The biological and social sciences of improving post-release survival in sockeye salmon following fisheries interaction in the lower Fraser River, British Columbia

By

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Dedication

I dedicate this work to my family for all their love, understanding, encouragement, and support for the decisions I have made so far. To my friends, who have introduced me to various aspects of life, and have helped me become who I am today. Dedication to all those who has been part of my decision-making committee, without you guys I would be lost. To Pete, for always being supportive and understanding, and giving me excuses to leave the country! To Cassone, for always being there to have Tim Horton's coffees and lunches in Nesbitt. To my friends back in England, you have given me an experience of a lifetime throughout my studies and provided me with new perspectives, memories and culinary skills. To the Cooke and Hinch Lab: thanks for the experiences, friendships, the wisdom, the unforgettable memories in Ottawa and BC, the Vindian title, some for being awesome interviewers, and for the great laughs (and the few awkward moments). To the Cultus Lake inhabitants, thanks for putting up with my cooking, snoring, 3-h long phone conversations, and much more. To Murray, for his patience, knowledge, guidance, and for the inspiring pub chats with a good pint in hand. To my advisor Steve, for his dedication, guidance, enthusiasm, and always believing in me; for providing me with endless opportunities over the past four years, for being patient with my decision-making skills, and for the enormous support.

Abstract

Fisheries bycatch problems have traditionally been explored using biological knowledge. However, social factors are often the primary determinants of a conservation success or failure. I investigated both the biological and social factors associated with Pacific salmon bycatch and fisheries interactions in the lower Fraser River, British Columbia. In Chapter 2, the relative consequences of injury, stress and facilitated recovery on migratory behaviour and success of sockeye salmon were assessed, and injury appeared to have a greater effect on fish. In Chapters 3 and 4, I used face-to-face interviews to collect information about recreational salmon anglers' attitudes, beliefs and behaviours relevant to salmon conservation and management. The latent-class models revealed a high degree of heterogeneity among salmon anglers; therefore, I recommend more nuanced approaches to management strategies. The interdisciplinary approach adopted here provided novel insight into bycatch management. Hence, I suggest that future bycatch-related studies combine biological and social sciences.

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Co-Authorship

Chapter 2: The roles of air-exposure, injury, and facilitated recovery on the post-release survival and behaviour of adult migratory sockeye salmon in freshwater fisheries. V.M Nguyen, E. G. Martins, G. D. Raby, M.R. Donaldson, A.G. Lotto, D.A. Patterson, D. Robichaud, A.P. Farrell, W.G. Willmore, S.G. Hinch, and S.J. Cooke

While this study is my own, the research was undertaken as part of a collaborative effort and each co-author played a valuable role in its completion. The project was conceived by Nguyen, Donaldson, Patterson, Hinch, and Cooke. Fieldwork was completed by Nguyen, Raby, Donaldson, Lotto, and Patterson, and laboratory tests were conceived and performed by Patterson and his group. All computer and data analysis was conducted by Nguyen and Martins. Data were interpreted by all authors. Telemetry tracking was conducted by Robichaud. All writing was conducted by Nguyen. All co-authors provided comments and feedback on the manuscript.

Chapter 3: Recreational anglers' attitudes and behaviours relevant for Pacific salmon conservation and management in British Columbia. V.M. Nguyen, M.A. Rudd, S.G. Hinch and S.J. Cooke

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Chapter 4: Recreational anglers' attitudes and behaviours relevant for Pacific salmon conservation and management in British Columbia. V.M. Nguyen, M.A. Rudd, S.G. Hinch and S.J. Cooke

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Glossary

A: Air exposed

BC: British Columbia

C: Captured-only

DFO: Department of Fisheries and Oceans Canada

FAO: Food and Agricultural Organization

HC: Head complex

I: Injured

IA: Injured + Air exposed

LC : Latent class

OR: Orientation

PSC: Pacific Salmon Commission

TG: Tail grab

VOR: Vestibular-ocular response

Chapter 1: General Introduction

The capture of non-target organisms as “bycatch” is one of the most significant issues affecting fisheries management today, and can create a conservation problem when endangered species are affected or when the level of take is not sustainable for non-target species (i.e. unintentional catch) (Alverson *et al*. 1994, Hall *et al*. 2000, Kelleher 2005, Davies *et al*. 2009). Bycatch issues are especially significant in mixed-stock fisheries, where various stocks and species co-mingle, making it challenging for managers to protect the weaker fishes while keeping fisheries open. The British Columbia Pacific salmon fishery, along with many other fisheries worldwide, have adopted a selective fishing approach to address this predicament by mandating the live-release of non-target species and the modification of fishing gears that allow non-target species to escape (DFO 2001). Still, all captured fish will interact with fishing gear and sustain varying degrees of injury and stress (e.g. Chopin & Arimoto 1995, Davis 2002). Although the intention is for released fish to recover and reproduce, there is evidence that fish can die directly from physical damage and stress (Davis 2002), and that fish exhibit indirect or delayed mortality due to reduced capacity to escape from predators or resist disease (Bartholomew & Bohnsack 2005). Moreover, fish can experience impaired growth and reduced reproductive capacity as a result of severe stress and damage from fishing gear interactions.

The severity of injury and stress (e.g. Davis 2002, Bartholomew & Bohnsack 2005, Cooke & Suski 2005), and the capacity for fish to recover (e.g. Milligan 1996, Farrell *et al*. 2000, 2001a, b) ultimately dictates the fate of caught and released fish. In turn, the effects of injury, stress, and recovery capacity are influenced by: 1) non-human factors including environmental conditions, fish characteristics, and fishing gear, and 2) human behavioural factors including handling, release and revival techniques. These factors can affect the physiological condition and behaviour of released fish, which can be investigated through biological studies. However, improving fish condition upon release can only be achieved through altering human behaviour and actions which can be investigated through social research. Mascia *et al*. (2003) noted that, “the disconnect between our biological knowledge and conservation success has led to a growing sense among scientists and practitioners that social factors are often the primary determinants of success or failure.” Often, conservation interventions are the product of human decision-making processes and require changes in human behaviour to succeed (Jacobson & McDuff, 1998, Mascia *et al*. 2003, Arlinghaus 2006, Fox *et al*. 2006). Therefore, my thesis adopts a holistic and integrated approach in that it is an investigation of both biological and social factors associated with a pressing conservation problem, more specifically the issue of Pacific salmon bycatch in the lower Fraser River, British Columbia, Canada.

The Fraser River is one of the most productive salmon fisheries in the world with significant importance to the regional and national economy. Here, three fishing sectors (commercial, recreational and First Nation) target salmon in coastal and inland waters of the Fraser, resulting in social, cultural and political pressure in addition to economic and ecological demands. As such, salmon fisheries managers must consider the social, economical, political impacts of their decisions and so should research.

Research Objectives

The overall objective of my thesis is to explore ways to reduce salmon bycatch mortality through investigating mechanisms of delayed mortality detailed in Chapter 2 and understanding fisher behaviour and attitudes relevant to salmon bycatch detailed in Chapters 3 and 4. The lower Fraser River, British Columbia, Canada is used as a common study area for all three chapters. In Chapter 2, I investigate the relative consequences of injury and fisheries-related stress using an experimental approach, coupled with gastric radio tagging, reflex assessments, physiological sampling, and telemetry tracking of post-release migration success in sockeye salmon. The secondary objective of chapter two was to test whether facilitated recovery tools could improve post-release outcomes for captured fish exposed to varying degrees of stress and injury.

In Chapters 3 and 4, I use the Fraser River sockeye salmon recreational fishery as a case-study to understand attitudes and beliefs that can be important for successful fish conservation through facilitating "responsible fishing" (FAO 1995) that minimizes risk to vulnerable non-target species and stocks. Specifically, I investigate the relationship between angler attitudes and conservation using latent-class modeling to characterize diversity among Fraser salmon anglers with regards to their: 1) fishing practices; 2) perceived threats to successful salmon upstream migration; 3) perceived risks to post-release survival of angled vulnerable fishes; 4) support for angler education programs on responsible fishing practices, and lastly, 5) communication preferences, which are explored in Chapter 3. Understanding angler response to environmental change, and to management actions to address those changes, is crucial in the Fraser watershed, as it is in many freshwater ecosystems around the world. To date, however, there are exceedingly few examples of integrative studies that combine both biological and human dimensions research to address conservation problems.

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Chapter 2: Disentangling the roles of air-exposure, injury, and facilitated recovery on the post-release mortality and behaviour of adult migratory sockeye salmon in freshwater fisheries

Abstract

We sought to improve the understanding of delayed mortality in sockeye salmon (*Oncorhynchus nerka*) captured and released in freshwater fisheries using telemetry, physiology, and reflex assessments. Specifically, we evaluated the relative roles of gillnet injury and air exposure, and investigated whether facilitating physiological recovery with a specially designed recovery box can improve survival. Fish (*n*=238) were captured by beach seine, and allocated to four treatment groups, *Captured-only* (C), *Air exposed* (A), *Injured-only* (I), and *Injured + Air exposed* (IA). Half of the fish in each group were provided with a 15-min recovery box treatment. After treatment, fish were radio tagged and released to resume their migration. An additional 36 untagged fish were captured, subjected to the same treatments and blood sampled 15-min post-treatment. Plasma lactate and cortisol concentrations were elevated for all treatment groups, relative to a subset of fish blood sampled immediate upon capture. Osmolality concentrations were highest for the two air-exposed groups (A and IA). Moreover, these same two air-exposed groups showed significant reflex impairment relative to C and I fish. Gillnet injury significantly reduced the overall mean migration speed of tagged fish. The differences in post-release survival of sockeye among treatment groups were generally consistent with expectations; the two injury groups (I and IA) had the lowest overall survival over ~145kms**.** Interestingly, there was no significant change in survival

associated with 15-min facilitated recovery, despite the improved reflex actions of recovered fish relative to fish released immediately. We suggest that injury and air-exposure both have sub-lethal consequences which can lead to delayed mortality, but during the cool water temperatures (13.2-15.6ºC) experienced in the current study, their effects on survival were small. Future studies on by-catch mortality should vary air-exposure times and the degree of injury across a range of temperatures to better understand the mechanisms that contribute to post-release mortality.

Introduction

Mixed-stock fisheries can operate under a selective fishing policy to allow the harvest of abundant species or stocks while protecting the vulnerable ones. Such protective management approaches include spatio-temporal closures, gear restrictions or modifications that reduce bycatch, or live-release of non-target species (i.e. discarding). A variable proportion of discarded fish may die or sustain serious behavioural or reproductive impairments (e.g. Chopin & Arimono 1995, Campbell *et al*. 2010). Losses from delayed mortality and reproductive failures go unobserved and are often unaccounted for, potentially causing significant uncertainties in mortality estimates and management models (e.g. Chopin & Arimoto 1995, Baker & Schindler 2009, Raby *et al*. 2012), and potentially increasing cryptic fishing mortality to unsustainable levels (Coggins *et al*. 2007).

Fish exposed to fishing gears may experience physical injury, physiological stress and exhaustion, and latent susceptibility to infections and diseases (e.g. Neish 1977, Pickering & Willoughby 1982, Pickering & Duston 1983, Davis 2002, Baker & Schindler 2009, Ingerslev *et al*. 2010). Physical damage from capture gear and inappropriate handling and release practices involve some degree of internal and external injuries that vary with gear type, and range widely in level of immediate severity (e.g. mucous and scale loss, wounding, crushing, net marks, abrasions, fin tear and loss, bleeding, barotrauma). Injury can also cause stress (e.g. through blood loss or problems with water balance) or serve as an entry point for pathogens. Components of the capture experience that result in physiological stress include, but are not limited to, handling, exercise, crowding, air exposure, and warm temperatures. The physiological stress resulting from capture can result in immediate (at time of capture) mortality or make fish susceptible to post-release predation or fallback (i.e. downstream movement of fish), and suppress immune function, leading to delayed mortality (Davis 2002, Lupes *et al*. 2006). Specifically, air exposure causes gill lamellae to collapse leading to severe anoxia and major physiological changes such as acid/base and cardiac output disturbances (Ferguson & Tufts 1992, Cooke & Suski 2005). To date, there has been relatively little direct examination of the consequences of injury on discarded and escaped fish (e.g. Davis 2005, Davis & Ottmar 2006, Baker & Schindler 2009), in contrast to a fairly extensive range of studies that measure capture stress (e.g. Davis & Olla 2001, 2002, Parker *et al*. 2003, Mandelman & Farrington 2007, Campbell *et al*. 2010, Raby *et al*. 2012). Furthermore, to our knowledge none have attempted to compare the relative impacts of injury and air exposure stress on delayed mortality. Such information could be useful for shaping management strategies for reducing post-release mortality in fisheries.

Of further interest to fisheries managers and scientists is the possibility that tools could be developed that facilitate metabolic recovery of fish from capture and prevent (or reduce) post-release mortality. Recovery tools have been developed with coho salmon (*Oncorhynchus kisutch*) in British Columbia (Canada) in the last decade (e.g. Blewett & Taylor 1999, Buchannan *et al*. 2002, Farrell *et al*. 2000, 2001a, b) as an initiative undertaken as part of British Columbia's selective fishing policy. Farrell *et al*. (2001a) demonstrated the possibility that lethargic or seemingly moribund coho salmon captured in marine fisheries can be revived using a specially designed box (known as a 'Fraser box') that holds fish into flowing water to provide gill ventilation. As a consequence, commercial fishing vessels are now required to carry and use a Fraser box with the aim to increase post-release survival. Despite positive results using Fraser boxes, they have only been tested in marine waters thus far, which may not reflect the nature of stressors during the in-river phase of migration (e.g. pathogens, water temperature, and osmotic pressures). It is also unknown whether facilitating recovery could benefit physically injured fish since there has only been evidence of metabolic recovery of exhausted fish to date (Farrell *et al*. 2001a, b). Lastly, survival benefits documented in previous work (Farrell *et al*. 2001a) relied on the use of net pens over a short time period; therefore an opportunity exists to address whether the Fraser box would be successful in physiologically recovering salmon caught in freshwater fisheries using more long-term assessment techniques, such as radio-tracking to investigate whether delayed mortality occurs (Donaldson *et al*. 2008).

In this study, we examined sources of fisheries delayed mortality in relation to three factors that have been documented to influence post-release behaviour and mortality in fish: physiological exhaustion (stress through air-exposure), physical damage (via gillnet entanglement), and facilitated recovery (using Fraser boxes). We used sockeye salmon (*Oncorhynchus nerka*) in the lower Fraser River as a model for this research. The study was designed to simulate gillnet fisheries because high levels of delayed mortality may have important harvest management in exploited and non-target salmon populations. Our primary objective was to distinguish the relative consequences of physical injury and air exposure stress using an experimental approach coupled with reflex assessments, physiological sampling, and telemetry tracking of post-release migration success. Specifically, we use reflex and physiological assessments to characterize the relative impacts of our experimental treatments. Our secondary objective was to test whether Fraser recovery boxes could reduce delayed mortality and improve migration speed for captured fish exposed to varying degrees of stress and injury.

Materials and methods

Study area and fish capture

Sampling occurred over three days (September 14, 15 and 17th, 2010) at Gill Road fishing bar located near Rosedale, on the south shore of the lower Fraser River, British Columbia (Fig. 2-1) at cool river temperatures (13.2-15.6ºC). Sockeye salmon were captured using beach seine nets (described in Donaldson *et al*. 2011). The fish-filled seine net was maintained in sufficiently deep water to minimize physical and physiological disturbances. All fish were subsequently transferred to two large in-river net pens (4 m x 4 m x 3 m) for holding using soft knotless nylon dip nets, which took up to 15 minutes from the start of the net set (when net was released into the water) until the last fish was transferred into the net pens. Fish were held in pens because only two to three fish could be processed at a time due to logistical limitations, and two net pens were used to minimize the crowding of fish during the holding period. Fish were held in net pens between 0-5 hours (mean time: 1h21 ± 1h25) and all remaining fish that were not sampled were released. We recognize that a net pen effect could be present (Portz *et al*. 2006), but it would have minimal effect on fish condition relative to the experimental treatments (see below). Additionally, the number of fish caught in each seine set was unpredictable and fishing days were limited; we thus held fish in net pens to ensure sufficient sample size. Individuals captured with injuries and/or visible infections were excluded from the study.

Experimental Treatments

Fish were randomly selected from net pens and subjected to experimental manipulations to simulate capture stress and injury according to four treatments groups (Table 2-1): a. *Captured-only* (C; *n*=54), a 'low stress, low injury' group where fish were captured by beach seine, handled, but were not subjected to any additional experimental manipulations; b. captured and *Air exposed* (A; *n*=55), a 'high stress, low injury' treatment that simply consisted of handling and 2-min air exposure; c. captured and *Injured-only* (I; *n*=56), a 'low stress, high injury' treatment where fish were handled and entangled in gillnet for approximately 30 s, and; d. captured and *Injured + Air exposed* (IA; *n*=56), our 'high stress, high injury' group where fish were handled, and subjected to gillnet injuries (~30 s) and exposed to air (2 min). All individuals were measured (fork length; FL to the nearest cm). Additionally, a subset of each treatment group was subjected to a 15-min recovery period (total *n* = 111, see below).

Air stress treatment **–** The 'high stress' treatment involved two minutes of air exposure in black Hypalon fish bags - which minimized physical damage. By exposing fish to air we elicited a secondary stress response, a common component of fish capture, particularly when fish are being sorted and/or disentangled from netting, which can last from a few seconds to greater than 60 min for large catches.

Injury treatment - Fish were injured using multifilament gillnet material of 5.25-inch mesh size mounted on a hand-held dip net frame. This type of net and mesh size is widely used for sockeye commercial gillnet fishing in British Columbia. Fish were tangled and disentangled approximately 30 s while submerged in a perforated plastic tub (Rubbermaid 151L, 36.89 x 21.25 x 18.61 inches) placed in the river allowing fresh river water to pass through the tub throughout the treatment. If the entanglement period was longer than 30 s, the net was cut to disentangle the animal and maintain consistent entanglement duration among treatments and minimize exhaustive stress relative to the air exposure treatment. Following entanglement, sockeye were examined for severity, location and type of injuries that were inflicted from the experimental injuring procedures. Injuries were categorized as: i) minor injuries, which consisted of fish with very faint net marks and minimal scale loss (<5%); ii) moderate injuries, which included visible and shallow net marks and 5-20% scale loss, and; iii) severe injuries, which included deep and dark net marks and >20% scale loss. Any bleeding from the gills was considered a severe injury. Location of injuries comprised of the mouth, nose, head, occiput, body, and fins; whereas types of injuries consisted of scale loss, net marks, bruising, bleeding and fin tear. Prior to sampling, a pilot study was conducted with 6 sockeyes to ensure that the injuring procedures were quick and easy enough to minimize stress. We tested various gillnet materials, mesh sizes, and time lengths for the injuring process. It is worth noting that it was not possible to induce injury without also causing some level of stress while retaining and handling fish but we believe that level of stress to be less than that obtained during the air exposure in the high stress treatment.

***Recovery treatment* -** A subset of fish from each of the four treatment groups was exposed to a 15-min recovery treatment using a Fraser box. Functionally, Fraser boxes assist gill ventilation by jetting river water aimed towards the mouth of the fish (at 0.6 L s^{-1}, following Farrell *et al*. 2001a). Fraser boxes were constructed following the blueprints for those currently utilized in marine fisheries. Each Fraser box consisted of a 40 x 40 x 90 cm black wooden box with a centre divider that allowed fish to be placed on both sides, a fastened lid to prevent fish from escaping, and a water inflow and outflow on each end of the channel (Blewett & Taylor 1999, Farrell *et al*. 2001a). Boxes were made of plywood and painted black to minimize sensory stimuli and disturbance. Our only modification to the Fraser box was the elimination of the rubber chute for releasing fish back into the water without handling. Instead, a runner quickly dip netted the fish and ran it back to the river with minimal air exposure (<10s).

Tagging procedures

Following each experimental treatment and prior to any recovery, sockeye were gastrically implanted with coded radio transmitters using established methods that have previously been validated for migratory salmon in the Fraser River system (Cooke *et al*. 2005, 2006, , Donaldson *et al*. 2010a, 2011), and technology described in Donaldson *et al*. (2010a, 2011). A yellow spaghetti tag (Floy Manufacturing, Seattle, WA) was inserted into the dorsal musculature adjacent to the dorsal fin for visual identification if fish were recaptured in fisheries, and a 0.5 g DNA adipose fin clip was taken for stock identification. The DNA clip was not used in this study as telemetry results as well as parallel stock assessment activity by management agencies indicated that the majority (i.e. > 95 %) of sockeye in the river at sampling time were Adams-Shuswap stock (Pacific Salmon Commission, unpublished data).

Physiological sampling

An additional 36 untagged fish were sampled for physiological assessment to minimize the added handling. We aimed to use this information to characterize the differences in physiological disturbances that occur during an air exposed event compared to a gillnet injury. For logistical and opportunistic reasons, physiological sampling occurred on the Harrison River at the Chehalis park site from September 20-24, 2010, during a separate study (near Harrison Confluence receiver, Fig.2-1). We replicated the experimental treatments (C, A, I, IA), and additionally sampled fish immediately and directly from the seine net, which we used as a baseline group (B). All fish were held in the recovery boxes for 15-min prior to physiological non-lethal sampling (as per Cooke *et al*. 2005). Because physiological blood variables have delayed responses (e.g. Barton 2002, Cook *et al*. 2011), we used this approach in attempt to obtain physiological values that were reflective of the treatments. Following treatment and recovery, individuals were placed in supine position, submerged in a V-shaped trough that was manually supplied with fresh river water for non-lethal blood sampling (as described by Cooke *et al*. 2005). A rapid 1.5-mL blood sample was taken using caudal venipuncture with a vacutainer syringe (3mL, lithium-heparinized vacutainer, 38mm, 21-gauge, 1.5” needle). Plasma was separated via centrifuge for 5 min at 10,000 g (Compact II Centrifuge, Clay Adams, Parsippany, NJ) prior to being frozen in liquid nitrogen in the field and then eventual storage in an ultra-cold -80ºC freezer at the laboratory. Assays were conducted at the Department of Fisheries and Oceans West Vancouver Laboratory based on procedures described in Farrell *et al*. (2001b) and Donaldson *et al*. (2011), and included plasma cortisol, ions (K^+, Cl^- and Na^+), glucose, lactate and osmolality.

Reflex assessments

Reflex Action Mortality Predictors (RAMP) was used in this study to characterize fish vitality in response to our capture simulation treatments. RAMP involves testing fish for reflex impairment, where reflex impairment is defined as any decrease or complete inhibition of normal baseline reflex action (Davis & Ottmar 2006). We used reflex actions adopted for coho salmon (Raby *et al*. 2012) which were modified from previous RAMP studies (Davis 2005, 2007). Five reflexes were tested (in < 15 s) after experimental treatments and tagging procedures, and each reflex was recorded as present (unimpaired) or absent (impaired). Fish were tested in order for: 1) Body flex (BF), where fish were restrained by holding the body out of water with two hands and observed for signs of vigorous whole-body response to restraint (~3 s); 2) Tail grab (TG), where the fish’s tail was grabbed while in water, inside a fish bag and observed for startle or burst-swim response; 3) Vestibular ocular response (VOR), where fish were rotated out of water on a body-length axis and noted for presence or absence of the eye rolling and tracking the handler; 4) Head complex (HC), for which fish were held out of water and examined for a pattern of regular ventilation, and; 5) Orientation (OR), which was conducted upon release by turning each fish upside-down just below river surface and observing if it re-equilibrated itself within 3 s. RAMP for each fish were cumulated into an index score, where RAMP score = reflexes impaired / total reflexes tested, which represents the proportion of reflexes impaired out of the 5 reflexes tested and ranged from 0.0 – 1.0, where 0 = no impairment and 1 = all reflexes impaired (Davis & Ottmar 2006, Davis 2007).

Telemetry and determination of survival and migration rate

To assess survival and behaviour of released fish, twenty one fixed radio-telemetry receiver stations strategically placed in the Fraser River Watershed (Fig. 2-1) were used to track tagged fish up to the Thompson Confluence (as described by English *et al*. 2005, Robichaud & English 2006, 2007, Donaldson *et al*. 2011). Detection of tagged fish at a fixed station receiver indicated fish survived to that point; however, failure of detecting individuals at subsequent receivers was termed en-route mortality (Robichaud & English 2006, 2007). Individuals that were reported as fisheries harvest were excluded from our study. We evaluated survival and migration behaviour (mean migration speed) of fish reaching Hope (~38 river km upstream from release site) to assess 24-48hr mortality and behaviour, and to the Thompson River confluence (~145km upriver from release site) to assess long-term (~ 7 days) survival and behaviour. Overall mean migration speed (km d^{-1}) was calculated from Release site to the Hope and the Thompson confluence using calculations described by Donaldson *et al*. (2011). We also examined specific migration rates for each reach between fixed receiver stations (Fig.2-1): Hope to Qualark (15km), Qualark to Sawmill (14km), Sawmill to Hell's Gate (22km), Hell's Gate to Thompson confluence (56km); however, we excluded Rosedale to Hope (38km) due to poor receiver detection rates.

Statistical analysis

Homogeneity of variance on migration speed, physiological and covariate metrics among treatments was assessed using Levene's test. These variables were subsequently $\log_{10}$ transformed to reduce heteroscedasticity where necessary. A one-way analysis of variance (ANOVA) was used to check for among-treatment differences in fish size (fork length) and time held in the net pen. Using a Bonferroni corrected alpha level of 0.007, one-way ANOVA was also used to test for differences in plasma lactate, glucose, ions, osmolality and cortisol variables among the five treatment groups (i.e. B, C, A, I, IA). Subsequently, Tamhane post-hoc tests were used for variables that did not meet the assumption of equal variances (even after transformations) and Tukey-Kramer post-hoc tests were used for all other variables. Because RAMP scores are ordinal in nature, the nonparametric Kruskal-Wallis ANOVA was used to compare RAMP score among non-recovered treatment groups followed by Mann-Whitney U post-hoc tests, while Wilcoxon Signed-Rank tests were used to compare RAMP score between fish immediately released versus those allowed to recover in a Fraser box.

A binary logistic regression model was used to test for the effects of stress, injury and recovery treatments on survival from Release to Hope and from Release to Thompson Confluence. In each analysis, the initial logistic model contained all three possible second-order interactions among variables. The interactions were sequentially removed if not significant (i.e. backwards selection) until only the main effects remained in the model. Finally, a three-way ANOVA (Bonferroni-corrected $\alpha = 0.01$) was used to test for differences among treatment groups in migration speed (km day^{-1}) for each reach between radio telemetry receivers until the Thompson confluence, and to assess overall short- (Release to Hope) and long-term (Release to Thompson) migratory behaviour (km day^{-1}) (Zar 1999). Binary logistic regression was done in R 2.14 (R Development Core Team 2011) and the remaining analyses were performed in PASW 18.0.

Results

Capture and experimental details

The average (± 1 SD) time required to remove fish from the net pen and conduct experimental procedures including treatments, gastric tagging, measuring fork length, inserting spaghetti tag and performing RAMP was 3.7 ± 1.2 min for *Captured-only* fish, 5.5 ± 1.5 min for *Air exposed* fish, 5.1 ± 1.7 min for *Injured-only* fish, and 6.9 ± 2.0 min for *Injured + Air exposed* fish (Table 2-2). Covariates were similar among treatment groups (fork length, ANOVA log transformed: $F_{7, 238}$= 0.292, p = 0.956 and time held in net pen: $F_{7, 237}$ =0.406, p = 0.898; Table 2-2).

Physiological variables

Significant differences were detected among groups for plasma cortisol ($F_{4, 38}$= 16.09, p < 0.001), lactate ($F_{4, 38}$= 28.76, p < 0.001), and osmolality ($F_{4, 38}$=6.66, p = 0.001), but there were no among group differences for Glucose, Cl^-, K^+, and Na^+ (Table 2-3). Relative to baseline values from fish sampled immediately, all individuals had significantly elevated plasma lactate, and all, except the injured group, had significantly elevated plasma osmolality. On average, I, IA, and A fish had significantly higher elevated plasma cortisol concentrations relative to the baseline group; however similar plasma cortisol levels were found between C and IA fish (Table 2-3).

Reflex Impairment

We detected significant differences between RAMP scores among groups that were not recovered ($H_3 = 23.09$, $p < 0.001$, $n = 247$) with the lowest mean rank of 86.04 for the *Captured-only* (C) and highest mean rank of 137.14 for group *Injured + Air exposed* (IA) fish , where C and I groups had similar RAMP scores, while A and IA groups were similar (Fig.2-2). Results indicated that reflex impairment decreased significantly following 15-min in the Fraser box across all treatment groups (*Captured-only*: $z = -3.63$, $p < 0.001$, $n = 26$; *Air exposed:* $z = -3.89$, $n = 28$, $P < 0.001$; *Injured-only*: $z = -3.79$, $p < 0.001$, $n = 26$; *Injured + Air exposed*: $z = -3.29$, $p = 0.001$, $n = 24$; Fig. 2-2).

Behaviour

No interactions among injury, air exposure stress and recovery treatments were detected in migration speed (km day^{-1}) for the reaches of interest and for overall mean migration; they were removed from the analysis. Migration rates among specific reaches between receivers were similar for all tagged fish (Fig. 2-3). Migration speeds from Release site to Hope did not vary significantly between air-exposed fish ($F_{1, 86} = 3.04$, $p = 0.83$) and recovered fish ($F_{1, 88} = 3.61$, $p = 0.59$); however, all fish injured with gillnet mesh differentiated significantly ($F_{1, 87} = 16.15$, $p < 0.001$), with slower migration speeds (mean ± SD) for fish subjected to gillnet injury (17.9 ± 5.4 km day^{-1}) than those that were not subjected to gillnet injury (21.3 ± 5.6 km day^{-1}; Table. 2-2). Similarly, injury-treated fish were significantly slower ($F_{1, 69} = 5.34$, $p = 0.02$) in their long-term migration speed to Thompson (18.0 ± 4.2 km day^{-1}, *n* =120) than those that were not subjected to injury (19.5 ± 3.5 km day^{-1}, *n* = 118; Table 2-2). Air-exposure stress ($F_{1, 72} =$ 2.13, $p = 0.15$) and recovery ($F_{1, 73} = 2.49$, $p = 0.18$) did not have statistically significant effects on long-term migration speed. The Fraser box facilitated recovery treatment demonstrated no statistically discernible benefit to migration rate (see Table 2-2).

Survival

Fifteen fish were captured in fisheries and were excluded from statistical analyses, resulting in a sample size of 206 tagged fish. A total of 15 individuals (6.6% of tagged fish) were never detected or reported as captures at up-river fixed station receivers and were considered en-route mortalities. Telemetry data revealed that 34 (15%) fish “fell back” (i.e. downstream detections of fish that did not resume upstream migration) and were considered en-route mortalities (Table 2-2).

No significant interactions were detected between the three effects (injury, air stress, recovery) on either short- or long-term survival (Fig. 2-4). We subsequently dropped the interactions and tested for main effects. There was no significant effect of injury ($z = 0.24$, $p = 0.81$, SE = 0.36), air stress ($z = 0.66$, $p = 0.51$, SE = 0.36) or recovery ($z = -0.54$, $p = 0.59$, SE = 0.36) on post-release survival to Hope (Fig. 2-4). Similarly, there were no significant effects of injury (z = -1.08, $p = 0.28$, SE = 0.28), air stress ($z = -0.27$, $p = 0.78$, SE = 0.28) or recovery (z = 0.35, $p = 0.73$, SE = 0.28) on survival to the Thompson Confluence (Fig. 2-4). However, non-significant trends show that both treatment groups that were subjected to injuries had approximately a 12-14% lower long-term survival rate (Fig. 2-4).

Discussion

Physiology

Relative to baseline values, the 3–fold and 10-fold increase in plasma lactate and cortisol levels for *air-exposed* and *injured-only* groups, respectively, combined with the elevated levels of plasma variables for both groups relative to simply handling alone (*captured-only* group), imply that both injury and air exposure are inherently and incrementally stressful to fish. Such stress can decrease their resistance to diseases and suppress their reproductive endocrinology and maturation process (Pickering 1993); therefore, potentially affecting long-term survival and behaviour. It also implies that our *injured-only* treatment was not a true isolation of injury and was paired with some physiological disturbances. Even though the objective of the *injured-only* treatment was to maintain a low level of stress (i.e. physiological disturbance), it was challenging to inflict injury without eliciting some degree of physiological response. With the gillnet entanglement approach, a commonly used capture method known for inflicting injury in adult sockeye salmon (Thompson *et al*. 1971, Baker & Schindler 2009), most fish struggled, which would elicit a physiological response reflecting anaerobic exercise as they attempted to burst swim to escape (Kieffer 2000). However, *injured-only* fish remained vigorous relative to both air-exposed groups, and displayed smaller change in mean concentrations of plasma osmolality (relative to *captured-only* fish). This suggest that the injury treatment was less intense and less disruptive to the ionic balance of salmon relative to other stressors; though it is unknown how severe our experimental treatment was relative to normal fisheries operations. This occurrence was also recorded by Farrell *et al*. 2001a where lethargic fish appeared to undergo a greater ion-osmoregulatory disturbance than vigorous fish. Nonetheless, a difference in sub-lethal effects was observed between our injury-only treatment and other stressors, which supports that our experimental treatments were physiologically different.

It was somewhat surprising that the combined injury and air exposure treatment showed similar cortisol values to captured-only fish given that the interaction of stressors are generally cumulative (e.g. Ferguson & Tufts 1992, Barton & Iwama 1991, Davis 2002, Gale *et al.* 2011). This could result from our relatively low sample size, and post-stress cortisol values for sockeye salmon known to peak at 25 min post stressor (Cook *et al.* 2011) could lead to variability in sampling. Sex and maturity level of salmon can also have significant effects on natural plasma cortisol levels, and could influence the variability of plasma cortisol levels measured in this study (Kubokawa *et al*. 2001, Robertson & Wexler 1960)**.** Even so, the cortisol values were statistically similar among the experimental treatments suggesting that all treatments elicited a stress response and physiological disturbance.

RAMP: characterizing reflex impairment of treatment groups

RAMP was developed as a rapid, simple and inexpensive tool to assess fish vitality and generate fisheries-induced mortality estimates (Davis 2002, 2005). Of late, it has also been validated in the wild as a predictive measure for delayed mortality in coho salmon caught in beach seine fisheries (Raby *et al*. 2012). Here, we used RAMP to characterize the relative vitality of our experimental manipulations and found that it was indicative of sub-lethal effects from air exposure but not from the injury-only treatment. Interestingly, it may suggest that RAMP does not capture sub-lethal effects from wounds and injuries, even with the evidence of physiological disturbance indicated by elevated plasma lactate and cortisol levels. It is also plausible that our injury treatment was not severe enough to cause immediate behavioural impairment, which supports our attempts in differentiating sub-lethal response of injury from air stress. Previous work have shown that reflex impairment is positively correlated with capture intensity (e.g. Davis 2005, 2007, Davis & Ottmar 2006, Humborstad *et al*. 2009, Raby *et al*. 2012); however, none have demonstrated a link between RAMP and consequences of physical injury. This is particularly important as wounds inflicted in fish during capture are highly variable and can be a major source of mortality for discards and escapees (Nelson *et al*. 1989, Trumble *et al*. 2000, Suuronen *et al*. 2005). In the case of migrating adult sockeye salmon, solely relying on RAMP to predict delayed mortality would not be sufficient as it does not appear to account for long-term consequences of physical injuries and the potential for infection (Pickering 1993, Pickering & Willoughby 1982). Quantitative indices for physical injuries in fishes have been developed and used in field settings such as visual assessments (e.g. Adams *et al*. 1993, Trumble *et al*. 2000, Davis 2005, Baker & Schindler 2009) or fluorescein, a non-toxic fluorescent dye used to rapidly and easily detect presence of skin ulcers and other lesions under ultra-violet light (Noga & Udomksomi 2003, Davis & Ottmar 2006). RAMP coupled with injury assessment could prove useful, but further research is required to investigate substitute measures for delayed mortality attributed to large range of physical injuries.

Survival

The trend in decreasing survival over distance reflects the natural mortality as fish reach natal sub-watersheds (e.g. English *et al*. 2005, Cooke *et al*. 2006, Martins *et al*.

2012). In this study, the mortality estimate caused by the experimental treatments (for non-recovered fish) based on our *captured-only* treatment values were negligible for *Air exposed* group and 13% for the *Injured-only* and *Injured + Air exposed* groups, respectively. These values are likely overestimated, as they do not account for unreported fisheries capture and natural mortality, which the latter have been suggested to be 5% for adult migrating Fraser River sockeye experiencing river temperatures similar to those of our study (Martins *et al*. 2011). Note, that this mortality estimate refers migration to spawning grounds (~ 488 km from river mouth), whereas our mortality rates refers to migration ~145km upstream from the release site so natural mortality in our study is likely less than 5%. Here, we consider our mortality estimates to be experimental and not necessarily representative of conditions that would be experienced in real fishing scenarios. For example, fish captured in a gillnet or seine net may be in the net for extended periods (e.g., > 30 minutes), and may also experience excessive crowding and hypoxia (e.g. Raby *et al*. 2012). Moreover, because our work was conducted in accordance with animal care regulations, we were especially careful with the removal of fish from fishing gear, which we have observed to be more injurious when done by actual fishers (personal observations). Because our work is the first to compare and contrast injury versus stress, there are no existing data to directly compare our findings. However, we use existing studies examining air exposure, exercise and physical injury, and the likely connection to infection, to discuss our findings.

There was no additional mortality attributable to air exposure at the cool temperatures used, similar to other studies (e.g. Schreer *et al*. 2005, White *et al*. 2008, Thompson *et al*. 2008, Gale *et al*. 2011). However, our study provides evidence for sub-lethal disturbances such as behavioural impairment or reduced migration speed in air exposed fish. A number of these cited studies examined the interaction of environmental stressors and exercise with air exposure. For example, Gale *et al*. (2011) observed no effects of exhaustive exercise in addition to 60 s of air exposure on the short-term mortality of sockeye salmon at three different temperatures (13, 19 and 21°C), but noted significant physiological disturbances and behavioural impairment (i.e. loss of equilibrium) of fish at warmer temperatures. Interestingly, the authors suggested that the low mortality rate can imply that Pacific salmon have the ability to recover from substantial (acute) instances of lactic acidosis in freshwater, confirming prior work on coho salmon (Farrell *et al*. 2001a,b) and in river work on sockeye salmon (Donaldson *et al*. 2010b). This ability to recover will be discussed in latter parts of this paper. The low mortality rate in our study could also suggest that at temperatures under 16°C, sockeye salmon can tolerate and compensate for oxygen debt and other physiological disturbances within two minutes of air exposure and brief exercise. Indeed, the optimal thermal migration window based on maximal aerobic scope (T-opt) is estimated at 16°C (Eliason *et al*. 2011) for sockeye salmon from the Adams-Shuswap complex, which likely comprised the majority of the fish used in this study.

Similar to previous work involving gillnet capture of salmon (e.g. Thompson *et al* 1971, 1973, Baker & Schindler 2009), our simulated gillnet injury showed that fish that experienced a modest 30 s gillnet entanglement had higher mortality to 145 km post-release. Interestingly, we noted that both our injury groups, with and without air exposure, had higher mortality, 13%, than the C and A groups to reach the Thompson Confluence. This suggests that injury played the primary role in causing delayed mortality. Furthermore, mortality estimates by Van der Haegen *et al*. (2004) for adult Chinook released from tangle nets (a more benign capture method) in the Columbia River was 7%; while fish released from 8-inch, 5.5-inch and 4.5-inch gillnet had 49%, 43%, and 32% mortality, respectively. Similar to our study, the authors demonstrated that gillnet entanglement caused increased mortality. Several authors have reported that physical damage can result in significant mortalities in fish (Thompson & Hunter 1973, Kaimmer & Trumble 1998, reviewed by Chopin & Arimoto 1995) that could be linked to the latent mortality seen in this study. The degree and location of injury, fish size and temperature have also been found to be significant factors determining whether fish survive or die (reviewed by Chopin & Arimoto 1995). Here, fish were most frequently injured with net marks and abrasions around the occiput (just behind the head/gills) and on the head (unpublished data). There is also evidence that injury greatly increase susceptibility of fish to parasites such as bacteria and fungus, particularly with damages to the gills (Trust 1986). *Saprolegnia spp.* is a facultative fungal infection common in freshwater ecosystems known to cause tissue damage, loss of epithelial integrity and osmoregulatory failure (Bruno & Wood 1999). It is associated with damaged epidermal tissue (Hatai & Hoshiai 1994, Pickering 1994), suggesting fish with gillnet injuries are particularly susceptible to such infections (Baker & Schindler 2009). These fungal infections have been highly correlated with pre-spawning mortality in Alaskan sockeye salmon (Baker & Schindler 2009), where up to 93% of fish with fungal infections on spawning grounds failed to spawn. The authors observed that11-29% of fish that reached spawning grounds sustained injuries, and of those, half failed to reproduce. These findings exclude en-route mortality, which we found to be at least 13 % for entangled fish relative to *Captured-only* fish, resulting in a fairly large number of potential delayed mortality. As such, long-term effects from capture-induced injuries on en-route and pre-spawn mortality should be considered in management strategies to help maintain viable populations and sustainable fisheries.

Post-release behaviour

Overall average migration speeds, from release site to the Thompson confluence, of injured sockeye salmon were significantly reduced, suggesting some degree of behavioural impairment and supporting the hypothesis that injured fish may sustain more long-term consequences. The relationship between stress response and swimming activity are not yet very clear. Studies have observed delayed upstream movement and increased downstream movement for Atlantic salmon after gillnet entanglement (Mäkinen *et al*. 2000); sulking and immediate deep-diving behaviour in Chinook salmon after release from purse seine capture (Candy & Quinn 1999); and decreased swimming activity for angled and air exposed largemouth bass (Thompson *et al*. 2008). In salmonids decreased activity has been suggested to be a result of compromised performance while fish recover physiologically from the stressor (Milligan 1996); however, increased activity (such as deep diving) has been proposed as a behavioural response to escape from a stressor (Candy & Quinn 1999, Quinn *et al*. 1989, Mäkinen *et al*. 2000). Here, injured fish may be swimming slower as a result of muscle fatigue or altered behaviour due to internal injuries and infections. As mentioned, injured fish are vulnerable to opportunistic pathogens that can lead to disease. Tierney and Farrell (2004) observed that severely ill fish could not perform repeated swimming tests, providing evidence for behavioural impairment and reduced swimming activity in unhealthy fish. To date, there has been virtually no research on the pathology of fisheries-induced injuries and resulting behavioural impairments; therefore we can only surmise that injury can play an important role in delayed mortality of migrating sockeye salmon, particularly with the association of pathogens.

Recovery

The intent of a facilitated recovery tool is to revive salmon before release, in order to increase the probability that an individual will survive, escape predators, evade fishing gears, and complete its migration. A rapid rate of recovery may be beneficial if the immediate activity post-release is important to survival and reproduction. For migratory salmon, expediting the recovery process could be particularly useful given the challenging and energetically costly migration they are attempting to complete using finite energy stores. Although the Fraser box promoted physiological recovery and 24-h post-capture survival of exhausted adult coho salmon from gillnets in marine waters (Farrell *et al*. 2001a), potential benefits for fish behaviour and long-term survival have not been evaluated until the present study. Here, 15-min recovery in the Fraser box was neither beneficial nor detrimental.

We suggest several hypotheses for the lack of benefits derived from the Fraser box treatment in our study. Firstly, fish from any treatment were likely not severely stressed to the extent that would cause serious physiological disturbance that needed assisted recovery, and the additional handling and confinement could potentially cause more stress than what fish experienced initially. Farrell *et al*. (2001a) noted that cortisol levels in coho remained high throughout the recovery experiment implying that the confinement of the box could cause additional stress that elevated plasma cortisol levels. As such, this stress must be weighed against the benefits of partial metabolic recovery. Consequently, the 15-min recovery period may not be long enough to drive potential change in metabolic recovery to compensate for the additional handling and confinement stress. However, 15 min was chosen to reflect the realism of what we felt a fisher would commit towards revival efforts. Farrell *et al*. (2001a) noted signs of physiological recovery after one hour, and further decrease in hematocrit, muscle lactate concentrations, plasma osmolality, cortisol and ion concentrations after 2-h recovery. Evidently, 15 min is a substantially shorter recovery period; however, Donaldson *et al*. *(In Review*), documented reduction in plasma cortisol, relative to non-recovered fish, after 15-min of recovery treatment in-river using a cylindrically shaped mesh-ended recovery bag (made of hypalon material) oriented in high river flow. Still, the authors note an incomplete recovery, as plasma lactate and osmolality were not reduced, which contrasts previous work post 2h recovery (Farrell *et al*. 2001a). These differences could reflect the different recovery methods used, the different salmon species investigated or the initial condition of fish. As such, the effectiveness of facilitated recovery methods may largely be dependent on the species’ capacity to recover and the severity of the fishing operations. Secondly, the Fraser box was designed with coho salmon in mind, and therefore, may not be a good fit for sockeye salmon. The box may not have restricted movement enough and fish could have potentially moved away from the jetted water rendering the recovery inefficient. We did find a number of fish facing into the corner of the box rather than directly into the water flow. Lastly, there are many physiological unknowns from the freshwater adult life stage of salmon, such as the additional physiological changes from sexual maturation, physical transformation and osmoregulatory adjustment to freshwater. Any of these physiological disturbances could alter the results of a recovery attempt using the Fraser Box. Nonetheless, our RAMP experiment showed significant improvement in reflex regained after 15-min relative to their initial state. Note, however, that the extent of which regained reflexes were attributed to the 15-min assisted recovery treatment is unknown as we do not have information on fish sampled at 15-min with no assisted recovery. As such, it demonstrates that salmon have the ability to recover from immediate reflex impairment, if given the time to recover, which would benefit fish for escaping from potential predators and recaptures. However, the long-term consequences still remain unclear and further research into recovery methods are worth considering as we have witnessed some beneficial results (e.g. improved reflex actions and slight increase in survival of injured fish) from facilitating recovery.

Conclusions and Management Implications

In summary, we found no discernable effects of air exposure and recovery on the post-release survival of migrating adult sockeye salmon, but fish subjected to gillnet injuries had slightly reduced survival rates. Moreover, injury significantly reduced overall migration speeds of released fish, which suggests further evidence that physical injury may pose longer-term consequences to migrating sockeye salmon, particularly if it is associated with infections. As such, more research is needed to investigate the mechanisms of pathology. . This information could improve our understanding of fish susceptibility to disease and allow for further exploration of appropriate management strategies that considers fisheries-related delayed mortality associated pathogens (Van west 2006, Miller *et al*. 2011, Jeffries *et al*. 2011). Past researches have indicated that the interaction of environmental stressors can increase behavioural impairment and even mortality. Injury and exhaustive stress can both cause sub-lethal consequences which can subsequently lead to delayed mortality, but during the moderate temperatures experienced in the current study, gillnet injury appeared to have a greater consequence than air exposure stress. Furthermore, the failure of facilitated recovery to reduce mortality or improve migration speed was surprising, especially in air exposed fish. Because recovery did not appear to be detrimental to fish, we believe there is merit in exploring further recovery methods, particularly in fisheries where fish being released are in extremely poor condition.

Our treatment groups reflect stressors that fish encounter when discarded or disentangled. We support the view that response to air exposure and physical injury are species- and context-specific (e.g. Davis 2002, Davis & Olla 2006, White *et al*. 2008), and if selective harvest is to be used as a fisheries management tool, there needs to be adequate research into the short- and long-term response of fish to physical injury and stress associated with gear encounters to determine post-release survival. Otherwise, attempts to increase the number of fish escaping from fishing gears could result in an increase in delayed mortality (Chopin and Arimoto 2005). Future studies should explore the interaction of injury and stress in a variety of fish species, gears and environmental conditions to better understand the mechanisms that contribute to post-release mortality.

Tables

Table 2-1. Summary of experimental treatments for radio-tagged Fraser River sockeye salmon

Treatment Group	Recovered	Not recovered	Total tagged fish (*N*)	Treatment description*	Justification
Capture-only (C): low stress, low injury	27	27	54	Captured by beach seine, minimal handling, not subjected to treatments	Control
Air exposed (A): high stress , low injury	28	27	55	Captured by beach seine, 2-min air exposure, minimal handling	Attempt to distinguish stress from injury
Injured-only (I): low stress, high injury	28	29	57	Captured by beach seine, Gillnetted for ~30 seconds, minimal air exposure	Attempt to distinguish injury from stress
Injured + Air exposed (IA): high stress, high injury	28	29	57	Captured by beach seine, gillnetted for ~30 seconds, 2-min air exposure	Control for interactions and cumulative effects

***All fish were also held in net pens varying from 0-5 hrs (mean time: 1h21 ± 1h25)**

Table 2-2. Mean migration rate (km day-1) from the release site to both Hope and the Thompson River Confluence, and descriptive details of covariates for radio-tagged sockeye salmon for *captured-only*, *air exposed*, *injured-only* and *injured + air exposed* experimental groups that were recovered (R) and not recovered (NR).

Treatment Groups	**No. Tagged**		**Mean ± SD Migration Rate from Release to Hope (km day^{-1})**		**Mean ± SD Migration from Release to Thompson (km day^{-1})**		**Mean ± SD handling time (min)**		**Mean ± SD Fork Length (cm)**				**Mean (hr) ± SD (min) Net pen time**			
	NR	R	NR	R	NR	R	All	*N*	NR	*N*	R	*N*	NR	*N*	R	*N*
Captured-only	27	27	24.6 ± 5.7	21.2 ± 5.1	21.3 ± 2.9	19.1 ± 2.4	3.7 ± 1.2	29	60.9 ± 4.2	28	61.2 ± 3.8	29	1:11±1:22	28	1:15±1:07	29
Air exposed	28	27	20.6 ± 5.5	18.8 ± 5.2	19.6 ± 3.4	17.9 ± 4.5	5.5 ± 1.5	31	61.0 ± 3.0	30	60.9 ± 4.4	31	1:28±1:27	30	1:37±1:28	31
Injured-only	28	29	18.1 ± 4.3	17.9 ± 5.8	19.1 ± 2.0	16.9 ± 3.4	5.1 ± 1.7	31	60.4 ± 3.6	30	60.5 ± 3.1	31	1:09±1:34	30	1:14±1:26	31
Injured + Air exposed	28	29	18.9 ± 4.3	16.9 ± 6.7	17.2 ± 5.1	18.7 ± 5.5	6.9 ± 2.0	30	61.2 ± 3.3	29	60.2 ± 3.8	30	1:27±1:29	30	1:27±1:28	30

Table 2-3. Relative effects of experimental treatments (baseline, captured-only, air exposed, injured-only, injured + air exposed), presented in mean ± SD, on plasma variables in mature wild sockeye salmon, captured on the Harrison River, measured 15 min post stressor, except for baseline value measured immediately from seine net. Significant effects are denoted by dissimilar letters. Values for lactate, potassium and cortisol were logged transformed for statistical tests.

Plasma variables	Baseline (*N* = 6)		Captured-only (*N* = 9)		Air exposed (*N* = 10)		Injured-only (*N* = 6)		Injured + Air exposed *N* = 5)		Fstat	Pvalue
Lactate (mmol·L^{-1})	5.7 ± 0.9	**a**	12.6 ± 4.8	**b**	17.3 ± 2.7	**b**	14.0 ± 1.1	**b**	18.4 ± 2.6	**b**	28.758	< **0.001***
Glucose (mmol·L^{-1})	4.9 ± 0.5		5.6 ± 0.9		6.8 ± 0.7		6.2 ± 2.1		6.4 ± 1.2		2.963	0.035
Osmolality (mOsm·kg^{-1})	315.2 ± 2.7	**a**	340.8 ± 13.8	**b**	349.9 ± 17.2	**b**	328.8 ± 20.3	**a**	346.1 ± 4.0	**b**	6.657	**0.001***
Chloride (mmol·L^{-1})	129.8 ± 4.3		135.0 ± 4.1		133.3 ± 6.2		129.1 ± 9.8		130.7 ± 4.6		1.303	0.291
Potassium (mmol·L^{-1})	3.0 ± 2.2		1.3 ± 0.4		1.2 ± 1.0		2.0 ± 0.8		2.2 ± 0.8		2.593	0.056
Sodium (mmol·L^{-1})	143.2 ± 3.9		153.4 ± 10.9		143.9 ± 14.7		138.3 ± 13.8		142.3 ± 7.1		1.847	0.145
Cortisol (ng·mL^{-1})	35.7 ± 23.7	**a**	111.8 ± 133.6	**ac**	331.5 ± 186.0	**b**	369.9 ± 118.5	**b**	231.4 ± 103.7	**bc**	16.09	< **0.001***

*** Bonferroni adjusted significance α= 0.007**

Figures

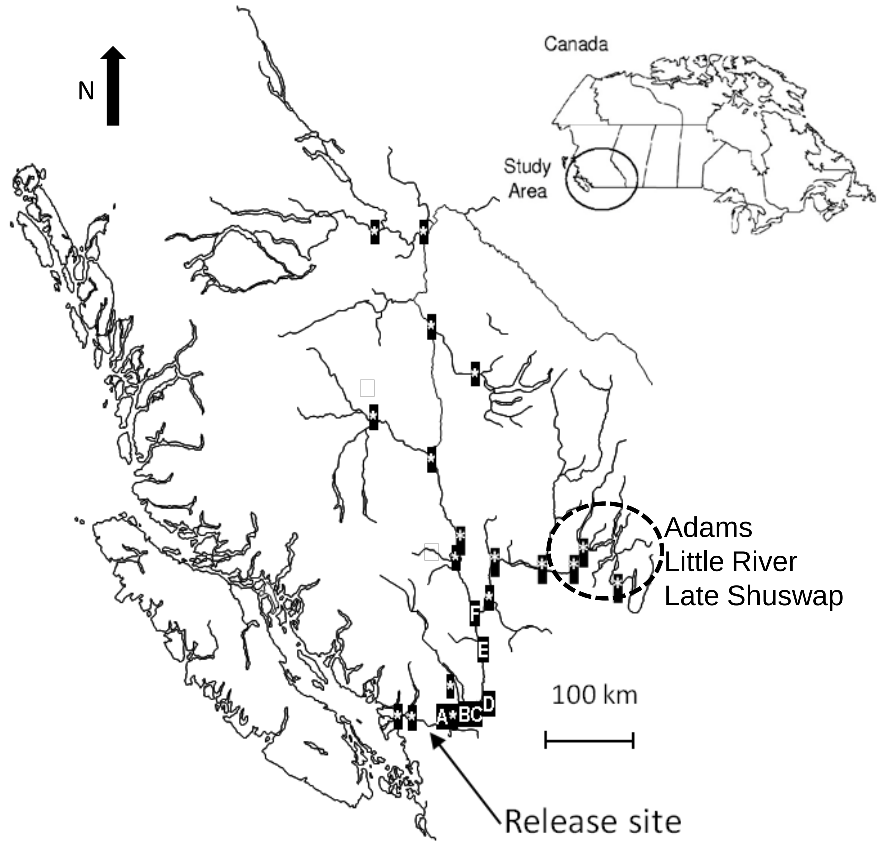

Figure 2-1. Map displaying the Fraser River Watershed, British Columbia, Canada, and the study, release and natal sub-watershed (Adams-Shuswap). Asterisks denotes radio receiver stations distributed throughout the Fraser River mainstem and into tributaries throughout the watershed. Letters represent receiver locations used in the calculation of migration rates, as follows: A (Harrison River confluence), B (Hope), C (Qualark), D (Sawmill), E (Hell's Gate), and F (Thompson River confluence).

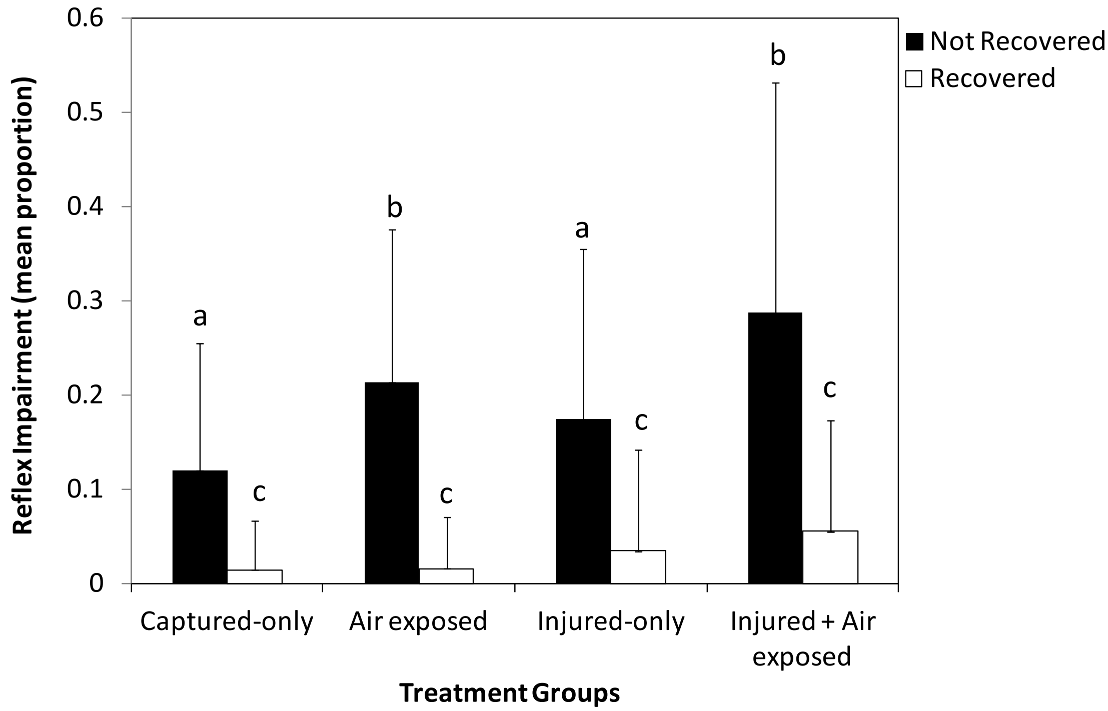

Figure 2-2. Impairment (proportion) of a suite of five reflexes (orientation, vestibular ocular response, tail grab, head complex, and body flex) in free swimming adult sockeye for all experimental treatments. Values are presented in mean ± SD proportion of reflex impairment. Dissimilar letters denote a significant difference at alpha value of 0.05.

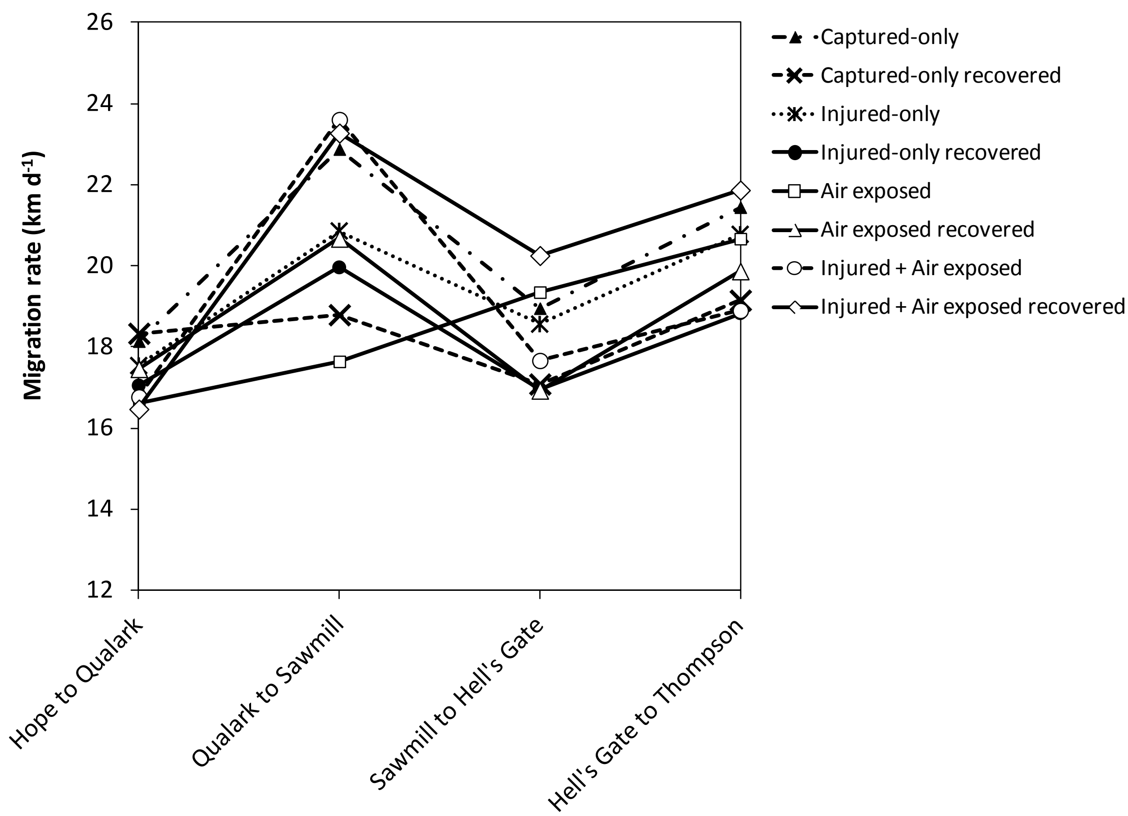

Figure 2-3. Migration rates (km d^{-1}) of adult sockeye salmon detected at each river section through the Fraser River mainstem for not recovered and recovered fish across four treatment groups (captured-only, air exposed, injured-only, injured + air exposed).

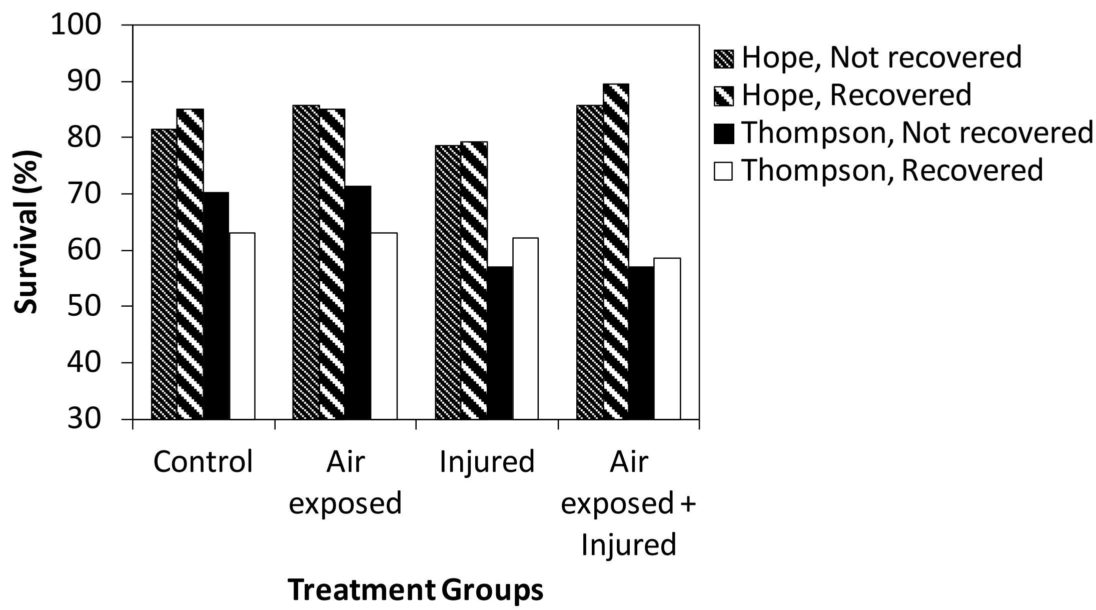

Figure 2-4. Survival (%) of sockeye salmon across four treatment groups for recovered fish and non-recovered up to Hope receiver station (short-term assessment) and the Thompson confluence receiver station (long-term assessment). Sample size was between 27-29 fish for each recovered and non-recovered experimental treatment group.

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Chapter 3: Recreational anglers' attitudes and behaviours relevant for Pacific salmon conservation and management in British Columbia

Abstract

Recreational anglers have the potential to positively influence aquatic conservation if they are successfully engaged by fisheries managers. For the lower Fraser River, British Columbia, we developed four latent class model based on interviews of recreational sockeye salmon anglers using latent-class cluster analysis: salmon angler typologies, perceived threats to successful salmon migration and spawning, perceived risks due to post-capture live release of salmon, and level of support for angler education programs. This information may help fisheries managers understand anglers' potential responses to new conservation initiatives as waters warm in the Fraser River. We identified three types of anglers: *salmon-dependent anglers* (33% of sample), *lake-species specialists* (46%), and *all-around anglers* (21%). These clusters were primarily differentiated by non-salmon fishing activities (e.g. other target species). Anglers' perceived threats to migrating salmon populations were grouped into four clusters oriented towards consumptive (*poaching* and *First Nation fishing*) and non-consumptive (*climate change* and *environmental*) factors. We identified five clusters based on anglers' perceived risks of recreational salmon fishing post-release fish survival: *fish fight time* (29% of sample); *air exposure* (26%); *revival effort* (17%); *fishing technique* (16%); and *water temperature* (11%). The final model revealed two groups of *supporters* (73%) and *non-supporters* (27%) of angler education programs. There were no correlations between clusters across models. Our results suggest that it would be challenging to predict angler

behavioural responses to changing environmental conditions or management initiatives based on standard demographic factors. We suggest that context-specific research and a nuanced approach to management interventions are needed in this fishery. By necessity, this would lead to integration of natural and social sciences to inform policy makers about targeted awareness-building activities and the likelihood of various regulatory changes being accepted by anglers. This type of information is needed to better encourage anglers' behavioural change in ways that effectively contribute to resource stewardship and have real impacts on fish conservation.

Introduction

There are increasing pressures on freshwater ecosystems worldwide from threats such as climate change, upland ecosystem degradation, and habitat fragmentation. The potential role of recreational fishing in affecting freshwater ecosystems is, however, often overlooked (Cooke & Cowx 2004). Anglers have access to some of the most sensitive ecosystems and critical habitats, often outnumber commercial fishers, and can represent a strong and vocal political constituency that may constrain managers' options for achieving conservation targets. Recreational angling may be a threat to ecosystem viability and fish survival in some contexts but, in other cases, anglers can positively influence conservation outcomes if successfully engaged in the management process (Granek *et al.* 2008, Gray & Jordan 2010, Danylchuk & Cooke 2011).

The potentially pivotal role of recreational angling in the conservation of freshwater species implies that close attention needs to be paid to recreational anglers' attitudes and behaviours. Anglers come from different socio-demographic backgrounds, seek different fishing experiences, and vary in avidity and commitment to fishing (Oh & Ditton 2008). Their motivations range from catching trophy fish to simply enjoying the outdoor experience. Just as their motivations vary, so too can anglers' attitudes towards management and their willingness to engage to find solutions to conservation challenges.

The Fraser River in British Columbia (BC) is one of the most productive salmon rivers in the world. Management of the Fraser is very complicated (Healey & Hennessey 1998) because multiple salmon species and stocks co-mingle during their migration upriver, and more vulnerable non-target species and stocks (e.g. endangered, undersized) are required to be live released when captured. Additionally, three different fishing sectors (commercial, recreational and First Nations) target salmon in the Fraser watershed. Recreational fishers target salmon for both food and catch-and-release purposes. First Nations depend on salmon for food, social, and ceremonial purposes (Muckle 2007).

Researchers have argued that climate change is playing a major role in en-route mortality of upriver migrating salmon as warming waters and changing hydrological regimes increase physiological stress on salmon (Battin *et al.* 2007, Martins *et al.* 2011). Given the important role of anglers in influencing the fate of captured and released fish through fish handling (Arlinghaus *et al.* 2007), the introduction of effective fish conservation strategies for the safe release of vulnerable non-target species becomes particularly important, especially in the face of warming river temperatures. Capture events during warm water temperatures can cause increased stress, behavioural impairment, and potentially increased mortality (Gale *et al.* 2011).

We use the lower Fraser sockeye salmon (*Oncorhynchus nerka*) recreational fishery as a case-study to explore how improving our understanding of anglers' diversity in latent characteristics (e.g. preferences, attitudes, and beliefs) may inform management strategies meant to shape behaviours important for successful fish conservation by facilitating "responsible fishing" that minimizes risks to vulnerable non-target species and stocks (Plate *et al*. 2009). Our exploratory study investigates four latent class models that characterize heterogeneity among Fraser River salmon anglers with regards to their: (1) fishing behaviours; (2) perceived threats to successful salmon upstream migration;

(3) perceived risks to post-release survival of angled vulnerable fishes; and (4) support for angler education programs on responsible fishing practices. Understanding angler potential response to environmental, and to management responses to address those changes, is crucial in the Fraser River watershed, as it is in many freshwater ecosystems around the world.

Methods

Survey instrument

We used face-to-face semi-structured interviews to collect both quantitative (rating and rankings) and qualitative (open end) data needed to explore the attitudes and behaviours of Fraser River anglers. Interviews followed a mixed-methods approach (Creswell 2009) to increase the external validity of quantitative data while generating new knowledge and capturing a diversity of qualitative opinions.

Interview questions relevant to policy makers were identified in collaboration with local fisheries managers, reviewed by fisheries experts, and tested in face-to-face pilot interviews with eight experienced salmon anglers. Interviews began with questions designed to help categorize angler typology with conventional segmentation variables (e.g. fishing experience and avidity, target species and fishing location preference). Insights from value-belief norm theory (Stern *et al.* 1999) suggest that anglers' support for particular conservation regulations should be affected by the salience of perceived threats to migrating salmon and the degree to which anglers perceive their personal behavioural or financial sacrifices to have an effect on salmon survival. Respondents ranked their three most important threats to migrating salmon populations from a list of 14 possibilities (climate change, commercial fishing, First Nation fishing, fish farms, fish health, habitat alterations, mismanagement, poaching, predation, recreational fishing, urban development, water quality, don't know, and other) and perceived risks to post-release survival of incidentally caught salmon from a list of 12 possibilities (air exposure, angler experience, beach dragging, capture location in river, fight time, fishing technique used, hook location, predation density, revival efforts, warm water temperatures, don't know, and other). Responses were subsequently dummy-coded (1=factors identified as top three) for analysis. We also asked open-ended questions that queried anglers about their general thoughts regarding angler education programs, whether there is a need for angler education programs, and whether participation in education programs should be required in order to obtain a fishing license. See Appendix 3-A for full wording of the relevant interview questions and definitions.

Standard demographic data (age, gender, ethnicity, education, occupation, and household income) was collected, as well as information about fishing and hunting club membership, self-reported knowledge of fisheries management, and importance of fishing to anglers' lifestyle. Four survey versions were administered to minimize the interview length for individuals. Closed-ended questions (i.e. demographics, threat perception rankings, fishing practices) were consistent across all interviews while the open-ended questions varied. Each version varied with one of the different issues/themes of interest to fisheries managers and researchers: education programs, communication preferences (Nguyen *et al.* In Press), support for fish revival gear (Donaldson *et al*. In Review), and angler awareness on DFO published catch and release techniques (unpublished data). The secondary interviewer focused only the latter topic and the closed-ended questions to minimize variation in responses given.

Sample frame and survey delivery

We defined our sample frame as age 18+ recreational anglers who were active in the Pacific salmon recreational fishery in the lower Fraser River. We used opportunistic sampling to select study sites and visited the busiest and most accessible fishing sites and boat launches during the 2010 sockeye opening which enabled us to sample a larger number of anglers on-site and target those engaged in salmon fishing. Sites were located primarily between Mission (49°N, 122°W) and Hope (49°N, 121°W), BC (Fig. 3-1) and visited everyday from approximately 7am until 5pm. Anglers were approached by one of two interviewers; with consent, responses were noted and audio recorded.

Data analysis

Open-ended questions relating to angler support for education programs were manually transcribed and coded following standard qualitative research protocol (e.g. Strauss 1987, Creswell 2009) by the lead interviewer. Codes were developed according to emergent themes based on keywords, phrases, and topics raised by anglers. Consistencies between codes (similar topics) revealed categories that identified angler support for education programs.

Latent-class (LC) cluster analysis (Vermunt & Magidson 2002) is an exploratory, probabilistic cluster analysis technique that can group items that share similar underlying characteristics in to “classes”. It can statistically identify unobserved (latent) class membership using information from a set of observed variables (indicators) that imperfectly measure underlying true class membership. It is a probabilistic and more flexible alternative to K-means clustering, which performs well only under strict conditions (i.e. if indicators are locally independent and if error variances are cluster invariant and equal across indicators). As a probabilistic methodology, items are not absolutely assigned to a particular class; instead, posterior probabilities of class membership are estimated. This LC approach has been applied in social science, tourism, and marketing research but is relatively novel in the conservation field (but see Morey *et al.* 2006 and Ward *et al.* 2008).

Information criteria diagnostics are typically used to identify parsimonious LC models. Generally, no single selection criterion is agreed upon as the best. Likelihood ratio tests can be used to test improved fit between various nested LC models but the likelihood ratio statistic is of limited use when data is sparse, as it does not have its usual chi-square distribution (Vermunt & Magidson 2002, Andrews & Currim 2003). Alternatively, model fit can be assessed using information criterion weighting both model fit and parsimony, often in conjunction with other measures of fit (e.g. Morey *et al*. 2006, Ward *et al.* 2008). We used the Akaike Information Criterion (AIC) and AIC3, and tested local independence between indicators using bivariate residuals. Significant bivariate residuals ($\chi^2 > 3.84$, 1 d.f., $p < 0.05$) indicate that two or more indicators are providing redundant information not useful for distinguishing classes in the model. We eliminated those indicators with the most and largest bivariate residuals sequentially when they were significant (See Appendix 3-B for goodness of fit measures for all LC models). Note that redundancy between two indicator variables does not mean that one is necessarily 'unimportant' to anglers; using both indicators is simply unnecessary for identifying heterogeneity in the sample. Wherever AIC and AIC3 did not agree, the model with the least number of clusters was preferred. Additionally, if AIC and AIC3 did not present a clear "best model", the model cluster profiles were consulted, and the final LC model was chosen based on logic, interviewer experience, and weighted information gained or lost with the addition or removal of clusters. Latent Gold software (Vermunt & Magidson 2005) was used to estimate all LC models.

Angler classes were derived based on response patterns to survey questions; we did not use demographic or other covariates in the actual cluster analyses. Chi-square tests (Bonferroni adjusted) subsequently tested for demographic and professional characteristics predictive of LC membership patterns (Magidson & Vermunt 2005). This is a preferred approach when the number of covariates is large and dependent variables are of different scale types. Specifically, we tested standard socio-demographic characteristics, self-reported management knowledge, fishing organization membership, and fishing centrality (i.e. importance) to lifestyle as predictors of LC membership. Analyses were conducted with the Chi-squared Automatic Interaction Detection (CHAID) software (Magidson 2005). Lastly, for each LC model, we used posterior probabilities from the LC analysis to assign each angler to the various classes in which they had the highest probability of membership and tested for correlations between classes and among LC models using Spearman rank correlation (PASW 18.0).

We examined four LC models (Table 3-2): A) *angler typology model*, which was based on indicator variables relevant to fishing behaviour (fishing experience, days fished in last 12 months, site access, other [than salmon] target species, and proportion of non-tidal fishing); B) *population threats model*, used data from respondents' top three perceived threat (from a list of 14 possibilities); C) *risks to post-release survival model*, which used the top three perceived threat factors (from a list of 12 possibilities) as indicator variables; and, D) *angler education program support model*, based on response patterns from relevant open ended questions (see Table 3-2 for model input details and questions).

Results

Socio-demographics and other characteristics

We approached 395 recreational anglers between 30 July and 27 August, 2010, on fishing sites and boat launches of the lower Fraser River. A total of 311 respondents (79%) consented to be interviewed; their demographic characteristics are summarized in Table 3-1. The demographic profile for the overall population of Fraser River anglers is unknown, so it was not possible to test how representative of the entire population our sample was.

Model A: angler typology

Our first LC model, *angler typology*, used data on anglers' (*n*=287) experience, avidity, fishing preferences (i.e. location, target species other than salmon) and site use and accessibility to categorize anglers according to their fishing behaviour, practices, and orientation. Descriptive findings of the sample population for these variables are summarized in Table 3-1.

AIC was minimized with a 3-class cluster model (Appendix 3-B). No significant bivariate residuals were detected, so the final *angler typology* model retained five indicator variables: days fished in last 12 months; number of years fishing; other target species; proportion of non-tidal (i.e. freshwater) fishing; and site access. Based on their patterns of recreational fishing, we labeled anglers (Fig. 3-2) as *lake-species specialists* (46%), *salmon-dependent anglers* (33%), and *all-around anglers* (21%).

Lake-species specialists were highly specialized in a single freshwater species (mainly trout) and preferred fishing in lakes. They fish often and a large proportion hike to the fishing sites or camp out, which can suggest that they may seek activity-general experiences (e.g. enjoying outdoors). *Salmon-dependent anglers* fished primarily for Pacific salmon (including steelhead, *Oncorhynchus mykiss*) and were not active anglers compared to others, suggesting that these seasonal anglers came out mainly during salmon season. Lastly, *all-around anglers* had a high level of commitment to fishing (i.e. high fishing frequency and experience), targeted a broad range of species, and were more likely than anglers in other clusters to own a boat. No significant predictors were identified in the CHAID analysis. Table 3-2 summarizes *angler typology* and other models.

Model B: population threats

The most frequently chosen threats (out of 879 responses) to salmon survival during migration were climate change (17%) followed by: commercial fishing (14%); First Nation fishing (13%); habitat destruction (11%); fish farms (11%); mismanagement (9%); poaching (8%); water quality (7%); and urban development (6%). Fish health, predators, recreational fishing, other, and ‘do not know’ each were chosen by less than 2% of respondents.

In the *population threats* model, AIC3 was minimized with a 3-class model, while AIC was minimized with a 4-class model (Table 3-2, Appendix 3-B). We chose to investigate the 4-class model as it provided more information. Four indicator variables (fish farms, mismanagement, fish health, and commercial fishing) were sequentially removed from the model to eliminate all significant bivariate residuals (Appendix 3-B). Commercial fishing, fish farms and mismanagement were important threats, but did not help differentiate classes. That is, commercial fishing, fish farms and mismanagement were viewed as equally important across classes. The final *population threats* model retained 10 indicator variables (climate change, water quality, recreational fishing, habitat alterations, First Nation fishing, predators, urban development, poaching, ‘do not know’, and ‘other’) and identified 4 distinct clusters of anglers (Fig. 3-3). Three clusters were most clearly defined by their focus on *climate change*, *First Nation fishing*, and *poaching*, whereas members of the fourth *environmental* cluster were focused relatively uniformly on non-climate environmental threats (i.e. habitat degradation, urban development, water quality) (Fig. 3-3).

In the CHAID analysis, self-reported management knowledge was a significant (χ^2= 12.80, 3 d.f., Bonferroni adj. p= 0.035) predictor of class membership. Anglers who reported their perceived management knowledge to be low were significantly more likely to perceive poaching as a threat to migrating salmon populations relative to anglers with higher management knowledge. Anglers who reported their management knowledge as moderate to high were more likely to perceive First Nation fishing as a risk to salmon migration success (Fig. 3-5; Table 3-2).

Model C: risks to post-release survival

Beach dragging was chosen by 18% of all responses (*n*=861) as the greatest risk to post-release fish survival. This was followed by angler's [lack of] experience (14%), hook location (14%), air exposure (13%), fight duration (13%), revival efforts (8%), water temperature (7%), and fishing technique (7%). Predation density, capture location in river, and other factors were chosen by less than 2% of respondents. See Appendix3-A supplemental information for full descriptions of these factors.

Upon close examination of model profiles among 4-, 5-, 6-, and 7-class models, the 5-class model appeared to provide the most relevant information. The final LC analysis minimized AIC with a 5-class model (Table 3-2). Three indicator variables (angler experience, beach dragging, and hook location) were sequentially removed from the model until all significant bivariate residuals were eliminated (Appendix 3-B). Our final *risks to post-release survival* retained 9 indicator variables (water temperature, fight time, air exposure, revival effort, technique used, predation density, capture location in river, 'do not know', and 'other'). The five clusters (Fig. 3-4), which we labeled according to the most prevalent perceived risk: *fight time* (29% of all respondents); *air exposure* (26%); *revival effort* (17%); *fishing technique* (16%); and *water temperature* (11%).

Model D: angler education program support

Participants were asked about their thoughts on education programs that taught responsible fishing in the *angler education program support* model. Six general types of thoughts were coded from open-end angler responses: negative protests responses (7%), responses that were negative but did not address the issue at hand (e.g. they simply criticized fisheries management); negative but legitimate responses (3%) that were negative for legitimate reasons reflecting the issue (e.g. education programs were not perceived to be helpful); neutral (10%); positive conditional (13%) responses that were positive but given a condition (e.g. education programs for first-time license buyers only); and fully positive (65%). Note that 82% of respondents believed there was a need for education programs in some form. When, however, asked to describe their support for mandatory education programs to obtain a fishing license, respondents were more negative. Coded responses for mandatory education program support consisted of: negative protest responses (10%); negative but legitimate (20%); negative conditional (16%); unsupportive but open to change; neutral (1%); positive conditional (19%); and positive fully *(*33%).

A 2-class model minimized AIC and there were no significant bivariate residuals (Appendix 3-B). The two clusters (Fig. 3-6) were labeled as *supporters* (73%), who included respondents that believed there was a need for education programs and were supportive of mandatory implementation, and *non- supporters* (27%), who were skeptical of the need for education programs (Table 3-2).

Model Correlations

No significant correlations were observed among angler typology, perceived threats to salmon migration, perceived effects of fish handling on post-release survival, and angler education program support models.

Discussion

Angler typologies have been studied to characterize preference groups and motivations that help managers understand and satisfy angler preferences, and predict responses to management change for diverse angler types (e.g. Fedler & Ditton 1994). The complexities of person-situation interactions and the variance in the degrees of angler diversity highlight the need for context-specific research to support adaptive management solutions that are targeted at specific angler types (Beardmore *et al*. 2011). Although respondents in our study were targeting the same species, we could identify angler typologies that cleaved apart primarily by their site use and non-salmon fishing activities (other target species and non-tidal fishing). This suggests that the primary underlying difference among these salmon anglers is their participation in other forms of fishing. Salmon anglers on the Fraser River are not a homogenous group despite participating in a specific sockeye sport fishery in a specific location and period.

Our s*almon-dependent anglers* primarily engaged in only one form of 'utilitarian' fishing. Beardmore *et al*. (2011) also found that anglers in Germany targeting Atlantic herring (a seasonal fishery) had consumptive motives, whereas small-bodied and abundant coarse fish (i.e. roach and bream) were sought by anglers who wished to enjoy nature. From a management perspective, s*almon-dependent anglers* likely have low fishing type substitutability and are more prone to adverse impacts of salmon fishing restrictions. On the other hand, *lake-species specialists* and *all-around anglers* engaged in various forms of fishing may respond to management restrictions more positively due to the enjoyment they derive from fishing other species and the fishing experience. If fisheries managers are influenced by economic valuation of ecosystem services, it is paradoxically possible that the least serious anglers incur the highest economic cost for lost fishing opportunities because there is no close substitute for their food-oriented recreational angling. Economic value is a function, in part, of the price of sockeye fishing, as well as the availability and price of substitute activities.

Past research has highlighted the importance of aligning environmental values with conservation strategies that facilitate behavioural change (Stern *et al.*, 1999). Gray and Jordan (2010) recommended that similar goals and perceptions shared by managers, scientists, and anglers need to be highlighted for effective outreach strategies in promoting ecosystem-based management. They suggest that education should be framed around what is valued by the audience, not simply by managers supplying information. Threat salience is particularly important, as it directly affects people's willingness to take action to reduce threats to valued resources (Stern *et al*. 1999). Threat salience can be influenced directly by improved awareness of threats (e.g. increased angler awareness of the effects of water temperature on post-release survival) and indirectly via changes to deeper core values or worldviews. How an angler reacts to a specific management measure – their propensity for compliance with water temperature-based fishery closures for example – depends on their perspectives on the legitimacy of that measure as well as the financial or other costs they personally bear.

Our *population threats* model highlighted underlying similarities and differences in threat perceptions among anglers regarding upriver migrating salmon populations. Anglers could be grouped into four LCs that fall into consumptive (*poaching* and *First Nation fishing*) and non-consumptive (*climate change* and *environmental*) themes. Respondents in the *environmental* cluster are likely more supportive of environmental management initiatives (e.g. pollution control, agricultural best management practices) while those in the *climate change* cluster are likely more supportive of temperature-related management changes (e.g. closures when temperature limits are exceeded). *Poaching* and *First Nation fishing* cluster members should be more supportive of harvesting restrictions (e.g. daily limits) that curtail use of existing fish resources. Our CHAID segmentation found that *management knowledge* was a predictor of threat perception. This finding was unanticipated but could imply potential evolution in threat perceptions from *poaching* to *First Nation fishing* classes as anglers learn more about management procedures. Insufficient information is currently available to explain these findings but they do suggest a potentially productive research question for the future.

Five classes were identified in the *risks to post-release survival* model. These classes shed light on what anglers believe to be the most important steps in a fish capture event. *Fight time* class members likely believe that minimizing time between hooking and landing is critical, whereas *air exposure* members emphasize time from landing to hook removal. This information is important for understanding potential support for, and compliance with, measures relating directly to fish capture, handling, and release practices, all of which have the potential to influence fish welfare and post-release survival (Arlinghaus *et al.* 2007). These clusters reveal alternative ways for managers to approach “heat stress” conservation. In the face of climate change, the *water temperature* cluster is likely to be more supportive of closures and restrictive regulations during high temperatures. The remaining groups believe that threats can be ameliorated at the level of the individual angler, who can make investments that cost money (e.g. investments in recovery bags to permit fish a prolonged recovery period prior to release) or time (e.g. learning about improved handling procedures) to reduce fish stress and mortality. These groups may be more opposed to “heat stress” fishery closures.

Generally, angler education program *supporters*’ felt that there were too many irresponsible anglers and that a lack of fishing etiquette warranted education programs, while *non-supporters* felt that most anglers knew what they are doing and there was no need for education programs. As such, fisheries managers need to consider opportunity costs for investments in education and outreach programs as they can be costly in terms of time, resources, and maintenance. Examples of mandatory angler education programs are found in Germany and Austria, but no evaluations of its effectiveness have been found in the literature. Here, the negative responses regarding mandatory education programs suggest that imposing such programs could deter participation. From a management cost perspective in the agriculture sectors, Wu and Babcock (1999) found that voluntary environment programs were relatively more efficient than mandatory ones as long as the benefits outweighed costs, including deadweight losses and costs of management. Acceptance for any regulatory effort is associated to some degree with the angler’s level of familiarity with the regulation (Reichers *et al*. 1991). Nonetheless, we found little research on the transaction costs of voluntary stewardship versus mandatory regulations in fisheries management.

Overall, our findings revealed a complex matrix of motivational and behavioural dimensions that create substantial diversity among the Fraser salmon angler population. It is unlikely that it will be possible to predict responses of anglers to management initiatives based on simple socio-demographic information (see Fedler & Ditton 1994). Instead, there is a need for a nuanced approach to management interventions. This poses a challenge for fisheries managers because they will need to consider customizing conservation initiatives by targeting angler segments rather than the fishing community as a whole.

While we acknowledge that interviews may be biased towards English-speaking anglers, our extensive in-person coverage of primary shore-based fishing sites and boat launches help ensure that our results captured perspectives from a wide array of active recreational anglers who have direct impact on salmon conservation. These are the active anglers that have potential to affect conservation outcomes of interest to fisheries managers. While latent class model validity, reliability, and power could be improved with a larger sample, we believe – based on our extensive interviews and interactions with anglers over the past three years – that the distinct behaviours and attitudes expressed in our sample of active Fraser River salmon anglers are relatively stable and capture core factors affecting angler heterogeneity along multiple lines. The value of further research in the future may arise because of the increased potential of data from large samples to be used to identify relatively subtle relationships between various types of anglers and their threat perceptions.

Our findings may help managers understand angler diversity, craft new conservation initiatives customized for particular market segments, and anticipate responses to those initiatives aimed at improving fish handling and reducing post-capture and release mortality in the Fraser River. In such a complex social-ecological systems like the Fraser River, there is clearly a strong role in salmon conservation for natural science research to determine where and why post-release mortality of vulnerable fish takes place and an equally strong role for social science in understanding how that new knowledge will be interpreted and if, or how, that knowledge will result in anglers changing their fishing behaviour. A holistic approach between the natural and social sciences is critical to inform management and build angler awareness in a way that meaningfully improves fish conservation.

Tables

Table 3-1. Socio-demographic and other covariates, and angler typology characteristics of the Fraser River recreational sockeye salmon angler sample

Socio-demographics and other covariates	Number of respondents	Percentage (%)	Socio-demographics and other covariates	Number of respondents	Percentage (%)	Angler Typology Variables	Number of respondents	Percentage (%)
Gender (n=311)			*Income in Canadian $[a] (n=241)*			*Fishing experience (n=311)*		
Female	19	6.1	< $50,000	73	23.5	< 5 yrs	28	9
Male	292	93.9	$50,000-99,999	23	7.4	5-9 yrs	31	10
Age (*n*=311)			$100,000- 149,999	52	16.7	10-14 yrs	28	9
< 20 years	9	2.9	$150,000-200,000	14	4.5	15-20 yrs	29	9.3
20-29 years	40	12.9	> $200,000	6	1.9	>20 yrs	195	62.7
30-39 years	51	16.4	Prefer not to answer	73	23.5	*Avidity: how many days did you fish in the last 12 months? (n=311)*		
40-49 years	66	21.2	*Occupation (n=263)*			< 10 days	93	29.9
50-59 years	75	24.1	White collar	67	25.5	10-29 days	77	24.8
60-69 years	43	13.8	Blue collar	114	43.3	30-50 days	67	21.5
> 70 years	27	8.7	Service industry	22	8.4	> 50 days	74	23.8
Education (n=311)			Student	9	3.4	*Site use and access (n=302)*		
No high school	12	3.9	Retired	45	17.1	Paved and easy access	107	35.4
Some high school	32	10.3	Un-employed	6	2.3	Hike and difficult access	109	36.1
High school completion	125	40.2	*Fishing club membership? (n=310)*			Boat access only	56	18.5
Post-secondary	126	40.5	Yes	32	10.3	Camping on site	21	6.9
Post-graduate	10	3.2	No	278	89.7	*Other target species (n= 288)*		
Incomplete	6	1.9	*Centrality to lifestyle (n=311)*			Sockeye only	82	28.5
Ethnicity (n=310)			Very low importance (1)	13	4.2	Other salmon species	21	7.3
Asian	55	17.7	Low importance (2)	25	8	Single FW species	115	39.9

Caucasian	230	74	Neutral (3)	79	25.4	Multiple FW species	45	15.6
European	21	6.8	High importance (4)	77	24.8	Single SW species	9	3.1
Other	4	1.3	Very high importance(5)	117	37.6	Multiple SW species	5	1.7
Knowledge of management decisions and strategies(n=310)						Anything	11	3.8
Low (1)	128	41.3				*Location: % of non-tidal fishing (n=298)*		
Moderate (2)	122	39.4				< 25	76	26
High (3)	60	19.4				25-75	99	33
						> 75	123	41

[a] $1.00 Canadian = $0.9614 USD (13 August 2010)
FW= Freshwater, SW= Saltwater

Table 3- 2. Summary and description of latent class models

Model		Questions	Indicator used for classification	Sample size	Class label	%	Class Description	CHAID significant predictors
A:	*Angler typology*	Fishing experience, fishing days in last 12 months, site access, other targeted species, % non-tidal/freshwater fishing,	Segmentation variables: fishing experience, days fished in last 12 months, site access, other target species, non-tidal fishing	87	**Class 1**: Salmon-dependent anglers	33	- Primarily fish for salmon species. Fish very few days per year	None significant
					Class 2: Lake-species specialists	46	- Prefer fishing in lakes. Primarily fish for trout. Fish numerous days per year.	
					Class 3: All-around angler	21	- Fish both fresh- and saltwater species. Very experienced and avid. Likely to own or have access to a boat.	
B:	*Population threats*	Rank the top three factors (of 12) you believe to have the greatest impact on upriver migrating salmon?	Climate change (CC), First Nation (FN) fishing, poaching, predation, recreational fishing, urban development, habitat loss and alternations, water quality, I don't know, and other	93	**Class 1:** First Nation focus	23	- 98% of group perceive FN fishing as a major threat with some concern with climate change.	Self-reported management knowledge
					Class 2: Climate change focus	41	- 86% of group perceive CC as major threat with some concern with water quality, habitat degradation, urban development, and poaching	None Significant
					Class 3: Environmental focus	19	- 0.01% of group did not choose CC as a threat, but had concerns over various factors (water quality, recreational fishing, habitat degradation, and urban development)	None significant
					Class 4: Poaching focus	17	- 96% of group perceive Poaching as a major threat with some concerns with FN fishing, urban development, habitat degradation, and water quality.	Self-reported management knowledge
C:	*Risks to post-release survival*	Rank the top three factors (of 10) you believe has the greatest influence on whether incidentally caught fish released will live or die.	Air exposure, capture location in river, fight time, fishing technique used, predation density, revival effort, warm water temperatures, I don't know and other	87	**Class 1:** Fight time focus	29	- 96% perceive fight time as a major influence with some concerns with air exposure and water temperatures.	None significant
					Class 2: Air exposure focus	26	- 76% perceive air exposure as a major influence with some concerns with water temperatures, revival efforts and capture location relative to river.	
					Class 3: Revival focus	17	- 96% perceive revival efforts as a major influence to survival with some concerns with fight time, air exposure and water temperatures	
					Class 4: Fishing technique focus	16	- 95% perceive fishing technique as a major influence with very little concern over water temperature and some concern with fight time, air exposure, and revival efforts.	
					Class 5: Water temperature focus	11	- 69% perceive water temperatures as a major influence with some concerns with fishing technique and predator density.	
D:	*Angler education program support*	1) What are your thoughts on angler education programs that focused on responsible fishing? 2) Should participation in these	1) Thoughts on education program: negative[1], neutral, positive[2]; 2) Need for education program: yes, no; 3) Support for mandatory	61*	**Class 1:** Supporters	73	- Positive attitude towards angler education programs, generally believe there is a need for education programs and supportive of mandatory implementation	None significant
					Class 2 Non-	27	- Primarily believe there is no need for angler education programs,	

	education programs be required in order to purchase a fishing license?	education programs: No support[3], Support[2]	supporters	showed more neutral attitude towards the idea of education programs and primarily unsupportive of implementation of education programs

[*]Sample size is a result of this model being based on open-ended questions and the questions presented in 1 of 4 interview versions only
[1]Includes negative protest and negative legitimate, [2]Includes fully and conditional, [3]Includes protest, legitimate and conditional

Figures

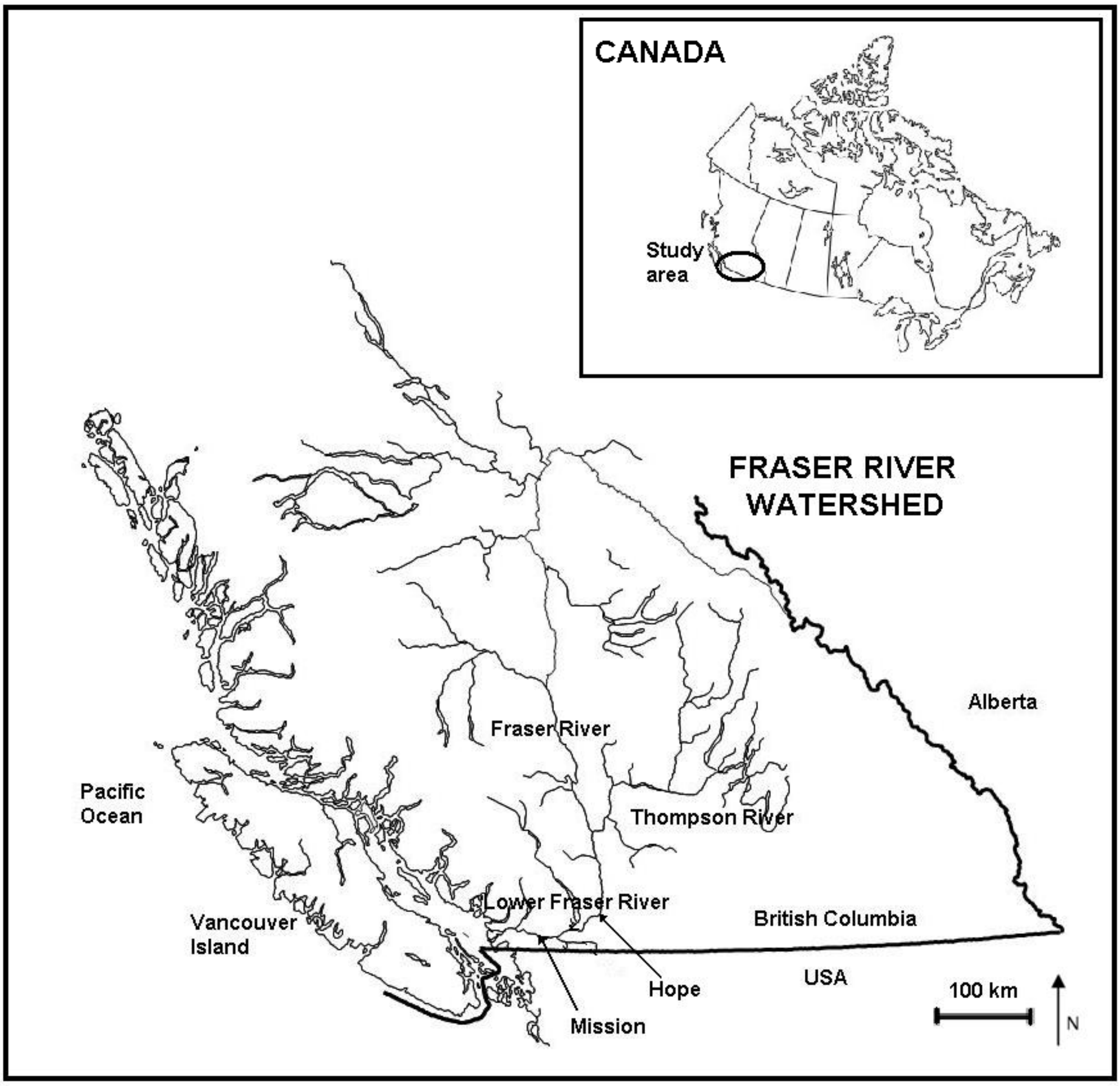
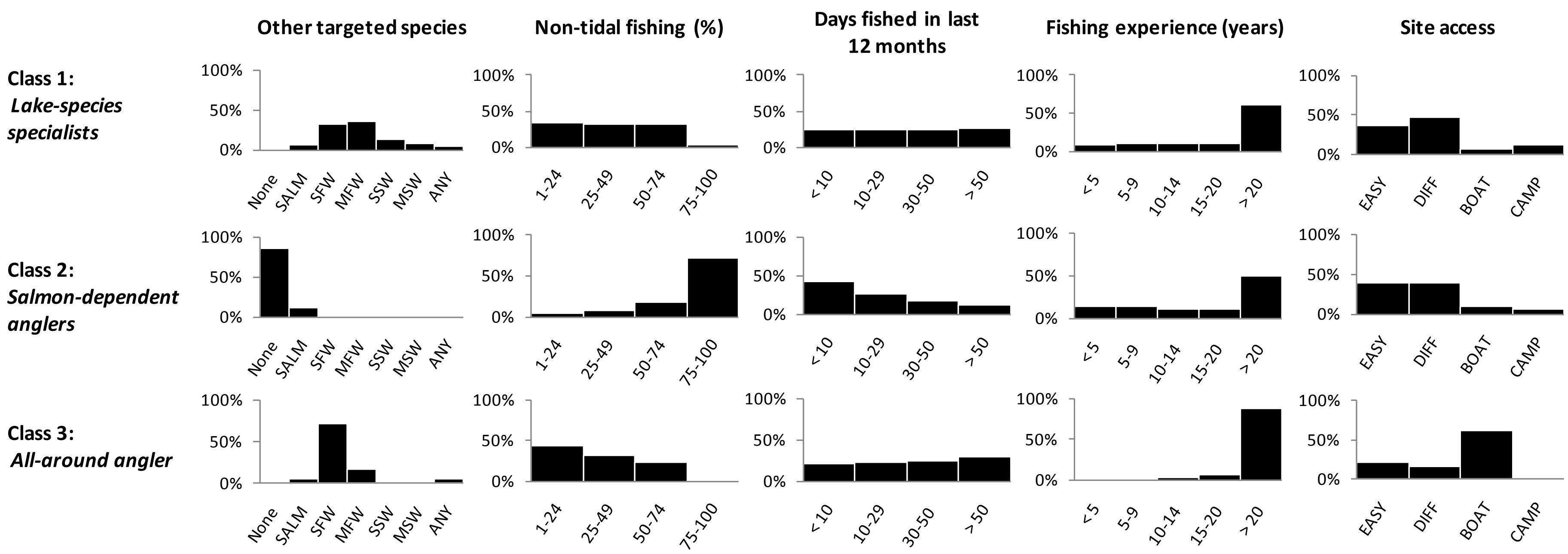


Figure 3-1. Lower Fraser River case-study area, British Columbia



Acronyms: SALM= salmon species only, SFW= single freshwater species, MFW= multiple freshwater species, SSW= single saltwater species, MSW = multiple saltwater species, EASY = easy access (paved), DIFF= difficult access (hike), BOAT= boat access, CAMP= common camp area

Figure 3-2. Latent-class membership profile for 3-class *angler typology* classes

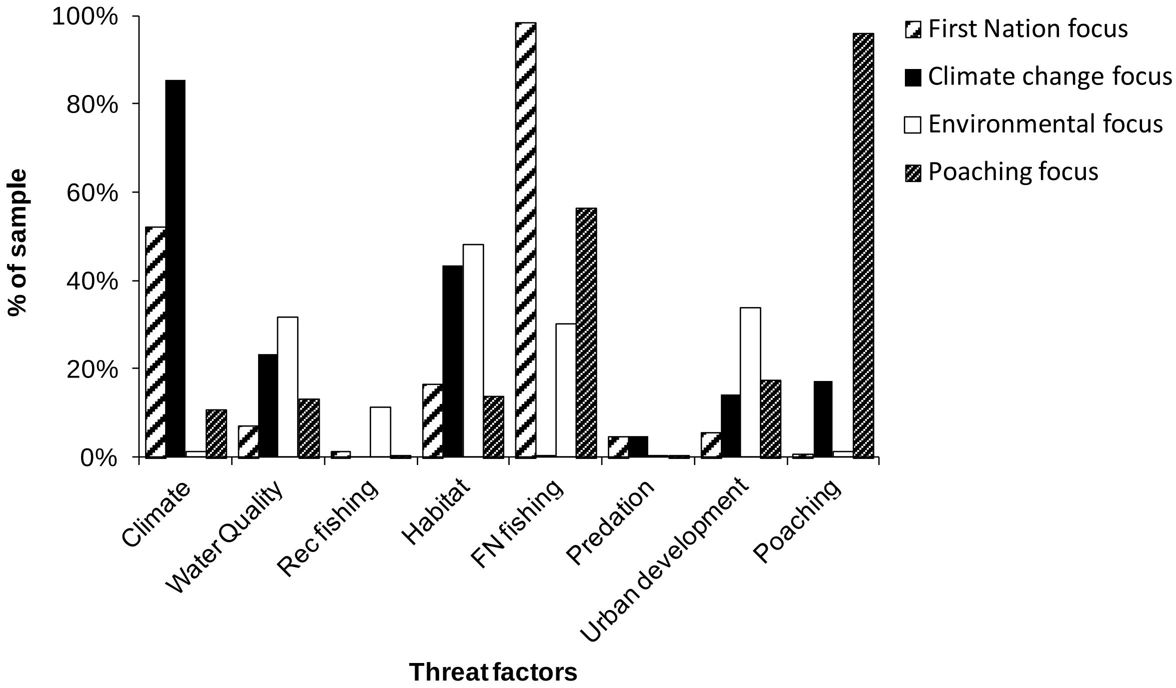


Figure 3-3. Latent-class membership profile for 4-class population threats model

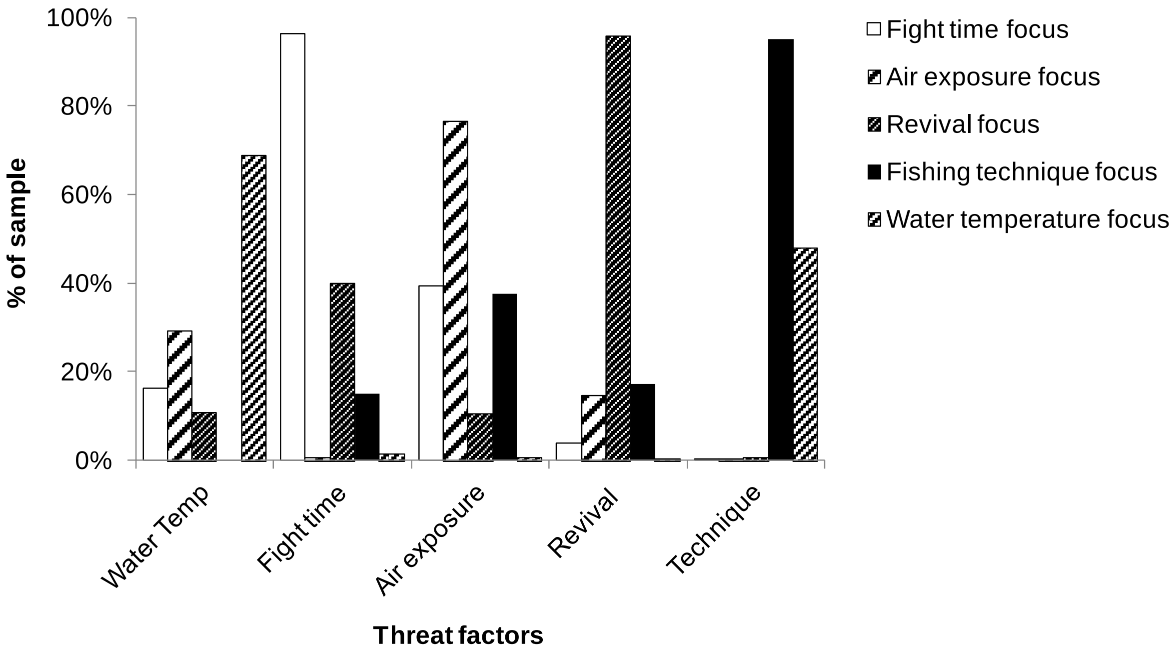


Figure 3-4. Latent-class membership profile for 5-class post-release survival threats model

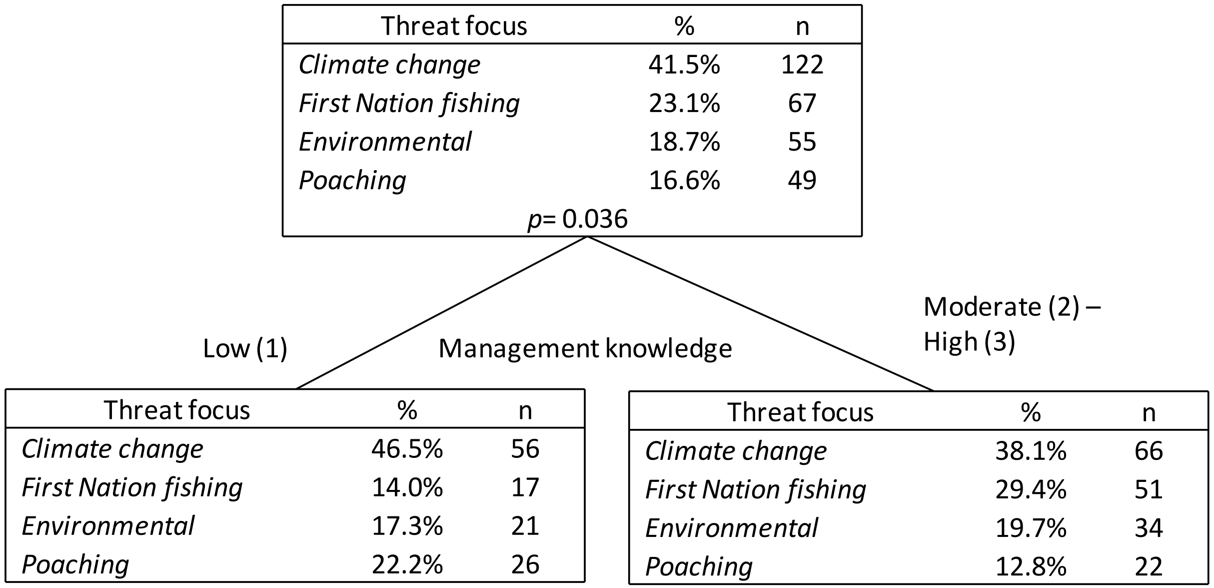


Figure 3-5. CHAID dendogram of sample segmentation based on self-reported management knowledge

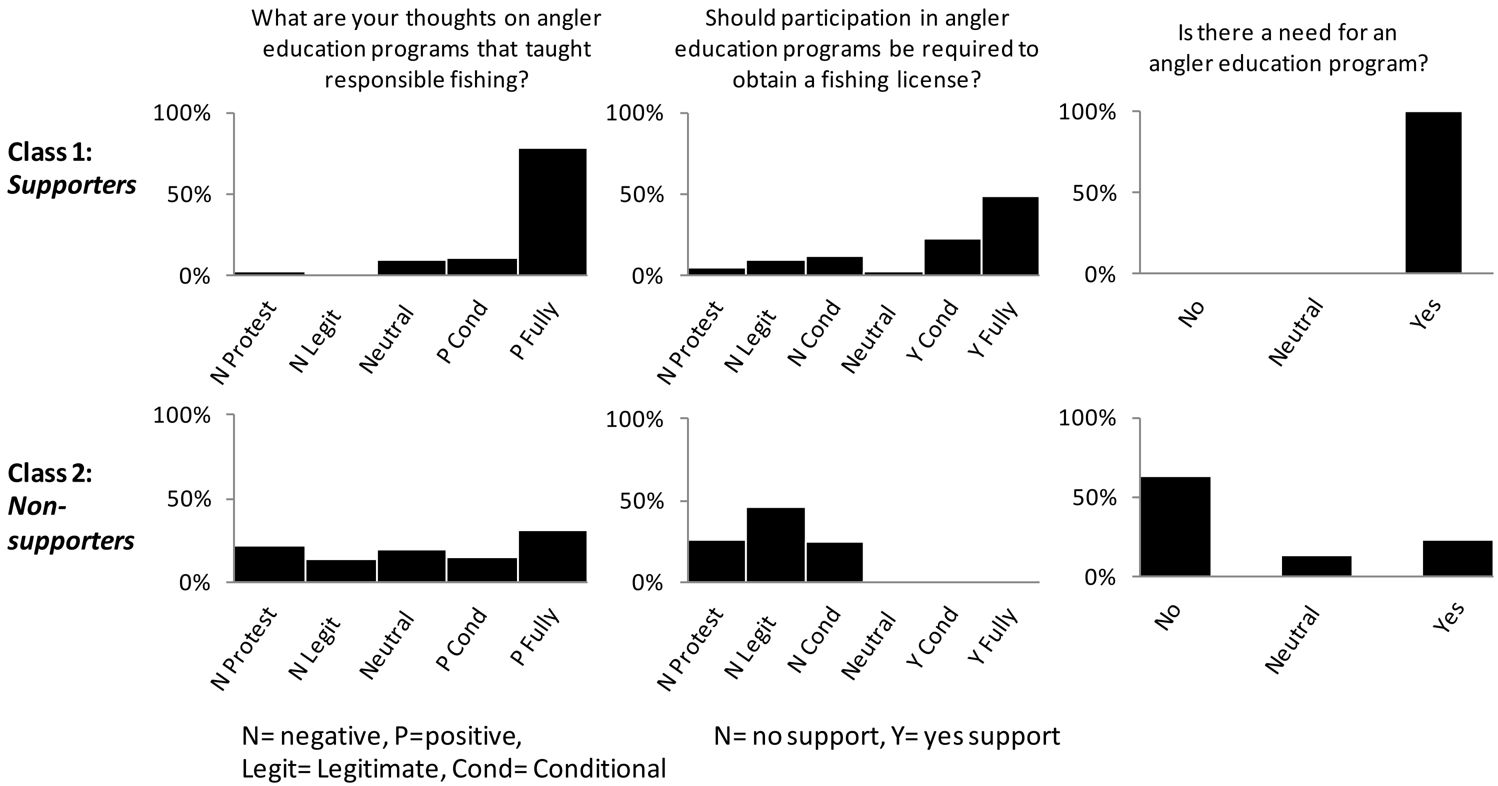


Figure 3-6. Latent-class membership profile for 2-class *angler education program* support model

Appendix 3-A – Supplemental Information

Full wording of relevant interview questions*:

1) How many years have you been fishing?
2) How many days/times have you fished in the last 12 months?
3) What percentage of your fishing is focused on migrating salmon in non-tidal water?
4) What other species [other than salmon] do you target?
5) On a scale of 1-5 (5= most important and 1= least important): How important would you rate fishing as part of your lifestyle?
6) On a scale of 1-3: How familiar are you with management technique, approaches and procedures used to make decisions about the recreational salmon fisheries? (1= not familiar, 2= somewhat familiar, 3= very familiar)
7) Considering the list below, could you rank the top 3 factors (in order) that you believe have the greatest impact on upriver migrating salmon?
8) Considering the list below, could you rank the top 3 factors (in order) that you think have the greatest effect on whether salmon that you release will live or die?
9) What are your thoughts on angler education programs/angling courses (for fishers) that focused on responsible fishing, and teaching local fishing regulations?

   Probe: Is there a need for one? What do you think these education programs should include?
10) Should participation in these angler education programs be required in order to purchase a fishing license? If Yes, why? If No, why not?

*Note that the full wording during interviews are not exact since we adopted a semi-structured interview which takes form as a conversation and adapted to each respondent

Description and context of threat factors related to upriver migrating salmon populations:

- **Climate change**: Water temperatures in the Fraser River have risen 2°C in the past 60 years due to global warming and changing hydrological regimes
- **Commercial fishing:** economic fishing in the ocean and water-mouth of the Fraser River
- **First Nation fishing:** economic, ceremonial, food and social fishing occurring inland of the Fraser River
- **Fish Farms:** Atlantic salmon fish farms positioned in the ocean off Vancouver Island, BC, potentially involved in the spread of sea lice on juveniles migrating to the ocean
- **Fish health**: the natural condition and health of individual fish migrating upriver
- **Habitat alterations:** any change to the environment where salmon tend to live and spawn which can include habitat fragmentation, degradation, loss, and so on
- **Mismanagement:** belief that improper management of the fisheries and poor management decisions are a threat to salmon populations
- **Poaching:** any form of cheating the regulations/law related to fish harvest for all three fishing sectors. For example, harvesting more fish than the law permits.

- **Predation**: the capture and presumably feeding on salmon by non-human organisms (e.g. seals, bears)
- **Recreational fishing:** the sport fishing and harvest of salmon using rod-and-reel
- **Urban development**: The expansion or process of building cities and other places for people to live
- **Water quality:** River water conditions that are sub-optimal for salmon. Examples include suspended sediment and contaminants.
- **Other:** option that allows respondent to name something that is not listed
- **I don't know:** option that allows respondent to indicate they are not aware of an appropriate response or do not have an opinion

Description and context of threat factors related to post-release survival of salmon:

- **Air exposure**: time fish are held out of the water
- **Angler experience**: the direct relationship between angler experience and the proper fishing, handling and release techniques
- **Beach dragging:** the process of keeping fish on the hook and line while landing and dragging entirely it on shore
- **Capture location in river:** location fish are captured relative to the ocean and spawning grounds and relative to salinity changes from tidal to non-tidal waters
- **Fight time:** the time a fish is hooked until landing
- **Fishing technique used:** method of which fish is hooked, particularly bottom-bouncing versus bar fishing in the context of salmon river fishing
- **Hook location:** where on the fish anatomy the hook has penetrated

- **Predation density:** the number of predators in the surrounding release site
- **Revival efforts**: the presence or absence of any revival attempt
- **Warm water temperatures:** increased temperature over sub-optimal conditions for salmon
- **Other:** option that allows respondent to name something that is not listed
- **I don't know:** option that allows respondent to indicate they are not aware of an appropriate response or do not have an opinion

Description of fishing characteristics in the anger typology model:

- **Site access:** the level of difficulty and method of physically getting to a fishing site (for example by boat, by foot via hiking or via paved trail)
- **Other target species:** fish species that the individual of interest focuses their fishing effort when not fishing for sockeye
- **Non-tidal fishing**: refers to fishing in the non-tidal portion of the Fraser River which is everything upriver from the CPR Bridge at Mission (Department of Fisheries and Oceans Canada website www.pac.dfo-mpo.gc.ca)
- **Years of fishing experience:** number of years the respondent has engaged in recreational fishing to assess angler fishing experience
- **Days fished in last 12 months:** approximate number of days the respondent has fished in the 12 months to assess angler fishing avidity

Appendix 3-B – Selection criteria and goodness of fit measures for all LC models

Model A: ***Angler Typology Model***

Model selection procedures	LL	BIC(LL)	AIC(LL)	AIC3(LL)	Npar	L^2	df	p-value
1-Cluster	-1943.55	4000.291	3927.101	3947.101	20	922.8965	267	4.20E-73
2-Cluster- min. BIC, AIC3	-1847.03	3897.805	3766.064	3802.064	36	729.8593	251	2.93-48
3-Cluster- minimized AIC*	-1830.08	3954.453	3764.16	3816.16	52	695.9553	235	3.80E-47
4-Cluster	-1815.64	4016.131	3767.286	3835.286	68	667.0818	219	8.60E-48
5-Cluster	-1805.68	4086.755	3779.359	3863.359	84	647.1544	203	8.20E-48
6-Cluster	-1790.23	4146.414	3780.466	3880.466	100	616.2613	187	2.90E-47
3-Cluster – FINAL MODEL	-1830.08	3954.453	3764.16	3816.16	52	6.96E+02	235	3.80E-47

*The 3-cluster model was chosen based upon examination of the cluster profile. The 3-cluster model revealed more relevant information, whereas the 2-cluster model would have a loss of information.

Model B: ***Population Threats Model***

Model selection procedures	Model	LL	BIC(LL)	AIC(LL)	AIC3(LL)	Npar	L^2	df	p-value
A1	1-Cluster	-1771.11	3621.745	3570.223	3584.223	14	955.2614	279	7.20E-75
A2	2-Cluster	-1735.18	3635.083	3528.358	3557.358	29	883.3967	264	8.10E-68
A3 – AIC3 minimized*	3-Cluster	-1710.34	3670.609	3508.681	3552.681	44	833.7198	249	3.50E-64
A4 - AIC minimized*	4-Cluster	-1688.29	3711.706	3494.576	3553.576	59	789.6149	234	2.20E-61
A5	5-Cluster	-1676.4	3773.138	3500.805	3574.805	74	765.8437	219	9.30E-62
A6	6-Cluster	-1661.54	3828.621	3501.085	3590.085	89	736.1241	204	3.00E-61
B4 dropped fish farm BVR	4-Cluster	-1514.33	3341.064	3138.654	3193.654	55	452.2199	238	1.80E-15

B4 dropped mismgmt BVR	4-Cluster	-1343.91	2977.516	2789.827	2840.827	51	267.7156	242	0.12
B4 dropped fish health BVR	4-Cluster	-1289.46	2845.888	2672.92	2719.92	47	210.9519	246	0.95
B4 dropped commercial BVR	4-Cluster	-1105.27	2454.787	2296.54	2339.54	43	113.0946	250	1
C1 re-run with eliminated BVRs	1-Cluster	-1157.71	2372.213	2335.411	2345.411	10	217.966	283	1
C2 - AIC3 minimized	2-Cluster	-1130.5	2380.283	2302.999	2323.999	21	163.5542	272	1
C3	3-Cluster	-1115.95	2413.667	2295.901	2327.901	32	134.4558	261	1
C4 AIC minimized=FINAL	4-Cluster	-1105.27	2454.787	2296.54	2339.54	43	113.0946	250	1
C5	5-Cluster	-1096.82	2500.375	2301.646	2355.646	54	96.2008	239	1
C6	6-Cluster	-1092.39	2553.99	2314.779	2379.779	65	87.3335	228	1

*Both 2- and 4-clusters are minimized by AIC3 and AIC, respectively. We chose to use run the 4-cluster model and eliminate significant BVRs as this model provided more relevant information that we believed would have been lost in the 2- and 3-cluster model

Model C: *Risks to Post-Release Survival Model*

Model selection procedures	Model	LL	BIC(LL)	AIC(LL)	AIC3(LL)	Npar	L^2	df	p-value
A1	1-Cluster	-1581.62	3231.156	3187.242	3199.242	12	826.2559	275	1.70E-56
A2	2-Cluster	-1547.88	3237.243	3145.756	3170.756	25	758.7697	262	7.70E-50
A3	3-Cluster	-1524.97	3265	3125.939	3163.939	38	712.9531	249	2.60E-46
A4 minimized AIC3*	4-Cluster	-1503.84	3296.312	3109.678	3160.678	51	670.6919	236	2.70E-43
A5	5-Cluster	-1487.41	3337.027	3102.82	3166.82	64	637.8336	223	1.30E-41
A6	6-Cluster	-1474.28	3384.337	3102.557	3179.557	77	611.5703	210	7.10E-41
A7 minimized AIC*	7-Cluster	-1457.42	3424.184	3094.83	3184.83	90	577.8438	197	4.40E-39
A8	8-Cluster	-1451.18	3485.278	3108.351	3211.351	103	565.3648	184	2.20E-40
A9	9-Cluster	-1440.41	3537.32	3112.82	3228.82	116	543.8342	171	2.00E-40
A10	10-Cluster	-1432.7	3595.481	3123.408	3252.408	129	528.4217	158	1.80E-41
A5 dropped experience BVR	5-Cluster	-1295.87	2925.641	2709.732	2768.732	59	286.824	228	0.005
A5 dropped hook location BVR	5-Cluster	-1119.68	2544.969	2347.357	2401.357	54	130.9159	233	1
A5 dropped beach drag BVR	5-Cluster	-932.888	2143.09	1963.776	2012.776	49	44.098	238	1

B1 re-run with eliminated BVRs	1-Cluster	-993.476	2037.887	2004.951	2013.951	9	165.2735	278	1
B2 - minimized AIC3	2-Cluster	-972.151	2051.833	1982.303	2001.303	19	122.625	268	1
B3 - potential	3-Cluster	-957.282	2078.688	1972.563	2001.563	29	92.8853	258	1
B4 - potential	4-Cluster	-943.444	2107.607	1964.887	2003.887	39	65.2095	248	1
B5 - minimized AIC**	5-Cluster	-932.888	2143.09	1963.776	2012.776	49	44.098	238	1
B6	6-Cluster	-927.643	2189.195	1973.286	2032.286	59	33.608	228	1

***5-cluster model was chosen based compromise between AIC and AIC3 in addition to the segmentation of the 5-cluster profile**
****5-cluster model minimizing AIC was chosen over the potential 2-, 3-, 4-cluster (minimized AIC3) models because it was believed to reveal more relevant information**

Model D: ***Angler Education Program Support***

Model selection procedure	Model	LL	BIC(LL)	AIC(LL)	AIC3(LL)	Npar	L^2	df	p-value
A1	1-Cluster	-122.419	269.5026	256.8374	262.8374	6	41.3379	20	0.0034
A2- minimized AIC, AIC3 = final	2-Cluster	-105.799	265.0391	237.5978	250.5978	13	8.0983	13	0.84
A3	3-Cluster	-103.533	289.2837	247.0662	267.0662	20	3.5667	6	0.74
A4	4-Cluster	-102.814	316.6208	259.6272	286.6272	27	2.1278	-1	.
A5	5-Cluster	-102.699	345.1682	273.3985	307.3985	34	1.8991	-8	.
A6	6-Cluster	-102.625	373.796	287.2501	328.2501	41	1.7507	-15	.

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Chapter 4: Differences in information use and preferences among recreational salmon anglers: implications for management initiatives to promote responsible fishing

Abstract

British Columbia salmon fisheries are encouraging anglers' adoption of responsible and selective fishing methods to avoid or live-release vulnerable non-target species. Promoting adoption of responsible fishing will require that managers understand angler motivations and fishing behaviour. During interviews with Fraser River recreational salmon anglers, we found that their most common information channel on responsible fishing was the Internet and interpersonal interaction while fishing. These did not necessarily align with their preferred information sources. Latent-class cluster analysis identified three patterns of anglers' current and preferred information sourcing. We found traditional (35% of sample), investigative (33%), and networking (32%) anglers, that were differentiated by their preferences for obtaining information via in-person communication, regulation handbooks, media, and the Internet. Heterogeneous communication preferences imply that fisheries managers need to use a mix of outreach approaches to effectively engage all anglers in responsible fishing practices, even when anglers are targeting the same species in a reasonably discrete geographic location.

Introduction

Stakeholder engagement is critical for successful recreational fisheries management and conservation (e.g. Arlinghaus *et al*. 2007, Granek *et al*. 2008). Indeed, engaging an informed and knowledgeable community should ultimately lead to more productive relationships between stakeholders and managers, and help increase stakeholder support for conservation and management efforts (e.g. Gray & Jordan 2010, Li *et al.* 2010). Efforts to engage fishers are relevant for fisheries around the world, especially those seeking to promote 'responsible fishing'. A 'responsible fishery' is conducted to *benefit all the people involved in the fishery without causing unacceptable changes in fish populations and their ecosystems* (Plate *et al.* 2009: p.3). Therefore, responsible fishing often includes fisher involvement with management initiatives such as catch-and-release fishing and special handling procedures that help ensure the survival of vulnerable stocks and species.

In the case of the Canadian Pacific salmon fishery in British Columbia (BC), a selective fishing approach is used to address mixed-stock harvesting which mandates fishers to avoid and release non-target species (e.g. undersized, juveniles, vulnerable stocks and species; DFO 2001). Ensuring that those fish destined for release after capture are handled in a manner that minimizes injury, stress, and mortality requires consideration of fish physiology (Cooke & Suski 2005, Cooke & Schramm 2007) and angler behaviour (e.g. fishing techniques and gear choice), both of which influence the biological outcomes of catch-and-release fishing. As such, it is important for managers to understand, communicate, and take measures that encourage responsible fishing behaviour that reduces stress and mortality for non-target species. An important first step is to understand where anglers engage with information about responsible fishing practices, and how information could be more effectively disseminated.

Some recreational angler typology studies have examined angler specialization (e.g. Fisher 1997, Kyle *et al.* 2007), or angler support for different types of fisheries management measures or policies (e.g. Arlinghaus & Mehner 2003, 2005). None, to our knowledge, have examined angler typology based on communication preferences. Communication and awareness-building exercises that are meant to encourage responsible fishing practices may not lead to the desirable conservation outcomes if information dissemination is ineffective. Nonetheless, government natural resource agencies frequently deliver outreach and education activities which could represent significant wasted efforts and resources. We use the lower Fraser River recreational salmon fishery as a case study to explore communication preferences by assessing different communication sources and channels associated with informing anglers about responsible fishing.

Methods

Between 30 July and 26 August, 2010, we conducted semi-structured, face-to-face interviews with recreational anglers targeting sockeye (*Oncorhynchus nerka*) salmon in the lower Fraser River. During 311 interviews completed at fishing sites and boat launches (as part of a broader study), we specifically asked open-ended questions regarding anglers' responsible fishing information sourcing and preferences in 71 of the interviews (see Table 4-1 for questions). Our focus was on anglers' current channels of information regarding fish handling and release practices that may improve fish survival, and on the best way for the federal management agency, the Department of Fisheries and Oceans Canada (DFO), to distribute information about responsible fishing practices.

To select the study sites, we used opportunistic sampling and visited fishing sites and boat launches primarily between the towns of Mission and Hope on the Lower Fraser River. On site, we approached every second angler along the river to ensure random sampling and avoid other anglers overhearing participants' responses. With angler consent, we audio-recorded responses, then subsequently transcribed and coded them following standard qualitative research protocol (e.g. Strauss 1987, Creswell 2009). Responses were coded by the lead interviewer according to emergent themes based on keywords, phrases, and topics raised by anglers. Consistencies between codes (similar meanings or pointing to a basic idea) revealed categories that identified current and suggested information sources and channels on how to better handle and release fish.

Emergent themes on anglers' current and suggested information sources were subsequently used as indicator variables in the latent class (LC) cluster analysis (Vermunt & Magidson, 2002) to characterize patterns of communication regarding responsible fishing practices. LC models can identify similar response patterns regarding information use and preferences within a sample by statistically analyzing a set of observed indicator variables (i.e. themes based on interview keywords, phrases, and topics). The methodology systematically separates sub-segments within which patterns of indicators are statistically similar and are a proxy for true underlying class membership (e.g. Morey, Thacher & Breffle 2006; Ward, Stedman, Luloff, Shortle & Finley, 2008). Essentially the LC expectation-maximization (EM) algorithm matches the observed and expected frequencies of anglers' responses as closely as possible.

We used the Akaike Information Criterion (AIC) to inform model selection (Appendix 4-A). The model with the number of latent classes which minimized AIC was chosen as the most parsimonious. We tested for redundancy between indicators using bivariate residual (BVR) statistics. Significant BVRs ($x^2 > 3.84$, $df = 1$, $p < .05$) signify local dependence, or direct relationships, between variables (Hagenaars, 1988) and functionally mean that two or more indicators provide redundant information for the clustering process. As such, we sequentially dropped indicators with the highest number of significant BVRs until all significant local interactions were eliminated. Latent Gold software (Vermunt & Magidson 2005) was used to estimate all LC models.

After identifying latent classes that varied significantly in current and suggested communication patterns, we tested for significant attitudinal and demographic predictors of LC membership patterns (i.e. gender, age, ethnicity, education, occupation, income, fishing club membership, centrality of fishing to lifestyle, and management knowledge) with a series of Bonferroni-adjusted Chi-square tests (Magidson & Vermunt 2005). Here, ‘centrality (i.e. importance) of fishing to lifestyle’ was measured on a 5-point scale (1=least important to 5=most important) and perceived ‘management knowledge’ was assessed on a 3-point scale (1=not familiar to 3=very familiar). Furthermore, we tested for correlations among our model and the four models (i.e. angler typology, population threats, risks to post-release survival, and angler education program support) generated in Chapter 3 using Spearman rank correlation (PASW 18.0).

Results

Sixty-eight of 71 respondents provided useful data for our analysis. When asked where they would get information about responsible fishing, respondents revealed information channels that fell into seven themes (Table 4-1). Respondents most frequently identified ‘Internet websites’ (55%), ‘talking and asking others on fishing sites’ (12%), and ‘other sources’ (12%), which mainly comprised of word-of-mouth from family and friends as their sources of fishing information. When asked about where they would prefer to get their information, respondents identified information channels that fell into nine themes (Table 4-1). The most frequently suggested information channels were: ‘having officers and managers in person at the fishing sites’ interacting with anglers (22%); via ‘the Internet’ (12%), and ‘other sources’ (15%) such as signs at boat launches and beaches, printing on fishing licenses, through fishing clubs, and via word-of-mouth.

In our model of angler communication preferences, the AIC was minimized with three classes. Anglers were differentiated based on their current and preferred communication channels (Fig. 4-1a,b), suggesting that in this small sample there were three distinct classes to which all anglers in the sample belonged. Within each class, patterns of information use and preference were indistinguishable but, between classes, patterns were statistically distinct. Only one indicator, Internet as current information channel, was important to all respondents but was dropped from the analysis because it provided redundant information. That is, although the Internet was the most frequent information channel identified, it did not play a role in differentiating patterns of current use of information channels among sample respondents.

Anglers in Class 1 (35% of the sample) most commonly received information via word-of-mouth at fishing sites, and via their social network, but did not often use the Internet (Fig.4-1a). They preferred to receive responsible fishing information in a structured form (e.g. handouts), through the media, or in formal settings (e.g. seminars, as part of mandatory angler testing; Fig. 4-1b). We refer to respondents in this class as *traditional* anglers as they tended to prefer established methods of communication. Anglers in Class 2 comprised 33% of the sample. These *investigative* anglers preferred to obtain their information via the Internet or from a regulation book (Fig.4-1a), had diverse ideas regarding alternative communication channels (Fig. 4-1b), actively sought information, and tended to be active in the angling community (i.e. fishing club membership). *Networking* anglers (32% of the sample) in Class 3 relied largely on tackle shops and publications (e.g. leaflets) for current information (Fig.4-1a) and would strongly prefer to obtain information through interactions and networking with other people (e.g. anglers, fishery officers, DFO managers, fishing shop staff; Fig.4-1b). Note that the classes of recreational anglers did not necessarily receive information about responsible fishing that they would like via their preferred channels or in their preferred forms (i.e. there are disparities between Figures 4-1a and 4-1b). Although the Internet was most frequently identified as current information channel among participants, Internet access was not a preferred source of information for either *traditional* or *networking* anglers.

After identifying the three distinct communication patterns, we found no demographic predictors of LC membership patterns (i.e. gender, age, ethnicity, education, occupation, income, fishing club membership, centrality of fishing to lifestyle, and management knowledge). That is, for this relatively small sample, we distinguished three statistically distinct patterns of information use and communication preference but it was not possible to predict what class an individual angler belonged to based on demographic characteristics or self-reported attitudinal variables about respondents' management knowledge or the centrality of recreational fishing to their lifestyle. No significant correlations were observed between the current communication behaviour LC model and the LC models generated in Chapter 3.

Management Implications

Our relatively small sample size and the opportunistic sampling approach cannot be scaled up to provide inferences about the entire population of BC recreational salmon anglers. Rather than develop inferences about the entire population, our latent class approach did identify *differences* in anglers' information use and communication preferences. Even if the classes were differentiated on somewhat different lines with a much larger sample, we believe that the distinctiveness in communication preferences for these three groups would remain an important factor characterizing anglers in the fishery. The existence of the three classes identified in this study cannot be ignored, and should be of importance to fisheries management because it alerts them of the need to customize methods of disseminating information about responsible fishing, and it highlights the importance of using different methods of communication for different types of anglers.

Similar to our findings, Gray and Jordan (2010) also observed diversity in marine recreational anglers in the United States with regards to their use of information about fishery management. The authors revealed that anglers obtained information from fishery trade magazines (53% of sample), fishing shops (49%), online sources (40%), and informally through other anglers (33%). These roughly corresponded with our top communication channels (Table 4-1). Our results are in relative agreement with findings from Cardona-Pons *et al*. (2010), who found that most anglers in their sample became aware of a tagging project through other anglers (57%), leaflets (46%), or information provided at fishing competitions (30%).

The *traditional* anglers in our survey obtained most of their information informally through other anglers at fishing sites and via their social network. While we cannot generalize and say that 35% of all Fraser River anglers belong to the *traditional* class, it is likely that a sizeable proportion of recreational anglers fall into that category. The identification of the *traditional* class has implication for fisheries managers as anglers in this class would likely not receive or benefit from online information. As one respondent stated, “We don’t know much about computers, and they keep changing it daily – it’s really confusing.” In addition, information about fish handling found in regulatory guides of many natural resource agencies are inconsistent with science-based best practices (Pelletier *et al.* 2007). Given the many *traditional* anglers that rely on this source for information about responsible fishing practices, it is essential that the fish handling information is accurate in guides and on licenses. Furthermore, *traditional* anglers rely heavily on word-of-mouth communication with other anglers for information, as have anglers in other regions (e.g. Cardona-Pons *et al.* 2010). Another respondent said: “For the most part, when you fish on the River you get tips from guys around. You watch the guy next to you and so forth. It’s word-of-mouth and there is good communication here.” Communication via social networks and word-of-mouth could be an influential tool for natural resource management (Pretty 2003). Clearly, the costs of different information dissemination strategies to fisheries management will differ substantially. The approaches suitable for reaching traditional anglers appear to be costly, for example, relative to dissemination of information via the Internet.

Investigative anglers are more likely than other anglers to get information from fishing clubs, to independently and actively seek out information, and provide more unique communication alternatives than other anglers, possibly reflecting their breadth of knowledge and awareness as fishing club members (e.g. Cardona-Pons *et al.* 2010). One respondent stated that: “Most guys who are part of a fish and hunting club are pretty well educated. DFO should go through fishing clubs to increase public education.” This group may be the easiest and least costly for managers to reach given their openness to obtaining information across a variety of sources.

Networking anglers obtained much of their current information on responsible fishing from tackle shops and by reading publications (i.e. leaflets). They had very strong preferences for seeing more DFO (i.e. managers and conservation officers) personnel walking the beach, interacting with fishers, and engaging them with regards to responsible fishing behaviours. For this segment, managers may need to look into more collaborative work with fishing shops and invest in more interactive and social ways to promote awareness. This group of anglers would require more effort and be more costly to reach because of the limited channels through which they receive information and their reliance on interpersonal interactions with fishing shop staff, managers, and conservation officers.

Identifying distinctive behaviour- and preference-based angler segments within the broader population can provide insights for fishery managers regarding effective communication strategies and awareness-building initiatives. Collaboration between managers and stakeholders, and the provision of information through these trusted sources can represent cost effective communication (Peters *et al.* 1997) and promote integrity and trust, important factors that influence the likelihood of whether a message is accepted or rejected (Trettin & Musham 2000). The reliance of anglers on information by word-of-mouth and personal contact (e.g. other anglers, fishing club members, fishing shop and DFO staff) highlights the potential of using social capital and norms to shape behaviour affecting resource use and the transaction costs of management (Rudd *et al.* 2002, Pretty 2003).

Our research revealed three distinct angler types, implying that, irrespective of which communication programs are considered, fisheries managers will need a mix of outreach approaches to effectively reach all anglers. As our sample was small, it may well be that there exists more angler types that may vary in other aspects of information use and communication preferences. Still, our key message, that recreational fishery managers need to be prepared to spend time and resources to reach anglers of different types using different means, remains valid. Different strategies of communication and engagement are likely to involve a relatively complex mixture of direct (e.g. communication materials, field staff time) and transaction (e.g. managerial time, planning, revising policies, etc.) costs that are often not accounted for in economic analyses of recreational fisheries (Rudd *et al.* 2002). From a biological perspective, it is not yet clear what the specific benefits of various responsible fishing practices are for fish survival. That is, are different information provision and communication strategies equally effective in reducing mortality of fish that are captured and released? Managerial choices regarding the optimal mix of communication and engagement strategies may be improved by better understanding fishers' communication preferences. Still, empirical investigations of the benefits, the ultimate impacts of various strategies on release mortality, and on the direct and transaction costs of various alternatives, are required to fully understand and predict benefits and consequences of management options. This requires close collaboration among social scientists, fishery ecologists, and fish physiologists in interdisciplinary research efforts. We believe that our case study on information provision and communication preferences in the Fraser River is one important step in that direction.

Tables

Table 4-1. Themes raised by respondents (*n*=68) regarding current information channels and suggested distribution channels for responsible fishing information

Current information channels ("As of today, where would you go to find more information about appropriate handling and release techniques?")	Label	Frequency of responses (%)
Internet websites	Internet	55.4
Talking with other anglers on fishing sites	Other anglers	12.2
Tackle shops	Tackle shops	6.8
Publications (e.g., magazines, books, handouts)	Publications	6.8
Media (e.g., television, videos, radio)	Media	4.1
Fishing clubs	Fishing clubs	2.7
Other (mainly comprised of word-of-mouth from family and friends)	Other	12.2
Suggested information channels ("What is the best way for DFO to distribute this kind of information?")	**Label**	**Frequency of responses (%)**
Interacting with officers/managers on fishing site	In person	22.3
Internet websites	Internet	12.3
Dedicate pages from regulation book for conservation and species identification	Regulation book	11.1
Media	Media	9.9
Handouts and publications	Handouts and publications	8.6
Tackle shops (i.e., staff and bulletins)	Tackle shops	7.4
Educational seminars	Seminars	7.4
Mandatory tests to obtain license	Mandatory tests	6.2
Other (e.g., signs at boat launch and beaches, printed on fishing license, promotion through fishing clubs, and word-of-mouth)	Other	14.8

Figures

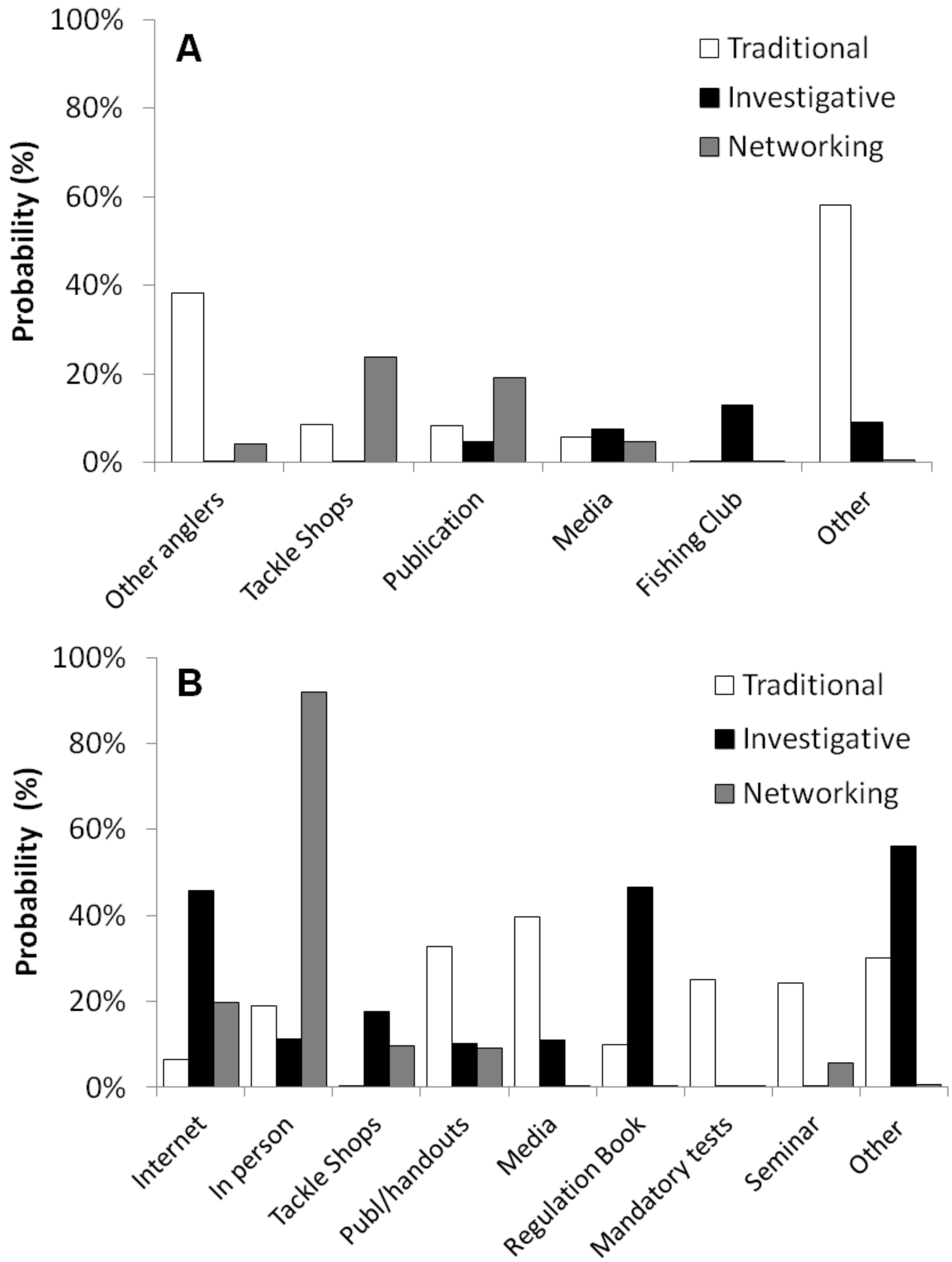

Figure 4-1. Latent-class membership profile for 3-class communication preference model: A) current sources of responsible fishing information; and B) suggested distribution channels for information

Appendix 4-A

Model choice procedures	Model	LL	BIC(LL)	AIC(LL)	AIC3(LL)	Npar	L^2	df	p-value	Class.Err.
A1	1-Cluster	-454.163	975.6009	940.3258	956.3258	16	400.3488	51	1.00E-55	0
A2	2-Cluster	-430.172	999.0982	926.3434	959.3434	33	352.3663	34	1.40E-54	0.0513
A3 - AIC minimized	3-Cluster	-408.406	1027.047	916.8121	966.8121	50	308.835	17	1.70E-55	0.0427
A4	4-Cluster	-396.947	1075.608	927.8931	994.8931	67	285.9161	0	.	0.0386
A5	5-Cluster	-385.62	1124.435	939.2405	1023.241	84	263.2634	-17	.	0.0431
A6	6-Cluster	-381.82	1188.314	965.6395	1066.64	101	255.6625	-34	.	0.0351
A3 - removed Internet	3-Cluster	-378.684	954.9882	851.3677	898.3677	47	252.1632	20	4.20E-42	0.062
B1 - re-run with removed BVRs	1-Cluster	-418.534	900.1383	867.0679	882.0679	15	331.8634	52	2.10E-42	0
B2	2-Cluster	-397.156	924.6574	856.312	887.312	31	289.1075	36	2.80E-41	0.0237
B3 - AIC minimized FINAL	3-Cluster	-378.684	954.9882	851.3677	898.3677	47	252.1632	20	4.20E-42	0.062
B4	4-Cluster	-368.526	1001.948	863.0525	926.0525	63	231.848	4	5.30E-49	0.0413
B5	5-Cluster	-361.576	1055.323	881.1527	960.1527	79	217.9483	-12	.	0.0527
B6	6-Cluster	-353.228	1105.901	896.4552	991.4552	95	201.2507	-28	.	0.0448

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Chapter 5: General Discussion

This dissertation uses an interdisciplinary approach to help understand the biological mechanisms of delayed mortality in sockeye salmon, while exploring social factors that could influence their post-release mortality, both within the context of fisheries bycatch. Delayed mortality was investigated by assessing relative consequences of stress, injury and facilitated recovery on the migratory behaviour and fate of captured and released sockeye salmon (Chapter 2) through the use of telemetry tracking, physiology, and reflex assessments. Furthermore, the severities of stress and injury as well as revival efforts on captured fish are highly dependent on angler behaviour such as handling and release techniques. As such, Chapters 3 and 4 explore differences in angler attitudes, beliefs and behaviours related to improving post-release survival of incidentally-caught fish with aims to improve understanding of angler response to environmental and management change, and inform conservation and management strategies. This thesis represents one of the first studies exploring both biological and social components to address the issue of salmon bycatch.

Findings and Implications

To date, very few studies have investigated freshwater bycatch, and few have applied long-term methods to track survival of released fish and assess latent mortality (Raby *et al.* 2011). Furthermore, no work, to my knowledge, directly compares the relative contribution of injury (by gillnet entanglement) and stress (by air exposure) to delayed mortality of captured and released Pacific salmon, and whether these fish have the capacity to recover from these stressors during their upriver migrations. This is relevant as management strategies to minimize injury or stress could be different. The research in Chapter 2 revealed no differences between the roles of gillnet injury, stress (i.e. air exposure), and facilitated recovery on the post-release mortality of migrating adult sockeye. However, trends showed that fish subjected to gillnet injuries had slightly reduced survival rates and significantly reduced mean migration speed. This suggests some evidence that physical injury may pose longer-term consequences to migrating sockeye, particularly associated with infections, even though these injured fish showed little sign of immediate reflex impairment. I suggest that injury and stress both cause sub-lethal consequences and contribute to delayed mortality, but during the moderate temperatures experienced in the current study dermal injury appeared to have a greater consequence than air exposure stress.

The experimental treatment groups reflect stressors that fish encounter when discarded or disentangled. This has implications for management, where attempts to promote live-release of captured fish and gear modifications that increase fish escaping from fishing gears, could result in an increase in latent mortality (Chopin & Arimoto 2005). Additionally, facilitated recovery failed to improve survival and migration speed of migrating adult sockeye salmon which was inconsistent with findings in the marine environment with coho salmon (Farrell *et al*. 2001) highlighting that life stage of salmon may be a critical consideration, and managers cannot assume fish responses are similar between marine and freshwaters. In general, managers should recognize that response to injury, stress, and the capacity to recover vary with different species and context (e.g. Davis 2002, Davis & Ottmar 2006, White *et al.* 2008), and if selective harvest is to be used as a fisheries management tool, there needs to be adequate research into the short- and long-term response of fish to injury and stress associated with gear encounters. In summary, although I did not show considerable en-route mortality from injuries in our study, fish sustaining injuries have a high chance of latent mortality and reproductive failure which could subsequently cause overestimation of viable spawners and affect the viability and health of the population (Baker & Schindler 2009). As such, the traditional use of short-term mortality estimates may not be appropriate for stock assessments, and considering long-term effects from fisheries' capture is critical to maintain viable populations and sustainable fisheries.

Chapter 3 presents findings from four latent-class models; salmon angler typologies, perceived threats to successful salmon migration and spawning, perceived risks due to post-capture live release of salmon, and level of support for angler education programs. This information may help fisheries managers understand anglers' potential responses to new conservation initiatives as waters warm in the Fraser River. My latent class model revealed three types of anglers: *salmon-dependent anglers* (33% of sample), *lake-species specialists* (46%), and *all-around anglers* (21%). These classes were primarily differentiated by non-salmon fishing activities (e.g. other target species) suggesting that anglers have complex matrix of motivational and behavioural dimensions that create considerable diversity among the Fraser salmon angler population. Anglers' perceived threats to migrating salmon populations were grouped into four clusters oriented towards consumptive (*poaching* and *First Nation fishing*) and non-consumptive (*climate change* and *environmental*) factors, which highlight potential responsiveness of anglers to interventionists management strategies versus educational and outreach strategies. Furthermore, I identified five clusters based on anglers' perceived risks of recreational salmon fishing post-release fish survival: *fish fight time* (29% of sample); *air exposure* (26%); *revival effort* (17%); *fishing technique* (16%); and *water temperature* (11%). This model highlights what anglers believe is important to fish survival in an angling event and provide indication to what type of management strategy they are likely to support (i.e. purchasing fishing gear that reduce fight time). The final model revealed two groups of *supporters* (73%) and *non-supporters* (27%) for angler education program, and provides detailed information and reasons for the segmentation of the two groups. Furthermore, the LC model revealed that the potential 'mandatory' education programs and the belief that there is no need for such programs are largely the reasons why a non-supporter group exists. As such, this research technique can prove to be very useful for fisheries managers to develop cost effective initiatives that have a higher likelihood of being accepted by user groups.

In Chapter 4, I present my final latent-class model exploring diversity in communication preferences of Fraser salmon anglers. I identified three types of communication preferences: *traditional* (35%), *investigative* (33%), and *networking* (32%) anglers, based on angler preferred and current use of information channels. These identified differences imply that fisheries managers need a mix of outreach approaches to effectively engage all anglers in responsible fishing practices, even when anglers are targeting the same species in a reasonably discrete geographic location.

In conclusion, my results from Chapters 3 and 4 suggest that it would be challenging to predict angler behavioural response to changing environmental conditions or management initiatives based on standard demographic factors alone. Managers will need to acknowledge the challenge of managing a heterogeneous group and consider customizing conservation initiatives by targeting angler sub-groups rather than applying a 'one-size-fits-all' management approach. My findings may help managers understand angler diversity, craft new conservation initiatives targeted for particular market segments, and anticipate responses to those initiatives aimed at improving fish handling and reducing post-capture and release mortality in the Fraser River.

Future Direction

This thesis has contributed important information towards improving the post-release survival of bycatch salmon both from a biological and social perspective. This is the first step towards providing a more holistic and complete picture to addressing salmon bycatch. From a biological perspective, my work suggests that potential for latent mortality, associated with infections, to contribute to significant unaccounted mortalities in estimates of spawning stocks should be considered. As such, more research is needed to investigate the mechanisms of pathology. With new genomics approaches, this information could improve our understanding of fish susceptibility to disease (Van west 2006, Miller *et al*. 2011, Jeffries *et al*. 2011). Furthermore, because recovery did not appear to be detrimental to fish, I believe there is merit in exploring further recovery methods, particularly in fisheries where fish being released are in extremely poor condition. From a social perspective, the notable shift in angler behaviour with change in context emphasizes the need for more nuanced research and management strategies. I also recommend that scientists and decision-makers adopt LC models as a technique to aid in indentifying distinct user groups and to customize appropriate conservation initiatives related to each.

In such a complex social-ecological systems like the Fraser River, there is clearly a strong role in salmon conservation for natural science research to determine where and why post-release mortality of vulnerable fish takes place and an equally strong role for social science in understanding how to communicate that new knowledge and if, or how, that knowledge will result in anglers changing their fishing behaviour. Not only is there a role for both the natural and social sciences but there is a need to bridge this gap, particularly among biologists, policy makers and funders (Fox *et al.* 2006). Relevant to this thesis, there is a need to align the natural and social sciences to determine whether efforts to influence angler behaviour result in direct positive outcomes for salmon survival and conservation objectives. Overall, a holistic approach between the natural and social sciences is critical to inform management and build stakeholder awareness in a way that meaningfully improves not only fish conservation but conservation initiatives worldwide.

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