	20-40min	60-120min	120-720min
35 to 45%	5	40-60min	40-60min	120-720min	12-48hr
45 to 100%	6	>1hr	>1hr	>12hr	>48hr

Definition: The mortality risk of capture is reflected in capture time. Capture time extends from the potential for a fishery encounter to handling of the catch; for a gill net it is the time from initiation of net deployment to complete net retrieval; for hook fisheries, time from hooking to landing; for seine nets, time from initiation of net deployment to net bagging (commencement of crowding); for traps, time from deployment and trap check.

Method: Select the main capture type and then select median capture time that best represents the fishery in question.

Rationale: An encounter with a fishery causes physiological stress due to threat perception, confinement, and physical contact with fishing gear and catch; attempts to evade and escape capture typically use anaerobic pathways associated with exhaustive exercise (fight response; see 2.3.1); longer capture times increase the physiological stress of the encounter, the duration of contact with gear and/or catch, and the potential for more exhaustive bouts (i.e., increased number of fight or flight responses); increased physiological perturbation can result in acute mortality (e.g., acidosis) and latent mortality (e.g., due to limited swim performance during physiological recovery). The differences in the capture time scoring criteria by gear type is based on variation in the magnitude of the physiological response (see 2.4.1); for gill nets the stress of capture includes a high number of fight responses, physical contact, and potential for suffocation (operculum restricted); for hook and line capture stress includes high number fight responses and physical contact; for seines capture stress includes confinement and some physical contact and exhaustive exercise; for traps capture stress includes confinement with limited potential for exhaustive bouts.

Notes: Meant to reflect both acute and latent mortality risk; longer capture times increase the risk of injury and this risk should be reflected in higher injury scores; longer capture times may increase the risk of depredation (depending on gear type and capture environment) and predation (depending on release environment; see 2.8.6), and this risk should be reflected in higher predator scores.

Table A.2. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for capture time. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data. Brackets contain the gear type that the results are most relevant to. All references to chapters are in Patterson et al. 2017.

Information Source	Empirical Result
Amy Teffer (UBC) unpublished data, Vancouver, B.C.	difference in mortality for 20sec vs. 20min ~30% (Gill Net)
Black 1957	15min vigorous exercise ~25% mortality (Gill Net, Hook)
Buchannan et al. 2002	difference in mortality for 40min vs. 140min ~50% (Gill Net)
Candy et al. 1996	difference 15-30min vs >30min ~30% (Seine)
Cook et al. 2014	higher capture stress response lead to higher risk of mortality (Trap)
Donaldson et al. 2011	24hr captive fish 30-40% higher mortality than immediate release (Hook, Seine, Trap)
Dunn and Lincoln 1978	24hr trap fish had immediate mortality of 22% chinook to 4% coho marine; only 52% Chinook good condition (Trap)
Gale et al. 2011	>3min high stress response (Gill Net, Hook)
Hargreaves and Tovey 2001	>60min = 55% vs 25% for 10 to 20min (Gill Net)
Parker and Black 1959	max lactate response after 10 mins exercise, hook time linked to lactate, lactate linked to mortality (Hook)
Portz et al. 2006	review of short-term confinement and physiological stress response (Seine, Trap)
Raby et al. 2015c	24hr holding coho ~20% mortality after 24hr in holding study (2X rate of immediate release) (Seine, Trap)
Robinson et al. 2013	>3min high stress response (Gill Net, Hook)
Robinson et al. 2015	difference <10min seine vs 10min seine + 3min sim hook + 30min trap ~30% increase in mortality (Seine)
Thompson et al. 1971	12hr set 70% immediate mortality, plus 80% post-release within 8 days (Gill Net)
Tufts et al. 1991	complete exhaustion equilibrium loss after 10min (Gill Net, Hook)
Vincent-Lang et al. 1993	no difference mortality <1min fight time; higher mortality >1min (Hook)
Wedemeyer and Wydoski 2008	<5min osmo and metabolic responses within normal tolerance ranges (Hook)
Wood et al. 1983	physiological mechanism relating severe exercise to mortality (All)

Table A.3. A list of factors, with associated rationale, that have the potential to either modify the capture duration or the capture time-mortality risk relationships. The former can assist in scoring the risk factor. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2). All references to chapters are in Patterson et al. 2017.

Capture duration

Modifying Factor	Rationale
catch size	large catch sizes can increase hook time (commercial troll) and set time (gill net)
fish size	large fish take longer to land and increase potential for repeat exhaustive exercise (e.g., rod and reel)
hydrology	sea state can influence capture time
mesh type	longer nets, longer set times (e.g., gill net, seine net)
species	fight time can vary by species
terminal tackle	line weight influence on duration of capture (e.g., rod and reel)

Capture - mortality relationship

Modifying Factor	Rationale
hydrology	fishing or current speed could alter sustained swimming and potential for exhaustive exercise (Seine)
maturity	potential resilience to stressors with increase maturation
pre-encounter condition	disease state, recaptures, would decrease resilience to capture stress
sex	differences in physiological stress response, females more vulnerable
water temperature	exacerbate physiological perturbation, infection, and disease progression

A.2 HANDLING

Table A.4. Mortality risk scoring table for the handling risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to handling time, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factors are provided in Table A.5. All references to section numbers are in Patterson et al. 2017.

Mortality Risk Range	Risk Score	Total Time Handling in Air	Total Time Handling in Water
0 to 5%	1	0-10sec	0-3min
5 to 15%	2	10-60sec	3-10min
15 to 25%	3	1-2min	10-40min
25 to 35%	4	2-3min	40-60min
35 to 45%	5	3-5min	60-180min
45 to 100%	6	>5min	>180min

Definition: Handling from capture until release of all non-retained catch; this includes but separates handling time in air and handling time in water; handling incorporates all instances of crowding, sorting and revival.

Method: Select the median total handling durations in air and in water that best represent the fishery in question; then, select the highest score of the two handling types.

Rationale: Handling causes further physiological stress due to crowding, physical contact with gear and/or catch, revival confinement, and exposure to air; attempts to escape handling typically use anaerobic pathways associated with exhaustive exercise (see 2.3.1); longer handling times increase the physiological stress of the encounter (see 2.4.2), the duration of physical interaction with gear and/or catch, and the potential for more exhaustive bouts (i.e., increased number of fight or flight responses); increased physiological perturbation can result in acute mortality (e.g., acidosis) and latent mortality (e.g., due to limited swim performance during physiological recovery); air exposure impedes aerobic respiration, limiting oxygen availability for physiological recovery and thereby exacerbating the physiological imbalance and prolonging recovery; extended air exposure can also cause direct acute mortality (see 2.4.4).

Notes: Meant to reflect both acute and latent mortality risk; confinement herein refers to the enclosure of catch without forcing physical interaction with gear and/or catch, whereas crowding refers to confinement and forced physical interaction; handling time in water (i.e., crowding) typically does not apply to loose seines (e.g., experimental fishing) or traps unless overloaded; the duration of this confinement (not crowding) in these examples would be reflected in capture time; longer handling times increase the risk of injury and this risk should be reflected in higher injury scores; longer handling times may increase the risk of predation (see 2.8.6), and this risk should be reflected in higher predator scores; air exposure can occur in all types of fisheries, but total time handling in water is typically an issue for seine fisheries.

Table A.5. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for handling. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data. All references to chapters are in Patterson et al. 2017.

Handling in air

Information Source	Empirical Result
Cook et al. 2014	high stress response from 2min air exposure and 40min water handling linked to survival
Cook et al. 2015	extensive review, >1min air exposure leads to higher mortality, should avoid
Ferguson and Tufts 1992	<1min exposure high mortality (contrast with Raby et al. 2013)
Gale et al. 2011	1min air ventilation impairment; 50% lost equilibrium, lactate increased
Gale et al. 2014	1min air increased lactate, lactate increased impairment, and air exposed higher mortality ~10%
K. Cook (UBC) unpublished data, Vancouver, B.C.	>1min air reflex impairment, >4 min of air exposure, 50% loss of orientation, orientation related to mortality; marine 10C
Raby et al. 2013	>1min equilibrium loss starts, >6min air 80% fish loss equilibrium, physiological disturbance also related to length of air exposure; spawning ground 12C
Raby et al. 2015a	3min air exposure = severe impairment of reflexes, resulted in most fish becoming unresponsive; 46% exhibited complete loss of reflexes (RAMP score = 1.0) and a further 45% lost four of five reflexes (0.8).
Schreer et al. 2005	less than 60sec air is best. More than that impacts swim performance, more than 120sec= further impairment, 50% not able to swim at all

Handling in water

Information Source	Empirical Result
Donaldson et al. 2012	15min crowding in seine increased mortality 13% after 5 days
Raby et al. 2012	reflex impairment increased with handling time (>6 to 9min), higher reflex impairment related to delayed mortality
Raby et al. 2015a	2min vs 15min of crowding large effect blood stress parameters; 18% mortality difference at 15C between 2 vs 15min
Robinson et al. 2013	increased handling time via ventilation assistance higher mortality
Robinson et al. 2015	<3min vs 5 to 45min handling in water + min air ~30% increase delayed mortality
Waring et al. 1992	9min crowding (net) - increased mortality and elevation of cortisol, glucose, lactate, osmolality, monovalent ion levels in 11C seawater

Table A.6. A list of factors, with associated rationale, that have the potential to either modify the handling time or the handling time-mortality risk relationships in either air or water. The former can assist in scoring the risk factor. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2). All references to chapters are in Patterson et al. 2017.

Handling duration

Modifying Factor	Rationale
capture time	long capture times increase probability of longer handling times for revival
capture time	short capture times can increase handling time if fish not fatigued
catch composition	target to non-target ratios can influence sort times
catch size	influences total handling time - lengthy for large catches; stress of repeated physical contact with conspecifics
gear type	removal times vary by gear type, e.g., barbed hook, hang ratio
gear variation	ramping versus brailing with influence both air and water handling times
handler technique/experience	potential for more exhaustive bursts (fight response) during handling; physiological stress of fish being touched; inexperienced handlers can lead to lengthier handling times/higher stress
revival method	trade-off may only benefit poor condition fish

Handling - mortality relationship

Modifying Factor	Rationale
catch size	catch density can potentially influence the magnitude of the stress response
dissolved oxygen	overcrowding can lower dissolved oxygen availability (e.g., beach seine); on-board tanks
maturity	potential resilience to stressors
pre-encounter condition	recaptures (i.e., stressed fish) can be more sensitive handling
sex	differences in physiological stress response
suspended sediment	abrasion and injury to gills (e.g., beach seine)
water temperature	exacerbate physiological perturbation, infection and disease progression

A.3 INJURY

Table A.7. Mortality risk scoring table for the injury risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to injury, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factor are provided in Table A.8. All references to section numbers are in Patterson et al. 2017.

Mortality Risk Range	Risk Score	Scale Loss	Tissue Damage	Blood Loss	Fin Damage	Puncture Wound
0 to 5%	1	<5% of body	no visible damage	none or negligible blood loss	none	surficial; non-critical location
5 to 15%	2	5-10% of body	minor/surficial abrasions	minor blood loss	minor fraying; a few fins	shallow; non-critical location
15 to 25%	3	10-25% of body	minor bruising (compression) wounds; gear markings	moderate blood loss; no gill damage	fraying; multiple fins	deep; non-critical location
25 to 35%	4	25-35% of body	small open wound (e.g., muscle); distinct gear markings	moderate blood loss; gill damage	fin split base to tip; damage at base	surficial; critical location
35 to 45%	5	35-50% of body	large open wound; severe compression or gear markings	heavy blood loss	partial fin loss	shallow (hook left in); critical location
45 to 100%	6	>50% of body	deep wound (e.g., bone); critical location; crushing injury	pulsatile blood loss (damage to artery)	loss of pectoral, pelvic, caudal fin	deep (hook removed); critical location

Definition: Visible injury likely to have occurred as a result of any aspect of a fishery encounter.

Method: Select the median injury score that best represents the fishery. Consider all five types of injury; if information is available for more than one type of injury, then select the highest score; non-critical locations include the head, body surface, fin and mouth cartilage; critical locations include the eye, roof of mouth, tongue, esophagus, gills and all major organs.

Rationale: Interaction with gear, catch, handler and/or predator during a fishery encounter can result in visible injuries that can be linked to acute mortality (e.g., severe blood loss) and latent mortality (e.g., infection). Severity ranking in the scoring criteria reflects an incremental increase in the risk of mortality (see 2.3.2 and 2.3.4). The scoring criteria links to mortality via stress response (all types), exsanguination (blood loss, scale loss, wounds), reduce mobility (tissue damage, fin damage), and increased risk of infection and disease (all types).

Notes: Meant to reflect both acute and latent mortality risk; there is variability in the level of interpretation required for each injury type due to the lack of empirical data (e.g., lots of information on puncture wounds but limited on fin damage).

Table A.8. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for injury. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data. All references to chapters are in Patterson et al. 2017.

Information Source	Empirical Result
A. Bass (UBC) unpublished data, Vancouver, B.C.	fin damage indicative of delayed post-release mortality, multiple fins, split fins
Baker & Schindler 2009	adult sockeye salmon with moderate to severe gill net injury experienced prespawn mortality; maturation and reproductive fitness were reduced in fish with minor injuries
Batholomew and Bohnsack 2005	review of 53 papers dealing with rod and reel fisheries, hook location a major determinant of mortality
Butler and Loeffel 1972	sublegal Chinook: higher immediate mortality if hooked in gills or isthmus (36.4% and 19.3% respectively) while hooked elsewhere: 2.9-7.4% immediate mortality
Cowen et al. 2007	critical hook locations and bleeding were significant predictors of immediate mortality; list of critical hook locations
Diewert et al. 2002	scale loss of Chinook significant impact on immediate mortality; Chinook and coho immediate mortality with blood loss: no bleeding (3.3%), light (6.6%), moderate (37.9%), heavy (87%)
DuBois & Dubielzig 2004	38% mean 48hr mortality for gill hook, vs less than 5% for jaw, mouth or external snag
Lindsay et al 2004	hooking mortality rates (delayed) for each of five anatomical locations (jaw, 2.3%; tongue, 17.8%; eye, 0.0%; gills, 81.6%; and esophagus-stomach, 67.3%); Chinook fresh water
Mongillo 1984	major review: deep hooks removed = up to 93% mortality vs deep hooks left in =33% mort; greater than 45-95% mort of those hooked in critical locations (eye, esophagus, gills, tongue); mortality less than 20% for jaw, mouth
Muoneke and Childress 1994	review of hooking locations in association with mortality, supporting critical locations
Rosseland et al. 1982	25% descaled Atlantic salmon mortality 20% (fresh water) to 60% (salt water) after 9 days
Schill 1996	rainbows delayed mortality (weeks), deep hook cut-line 40-55% mortality; deep hook removed 66-83% mortality, light hook 0-5%, high mortality >50% for major organ hook locations
Thompson et al. 1971	40% descaled sockeye marine ~50% mortality vs. ~15% controls 6 days
Vincent-Lang et al. 1993	~5 day coho; mortality gills or esophagus hook location 5X higher than other head locations, higher scale loss and bleeding higher mortality
Wertheimer 1988	Chinook marine troll 5 day mortality: hook in gills had highest mortality (50-90.8%), followed by eyes (16-26%), lowest (0-6%) maxillary; more severe wounding and shorter Chinook had higher mortality

Table A.9. A list of factors, with associated rationale, that have the potential to either modify the injury response or the injury-mortality risk relationships. The former can assist in scoring the risk factor. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2). All references to chapters are in Patterson et al. 2017.

Injury response

Modifying Factor	Rationale
bait or lure	influences hook depth or ingestion of hook
catch composition	mixed catches of size or coarse fish can influence injury
catch size	increase capture and handling time, increasing probability of injury
catch size	large catches can increase bag or trap densities - lead to crushing injuries
gear variation	brailing versus ramping can influence crushing injuries, scale loss
hook location	anatomical location that hook enters body
hook size	ratio of fish size to hook size
hydrology	sea state can influence decision to ramp or brail
hydrology	flow conditions for safety can influence bag density
landing net	scale loss for marine especially, connected to size
mesh size	ratio of fish size to mesh size, can either increase or decrease injury
predators	longer capture times increase risk of wounding from predators

Injury - mortality relationship

Modifying Factor	Rationale
predators	attractant
pre-encounter condition	pre-existing condition altering experience and response
salinity	scale loss impact reduced in isotonic water (10-12ppt)

A.4 WATER TEMPERATURE

Table A.10. Mortality risk scoring table for the water temperature risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to water temperature, provides the definition of the risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factor are provided in Table A.11. All references to section numbers are in Patterson et al. 2017.

Mortality Risk Range	Risk Score	Water Temperature	Detailed Rationale for Level
0 to 5%	1	<14°C	warm water diseases suppressed; high oxygen content of water during capture and post-release recovery; lower oxygen debt resulting from exhaustive exercise
5 to 15%	2	14-16°C	optimum aerobic scope for most salmon; low virulence strains of pathogens can start to proliferate
15 to 25%	3	16-18°C	reduced capacity to recover from exercise; infection rates increase, elevated risk of disease
25 to 35%	4	18-20°C	reduced aerobic scope, limits recovery exhaustive exercise, increase vulnerability; proliferation of warm water pathogens and higher disease risk
35 to 45%	5	20-22°C	collapse of aerobic scope, reduce mobility, increased predation risk; inability to deal with stress, increase risk of infection
45 to 100%	6	>22°C	cessation of migration, vulnerable to predation/recapture; suppressed stress response, increase infections and very high disease risk

Definition: Temperature experienced during and after a fishery encounter.

Methods: Calculate the expected average water temperature a fish would experience for 72 hours after the initiation of fishing encounter and match the value to a risk score.

Rationale: Water temperature plays a pivotal role in modulating fish survival independent of FRIM (see 2.3.4 and 2.8.1). The mortality risk reflected in this table represents the incremental change in mortality risk associated with fishing at different water temperatures, above the natural effect that water temperature would have on survival. The scoring reflects the incremental cost of recovery from exhaustive exercise, change in in physiological stress response, and the increased risk of infection and disease associated with warmer water temperatures.

Notes: Meant to reflect both acute and latent mortality risk.

Table A.11. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for water temperature. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data. All references to chapters are in Patterson et al. 2017.

Information Source	Empirical Result
Eliason et al. 2011	optimum aerobic scope curves for Fraser sockeye populations ~16C; >19-21C scope reduced; >21C 50% collapse
Eliason et al. 2013	detailed examination of cardio-respiratory performance with increasing temperatures highlighting decrease performance from thermal optimums of 16 to 17C.
Gale et al. 2011	no equilibrium loss at 13C or 19C for reference fish, but simulated capture >50% loss at 19C and 21C; ~50% mortality within 72hr at 21C for all treatment fish, zero mortality for 13C and 19C for 72hr
Gale et al. 2013	major review paper on consistent increase in temperature dependent mortality for release mortality
Gale et al. 2014	19C 30% higher than 13C, 16C 10% higher than 13C
Jain and Farrell 2003	repeat critical swim speed performance lower at 15C than 9C
Jeffries et al. 2012b	transcriptome response to high temperatures 14C vs.19C indicating overlap of immune response and water temperature
Martins et al. 2011	13C to 20C tag data, modelled differences between marine and river tag fish represent the incremental cost of water temperature, main basis for above relationship
McCullough et al. 2001	literature review of thermal impacts on salmon indicating problems above 18C for adult migration
Miller et al. 2014	review of pathogens associated with temperature increase and immunosuppression and high temperatures
Raby et al. 2015a	~10% mortality of fish at 15C vs 10C for 2 and 15min crowding
Robinson et al. 2013	16C - control fish ~10- 40% higher survival than simulated captured fish

Table A.12. A list of factors, with associated rationale, that have the potential to either modify the temperature experience or modify the temperature-mortality risk relationship. The former will assist in measuring the temperature experience. The latter is relevant to understanding the current uncertainty in the scoring table and highlighting areas for future research. See the factor analysis for more details (Chapter 2). All references to chapters are in Patterson et al. 2017.

Temperature experience

Modifying Factor	Rationale
species	behaviour differences in fish response to capture, fall-back, thermal refuge

Temperature - mortality relationship

Modifying Factor	Rationale
injury	opportunistic infections
physiological condition	severity of physiological perturbation
salinity	lower D.O. in marine versus fresh water for same temperature, higher basal MO2 in salt water
size/age	possible to have size-dependent temperature effects
species	species-specific thermal optima; population specific potential

A.5 PREDATORS

Table A.13. Mortality risk scoring table for the predator risk factor. This table, formatted as a stand-alone reference for scoring the risk of a fishery as it relates to predators, provides the definition of this context-specific risk factor and the rationale for its utility. The method developed for scoring a fishery using this factor is presented alongside any additional notes relevant for interpretation. Key sources of information used to score the risk factors are provided in Table A.14. All references to section numbers are in Patterson et al. 2017.

Mortality Risk Range	Risk Score	Evidence of Predation	Evidence of Predator Abundance
0 to 5%	1	<5% loss rate; or very few visual signs	none or very few observed and a non-marine mammal area
5 to 15%	2	>5% loss rate; consistent observations but dispersed	few observed and marine mammal area
15 to 25%	3	>15% loss rates; low landing rate, some net damage	daily observations of a few predators
25 to 35%	4	>25% loss rates; with consistent evidence of predation	daily observations of a few habituated predators
35 to 45%	5	>35% loss rate; extensive net damage and terminal gear loss	daily observation of a lots of predators
45 to 100%	6	>45% loss rate; high persistent evidence of predation	daily observation of a lots of habituated predators

Definition: Change in the likelihood of predator encounters as a result of a fishery.

Method: Select the scores that best represent both the direct evidence of predation and the direct evidence of predator abundance and use the higher of the two scores. Loss rate refers to depredation estimates only, not landing rates although they are likely related.

Rationale: Unambiguous relationship between the interaction with predators and the mechanism and likelihood of mortality (see 2.8.6); the observable impact and/or abundance of predators in the environment reflects the potential risk of an encounter and ultimately mortality. High depredation loss rate would also imply a higher escapee or release mortality risk, which is why it could be relevant to both drop-off and release mortality risk. Key sources of information to score the table are based on Raby et al. 2014 and judgment.

Notes: Meant to be used for all forms of predator-related mortality (e.g., depredation and post-release predation); assessed risk can be different for depredation (i.e., drop-off mortality) and predation (i.e., release mortality).

Table A.14. Main sources of information and associated empirical results used to generate the mortality risk scoring criteria for predators. These criteria were derived from information sources collected in the factor analysis repository (Chapter 2) and the mortality evidence catalogue (Chapter 3), as well as unpublished data. All references to chapters are in Patterson et al. 2017.

Information Source	Empirical Result
Diewert et al. 2002	summary of information to estimate encounter rate of predators for recreational troll fishing
French and Dunn 1973	estimates of depredation rates for gill nets marine linked to predator observation and loss evidence
Gilhousen 1989	estimates a 25% escapee wounding rate for troll fisheries using
Nagasawa 1998	impact of salmon sharks on ocean mortality of Pacific Salmon, fisheries catch of salmon sharks synchronized with those of salmonids
Raby et al. 2014b	review of the importance of predation in assessing the mortality of fish released from fishing gear
Thompson et al. 1971	evidence of depredation rates from sockeye caught in gill nets

Table A.15. A list of factors, with associated rationale, that have the potential to modify the likelihood of predation. This will assist in estimating the predator score. See the factor analysis for more details (Section 2). All references to section numbers are in Patterson et al. 2017.

Predator experience

Modifying Factor	Rationale
bait	act as an attractant
capture time	increased exposure for gill net and hook; increased duration will increase severity of fish response
catch size	predator saturation with larger catch size; evidence of impact in proportion to catch size
gear type	fish in gill nets or on hooks more vulnerable
handling	type and increased duration will increase severity of fish response
injury	predator attractant
species	predator choice and preference, e.g., large Chinook
water temperature	can change predator species composition

A.6 REFERENCES FOR SCORING TABLES

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APPENDIX B: SCORING NOTES FOR VALIDATION STUDIES

A single researcher that was involved in all twelve pilot studies was primarily responsible for summarizing the available information on each of the key risk factors used to estimate overall mortality risk. For each study, the mean scores for each of the risk factor were generated using information recorded in field notes during each study. Additional information was based on memory and judgement on the part of the researcher. The fact that the scoring tables were designed to assess the mortality risk associated with normal fishery operations, not research studies, did pose some challenges. Although each of the studies were conducted under conditions that were similar to many aspects of a normal fishery (e.g., gear, method, and location), there were a few notable differences in the 'fishing operations' (e.g., biopsy/tagging, net pen holding, and capture simulations) that required modifications to the application of the risk scoring tables. In all cases, the default was to refer to the main fish response features that each of the risk scoring factors were designed to represent. The following provides more detailed information and points of clarification for scoring the pilot studies used in the validation (see Section 2.3). It should be repeated that the purpose of this validation was to assess the confidence of the risk assessment approach, and not to come up with a definitive relationship between mortality risk scores and FRIM rates for use in management. More information on the rationale behind the scoring of each of the key risk factors is available in Appendix A and Patterson et al. (2017).

Capture: This key risk factor is scaled to time to account for the duration of stress associated with the capture process (see Table A.1). More specifically, the physiological stress of gear interaction, the influence of exhaustive exercise associated with fight and flight responses, and the confinement stress from the time the fish encounters fishing gear until the fisher has complete control over the fish.

Research studies: Capture times were recorded to the nearest minute for all capture events. The minimum, maximum, mean, and median capture times were calculated for each study. The median value was used to assess the duration of the capture process. However, additional capture time was incorporated for all studies to account for pre-tag holding periods. Holding periods were reported for all studies, and the median value was calculated. The added mortality risk associated with the pre-tag holding was added to capture time, not handling time, because the time spent in a holding net is more akin to confinement stress in a seine net or a trap than it is to direct handling in water or air. The decision to use either seine or trap capture time values was based on whether the holding environment was judged to be more similar to that of a seine or trap fishery. As an example, fish held at Seton dam were captured in large weir traps prior to being dip netted. The addition of holding time to the capture time is an artefact of the research studies and it is not expected to play a role in assessing the mortality risk of normal fisheries.

Handling: This key risk factor is scaled to account for the duration of stress associated with handling (see Table A.4). The main stressors that are experienced by fish during handling include air exposure, fisher handling, sorting gear, and crowding (i.e., continuous and direct contact with gear and/or other fish). Each of these stressors increase the probability of severe exhaustive exercise due to attempts to avoid air exposure or physical interaction. Air exposure time and handling time in water are used as proxies to estimate the physiological stress of handling. The greater of the two proxies is used to assess the mortality risk level for a given fishery.

Research studies: The handling times for all studies, except the two capture simulation studies, were similar given that they were designed to minimize the handling time when collecting biosamples from fish (e.g., scale, DNA, biopsy), recording information on fish condition, applying radio tags to fish, and releasing tagged fish. For the ten non-simulation studies, the total air exposure time associated with the fish transfer and tagging was estimated to be between 10s and 1min, and the total in-water handling time was estimated to be between 3 and 6min; these times include all handling associated with net transfers, tagging, and fish condition assessments. These median air exposure and in-water handling times both equate to an overall risk score of 2. For the two simulation gill net studies, the incremental handling time associated with the simulation was added to handling, not capture. This reflects that the investigator(s) were directly handling or in very close proximity to the study fish (i.e. not a normal capture event during the handling event, in contrast to simply being confinement in a holding pen). This added handling time in water created a total time of 10 to 20min and thus, a risk score of 3 was applied.

Injury: This key risk factor is scaled to account for the influence of observable injury and associated vulnerability to infection on mortality risk (see Table A.7). The scoring of this information represents a challenge to any fishery expert or researcher because of the lack of survey information.

Research studies: To determine the median injury risk level for each of the pilot studies, the researcher relied on matching field notes to the injury scoring table. The field notes included injury information on the following: overall injury (none, minimum, moderate, and severe); percent scale loss (nearest 10%); percent skin loss (nearest 10%); percent fungus (nearest 10%); eyes (number lost); fin damage (number of fins damaged and severity); vent wound; general wound depth (1 to 4 scale); gill damage (0 to 3 scale); old wound (yes/no); and general comments related to injury. Not all injury metrics were recorded for all fish, but all fish did have an overall injury report and individual comments regarding notable injuries. From this information, an overall injury value was estimated for each fish using a scale of 0 to 3, and for each study, the minimum, maximum, median, and mean scores were calculated. A comparison of the injury information recorded from the studies with the injury risk scoring table was then conducted to generate the best comparison of the field information to the six levels in the table. This did require some judgment on behalf of the researcher given that not all injury information is common across both sets of injury forms used. While attempts were made to reduce this subjectivity, we do acknowledge that there were challenges with comparing injury scores from the two different scaling systems. This will contribute to the overall uncertainty in assessing the mortality risk from injury.

Water temperature: This key risk factor is scaled to account for the incremental effect of thermal stress on FRIM above natural mortality associated with water temperature. The table is scaled to account for the influence of warm water temperature on mortality risk via the acute physiological stress of exhaustive exercise at high temperatures and the increased risk of infection and cumulative stress leading to disease and higher mortality risk (see Table A.10). To scale for the mortality risk, the mean water temperature a fish is expected to experience over 72 hours after capture is used.

Research studies: Daily mean water temperature information collected by either DFO's Environmental Watch program or Environment Canada's water survey unit were used to estimate the 72 hour mean water temperature exposure for the fish in the twelve pilot studies (Patterson et al. 2007a). The temperature stations used include the Fraser River at Hope, Seton River at Seton Dam, Chilliwack River above Slesse Creek, and Thompson River at Ashcroft.

Predators: This key factor is scaled to account for the incremental impact of predators associated with fishing activity on mortality risk. Predation risk is assessed based on a combination of direct evidence of predation within a fishery and evidence of predator abundance (see Table A.13).

Research studies: The major predator for the fish targeted in these twelve studies was assumed to be seals. Seals are present in all mainstem locations of the Fraser River below Hells Gate. However, there was no direct evidence of depredation or post-release predation reported in any of the studies. Therefore, the evidence of seal presence and/or expectation of their presence was used to give a score of 2 for all mainstem Fraser River locations. A score of 1 was applied to all other locations (i.e., Seton, Savona, Chilliwack; see Table 3) because of the lack of indirect signs of predation and the lack of expectation of large predators.