Lower Fraser River Sockeye Recreational Hook and Release Mortality Study

Final Investigations into Short-term (0 to 24 h) Hooking Mortality of Sockeye (Oncorhynchus nerka) Caught and Released at Grassy Bar, Fraser River, British Columbia, 2011

Prepared for:
Fraser Salmon and Watersheds Program
(jointly managed by the Pacific Salmon Foundation and Fraser Basin Council) and
Fisheries and Oceans Canada,
Lower Fraser Area

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February 2012

2011

J.O. THOMAS AND ASSOCIATES LTD.

Fraser Salmon & Watersheds Program

Fisheries and Oceans Canada / Pêches et Océans Canada

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EXECUTIVE SUMMARY

The non-tidal portion of the Lower Fraser River supports a substantial recreational fishery during the summer when chinook (*Oncorhynchus tschawytscha*), sockeye (*O. nerka*), and pink salmon (*O. gorbuscha*) (in odd years) are migrating upstream. Bottom bouncing is the predominant angling technique for sockeye in the Fraser River. Sockeye retention periods vary inter-annually and range from less than one week to several weeks, depending on sockeye abundance and co-migrating stocks of concern. An estimated 786,100 sockeye have been harvested in the Fraser River recreational fishery over the last 12 years. Although this fishery is primarily a catch-and-keep (CK) fishery, an additional 506,800 sockeye have been estimated to have been released over the same time period with almost one-fifth (100,900) of this amount occurring in 2010 alone (Fisheries and Oceans Canada website – Pacific Region – Fraser River Area – Recreational Fisheries - Fraser River Creel Survey Results). Based on these numbers, the ability to estimate the impacts of catch-and-release of sockeye in the Fraser River bottom bounce fishery is important to the successful management and conservation of these stocks and yet, prior to 2008, no studies had been conducted to estimate catch-and-release (CR) mortality in this fishery.

This report details the methods and results from the final year of a four year study to quantify short-term (0 – 24 h) mortality rates of angled sockeye salmon using bottom bounce gear in a typical Fraser River recreational fishery. Analysis of the influence of angling-related, temporal, and environmental variables on mortality are included.

This year's study was conducted using volunteer anglers over 15 days between August 15 and September 2, 2011 at Grassy Bar in the Fraser River. In total, the study collected and analyzed data from 242 hooked and landed sockeye (angled treatment group) and 62 sockeye captured by beach seine (reference treatment group). All captured sockeye in the study were Floy® tagged and held in net pens for a minimum of 24 h prior to release back into the river. Net pens were situated in a protected side channel close to the angling site.

Primary hooking locations were observed to be on the outside of the mouth, head, or body (87% of all landed sockeye). Of this group, most were specifically hooked in the left maxillary bone (72%). Approximately 21% of the hooked fish exhibited bleeding at the time of capture. However, all sockeye that were hooked and released alive after being held 24 h in the net pens, showed no signs of bleeding and all but three (1.2%) were released in vigorous condition.

Total mortality was calculated using a simple adjusted (additive finite) method where the hooking mortality is computed as the difference between the mortality rate observed in the hooked group of sockeye and the mortality rate observed in the reference group (after Nelson 1998, Wilde et al. 2003, Wilde and Pope 2008, Millard et al. 2003, 2005). Four mortalities from the angled group were observed in the 2011 study, resulting in an estimated short-term (0 to 24 h) catch-and-release mortality of 1.7% with 95% confidence intervals of 0 to 4.2%. Similar mortality rates of 1.4%, 1.7%, and 2.4%, were found in the 2008, 2009, and 2010 studies; respectively. Of

the four fish that died in the 2011 study, two were initially hooked through the left maxillary bone, and two were hooked on the ventral surface, posterior to the head. Cause of death was associated with arterial damage caused by the hook to the gills (maxillary hooking) or to the heart (ventral hooking). No mortalities were observed in the reference group (beach seined).

Radio-tagging of individual sockeye was also undertaken during the hook and release study by a joint research team from Carleton University (Ottawa) and the University of British Columbia (Vancouver). Tracking and analysis of radio-tagged sockeye will provide insights into migration routes and timing, longer-term post-capture survival and stock composition (from DNA tissue sample analysis). Results from the 2010 and 2011 studies are pending and are anticipated to be published in separate reports.

The results presented in this report are specific to the environmental conditions, stock assemblages, fishing location, fishing effort, angler profile, capture techniques and time periods discussed. Mortality rates presented are short-term (0 to 24 h) estimates only. Our study provides some discussion but does not conclude what the long-term or cumulative effects associated with hooking, handling or holding have on ultimate survival or successful spawning of sockeye encountered in the study.

INTRODUCTION

The non-tidal portion of the Lower Fraser River (from Chilliwack to Hope, British Columbia) supports a substantial recreational fishery during the summer when adult chinook (*Oncorhynchus tschawytscha*), sockeye (*O. nerka*), and pink salmon (*O. gorbuscha*) (in odd years) are migrating upstream to spawn. Sockeye retention fishing periods vary inter-annually and range from less than one week to several weeks, depending on inseason estimates of sockeye abundance. If abundance permits a fishery, the regulations have generally allowed the daily harvest of two (2) sockeye. While these regulations offer a traditional “catch-and-keep” (CK) fishery, the “catch-and-release” (CR) of sockeye is also common for anglers that have either reached their daily limit or choose to release undersized fish, when fish are beginning to display secondary sexual characteristics, or during other recreational fishery openings where sockeye are non-target species (Kristianson and Strongitharm 2006). As a result, substantive numbers of sockeye can be released in this fishery. Between 2000 and 2011, DFO creel surveys have estimated a total harvest of close to 786,100 sockeye in the Fraser River summer recreational fishery and an additional release of almost 506,800 sockeye (this includes sockeye hooked during directed chinook fisheries) (Source: Fisheries and Oceans Canada website).

Fraser River sockeye do not actively feed just prior to and during the freshwater stage of their adult spawning migration (Brett 1995; Hinch et al. 2006). As a result of this, the predominant angling technique to catch sockeye in the Fraser River bar fishery is bottom bouncing (also known as “flossing”). Bottom bouncing employs long leaders (usually greater than 3 meters in length) and barbless J-shaped hooks, commonly sized 1/0 to 4/0. Often the hook is “baited” with wool and/or a brightly coloured corkie. The gear is cast into the river with a weighting system that “bounces” on the river bottom. As the line drifts or travels along the river bottom, the leader/hook combination drags near the body of resting or swimming salmon. Frequently the line passes near the head and “flosses” through the mouth causing the line to stop or hesitate. The angler reacts to this hesitation by abruptly dragging back on the line causing the hook to embed into the salmon. The primary hooking location is often on the left side of the salmon in the upper jaw (maxillary bone) (J. O. Thomas and Associates 2009, 2010, 2011). Other hooking locations outside the mouth or head and occasionally inside the mouth are possible, however they have been observed much less frequently. Other salmon species such as chinook, coho, and pink (usually only in odd years and when abundant) are also caught using this method.

Capture in any recreational fishery can result in a number of consequences to the physical and physiological condition of the fish. For example: hooking injuries, bleeding, scale loss, fin fraying, tissue abrasion, mucous loss, and sub-dermal injuries can be common during the hooking, fighting, landing, unhooking, and release procedures. Recovery from these injuries as well as the physiological changes that occur during and after capture can lead to premature mortality. It has been speculated, and substantiated to some degree during the first three years of this study, that hooking and release of sockeye in a bottom bounce fishery results in very low mortality rates. Given the substantial numbers of sockeye that can be hooked and released during this fishery, it is important to quantify what the mortality is and understand what factors influence it. In order to estimate mortality rates in this fishery, the first of a series of studies was conducted in 2008, primarily to establish an approved sample design and gather and analyze CR data originating from a typical bottom bounce fishery targeting sockeye in the Fraser River (J. O. Thomas and Associates 2009). Analysis of data collected in the 2008 study suggested that the location and degree of the hooking injuries results in very low short-term mortality. The mortality rate in the study was estimated to be 1.2% with 95% confidence intervals of between 0 and 4.1% (J. O. Thomas and Associates 2009).

A second study was repeated during August 2009 using similar methodology and procedures as described in the 2008 report. Short-term mortality rates in the 2009 study were very similar to those seen in 2008 with an estimated mortality rate of 1.7% (95% C.I.: 0 to 4.0%) (J. O. Thomas and Associates 2010). In addition to collecting basic CR data and estimating short-term mortality rates, physiological sampling and radio-tagging was also conducted concurrently on a cross-section of sockeye captured during the 2009 study. Radio-tagging and physiological sampling was coordinated by Michael R. Donaldson (Ph.D.) and his research team at the Centre for Applied Conservation Research, Forest Sciences Centre, University of British Columbia. Non-destructive and destructive physiological sampling was conducted to gather information related to stress levels, changes in osmolality, DNA, and energy reserves from sockeye in each of the capture treatment groups as well as the angled sockeye after 24 h recovery in the net pens. The radio telemetry component was added in 2009 in order to collect additional information related to stock identification, migration timing, and ultimate fate of some of the individual sockeye captured in the study. Preliminary summaries of the physiological sampling conducted during 2008 and the radio telemetry results from 2009 were presented in the 2009 final report. A more complete reporting of these components was compiled in a journal report and published by the UBC research team (Donaldson et al. 2011).

The third year of the study was conducted over three weeks in August 2010. A record return of over 30 million Fraser River sockeye was witnessed in 2010. A total of 379 sockeye were hooked in the study and resulting short-term mortality rates were again found to be a relatively low 2.4% (95% C.I.: 0 to 4.5%). Concurrent radio-tagging and physiological sampling was again conducted by Michael R. Donaldson (Ph.D.) and his UBC research team using a variety of treatment groups testing revival techniques on angled sockeye.

The fourth and final year of the study was conducted in August and early September 2011 with similar methodology and procedures used during the three previous study years; the primary goal remaining to investigate and estimate short-term mortality rates of sockeye in the bottom bounce fishery. Additional radio tagging was also conducted separately by Graham D. Raby, a Ph.D. candidate at Carleton University (Ottawa) and a joint Carleton/UBC research team. The radio-tagging component was similar to the 2010 study and focused on the angled sockeye and treatment groups that tested the use of various revival techniques on longer term survival.

The following report details the methodology and results of the CR and short-term mortality component of the 2011 study. It is specific to the environmental conditions, stock assemblages, fishing location, fishing effort, angler profile, capture techniques and time periods discussed. Mortality rates presented are short-term (0 to 24 h) estimates only. Our study does not conclude what the long-term or cumulative effects associated with hooking, handling or holding have on ultimate survival or successful spawning of sockeye encountered in the study.

Detailed analysis and reporting of the radio-tagging component are being coordinated by Graham Raby and the Carleton/UBC research team.

METHODS

STUDY AREA

Grassy Bar was chosen again in 2011 as the study area (Appendix 1, Figures 1 and 2). This bar is located in the Fraser River, 4 km downstream of the Island 22 Park boat launch, near Chilliwack, British Columbia. Despite being only accessible by boat, this is one of the more popular bars on the Fraser River for angling sockeye (Mahoney 2005, 2006). Grassy Bar allows opportunities for anglers to bottom bounce, primarily targeting sockeye, by casting directly from the shore, or by casting from boats anchored very close to shore (usually in water less than 1 m deep with relatively slow river current ($< 1.0\ m \cdot s^{-1}$)).

Appendix 6 – Figures 1 and 2 illustrate the effects of high water in the Fraser River on the Grassy Bar study site during the 2011 study.

Appendix 6 - Figure 3 shows the crowding of shore-based anglers fishing just off the beach on the mainstem Fraser River side of Grassy Bar as a result of high water during the 2011 study.

DATA COLLECTION

Angled (Experimental) Group

Angling Catch and Effort

Volunteer anglers of varying experience and skill level were recruited for the study. Anglers without boats were provided boat transport to and from the fishing site at the beginning of the day and at the end of a typical 7-hour shift (usually 8 am to 3 pm). Anglers were allowed to use their own gear or gear was loaned to them during the study. Each angler also chose their own hook size, weight size and leader length. All anglers and gear used in the study were representative of the Fraser River recreational sockeye fishery and were endorsed on-site by local experts, Ed George of the British Columbia Wildlife Federation (BCWF) and Frank Kwak of the Fraser Valley Salmon Society (FVSS). A typical bottom bounce configuration is presented in Appendix 6 - Figure 4.

Fishing catch and effort data was collected hourly by technicians. Data included the number of anglers fishing, the number of fish hooked, fish lost and fish landed (Daily Encounter Form - Appendix 2 - Figure 1).

Sockeye Handling and Transport

Technicians were situated along the bar to observe angler strikes, record fish playing times and to intercept and recover sockeye that were landed. Each fish hookup was noted and timed. When a sockeye was landed, it was placed into a black, Hypalon® holding/transport bag. The Hypalon® bags are 1 m in length and 0.25 m wide with mesh ends to facilitate water flow in and out of the bag and are opened and closed with a full-length zipper. The bags are also equipped with handles to assist with their handling in the river and transport from the capture location to the net pens. Each landed sockeye was unhooked in the transport bag and adjudicated for fish health, hooking location and degree of bleeding. Each fish was then tagged with a numbered Floy® anchor tag. Tags were inserted into the musculature immediately below the dorsal fin. Appendix 6 - Figure 5 shows a typically hooked and landed sockeye being assessed and prepared for transport to the holding pen. Data related to fish capture, hooking location, fish condition and Floy® tag number were recorded for each fish (Individual Sockeye Landing Form and Hooking Location diagram - Appendix 2 - Figures 2 and 6). Transport bags containing sockeye were then slowly walked in-river from the point of landing to the holding net pen site located downstream of the angling site.

During active catch and landing periods, technicians only observed the anglers they could properly track and record all aspects of the fish playing and landing process. If needed, transport/holding bags containing sockeye were tethered and held in-river until they could be properly transferred to the holding pens. The bags were anchored in-river using rebar hammered into the riverbed. In-river holding areas were carefully selected to provide sufficient flow, depth and water temperature conducive to optimum fish health and situated so as not to interfere with angling.

During 2011, anglers in the Fraser River were permitted by the DFO to keep a maximum of two sockeye per day. This retention-style fishery complicated the random acquisition of sockeye for the study. In response, study “rules” assigned the first captured sockeye to the angler, the second to the study, third to the angler, and all additional captures for the day to the study (either for study of short-term mortality or for radio-tagging). This system eliminated angler selection of sockeye by size, sex, or quality and ensured sockeye in the study represented an unbiased sample from the overall population.

During 2011, anglers also caught a substantial number of chinook salmon at the Grassy Bar site (Appendix 6 – Figure 6).

Sockeye Holding and Release

Angled sockeye were held for a minimum 24 h observation in holding pens comprised of a floating square frame (4 m x 4 m) with an attached net of similar length-width dimensions and a maximum hanging depth of 3 m. The four bottom corners of the net were secured to the river bottom with 14 kg anchors. The floating frames were constructed of 125 mm diameter PVC piping, filled with urethane foam at the connection joints to enhance strength and flotation. The netting was comprised of 25 mm knotless mesh seine webbing. Floating Styrofoam® sheets and an anti-predator frame were placed on the water surface of the pen to ensure sockeye would not jump out of the pen or be attacked by predators. Three net pens were used in the 2011 study. Net pens that had fish holding in them were also surrounded by an anchored and floated anti-predator net measuring 30 m (L) x 6 m (D).

Given the dimensions of the net, the maximum volume of each holding pen was 48 m^3. However, the volume of water in the net pen varied depending on the bottom topography where the net pen was situated and the amount of water flow around the net that would cause some billowing. Assuming a standard maximum fish holding density of 5 $kg \cdot m^{-3}$, the holding capacity of each net pen when situated in 2 m uniform depth was estimated to be approximately 64 adult sockeye (average weight per sockeye = 2.5 kg, net pen volume = 32 m^3). To insure minimum negative effects associated with crowding, holding capacities were further restricted to a maximum of 30 fish per net pen at any given time (i.e. approximately 1 sockeye per 1100 liters (1.1 m^3) of water).

Net pens were located in a side channel approximately 40 m south of the primary angling site on Grassy Bar (see Appendix 1 - Figure 2 and Appendix 6 - Figure 7). This location was within close in-river walking distance from the angling or beach seine site and out of the main navigation channel of the river and therefore did not intrude into any of the shore or boat-based fishing operations. This site normally provided a relatively calm refuge with low flow ($<0.5\ m \cdot sec^{-1}$). However, due to high water and discharge levels in the Fraser River during this year's study, flows and water depths were increased over previous years ($>1.0\ m \cdot sec^{-1}$ flow, >2 m deep). In order to comply with Transport Canada under the Navigable Waters Protection Program, the net pens were marked with signs and high-visible flagging for safety and as a navigation aid.

All sockeye delivered to the net pens were released into the pens by placing the handling/transport bag inside the net and opening the zipper to allow the sockeye to swim freely into the pen. The Floy® tag number, time of entry into the pen and condition of each fish was recorded (Fish Holding Form - Appendix 2 - Figure 3).

At the completion of the 24 h holding period, all sockeye in the pen were individually caught by a long-handled knotless mesh net. The physical condition of the fish was adjudicated, the Floy® tag number was noted and the time of release recorded on the Fish Holding Form. Random fish were also physiologically sampled, measured for fork length and biological tissue samples taken for DNA analysis. In this year's study, none of the angled sockeye that were held for 24 h were fitted with radio tags prior to release. All live sockeye were released directly into the river to continue their migration. All sockeye that died during the 24 h holding period were necropsied to assess the cause of death.

Appendix 6 - Figure 8 shows a typical release of a live and vigorous sockeye after the 24 h holding period in the net pen.

To alleviate concerns of vandalism, theft and liability, a campsite was set up near the net pen site and staffed by study personnel to provide around-the-clock (24 h) monitoring and security for the duration of the study.

Beach Seined (Reference) Group

Experimental handling and holding of fish for observation can potentially introduce additional or unknown biases when estimating hooking mortality rates. While the magnitude of these biases may be unknown, our methodology followed similar studies and analyses (Nelson 1998; Millard et al. 2003, 2005; Pollock and Pine 2007) that assume that instantaneous mortality associated with hooking and release is independent of the mortality associated with experimental handling and holding. By incorporating an additional group of sockeye that were captured using a beach seine and by standardizing the handling and holding methods for both groups of fish, we were able to estimate hooking mortality as the difference between the finite total mortality rate observed in the angled (experimental) group of fish and the finite mortality rate observed in the beach seined (reference) group of fish.

Beach Seine Catch and Effort

The beach seine used was 123 m (L) x 5.5 m (D) with 5 cm mesh webbing. Beach seining was conducted immediately upstream of the primary Grassy Bar angling site to minimize disruption to angler effort. The seine was set in a downstream direction from an outboard-powered aluminum boat. Once the full net length was deployed and towed, the net was then closed and hauled into shore, enclosing a small area of water along the river bank. Efforts were taken to minimize escapes of fish by securing the lead line to the river bottom and elevating the cork line. Once the net was secured, technicians first counted, recorded and released all non-sockeye species. Start and end times were recorded for each set, along with the number of fish caught and released by species, and the adipose fin-clip mark status for chinook and coho. All daily beach seine catch and effort data was recorded on Beach Seine Summary Forms (Appendix 2 - Figure 4).

During beach seining, anglers were repositioned further downstream on the bar to avoid gear conflicts with the seine and seining crew (Appendix 6 – Figure 9).

Appendix 6 - Figure 10 shows the beach seining crew hauling in the net for collection of sockeye for the reference group

Sockeye Handling and Transport

Sockeye that remained in the beach seine were placed individually in the handling/transport bags. Sockeye were then walked in-river to the net pen, where they were individually Floy®-tagged, recorded and released into the pen. Date and time released into the net pen were recorded on Fish Holding Forms along with physical condition (vigorous/lethargic, bleeding/not bleeding, or dead). Care was taken to minimize undue stress to captured fish while maintaining similar handling and transfer methods to the net pens as those used for angled fish.

Sockeye Holding and Release

Holding and release methods for sockeye captured in the beach seine were identical to those used for the angled group of sockeye. Beach seined sockeye were held in the same net pen (or pens) as angled sockeye. To assist in identifying beach seined from angled sockeye, different number sequences of Floy® tags were used for each treatment group. At the completion of the 24 h holding period, all sockeye in the pen were individually caught by a long-handled knotless mesh net. The physical condition of the each sockeye was adjudicated, the tag number was noted and the time of release recorded on the Fish Holding Form. All live sockeye were released directly into the river to continue their migration. All sockeye that died during the 24 h holding period were necropsied to determine the cause of death.

Necropsies

All sockeye mortalities were examined externally and internally in an effort to determine the cause of death (Necropsy Form - Appendix 2 - Figure 5). External observation focused on scale abundance/loss, the location and degree of lacerations, wounds, bleeding, or infections, number of sea lice, and condition of fins. The internal examination looked for lacerations, wounds and bleeding inside the mouth, body cavity and gill area, with gill observations to include colour, degree of siltation on gill filaments and presence of mucous. The gut cavity was examined to determine internal bleeding, damage to organs, tissue bruising or gaping and to identify sex and gonad maturity. Each sockeye that died was measured for fork length (nearest 0.5 cm).

Radio-tagging and DNA sampling

In order to assess long term post-release survival, an additional 70 angled sockeye were gastrically implanted with individually-coded micro radio transmitters (Lotek Wireless Inc.® model MCFT-3A or Sigma Eight Inc.® model Pisces 5). Each radio-tagged sockeye was also measured (fork length, nearest cm) and had a small (< 0.5 g) clip of adipose fin tissue removed for DNA-based stock identification. Finally, upon release, each fish was subjected to a rapid (< 15 s) reflex impairment assessment in order to characterize animal vitality/condition. In addition to simply tagging and releasing angled sockeye (n = 24), there were two additional experimental treatments that were designed as a follow-up to the 2010 tagging study:

1) sockeye that were air exposed for 1 minute following capture, tagged and released (n = 23) and 2) fish that were air exposed for 1 minute following capture, tagged, revived by being held by hand facing into strong river current for 1 minute, then released (n = 23). After release, all radio-tagged sockeye were tracked passively using an array of eight riverside radio receiving stations positioned at strategic locations throughout the watershed, with the furthest upstream receiver being at the confluence of the Nicola and Thompson Rivers (Spences Bridge) and the furthest downstream at Mission. Analysis and reporting of the radio-tagging component of the study is being coordinated by Graham D. Raby, Ph.D. student in the Fish Ecology and Conservation Physiology Laboratory at Carleton University (Ottawa, Ontario).

Appendix 6 - Figure 11 shows technicians performing a typical nondestructive physiological sample for blood on a recently hooked and landed sockeye.

Gastric insertion of a radio tag into a live captured sockeye and subsequent tracking using a mobile radio antenna are illustrated in Appendix 6 - Figures 12 and 13, respectively.

Environmental Data

Air and water temperatures and meteorological conditions were recorded hourly during the day by technicians at the angling site. In addition, water temperature in the net pen and several meters offshore at the lower end of the angling site were continuously monitored over the study period using submerged Onset® Computer HOBO Water Temp Pro v2 data loggers. Data loggers were programmed to record temperatures every 15 minutes.

ANALYSIS OF MORTALITY DATA

Hooking Mortality Rate

The primary objective of our study was to evaluate the short-term (0 to 24 h) mortality rate of hooked sockeye using gear common to the non-tidal Fraser River sockeye recreational fishery. We used a simple, “additive” or “adjusted” hooking mortality rate for our analysis. This is equivalent to the “adjusted mortality rate” as discussed by Nelson (1998), the “simple model” used by Wilde et al. (2003) and Wilde and Pope (2008), and the “additive finite mortality rate” defined by Millard et al. (2003, 2005). This method assumes that the two mortality components associated with hook and release and experimental handling and holding were independent. An additive relationship is assumed between the two rates observed at the end of the 24 h holding period, and finite hooking mortality is computed as the difference between the total mortality rate observed in the hooked fish (angled group) and the total mortality rate observed in the reference fish (beach seined group). In our study, confidence limits for d, the simple difference between two proportions, were generated using the Newcombe-Wilson Hybrid Score method (Newcombe 1998). Appendix 9 details the derivation of the Newcombe-Wilson hybrid score confidence intervals from the classical “Wald” type method.

Factors Influencing Mortality

A secondary objective of our study was to evaluate the factors that influenced mortality. The effect of angling-related variables on mortality of hooked fish has been evaluated in similar studies with simple logistic regression analysis (Menard 1995; Millard et al. 2003, 2005). In these studies, the data is fit using the standard logistic regression model $p_i = e^{\lambda} / (1 + e^{\lambda})$, where p_i is the probability of mortality and e^{λ} is a linear function of explanatory variables (for example: hook size, hooking location, presence of external bleeding, sex, length, scale loss, etc.). Pearson's Chi-square or Likelihood Ratio chi-square (LRX) estimates of the coefficients are evaluated for goodness of fit prior to inclusion in the logistic regression analysis. Variables exhibiting significance ($P < 0.05$) in mortality rates are further evaluated to provide odds ratios and other associated logistic regression parameters.

In our study, Pearson's chi-square, Likelihood Ratio chi-square, and Fisher's Exact tests, and all other logistic regression analyses were performed using 2x2 or 2x*n* contingency table software developed by the Consultancy for Research and Statistics, Quantitative Skills Website – Simple Interactive Statistical Analyses (SISA) (see References: Other resources).

RESULTS

Data was collected over the course of three consecutive weekly study periods: August 15 to 19, August 22 to 26, and August 29 to September 2, 2011. Cooler than average air temperatures in June and July followed by warmer temperatures in late July and early August resulted in a protracted melting of the regional snowpack and record high water levels in the Fraser River at the beginning of the study period. The higher water conditions resulted in unsafe conditions for both anglers and study personnel at Grassy Bar and delayed the start of the study by approximately one week from the original start date of August 8.

Similar to findings in the past three years of the study, results from the 2011 study showed there were no significant differences between the primary hooking location (maxillary bone) and all other hooking locations over the three weeks of the study (Pearson's chi-square < 0.001, 2 d.f., P = 0.266). There was also no significant difference noted in mortalities between study weeks (Pearson's chi-square = 2.35, 2 d.f., P = 0.309). As a result of these findings and due to the low overall number of mortalities and relatively small weekly sample sizes for some weeks in the study, data from all three weeks were combined and analyzed collectively for the majority of analyses in this report.

SUMMARY BY TREATMENT GROUP

Angled (Experimental) Group

Catch, Fishing Effort and Mortality

Participating anglers hooked and landed 448 sockeye during the 15 study days between August 15 and September 2. Two hundred and forty-two angled sockeye were kept for 24 h observation in the net pens and 70 sockeye were fitted with radio tags and released back into the river. Four of the sockeye that had been radio-tagged and released were recaptured on subsequent casts by anglers. These sockeye were released back into the river as soon as possible after recapture. (Appendix 3 – Table 1).

In addition to sockeye, anglers in the study also caught and landed a total of 85 chinook and 88 pink salmon. Aside from noting the total number hooked and landed, no other angling statistics were collected and no mortality estimates were made for species other than sockeye.

Based on hourly angler counts taken each day, mean daily angler effort during the study ranged from a low of 10 anglers on August 18 to a high of 20 anglers on August 25 (Appendix 3 – Table 1). The mean number of anglers for the study was approximately 14 per day and the mean daily sockeye catch per angler was approximately 2 sockeye (range: 0.3 to 4.5). Hourly catch rates ranged from 0.10 to 0.64 sockeye per angler·hour. Angler success in our study was very similar to that estimated for the entire lower Fraser River (from Chilliwack to Hope) from angler creel surveys conducted by Fisheries and Oceans Canada over a similar time period. The overall mean catch rate for this study was 0.33 sockeye per angler·hour (August 15 to September 2) compared to 0.35 sockeye per angler·hour (kept and released) (August 13 to September 5) from DFO angler creel surveys (2011 Fraser River Recreational Fishery Preliminary In-season Summary).

Of the 242 angled sockeye that were caught and held for observation, four (1.7%) died within the 24 h holding period.

Sockeye Handling and Transport

Angler playing times ranged from approximately 1 to 6 minutes with a mean angler play time of 1 min:38 sec (SD = 0.77) (Figure 1). Transport handling times (time taken from unhooking to release into holding pens) were more variable, ranging anywhere from 1 minute up to 39 minutes, with an overall average of about 7 min:24 sec (SD = 5.63). Of the four mortalities observed, angler playing times for these fish ranged from 1 to 3 minutes, and transport handling times ranged from 3 to 16 minutes. Overall handling time (angler play time plus transport handling time) for the hooked sockeye averaged 9 min:2 sec (SD = 5.62). Three of the four observed mortalities occurred in sockeye that had overall handling times less than the mean overall handling time. However, there was no significant difference found in observed versus expected mortalities in hooked sockeye with overall handling times below or above the mean overall handling time (Pearson's chi-square = 0.05, 1 d.f., P = 0.830).

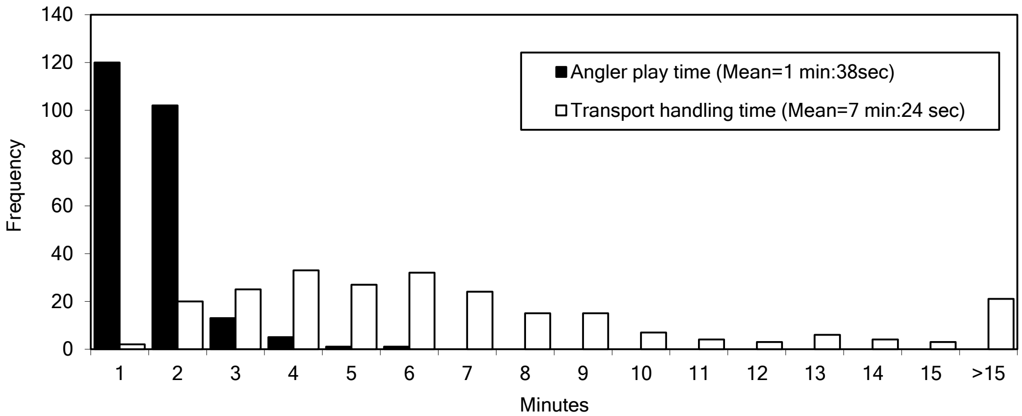

Figure 1. Frequency distribution of angler play time and transport handling time to holding pens for sockeye hooked in a bottom bounce hook-and-release study at Grassy Bar in the Fraser River in 2011.

Hooking Locations and Angling-related Factors

Of the 242 sockeye landed and held, 175 (72%) were hooked in the maxillary bone, 36 (15%) were hooked in other outside locations, and 31 (13%) were hooked on the inside of the mouth (Table 1). The percent of fish that were beached (i.e. brought ashore or into shallow water and partially or wholly exposed to air) after hooking was 10%. For sockeye dragged onto dry ground, the substrate comprised a mix of gravel (70%) and fine sand (30%). The remainder (90%) of landed sockeye were netted or transferred directly to handling/transport bags in shallow water without being brought ashore. The majority of hooks (98%) were removed from sockeye by technicians using their hands, or pliers when necessary. Six sockeye (2%) had hooks that could not be removed easily and the lines were cut, leaving the hook in place for the 24 h holding period. Approximately 21% of the hooked fish exhibited some bleeding (light to moderate) at the time of landing or after hook removal. Fish that were hooked on the outside of the body exhibited the most amount of bleeding (36%) compared to those hooked on the inside of the mouth (23%) and in the maxillary bone (18%). The majority (95%) of hooked sockeye, regardless of hooking location, were evaluated as being in a vigorous condition at the time of landing.

There were a variety of hook sizes and leader lengths used by the anglers in the study. Hook sizes ranged from 1/0 to 3/0, with the majority of anglers choosing the 3/0 size (84%) followed by the 2/0 size (15%). One angler was recorded using a 1/0 size hook. Leader lengths in the study ranged from 10 to 20 feet. The vast majority (92%) of leader lengths were in the range of 12 to 15 feet.

Table 1. Descriptive statistics for catch and short-term (0 – 24 h) mortality of sockeye caught by bottom bounce gear at Grassy Bar in the Fraser River in 2011, by primary hooking location[a].

	----- Hooking location -----			
Variable	Inside mouth	Maxillary bone	All other outside	Total
Total number caught	31	175	36	242
Mortality (%)	0	1.1	5.6	1.7
Mean Playing Time (min:sec)	1:33	1:34	1:58	1:38
Beached (%)	25.8	8.0	2.8	9.5
Bleeding observed (%)	22.6	17.7	36.1	21.1
Vigorous condition at capture (%)	96.8	96.0	86.1	94.6
Mean transport handling time (min:sec)	9:19	7:08	7:03	7:24
Predominant hook size (type: %)	3/0: 67.7	3/0: 86.3	3/0: 88.9	3/0: 84.3
Predominant leader lengths (range ft: %)	12-15: 93.5	12-15: 91.4	12-15: 91.7	12-15: 91.7

a. 70 additional sockeye that were implanted with radio tags and released shortly after tagging are not included.

Beach Seine (Reference) Group

Catch, Effort and Mortality

Unusually high water levels and fast water precluded safe operation of the beach seining component of the study until the final two weeks of the study. A total of 104 sockeye were caught using a beach seine on August 25 and 26 and September 1 and 2, 2011 (Appendix 3 – Table 2). Seventeen sockeye were released immediately back into the river (without tagging) and 25 were taken for independent physiological sampling, leaving a total 62 reference group sockeye for holding 24 h in the net pens. Beach seining also caught and released 2 coho, 30 chinook adults, 40 chinook jacks, 687 pink, 4 peamouth chubs, 6 northern pike minnows and 1 dolly varden.

Of the 62 sockeye retained for holding, none died during handling or within the 24 h holding period.

Sockeye Handling and Transport

Handling and transport times for the beach seined group of fish were not recorded for each individual fish. However, aside from hook removal, handling and transport methods to the net pen for the reference fish were similar to those used for angled fish. Due to the location of the beach seining, mean transport distances and therefore transport times overlapped with angled sockeye caught in the upper 25% of the angling zone and in some cases may have been slightly greater (2 to 4 minutes) than those observed for angled sockeye caught closer to the net pen site. Due to the absence of mortalities observed in the beach seine group, we assume that slight increases in handling and transport times for some beach seined sockeye had no notable influence on short-term mortality.

FISH CONDITION

The physical condition of angled and beach seined sockeye was visually assessed at time of capture and after the 24 h holding period using the following criteria: 1) vigorous and not bleeding, 2) vigorous and bleeding, 3) lethargic and not bleeding, 4) lethargic and bleeding, and 5) dead. The majority (95%) of angled sockeye were in a vigorous condition at time of capture (77% not bleeding, 17% bleeding) (Table 2). Only 5% of the angled sockeye were reported as lethargic (4% not bleeding, 2% bleeding). No beach seined sockeye exhibited bleeding at the time of capture with 97% being reported as vigorous and 3% as lethargic. No sockeye died during handling or transport either by angling or by beach seining. At the time of release, no fish were reported as bleeding in either treatment group. Aside from the four mortalities (1.7%) noted in the angled group, 97% of the angled sockeye were released after 24 h as vigorous with no bleeding and 1% as lethargic with no bleeding. In the beach seined group, all sockeye were released alive after 24 h, of which 97% were in vigorous and 3% were in lethargic condition.

Table 2. Comparison of fish condition at time of capture (A) and at time of release after the 24 h holding period (B) for sockeye angled by bottom bounce gear (angled group) and captured by beach seine (reference group) at Grassy Bar, Fraser River, in 2011.

A. Condition at time of capture:

Study Group	Vigorous, not bleeding	Vigorous, bleeding	Lethargic, not bleeding	Lethargic, bleeding	Dead	Total
Angled	187	42	4	9	0	242
Percent of total	77.3	17.4	1.7	3.7	0	100.0
Beach Seine	60	0	2	0	0	62
Percent of total	96.8	0.0	3.2	0	0	100.0

B. Condition at time of release after 24h in the holding pens:

Study Group	Vigorous, not bleeding	Vigorous, bleeding	Lethargic, not bleeding	Lethargic, bleeding	Dead	Total
Angled	235	0	3	0	4	242
Percent of total	97.1	0	1.2	0	1.7	100.0
Beach Seine	60	0	2	0	0	62
Percent of total	96.8	0	3.2	0	0	100.0

FISH SIZE

Fork lengths of sockeye caught in the 2011 study were only recorded for the four sockeye that died. From data collected in previous years, we assume that size was not a significant factor in overall mortality, and that both angled and beach seined sockeye were sampled from similar migrating stocks.

HOOKING MORTALITY ESTIMATES

No sockeye that were angled and held in the 2011 study were subjected to nondestructive physiological sampling at time of capture or after the 24 h holding period. As a result, mortality estimates include all sockeye held for observation. The short-term hooking mortality rate using the adjusted (additive) model was estimated to be 1.7% with lower and upper 95% confidence intervals of zero to 4.2%, respectively. The adjusted mortality rate is equivalent to the straightforward percent mortalities (the number that died (*n*) divided by the number landed (*N*)), since no mortalities were observed in the beach seined (reference) group. The estimated hooking mortality is presented in Table 3 with comparisons to those estimated in the three previous study years; 2008 to 2010.

Table 3. Comparison of estimates of short-term (0 to 24 h) catch-and-release mortality of sockeye salmon at Grassy Bar in the Fraser River in 2011, 2010, 2009 and 2008, using bottom bounce gear, uncorrected and corrected for handling mortality using an adjusted rate estimator. The 95% confidence interval (95% CI) for the adjusted rate estimator is provided in parentheses. Mortalities are provided by number (*n*) and percent.

Study year	Treatment group	Total caught (*N*)	Mortalities		Adjusted catch-and-release mortality estimate (%) (95% CI)
			n	Percent	
2011	Angled (experimental group)	242	4	1.7	1.7 (0 - 4.2)
	Beach seine (reference group)	62	0	0	
2010	Angled (experimental group)	379	9	2.4	2.4 (0 - 4.5)
	Beach seine (reference group)	90	0	0	
2009[a]	Angled (experimental group)	291	5	1.7	1.7 (0 - 4.0)
	Beach seine (reference group)	63	0	0	
2008[b]	Angled (experimental group)	173	2	1.2	1.2 (0 - 4.1)
	Beach seine (reference group)	103	0	0	

a. includes 10 angled sockeye that were non-destructively physiologically sampled.
b. includes 25 angled and 17 beach seined sockeye that were non-destructively physiologically sampled.

For added comparison, adjusted mortality estimates and 95% confidence intervals associated with individual angling and study-related factors are presented in Appendix 4. However, caution should be taken when assessing the mortality estimates associated with each individual angling or study-related factor. High mortality rates and large confidence intervals for some angling-related factors result from very small sample sizes for some factors that have many individual variables (e.g. hooking locations and leader lengths).

FACTORS INFLUENCING MORTALITY

Angling-related factors, fish holding densities, and temporal and environmental factors were evaluated for significance on short-term (0 to 24 h) mortality ($P < 0.05$) using 2 by 2, or in some cases, 2 by 3 contingency tables. Factors influencing mortality were grouped into categories and assessed for the ultimate condition at release (dead or alive). Significance was evaluated using Pearson's chi-square (GFX). Likelihood Ratio (LRX) chi-squares were also evaluated when mortalities existed in both independent variable categories being assessed. Due to relatively small sample sizes in some categories and few observed mortalities, Fisher's exact tests (sum of small p's) were also calculated as a comparative test of significance. Odds ratios (OR) were also performed in cases where mortalities were present in both independent variable categories. The results of these tests are presented in Table 4.

Angling-related Factors

Due to the variety of possible hooking locations noted in the study (15 in total), individual assessment of this variable on mortality can be difficult to quantify. However, visual observations and post-mortem assessment concluded that all four mortalities in this study were directly attributable to injuries from hooks that pierced or tore arteries in the mouth (under the tongue), gills, or heart in a relatively small number of hooking locations. Two of the four mortalities were sockeye that were hooked in the left maxillary bone. The other two mortalities occurred in sockeye that were hooked on the ventral surface of the body posterior to the head. Necropsies indicated lacerations or tearing of gill arches on two of the sockeye that were hooked in the maxillary bone and all had white gills indicating these fish most likely bled out and died relatively quickly after being hooked. The other two sockeye that were hooked in the ventral surface were believed to have died as a result of the hook penetrating the heart or coronary artery.

Based on the relatively small number of hooking locations associated with mortalities in all four study years (i.e. maxillary bone, inside mouth, or ventral snag), and to compare the results observed between years, hooking locations were grouped into two major categories as follows: hook location grouping 1, comparing fish snagged on the outside of the body versus all other hooking locations (either inside or outside), and hook location grouping 2, comparing those fish hooked in the maxillary bone versus all other outside the mouth or body hooking locations.

As witnessed in previous years, the majority of sockeye in 2011 were hooked in the maxillary bone; 72% in 2011 compared to 65% in 2010, 75% in 2009, and 66% in 2008. The incidence of hooking events on the outside of the body increased substantially in 2010 to 22% compared to 9% witnessed in 2008 and 6% in 2009.

Table 4. Pearson's chi-square (GFX), Likelihood Ratios (LRX), Fisher's Exact Test results, and Odds Ratios (OR) assessing various angling-related factors, fish holding densities, and temporal biases influencing the short-term (0 to 24 h) mortality of sockeye caught with bottom bounce gear at Grassy Bar, Fraser River in 2011. Factors that significantly influenced mortality are in bold. Coding for independent variables is shown in parentheses.

Angling-related or study variable[a]	Pearson's Goodness of Fit Chi-square (GFX)	Likelihood Ratio Chi-square (LRX)	Fisher's Exact Test[b]	Odds Ratio (OR)[c] (95% CI)
Hook location (grouping 1) (body snag = 0; all other locations = 1)	**8.24 (p=0.004)**	**4.57 (p=0.033)**	**0.042**	**10.90 (1.46-81.58)**
Hook location (grouping 2) (maxillary bone = 0; all outside locations = 1)	3.13 (p=0.077)	2.34 (p=0.126)	0.136	0.20 (0.03-1.44)
Hook Size (hook size <3/0 = 0; hook size 3/0 = 1)	0.76 (p=0.384)	--	1.000	--
Leader Length (14ft length = 0; All other lengths = 1)	2.07 (p=0.151)	2.05 (p=0.153)	0.305	4.60 (0.47-44.8)
Casting weight (casting weight <3 oz = 0; casting weight >=3 oz = 1)	0.95 (p=0.329)	--	1.000	--
Condition at capture (lethargic = 0; vigorous = 1)	**15.94 (p<0.001)**	**6.65 (p=0.010)**	**0.015**	**20.64 (2.65-160.51)**
Bleeding at capture (yes = 0; no = 1)	**15.23 (p<0.001)**	**--**	**0.002**	**--**
Scale loss (none = 0; light to moderate = 1)	0.18 (p=0.675)	--	1.000	--
Angler play time (<5 min = 0; >5 min = 1)	0.03 (p=0.854)	--	1.000	--
Beaching (no = 0; yes = 1)	0.43 (p=0.513)	--	1.000	--
Air Exposure (Exposed <15 sec = 0; Exposed >15 sec = 1)	2.01 (p=0.156)	1.28 (p=0.258)	0.254	0.22 (0.02-2.20)
Predator wounds (none = 0; minor or major = 1)	0.10 (p=0.748)	--	1.000	--
Fish densities in the holding pen[d] (<20 fish/day = 0; >20 fish/day = 1)	0.00 (p=0.988)	0.00 (p=0.988)	1.000	0.98 (0.10-9.59)
Temporal bias (hook location by study week) (Independent variable: Study week) (Dependent variable: Maxillary bone = 0; All other locations = 1)	0.00 (p=0.266)	2.68 (p=0.261)	0.280	--
Temporal bias (mortalities by study week) (Independent variable: Study week) (Dependent variable: Dead = 0; Alive = 1)	2.35 (p=0.309)	2.82 (p=0.244)	0.400	--

a. Except where noted, dependent variables are 0=Dead, 1=Alive.
b. Two-sided, O>=E|O<=E, sum of small p's.
c. OR=Odds1/Odds2=p1n1/p2n2.
d. Includes both hooked and beach seined (reference group) sockeye.

Higher overall abundance of sockeye in 2010 and perhaps increased fishing effort were believed to be major factors in the increase in hooking events on the outside of the body. Hooking incidence on the outside of the body was 15% in 2011. Hooking in the inside of the mouth has remained approximately the same for all years (12% in 2008, 10% in 2009, 13% in 2010, and 13% in 2010).

Despite the low incidence (8.7%) of dorsal or ventral snags in 2008, this type of hooking event had a very significant influence on short-term (0 – 24 h) mortality (**Pearson's chi-square = 21.31, 1 d.f., P < 0.001**) (J. O. Thomas and Associates 2009). In fact, the only two observed mortalities in 2008 were both associated with this type of hooking event. In 2009, six mortalities were observed and all were associated with hooking in the left maxillary bone (J. O. Thomas and Associates 2009). Despite this finding, hooking in the maxillary bone did not have a significant influence on short-term mortality when compared to all other outside hooking locations (Pearson's chi-square = 1.01, 1 d.f., P = 0.316) (J. O. Thomas and Associates 2010). In 2010, none of the primary hooking location groupings (snags vs. all other, or maxillary bone vs. all other outside) exhibited significance in short-term (0 – 24 h) hooking mortality. The fact that hooking mortalities were relatively rare and those that did occur were found in each of the hooking location groupings may be the primary reason for this finding. In 2011, dorsal or ventral body snags were again found to exhibit a significant influence on short-term (0 – 24 h) mortality (**Pearson's chi-square = 8.24, 1 d.f., P =0.004**). Two of the four mortalities observed in 2011 were the result of ventral surface hooking.

For the majority of other angling-related factors, no significant influence on short-term mortality was found in the 2011 study. However, the condition of sockeye at time of capture and the incidence of bleeding were found to be significant factors in short-term mortality. Sockeye that were noted to be lethargic at time of capture were found to have a 21 fold increase in the odds of dying during the 24 h observation period (**Pearson's chi-square = 15.94, 1 d.f., P < 0.001**). Sockeye that were observed to be bleeding at the time of capture were also found to be significantly more likely to die (**Pearson's chi-square = 15.23, 1 d.f., P < 0.001**). All four short-term mortalities in 2011 occurred in sockeye that were observed to be bleeding at the time of capture. Bleeding at the time of capture was also noted as having a significant influence on mortality in the 2008 and 2010 studies (2008: **Pearson's chi-square = 9.27, 1 d.f., P = 0.002,** and 2010: **Pearson's chi-square = 20.94, 1 d.f., P < 0.001**) and was close to being significant in the 2009 study (**Pearson's chi-square = 3.30, 1 d.f., P = 0.069**) (J. O. Thomas and Associates 2009, 2010, 2011). Approximately 1 in 4 to 1 in 5 of the hooked sockeye observed in this study has exhibited bleeding at time of capture in each of the study years (18% in 2008, 25% in 2009, 24% in 2010, and 21% in 2011).

Number of Fish Held

The daily number of sockeye held in the net pens ranged from a low of five (angled) on August 15 to a high of 39 (angled and beach seined) on September 2 (Figure 2). The average number of angled sockeye that were held in net pens was 20 per day, and the average number of beach seined sockeye in the holding pens was 31 per day. Capacity in individual net pens never exceeded the maximum of 30 fish per day.

Mortalities were observed on three of fifteen study days: August 19 (1 mortality; 30 holding), August 24 (2 mortalities; 22 holding), and August 26 (1 mortality; 11 holding). All mortalities were observed on days when the number of fish being held was less than or equal to 30 fish. In this study, fish holding densities showed no significant influence on short-term mortality when the number of fish being held was less than 20 fish/day compared to densities of greater than 20 fish/day in the net pen (Pearson's chi-square = 0.00, 1 d.f., P = 0.988).

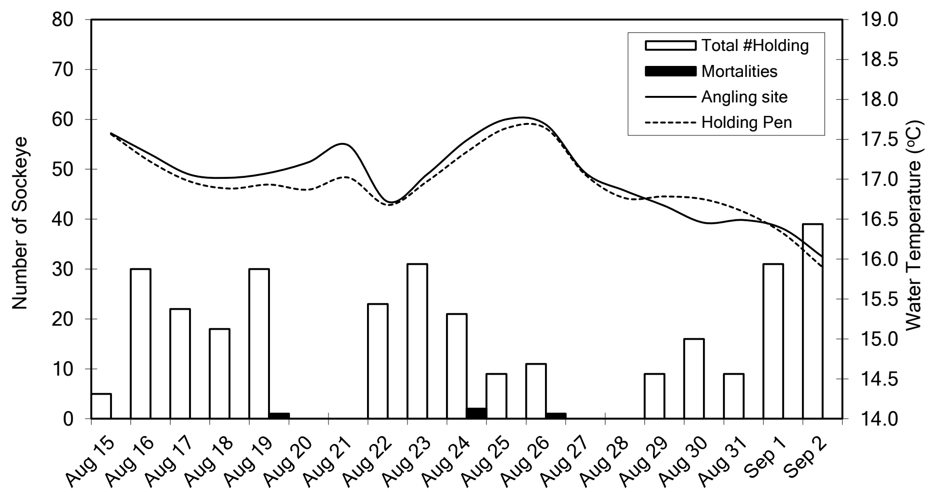

Figure 2. Daily number of fish held for 24 h observation in the net pens and observed mortalities (bars) compared to mean daily water temperatures from in-situ data loggers located in-river near the angling site and the holding net pen (lines) at Grassy Bar in the Fraser River in 2011.

Temporal Factors

Hooking location (maxillary bone vs. all other) and number of mortalities by study week were evaluated to determine if there were any significant temporal biases in the primary hooking location (maxillary bone) or mortalities between weeks. No significant bias was noted in the number of hooking events in the maxillary bone compared to all other hooking locations between weeks (Pearson's chi-square = 0.00, 1 d.f., P = 0.266). There was also no significant bias noted in the number of mortalities between weeks (Pearson's chi-square = 2.35, 1 d.f., P = 0.309).

Environmental Factors

Water temperatures were continuously monitored in the Fraser River near the angling site and in the holding pen throughout the study period. A plot of temperatures taken every 15 minutes at the two sites is presented in Appendix 5 – Figure 1. Mean daily temperatures at the two sites are presented in Figure 2.

In general, temperatures remained steady for the first two study weeks then decreased in the third week. The mean daily water temperature in the river ranged from a high of 17.8°C near the angling site on August 25 to a low of 15.5°C on September 2 (the last study day) in the net pen and at the angling site. Except for the first three days of the last study week, mean daily temperatures in the holding pen were lower than those at the angling site and deviated anywhere from 0.3°C above to 0.4°C below water temperatures at the angling site. Water temperatures noted during the entire study were below critical temperatures often associated with decreased swimming performance and early signs of physiological stress as well as slowed migration in Fraser River sockeye (temperature ranges between 18°C and 19°C) (Fraser River Environmental Watch Report, August 27, 2010, Lee et al. 2003). Temperatures above 20°C have been associated with high pre-spawn mortality and disease.

One of the hooking mortalities occurred during a mean daily water temperature of 16.9°C in the holding pen on August 19, two occurred on August 24 when the mean holding temperature was 17.3°C and one occurred on August 26, a day after the maximum temperature was observed (17.8°C at the angling site and 17.6°C in the net pen). Comparison of the number of mortalities that occurred at temperatures below the study mean (17°C) and equal to or above the study mean suggested there was a significant influence of temperature on short-term mortality in the holding pen (**Pearson's chi-square = 5.40, 1 d.f., P = 0.020**) and a marginally significant influence at the angling site (Pearson's chi-square = 3.70, 1 d.f., P = 0.054).

Water levels in the Fraser River during August 2011 were the highest observed over the four year study period and ranged from 11% to 26% higher than the historical means (Appendix 5 – Figure 2).

RADIO TAGGING AND DNA SAMPLING

A summary of results from the radio-tagging and DNA sampling conducted by the Carleton/UBC research team was unavailable for inclusion in this report. Results are anticipated in a separate journal report.

DISCUSSION

Preseason forecasts of sockeye returning to the Fraser River in 2011 provided by Fisheries and Oceans Canada (DFO) were highly uncertain due to variability in annual survival rates and uncertainty about recent changes in their productivity. The Fraser River Panel (the Panel) adopted preseason forecasts of abundance from DFO of approximately 3.18 million returning sockeye (50% probability level for Early Stuart, Early Summer-run, Summer-run, Birkenhead and True Late-run stocks). These forecasts were below the cycle year average (1955-2007) due to lower than average spawning escapement in 2007 combined with lower than average productivity assumptions used in the forecast model.

Actual run sizes exceeded the preseason forecasts with the total Fraser River run size estimated to be around 5.08 million sockeye salmon by October 7, 2011 (Appendix 8 – Figure 1). Based on PSC escapement estimates at Mission, approximately 1.03 million sockeye migrated past Grassy Bar on study days between August 15 and September 2 (Appendix 8 – Table 1). Abundance estimates at Grassy Bar were over 400,000 sockeye per week during the first two weeks, declining to about 140,000 in the third study week.

For the conditions noted in this year's study, short-term (0 to 24 h) mortality estimates of hooked sockeye was relatively low (1.7% mortality with a 95% confidence interval of zero to 4.2%). This was similar to mortality rates observed in each of the previous three years of the study; 2.4% in 2010, 1.7% in 2009, and 1.2% in 2008.

Similar to results seen in the three previous study years, the majority of sockeye caught by anglers were hooked in or near the maxillary bone, usually on the left side, with little to no bleeding observed. In all years, mortalities resulting from hooking were witnessed in a small number of primary hooking locations: maxillary bone, inside mouth, and ventral snags. Assessment of angling-related factors did not conclude that hooking in the maxillary bone had a significant influence on short-term (0 – 24 h) hooking mortality in any year. Of all the angling-related factors assessed, bleeding and lethargic condition at time of capture were noted as the only factors that were significant in predicting mortality across all study years. Necropsies of sockeye that died revealed that most died from wounds in or near the gills, or in vulnerable arteries or organs near the ventral surface.

Physiological samples collected by the UBC research team in 2008 and 2009 provided valuable insights into the impacts of both capture (hooking and by beach seine) and experimental holding of sockeye for 24 h. Initial findings from 2008 suggested there are negative impacts on sockeye associated with capture and holding in net pens for 24 h prior to release. Sockeye that were captured and immediately released had lower levels of physiological stress indicators (glucose, cortisol) than those that were held in the net pens for 24 h. Significantly lower levels of sodium and chloride ions and lower osmolality in the angled sockeye after being held 24 h in the net pen also suggest that osmoregulatory function was somewhat impaired in this group of fish. Results from 2010 and 2011 were not available for inclusion in this report. However, it is anticipated that results of these tests will provide more insight into the physiological changes associated with capture and post-capture recovery and longer term survival of sockeye salmon in this fishery.

Final results of the radio-tagging conducted in 2010 and 2011 were also not available at the time of this report. However, preliminary results in 2010 suggest that survival was highest for the beach seine group. The use of recovery bags in 2010 resulted in an approximate 23% increase in survival for fish that were angled and exposed to air. However, the recovery bags did not affect survival for the non-air exposed groups. This finding suggests that the recovery bags may be beneficial to survival for individuals that are in poor condition, but individuals in good condition may be just as likely to survive if they are released immediately rather than being placed in recovery bags (M. Donaldson, pers. comm.). Further analysis of radio telemetry data in sockeye that were caught and released immediately after tagging in 2011 is anticipated to shed even more light on survival of captured sockeye in the study and by individual stock or stock grouping through DNA analysis.

RECOMMENDATIONS AND LIMITATIONS

For this study, we assumed that the effects of handling, transport and holding worked independent between the angled (hooked) group and the beach seined (reference) group. We also assumed that the beach seine method of capture for the reference group had no measurable effect on short-term (0 – 24 h) mortality. Based on our results, and particularly the lack of any mortalities observed in the sockeye captured by beach seine in all three years of the study, our assumptions continue to be reasonable. A simple, adjusted method was therefore used to provide an estimate of short-term (0 – 24 h) CR hooking mortality and confidence intervals around this estimate. If mortalities had been observed in the reference group, it would have been relevant to further estimate and compare mortalities using a “conditional” mortality methodology that does not make similar assumptions of independence between the hooked fish and the reference group. This model is described in detail by Millard et al., 2005 and suggests there is a measurable and dependent impact of confinement (holding-related mortality) that affects the mortality of both the hooked fish and the reference group of fish. The use of a reference group of fish is critical to the assessment of hooking mortality regardless of which methodology (adjusted or conditional) is used. We therefore highly recommend the use of a suitable reference group of sockeye in any future catch-and-release studies to insure these assessments of mortality can be suitably evaluated. The reference group must be taken from the same population of sockeye as the angled sockeye and similar numbers of fish should be obtained for both groups. Although the number of sockeye captured in the beach seine and held for observation was less than ideal in each year of the study, it is important to note that the beach seine method proved to be the most practical method for capturing sockeye with minimal harm. No sockeye that were caught by beach seining died during observation in the four years of the study.

We produced a single short-term (0 to 24 h) CR mortality estimate using a sample of anglers that we believe to be representative of a typical Fraser River bottom bounce bar fishery that targets sockeye. Techniques are variable among anglers and locations and as such, may be indicative only of the study group and location. Comparison with creel survey estimates from DFO covering an area from Mission to Hope, suggests that mean angler catch success was slightly higher in our study during similar time periods (DFO – Fraser River Area). However, the similarity in predominant hooking locations observed in all four years of the study coupled with consistently low mortality rates, suggests that angling techniques were similar between years, despite possible variation in individual angler catch success.

Our analysis was restricted solely to short-term (0 to 24 h) hooking mortality estimates for sockeye caught using bottom bounce gear. No other fishing techniques (for example, bar fishing, spin and glow lures) were used. Other species were hooked using this type of fishing gear; however, they were not included in the analysis.

Beyond a single short-term (0 to 24 h) CR mortality estimate, we cannot quantify actual spawner success (percent spawned) of the hooked or beach seined groups of sockeye encountered in this study. It is possible for example, that sockeye observed in this study are more likely to succumb to increased predation (both natural and fishing) as a result of physiological stresses, or increased disease progression associated with handling or hooking (scale or slime loss, abrasions, infection, blood loss). Ultimately, this could lead to reduced spawner success, embryo viability, and egg-to-fry survival. Additionally, holding sockeye in net pens after capture does not mimic conditions in a true catch-and-release fishery. Physiological sampling to-date appears to indicate that holding, even for short periods of time in low flow or in crowded, unnatural environments may actually cause additional stress as well as critical delays in reaching the spawning grounds. These combined factors may ultimately lead to elevated post-capture mortality when compared to sockeye that were captured and immediately released back into the river.

Additional data was collected in 2009, 2010 and 2011 regarding predator wounds. In 2011, six hooked sockeye were noted to have minor or major predator wounds, and none died during the 24 h observation period. In 2010, 27 hooked sockeye exhibited minor wounds and three exhibited major wounds. One sockeye noted with minor predator injuries died during the study. Almost identical results were noted in the 2009 study; 27 hooked sockeye with minor and three with major predator injuries of which, none died. Despite the low number of mortalities witnessed in sockeye that exhibited predator injuries in the study, assessment of this data is believed to be important in the overall assessment of mortality and it is recommended that this factor be considered and analyzed in future studies.

Collection of data regarding casting weights used by anglers was also added to the study in 2009 and continued in 2010 and 2011. Similar to most angling-related factors, no significant influence was noted for this variable on short-term (0 – 24 h) hooking mortality in either year. Despite this, casting weight is believed to be an integral factor associated with the angling technique and gear behavior and may have a measurable effect on hooking success. It is therefore of interest to collect and analyze this data to assess the possible influence on hooking mortality.

One angling-related factor that was found to be of significance to short-term mortality in the 2010 study was the use of 20 foot leader lengths. Based on this finding, a conscious effort was made in 2011 to minimize the use of exceptionally long leader lengths (greater than 15 feet). As a result, it was difficult to test in this year’s study whether 20 foot leader lengths had a similarly significant influence on hooking mortality. No significant influence on mortality was noted in 2011 for any of the individual leader lengths or groupings of leader lengths tested.

The development of secondary sexual characteristics has also been suggested as a factor leading to the release of sockeye in a typical bottom bounce fishery. The sex or the extent of sexual maturity may also be a contributing factor in the survival of these fish after a hooking event. Male or female fish or fish that are more mature may be less able to tolerate the stresses associated with catch-and-release. Unfortunately, determination of sex based solely on outward physical appearance is not reliable during the time periods and location of this fishery. Therefore we could not estimate separate hooking mortalities by sex or quantify the influence of sex or stage of sexual maturity on hooking mortality.

This study was conducted at a single location (Grassy Bar) for all study years. Although this site is a popular fishing location and is believed to be typical, given its limited spatial and temporal scope, the results presented here may not necessarily be representative of the wider range of environmental conditions and locations that are available in the Fraser River for these types of fisheries. Given the opportunity, studies and comparisons of angling characteristics, techniques, gear and short-term hooking mortality rates at other sites may help to determine if significant geographic differences exist for this fishery.

This year’s study also was conducted in a year when there was considerable targeted fishing effort on sockeye from commercial, recreational, and aboriginal sectors in both marine and freshwater fisheries. As a result, individual sockeye may have had multiple captures by fisheries along their migration route. Additional hooking captures may also have occurred in bars further upstream from our study location. Therefore, the short-term mortality results at Grassy Bar may not be totally representative of angling mortality for fish that are hooked and released multiple times in fisheries further upstream. Future studies should be aware of this variable and assess multiple hooking events, if possible, for potential added influence on mortality.

Fraser River sockeye have multiple stock compositions and varying abundances over a typical four-year cycle. They also experience variable in-river conditions during their migration upstream in any given year. To account for inter-annual variability in in-river fishing and environmental conditions, fish abundance and stock composition, this study was conducted over a full four-year cycle period. Timing of the study was coordinated with up-to-date inseason escapement estimates in order to maximize sample sizes while maintaining conservation principles and improving cost:benefit ratios to the study. Short-term (0 to 24 h) hooking mortality rates for all four years of the study (2008 to 2011) have been low. The first two years were conducted during periods of relatively low sockeye abundance. In 2010, sockeye abundance in the Fraser River was the highest witnessed in the past 100 years, and although mortality rates increased, they remained within virtually identical 95% confidence intervals for all years (0% to 4.5%).

Very high water discharge and associated high water levels were witnessed in the Fraser River during the 2011 study. Despite this, catchability of sockeye and estimated hooking mortality rates remained similar when compared to other study years. In general, water temperatures were relatively favourable for sockeye migration over the four study years. However, mortality rates may be expected to increase in years when in-river temperatures are steadily high (above 18°C) and unfavourable for sockeye migration. The influences of angling-related factors on hooking mortality have also been found to be relatively similar and predictable among study years despite varying environmental, regulatory, biological, or abundance-based components.

Substantive numbers of other salmon were captured in this study by the beach seine during 2008 (primarily chinook jacks and adults) and 2009 and 2011 (primarily pinks). Angling also contributed to capture of large numbers of chinook adults or jacks in 2008 and 2011. Captures of other species were noted to a much lesser extent in all study years. Despite the focus of this study on sockeye, the relative abundance of other species is of importance to the management of these fisheries and should therefore be monitored in future studies.

Physiological sampling and radio-tagging of individual sockeye was conducted independently to this study and are therefore not discussed in depth in this report. A complete analysis and discussion of these findings is currently being conducted by the Carleton University/University of British Columbia research teams. It is hoped that this work will provide valuable additional insight into capture and post-capture recovery and ultimate survival of sockeye hooked in these types of fisheries.

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Figure 3. 2011 study team and volunteer anglers.

REFERENCES

Bjornn, T. C., and D. W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. American Fisheries Society Special Publication 19: 83-138. (Note: this publication is in Chapter 4 in *Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats* [W. R. Meehan, editor].).

Brett, J. R. 1995. Energetics. Pages 1-68 *in* C. Groot, L. Mergolis, and C. Clarke, editors. Physiological ecology of Pacific salmon. UBC Press, Vancouver.

Donaldson, M.R., S.G. Hinch, D.A. Patterson, J. Hills, J.O. Thomas, S.J. Cooke, G.D. Raby, L.A. Thompson, D. Robichaud, K.K. English, and A.P. Farrell. 2011. The consequences of angling and beach seine capture on the physiology, post-release behaviour and survival of adult sockeye salmon during upriver migration. Fisheries Research 108:133-141 [pdf, 643 KB]

Fisheries and Oceans Canada website: Pacific Region, Fraser River/BC Interior Area, Recreational Fisheries, In-season and Post-Season Recreational Fisheries Assessments, Creel Survey Results.
http://www.pac.dfo-mpo.gc.ca/fraserriver/recreational/recfisherystudies_e.htm
http://www.pac.dfo-mpo.gc.ca/fraserriver/recreational/recfisherycreel_e.htm

Hinch, S. G., S. J. Cooke, M. C. Healey, and A. P. Farrell. 2006. Behavioral physiology of fish migrations: salmon as a model approach. Pages 240-296 *in* K. A. Sloman, R. W. Wilson, and S. Balshine, editors. Behavior and physiology of fish. Fish Physiology Volume 24, Elsevier, Amsterdam.

J. O. Thomas and Associates Ltd. 2009. Preliminary Investigations into Short-term Hooking Mortality of Sockeye Caught and Released at Grassy Bar, Fraser River, British Columbia, 2008. Report prepared for the Fraser Salmon and Watersheds Program (jointly managed by the Pacific Salmon Foundation and the Fraser Basin Council) and Fisheries and Oceans Canada, Lower Fraser Area. February 2009, 49 pp.

J. O. Thomas and Associates Ltd. 2010. Further Investigations into Short-term Hooking Mortality of Sockeye Caught and Released at Grassy Bar, Fraser River, British Columbia, 2009. Report prepared for the Fraser Salmon and Watersheds Program (jointly managed by the Pacific Salmon Foundation and the Fraser Basin Council) and Fisheries and Oceans Canada, Lower Fraser Area. March 2010, 60 pp.

J. O. Thomas and Associates Ltd. 2011. Further Investigations into Short-term Hooking Mortality of Sockeye Caught and Released at Grassy Bar, Fraser River, British Columbia, 2010. Report prepared for the Fraser Salmon and Watersheds Program (jointly managed by the Pacific Salmon Foundation and the Fraser Basin Council) and Fisheries and Oceans Canada, Lower Fraser Area. January 2011, ix + 55 pp.

Kristianson, G., and D. Strongitharm. 2006. The evolution of recreational salmon fisheries in British Columbia. Report to the Pacific Fisheries Resource Conservation Council.

Lee C. G., A. P. Farrell, A. Lotto, M. J. MacNutt, S. G. Hinch, and M. C. Healey. 2003. The effect of temperature on swimming performance and oxygen consumption in adult sockeye (*Oncorhynchus nerka*) and coho (*O. kisutch*) salmon stocks. Journal of Experimental Biology 206: 3239-3251.

Mahoney, J. 2005. Fraser River Recreational Fishery Assessment. DFO Memorandum, November 1, 2005.

Mahoney, J. 2006. Fraser River Recreational Fishery Assessment. DFO Memorandum, November 2, 2006.

Menard, S. 1995. Applied logistic regression analysis. Sage University Paper Series on Quantitative Applications in the Social Sciences, Series 07-106, Thousand Oaks, California.

Millard, M. J., S. A. Welch, J. W. Fletcher, J. Mohler, A. Kahnle, and K. Hattala. 2003. Mortality associated with catch and release of striped bass in the Hudson River. Fisheries Management and Ecology 10: 295-300.

Millard, M. J., J. W. Mohler, A. Kahnle, and A. Cosman. 2005. Mortality associated with catch-and-release angling of striped bass in the Hudson River. North American Journal of Fisheries Management 25(4): 1533-1541.

Nelson, K. L. 1998. Catch-and-release mortality of striped bass in the Roanoke River, North Carolina. North American Journal of Fisheries Management 18(1): 25-30.

Newcombe, R. G. 1998. Interval estimation for the difference between independent proportions: comparison of eleven methods. Statistics in Medicine 17: 873-890.
Pollock, K. H., and W. E. Pine, III. 2007. The design and analysis of field studies to estimate catch-and-release mortality. Fisheries Management and Ecology 14: 123-130.

Tandberg, D. 1998. Calculator for Confidence Intervals around the Difference between Two Proportions (Microsoft Excel). Download available from the Center for Evidence-based Medicine (CEBM) website, Department of Primary Care, Old Road Campus, Headington, Oxford, OX3 7LF, United Kingdom. http://www.cebm.net/?o=1011.

Wilde, G. R., K. L. Pope, and R. E. Strauss. 2003. Estimation of fishing tournament mortality and its sampling variance. North American Journal of Fisheries Management 23(3): 779-786.

Wilde, G. R., and K. L. Pope. 2008. A simple model for predicting survival of angler-caught and released largemouth bass. Transactions of the American Fisheries Society 137(3): 834-840.

Other resources:

Consultancy for Research and Statistics, Quantitative Skills website - Simple Interactive Statistical Analysis (SISA) Two by Two table, Fisher Exact test.
http://www.quantitativeskills.com/sisa/statistics/twoby2.htm
http://www.quantitativeskills.com/sisa/statistics/fisher.htm

Logistic Regression calculator, version 05.07.20, by John C. Pezzullo with instruction modifications by Kevin M. Sullivan. http://statpages.org/logistic.html

Hosmer, D.W., and S. Lemeshow. 2000. *Applied Logistic Regression, 2nd Edition.* John Wiley & Sons, New York: 392 pp.

Rosner, B. 2006. *Fundamentals of Biostatistics*. Thomson/Brooks Cole Publishers; 6th Revised edition (March 16, 2005): 868 pp.

APPENDICES

Appendix 1 – Study location maps.

Appendix 2 – Data forms.

Appendix 3 – Catch summaries.

Appendix 4 - Adjusted mortality rate estimates by primary hooking location and other angling-related factors.

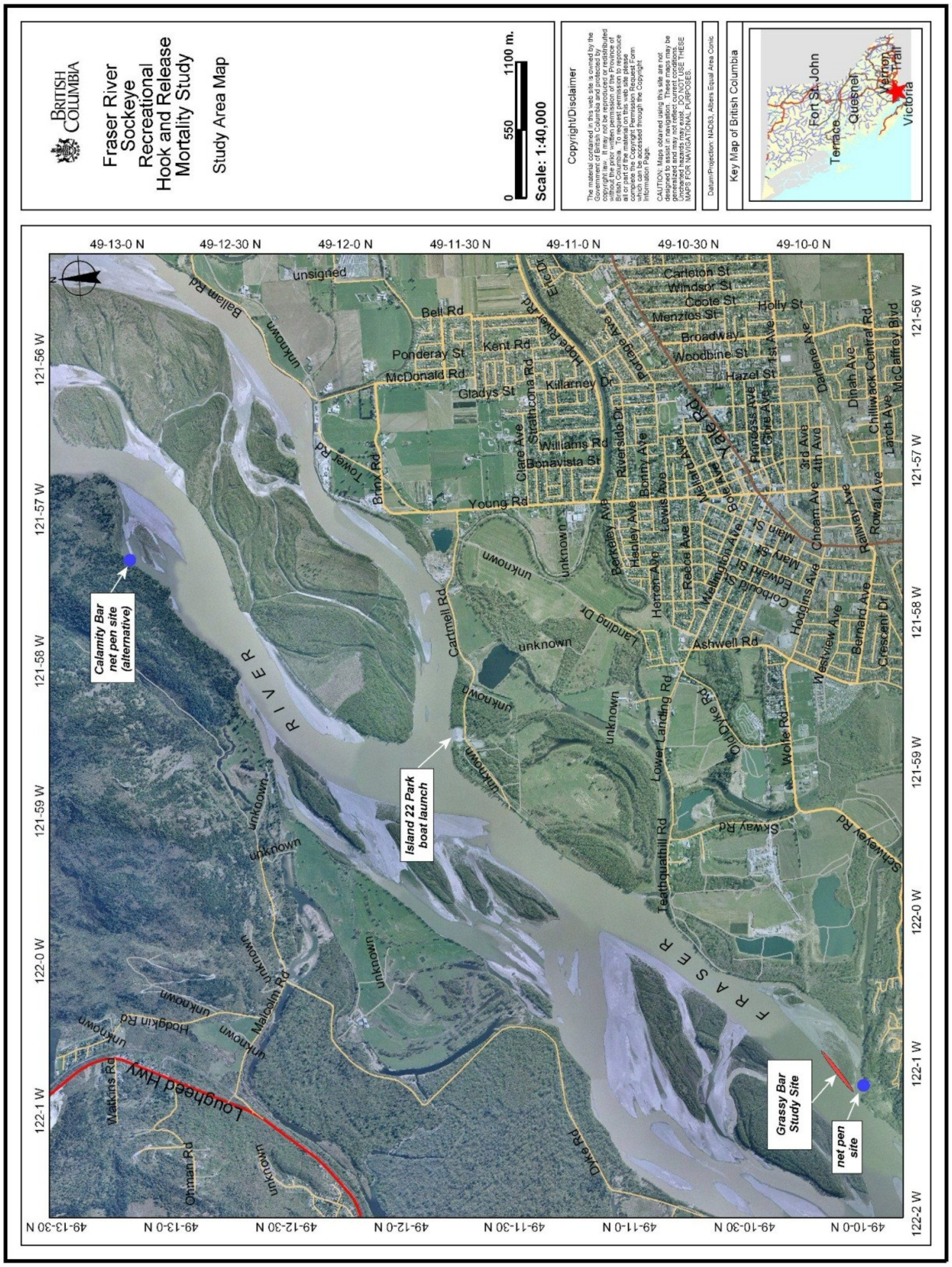
Appendix 5 – Water temperature profiles.

Appendix 6 – Study photos.

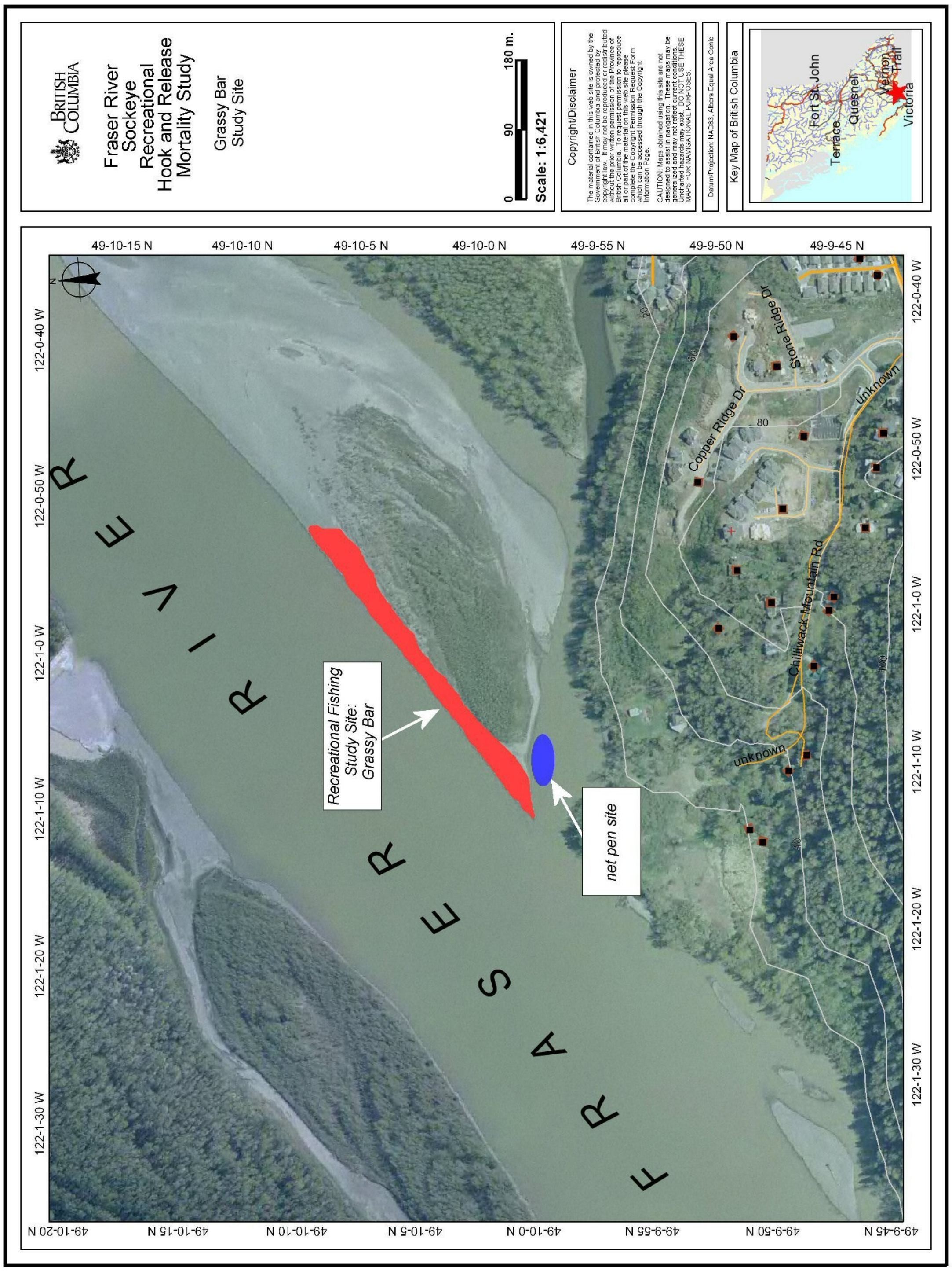
Appendix 7 – Fraser River sockeye escapement and abundance estimates.

Appendix 8 – Newcombe-Wilson hybrid score confidence interval derivation.

Appendix 1 - Figure 1. Detailed orthophoto mosaic map of the general location of the lower Fraser River Sockeye Recreational Hook and Release Mortality Study showing boat access at Island 22 Park, the Grassy Bar study site (red, blue dot) and alternate net pen site at Calamity Bar (blue dot). Fraser River flows southwest.



Appendix 1 - Figure 2. Detailed orthophoto mosaic map of the Grassy Bar study site for the lower Fraser River Sockeye Recreational Hook and Release Mortality Study showing the primary angling site (red) and the location of the holding net pens (blue) . Fraser River flows southwest.



Appendix 2 - Figure 1. Daily Encounter Form – Angled Group.

Fraser River Sockeye Recreational Hook & Release Mortality Study
Daily Encounter Form

Date: - - (dd-mmm-yyyy)
Observer Name:
Location:

Hour	Time	Angler Count	Weather	Strikes	Species	Hookups	Losses	Landings
1					SO			
					CN			
2					SO			
					CN			
3					SO			
					CN			
4					SO			
					CN			
5					SO			
					CN			
6					SO			
					CN			
7					SO			
					CN			
8					SO			
					CN			

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Weather Codes:
1 = Clear
2 = Broken Cloud
3 = Overcast
4 = Rain
5 = Windy
6 = Calm
7 = Fog

Species Codes:
CO = Coho
CN = Chinook
ST = Steelhead
CM = Chum
PK = Pink
SO = Sockeye
DV = Dolly Varden
CT = Cutthroat Trout
SR = Sturgeon
SU = Sucker

Appendix 2 - Figure 2. Individual Sockeye Landing Form (Angled Group)

Fraser River Sockeye Recreational Hook & Release Mortality Study
Individual Sockeye Landing Form

IDENTIFICATION

Date: [- -] (dd-mmm-yyyy) **Location:** *Grassy Bar*

Observer: [ ] **Angler:** boat shore

Fish Bagged?: Y N **Floy Tag Number :** [| | |] **Sex:** M F U

CAPTURE CONDITION DATA (**circle one condition per variable only**)

Time Hooked:	[:] (hh:mm - 24 h clock)		**Hook Retrieval:**	hook removed	line cut	
Time Landed:	[:] (hh:mm - 24 h clock)		**Fish Condition:**	vigorous	lethargic	dead
Netted?:	Y	N	**Bleeding:**	none	light	moderate	heavy
Beached?:	Y	N	**Scaling:**	none	light <5%	moderate 5 to 25%	heavy >25%
Air exposure:	< 15 sec	> 15 sec	**Predator Injury:**	none	minor scrape, healed scar	major open wound, bleeding

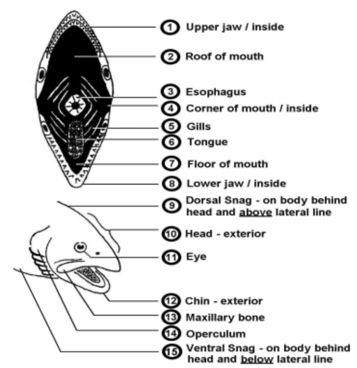
GEAR DESCRIPTION (**circle one per variable**)

Gear Type: bottom bouncing bar fishing other [ ]

Hook Size: 0 1 1/0 2/0 3/0 other [ ]

Leader Length (ft.): [ ] **Weight (oz.):** [ ] **Corkie colour:** [ ]

HOOK LOCATION (**see diagram - check one only**)



Inside Mouth

Upper jaw / inside [ ] 1		Gills [ ] 5	
Roof of mouth [ ] 2		Tongue [ ] 6	
Esophagus [ ] 3		Floor of mouth [ ] 7	
Corner of mouth / inside [ ] 4		Lower jaw / inside [ ] 8	
		Other (specify) [ ]	

Outside Mouth

rsal Snag (body behind head & above lateral line) [ ] 9	Maxillary bone [ ] 13
Head - exterior [ ] 10	Operculum [ ] 14
Eye [ ] 11	Ventral Snag (body behind head & below lateral line) [ ] 15
Chin - exterior [ ] 12	Other (specify) [ ]

Radio Tag Data: **Radio Tag Code:** [ ] **Radio Frequency:** [ ]

COMMENTS:

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Appendix 2 - Figure 3. Holding Form (Angled and Beach Seine Groups).

Fraser River Sockeye Recreational Hook & Release Mortality Study

Holding Form

Location: ____________ **Study Year:** ____________

	Floy Tag Number	Hooked or Control (H or C)	Sex (M,F,U)	Date Captured (dd-mmm)	Time into Pen (24h clock) (hh:mm)	Initial Condition (circle one)	Date Released (dd-mmm)	Time Released (24 h clock) (hh:mm)	Fork Length (mm)	DNA Vial No.	Radio Tag No.	Release Condition (circle one)	Physio ? (Y/	Comments
1						VNB VB LNB LB D						VNB VB LNB LB D		
2						VNB VB LNB LB D						VNB VB LNB LB D		
3						VNB VB LNB LB D						VNB VB LNB LB D		
4						VNB VB LNB LB D						VNB VB LNB LB D		
5						VNB VB LNB LB D						VNB VB LNB LB D		
6						VNB VB LNB LB D						VNB VB LNB LB D		
7						VNB VB LNB LB D						VNB VB LNB LB D		
8						VNB VB LNB LB D						VNB VB LNB LB D		
9						VNB VB LNB LB D						VNB VB LNB LB D		
10						VNB VB LNB LB D						VNB VB LNB LB D		
11						VNB VB LNB LB D						VNB VB LNB LB D		
12						VNB VB LNB LB D						VNB VB LNB LB D		
13						VNB VB LNB LB D						VNB VB LNB LB D		
14						VNB VB LNB LB D						VNB VB LNB LB D		
15						VNB VB LNB LB D						VNB VB LNB LB D		
16						VNB VB LNB LB D						VNB VB LNB LB D		
17						VNB VB LNB LB D						VNB VB LNB LB D		
18						VNB VB LNB LB D						VNB VB LNB LB D		
19						VNB VB LNB LB D						VNB VB LNB LB D		
20						VNB VB LNB LB D						VNB VB LNB LB D		

Condition: VNB=Vigorous,Not Bleeding **VB**=Vigorous,Bleeding **LNB**=Lethargic,Not Bleeding **LB**=Lethargic,Bleeding **D**=Dead

Time: Use 24 hour clock. eg. 7 AM = 07:00

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Appendix 2 - Figure 4. Beach Seine Daily Summary Form.

Fraser River Sockeye Recreational Hook & Release Mortality Study
Beach Seine Summary

Date: ________/________/__________
(dd-mmm-yyyy)

Set#	Time (start - finish)	Number of Fish Caught								
		Kept	--------------- Released --------------							
		Sock	Sock	Coho	Chin	Chin Jk	Pink	Chum	Sturg	Other
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
Total										

Comments:

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Appendix 2 - Figure 5. Necropsy Form.

Fraser River Sockeye Recreational Hook & Release Mortality Study

Necropsy Form

Date (dd-mmm-yyyy)	Time (hh:mm)	Floy Tag Number	Fork Length (cm)	Sexual Maturity (IF,MF,IM,MM)	Scale Loss (L,M,H)	DNA Vial No.	Cause of Death, Comments, etc.

Sexual Maturity: IF= Immature Female MF= Mature Female IM= Immature Male MM=

Scale Loss: L=0-5% M=6-25% H=>25%

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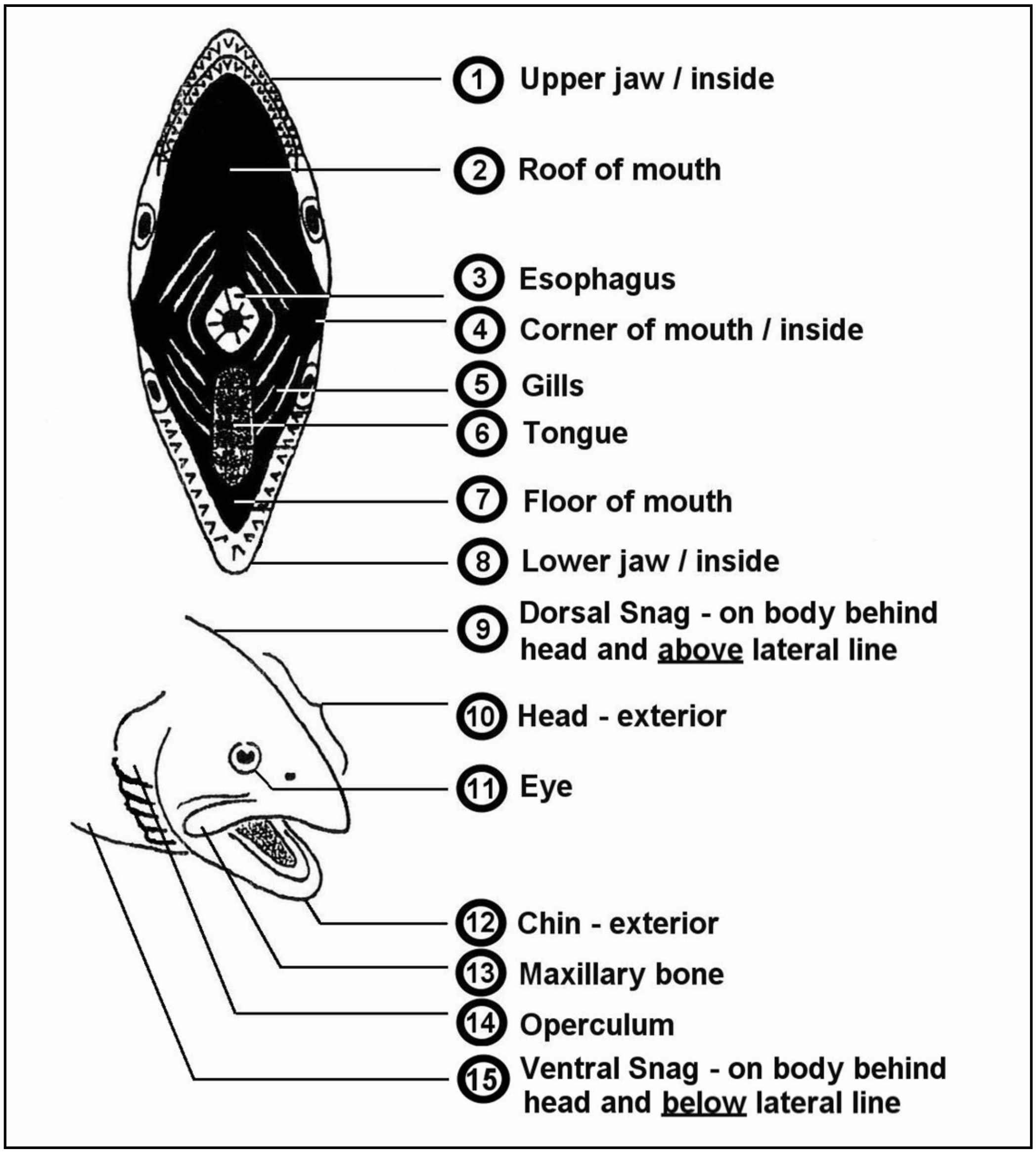
Appendix 2 - Figure 6. Diagrammatic view of a salmonid head illustrating hook injury locations (adapted from Mongillo 1984).



Appendix 3 - Table 1. Angled group catch summary for sockeye by date and study week at Grassy Bar, Fraser River, 2011.

Date	Average number of anglers	Number of sockeye kept or released by anglers	Number of sockeye radio-tagged and released	Total number of sockeye held for 24 h	Total number of sockeye landed	Angler effort (angler·hrs)	Mean Catch per angler·hr
15-Aug	18	0	1	5	6	72	0.08
16-Aug	13	18	11	30	59	92	0.64
17-Aug	18	13	5	22	40	123	0.33
18-Aug	10	11	5	18	34	70	0.49
19-Aug	18	17	9	30	56	126	0.44
Week 1	**15**	**59**	**31**	**105**	**195**	**483**	**0.40**
22-Aug	11	18	6	23	47	77	0.61
23-Aug	16	16	10	30	56	110	0.51
24-Aug	12	6	0	22	28	84	0.33
25-Aug	20	7	3	9	19	141	0.13
26-Aug	11	3	6	11	20	76	0.26
Week 2	**14**	**50**	**25**	**95**	**170**	**488**	**0.35**
29-Aug	13	6	3	9	18	90	0.20
30-Aug	12	10	5	16	31	87	0.36
31-Aug	12	5	2	9	16	84	0.19
1-Sep	13	2	1	2	5	51	0.10
2-Sep	12	4	3	6	13	86	0.15
Week 3	**12**	**27**	**14**	**42**	**83**	**398**	**0.21**
Total	**14**	**136**	**70**	**242**	**448**	**1369**	**0.33**

Appendix 3 - Table 2. Beach seine (reference group) catch summary by date, study week and species at Grassy Bar, Fraser River, 2011.

			---------- Released ---------									
Date	Number of sets	Kept Sockeye	Sockeye (Destruct-Physio)	Sockeye (Radio-tag)	Sockeye (Released)	Coho	Chinook Adult	Chinook Jack	Pink	Chum	Sturgeon	Other[a]
15-Aug	0	0	0	0	0	0	0	0	0	0	0	0
16-Aug	0	0	0	0	0	0	0	0	0	0	0	0
17-Aug	0	0	0	0	0	0	0	0	0	0	0	0
18-Aug	0	0	0	0	0	0	0	0	0	0	0	0
19-Aug	0	0	0	0	0	0	0	0	0	0	0	0
Week 1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
22-Aug	0	0	0	0	0	0	0	0	0	0	0	0
23-Aug	0	0	0	0	0	0	0	0	0	0	0	0
24-Aug	0	0	0	0	0	0	0	0	0	0	0	0
25-Aug	7	0	11	0	0	0	10	17	115	0	0	3
26-Aug	7	0	9	0	3	1	7	3	150	0	0	8
Week 2	**14**	**0**	**20**	**0**	**3**	**1**	**17**	**20**	**265**	**0**	**0**	**11**
29-Aug	0	0	0	0	0	0	0	0	0	0	0	0
30-Aug	0	0	0	0	0	0	0	0	0	0	0	0
31-Aug	0	0	0	0	0	0	0	0	0	0	0	0
1-Sep	4	29	5	0	1	1	4	17	214	0	0	0
2-Sep	2	33	0	0	13	0	9	3	208	0	0	0
Week 3	**6**	**62**	**5**	**0**	**14**	**1**	**13**	**20**	**422**	**0**	**0**	**0**
Total	**8**	**62**	**25**	**0**	**17**	**2**	**30**	**40**	**687**	**0**	**0**	**11**

a. Other fish includes 4 pea-mouth chubs, 6 northern pike minnows, and 1 dolly varden.

Appendix 4 - Table 1. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for transport/handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for the primary hooking locations (inside mouth, maxillary bone, or other outside mouth) and specific hooking location. 95% confidence intervals (95% CI) are provided.

		Release condition						
Primary hooking location	Specific hooking location	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
Inside mouth	Upper jaw	12	0	0	12	--	5.0	0
	Roof of mouth	3	0	0	3	0	1.2	0
	Esophagus	0	0	0	0	--	0	0
	Corner of mouth	5	0	0	5	0	2.1	0
	Gills	1	0	0	1	0	0.4	0
	Tongue	0	0	0	0	--	0	0
	Floor of mouth	5	0	0	5	0	2.1	0
	Lower jaw	4	1	0	5	0	2.1	0
	Other	0	0	0	0	--	0	0
Inside mouth total		30	1	0	31	0	12.8	0
Maxillary bone total		171	2	2	175	1.1	72.3	1.1 (0-4.1)
Other outside mouth	Dorsal snag	6	0	0	6	0	2.5	0
	Head	2	0	0	2	0	0.8	0
	Eye	0	0	0	0	--	0	0
	Chin	11	0	0	11	0	4.5	0
	Operculum	1	0	0	1	0	0.4	0
	Ventral snag	14	0	2	16	12.5	6.6	12.5 (0.8-36.0)
	Other	0	0	0	0	--	0	0
Other outside mouth total		34	0	2	36	5.6	14.9	5.6 (0-18.1)
Grand total		235	3	4	242	1.7	100.0	1.7 (0-4.2)

Appendix 4 - Table 2. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for the primary hooking locations (inside mouth, maxillary bone, or other outside mouth) and leader length (feet). 95% confidence intervals (95% CI) are provided.

		Release condition						
Primary hooking location	Leader length (ft)	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
Inside mouth	11	2	0	0	2	0	0.8	0
	12	8	0	0	8	0	3.3	0
	13	1	0	0	1	0	0.4	0
	14	11	1	0	12	0	5.0	0
	15	8	0	0	8	0	3.3	0
Inside mouth total		30	1	0	31	0	12.8	0
Maxillary bone	10	1	0	0	1	0	0.4	0
	11	3	0	0	3	0	1.2	0
	12	40	0	0	40	0	16.5	0
	13	10	1	0	11	0	4.5	0
	14	67	1	1	69	1.4	28.5	1.4 (0-7.8)
	15	39	0	1	40	2.5	16.5	2.5 (0-12.9)
	16	5	0	0	5	0	2.1	0.0
	18	1	0	0	1	0	0.4	0
	20	5	0	0	5	0	2.1	0
Maxillary bone total		171	2	2	175	1.1	72.3	1.1 (0-4.1)
Other outside mouth	11	2	0	0	2	0	0.8	0
	12	6	0	0	6	0	2.5	0
	13	4	0	0	4	0	1.7	0
	14	14	0	2	16	12.5	6.6	12.5 (1.8-36.0)
	15	7	0	0	7	0	2.9	0
	18	1	0	0	1	0	0.4	0
Other outside mouth total		34	0	2	36	5.6	14.9	5.6 (0-18.1)
Grand total		235	3	4	242	1.7	100.0	1.7 (0-4.2)

Appendix 4 - Table 3. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for the primary hooking locations (inside mouth, maxillary bone, or other outside mouth) and hook size. 95% confidence intervals (95% CI) are provided.

		Release condition						
Primary hooking location	Hook size	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
Inside mouth	1/0	0	0	0	0	--	0	0
	2/0	10	0	0	10	0	4.1	0
	3/0	20	1	0	21	0	8.7	0
	4/0	0	0	0	0	--	0	0
Inside mouth total		30	1	0	31	0	12.8	0
Maxillary bone	1/0	0	0	0	0	--	0	0
	2/0	23	1	0	24	0	9.9	0
	3/0	148	1	2	151	1.3	62.4	1.3 (0-4.7)
	4/0	0	0	0	0	--	0	0
Maxillary bone total		171	2	2	175	1.1	72.3	1.1 (0-4.1)
Other outside mouth	1/0	1	0	0	1	0	0.4	0
	2/0	3	0	0	3	0	1.2	0
	3/0	30	0	2	32	6.3	13.2	6.3 (0-20.1)
	4/0	0	0	0	0	--	0	0
Other outside mouth total		34	0	2	36	5.6	14.9	5.6 (0-18.1)
Grand total		235	3	4	242	1.7	100.0	1.7 (0-4.2)

Appendix 4 - Table 4. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for the primary hooking locations (inside mouth, maxillary bone, or other outside mouth) and amount of bleeding at time of capture. 95% confidence intervals (95% CI) are provided.

		Release condition						
Primary hooking location	Bleeding at capture	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
Inside mouth	None	24	0	0	24	0	9.9	0
	Light	4	0	0	4	0	1.7	0
	Moderate	1	0	0	1	0	0.4	0
	Heavy	1	1	0	2	0	0.8	0
Inside mouth total		30	1	0	31	0	12.8	0
Maxillary bone	None	143	1	0	144	0	59.5	0
	Light	25	1	0	26	0	10.7	0
	Moderate	3	0	2	5	40.0	2.1	40.0 (11.2-76.9)
Maxillary bone total		171	2	2	175	1.1	72.3	1.1 (0-4.1)
Other outside mouth	None	23	0	0	23	0	9.5	0
	Light	9	0	1	10	10.0	4.1	10.0 (0-40.4)
	Moderate	2	0	1	3	33.3	1.2	33.3 (5.5-79.2)
Other outside mouth total		34	0	2	36	5.6	14.9	5.6 (0-18.1)
Grand total		235	3	4	242	1.7	100.0	1.7 (0-4.2)

Appendix 4 - Table 5. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for the primary hooking locations (inside mouth, maxillary bone, or other outside mouth) and amount of scale loss. 95% confidence intervals (95% CI) are provided.

		Release condition						
Primary hooking location	Scale loss at time of capture	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
Inside mouth	None	29	0	0	29	0	12.0	0
	Light	1	1	0	2	0	0.8	0
	Moderate	0	0	0	0	--	0	0
Inside mouth total		30	1	0	31	0	12.8	0
Maxillary bone	None	167	2	2	171	1.2	70.7	1.2 (0-4.2)
	Light	4	0	0	4	0	1.7	0
	Moderate	0	0	0	0	--	0	0
Maxillary bone total		171	2	2	175	1.1	72.3	1.1 (0-4.1)
Other outside mouth	None	30	0	2	32	6.3	13.2	6.3 (0-20.1)
	Light	4	0	0	4	0	1.7	0
	Moderate	0	0	0	0	--	0	0
Other outside mouth total		34	0	2	36	5.6	14.9	5.6 (0-18.1)
Grand total		235	3	4	242	1.7	100.0	1.7 (0-4.2)

Appendix 4 - Table 6. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for the primary hooking locations (inside mouth, maxillary bone, or other outside mouth) and size of casting weight (ounces). 95% confidence intervals (95% CI) are provided.

		Release condition						
Primary hooking location	Casting weight (oz)	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
Inside mouth	2	6	0	0	6	0	2.5	0
	3	24	1	0	25	0	10.3	0
	4	0	0	0	0	--	0	0
Inside mouth total		30	1	0	31	0	12.8	0
Maxillary bone	2	30	1	0	31	0	12.8	0
	3	140	1	2	143	1.4	59.1	1.4 (0-5.0)
	4	1	0	0	1	0	0.4	0
Maxillary bone total		171	2	2	175	1.1	72.3	1.1 (0-4.1)
Other outside mouth	2	9	0	0	9	0	3.7	0
	3	24	0	2	26	7.7	10.7	7.7 (0-24.1)
	4	1	0	0	1	0	0.4	0
Other outside mouth total		34	0	2	36	5.6	14.9	5.6 (0-18.1)
Grand total		235	3	4	242	1.7	100.0	1.7 (0-4.2)

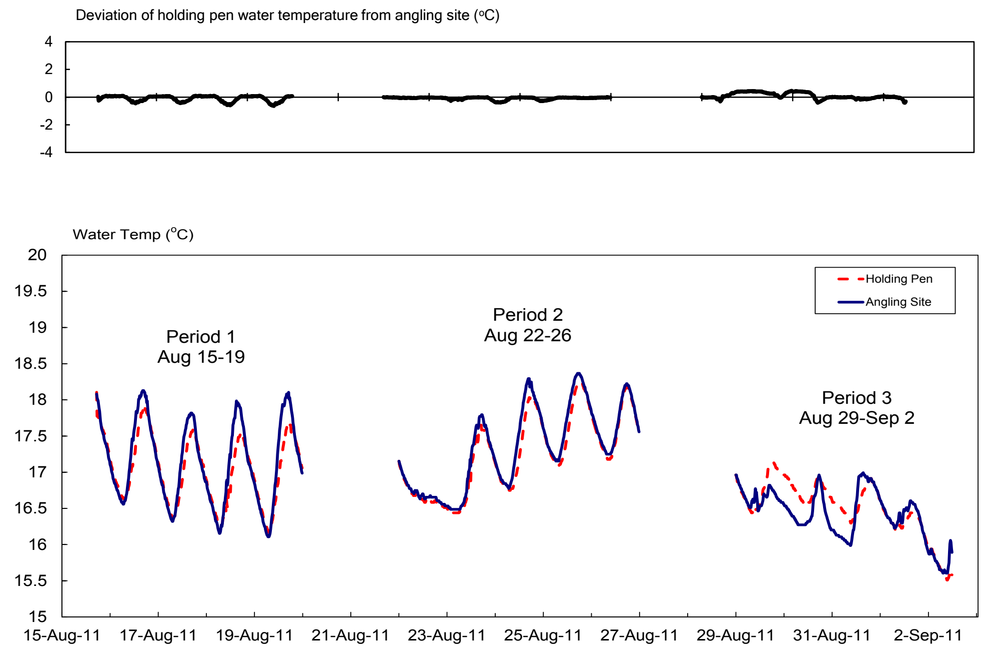
Appendix 4 - Table 7. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for fish that were beached or not beached at time of capture. 95% confidence intervals (95% CI) are provided.

	Release condition						
Beached?	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
Yes	23	0	0	23	0	9.5	0
No	212	3	4	219	1.8	90.5	1.8 (0-4.6)
Grand total	235	3	4	242	1.7	100.0	1.7 (0-4.2)

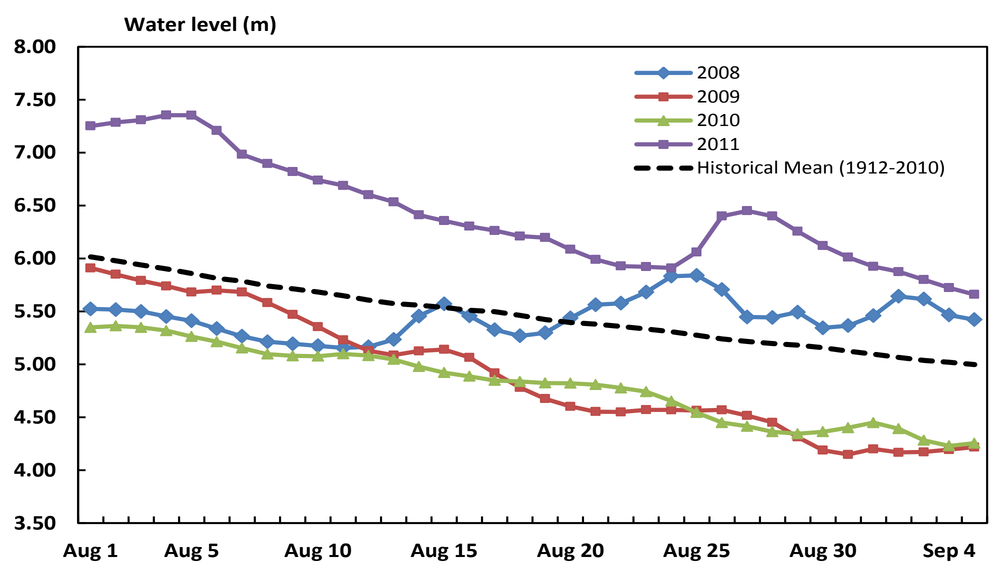
Appendix 4 - Table 8. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2011, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding period and the percent in the sample are presented for fish that exhibited predator wounds at time of capture. 95% confidence intervals (95% CI) are provided.

	Release condition						
Predator wounds	Vigorous, not bleeding	Lethargic, not bleeding	Dead	Total	Percent dead	Percent of total	Adjusted mortality rate (%) (95% CI)
None	214	1	4	219	1.8	90.5	1.8 (0-4.6)
Minor	17	0	0	17	0	7.0	0
Major	4	2	0	6	0	2.5	0
Grand total	235	3	4	242	1.7	100.0	1.7 (0-4.2)

Appendix 5 - Figure 1. Comparison of holding pen (dashed) and angling site (solid) water temperatures recorded every 15 minutes at Grassy Bar, Fraser River, 2011 (lower plot). The upper plot shows deviation of the holding pen water temperature from that of the angling site.



Appendix 5 - Figure 2. Comparison of water levels (m) in the Fraser River at Hope, BC (08MF005), from August 1 to September 4 for each of the four study years; 2008 to 2011, compared to the historical mean (1912 to 2010).



Source: Environment Canada, Water Office, Real-time hydrometric data (http://www.wateroffice.ec.gc.ca).

Appendix 6 - Figure 1. High water in the Fraser River in July and August, 2011 resulted in significant erosion of the banks on Grassy Bar and loss of beachfront. (photo: Jim Thomas).

Appendix 6 - Figure 2. Bank erosion near the downstream edge of Grassy Bar caused by high water in the Fraser River in 2011. (photo: Jim Thomas).

Appendix 6 - Figure 3. Typical bottom bounce gear (photo: Cathy Ball).

Appendix 6 - Figure 4. High water in 2011 resulted in angler crowding on the available beach (photo: Jim Thomas).

Appendix 6 - Figure 5. Typical hooking location (left maxillary) observed in the recreational sockeye bottom bounce fishery at Grassy Bar, Fraser River (photo: Bill Otway).

Appendix 6 - Figure 6. Chinook catches by anglers were prominent during the 2011 study (photo: Jim Thomas).

Appendix 6 - Figure 7. Holding pens and predator net configuration in the side channel situated at the southern (downstream) end of Grassy Bar, Fraser River (photo: Jim Thomas).

Appendix 6 - Figure 8. Release of a live, vigorous sockeye after the 24 h holding period (photo: Cathy Ball).

Appendix 6 - Figure 9. Anglers were required to fish downstream during beach seining operations (photo: Jim Thomas).

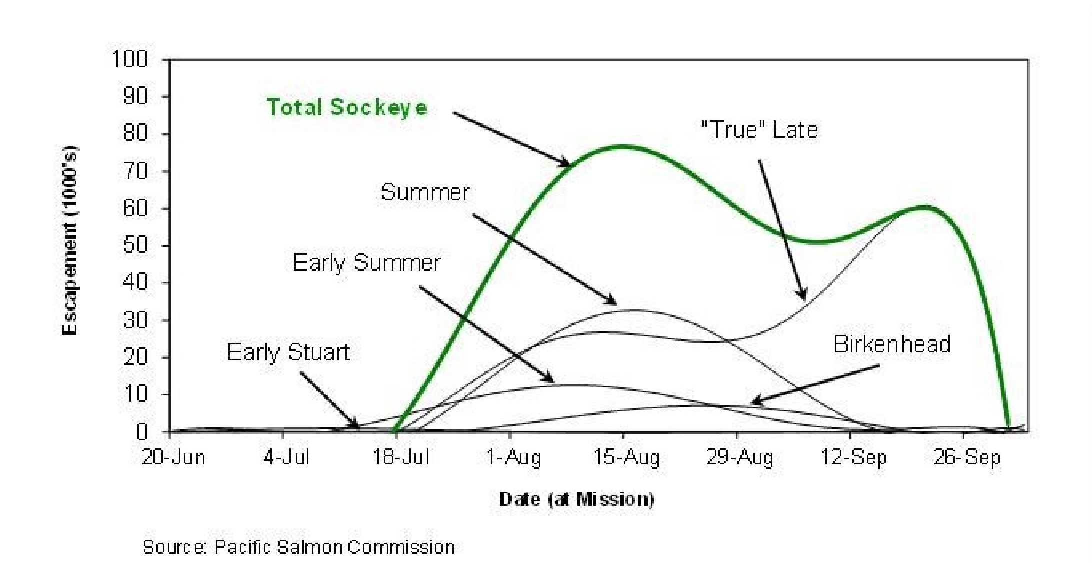
Appendix 6 - Figure 10. Beach seining for reference group fish (photo: Cathy Ball).

Appendix 6 - Figure 11. Nondestructive physiological sampling of a hooked and landed sockeye (photo: Cathy Ball).

Appendix 6 - Figure 12. Insertion of a micro-coded radio tag into the stomach of a captured sockeye. (photo: Jim Thomas).

Appendix 6 - Figure 13. Mobile tracking of a radio-tagged and released sockeye (photo: Jim Thomas).

Appendix 7 - Figure 1. Fraser River sockeye timing and daily escapement estimates (smoothed) past Mission, British Columbia, by major stock group (June 20 to October 3, 2011).



Appendix 7 - Table 1. Daily and weekly study period estimates of sockeye abundance at Grassy Bar, Fraser River based on estimates of sockeye migrating past Mission from August 13 to 31, 2011. (Source: Pacific Salmon Commission, October 19, 2011). The number of sockeye hooked in the study and the percent of hooked to migrating sockeye are presented.

Date at Mission	Date at Grassy Bar[a]	Early Stuart	Early Summer	Summer	Late (Birkenhead)	"True" Late	Total	Number hooked in study	Percent hooked to migrating
13-Aug	15-Aug	0	14,889	46,769	6,011	20,963	88,631	6	0.01%
14-Aug	16-Aug	0	5,777	16,203	1,260	50,233	73,472	59	0.08%
15-Aug	17-Aug	0	5,134	33,337	6,534	46,795	91,800	40	0.04%
16-Aug	18-Aug	0	5,718	31,352	11,676	42,354	91,100	34	0.04%
17-Aug	19-Aug	0	5,319	24,849	14,156	32,076	76,400	56	0.07%
Study Week 1		**0**	**36,835**	**152,510**	**39,637**	**192,420**	**421,403**	**195**	**0.05%**
20-Aug	22-Aug	0	10,402	22,536	3,874	39,711	76,523	47	0.06%
21-Aug	23-Aug	0	2,354	51,784	11,673	16,789	82,600	56	0.07%
22-Aug	24-Aug	0	6,074	85,997	12,001	39,528	143,600	28	0.02%
23-Aug	25-Aug	0	6,462	32,298	12,638	50,003	101,400	19	0.02%
24-Aug	26-Aug	0	5,238	26,877	6,290	18,095	56,500	20	0.04%
Study Week 2		**0**	**30,529**	**219,491**	**46,476**	**164,126**	**460,623**	**170**	**0.04%**
27-Aug	29-Aug	0	4,698	13,582	6,554	1,409	26,243	18	0.07%
28-Aug	30-Aug	0	2,844	8,589	3,051	2,365	16,849	31	0.18%
29-Aug	31-Aug	0	8,241	28,371	10,077	7,812	54,500	16	0.03%
30-Aug	1-Sep	0	4,158	14,316	5,085	3,942	27,500	5	0.02%
31-Aug	2-Sep	0	419	6,409	3,498	7,874	18,200	13	0.07%
Study Week 3		**0**	**20,359**	**71,267**	**28,264**	**23,402**	**143,292**	**83**	**0.06%**
Total		**0**	**87,724**	**443,269**	**114,377**	**379,948**	**1,025,318**	**448**	**0.04%**

a. In-river migration time for sockeye from Mission to Grassy Bar is estimated to be 2 days.

Appendix 8- 1. Derivation of Newcombe-Wilson hybrid score confidence intervals for the difference between two binomial proportions.

I. Derivation of the classical, Wald-type confidence intervals for a single binomial proportion (e.g. mortality rate) and for the difference between two binomial proportions (e.g. hooking/handling/holding mortality rate – handling/holding (reference) mortality rate).

Let X equal the number of mortalities out of a sample of n trials. Let $\hat{p}$ equal the observed mortality rate, X/n. Let π equal the true population mortality rate. Let z_α equal the $1-\alpha$ quantile of the standard normal distribution, with α being the type I error rate. The Wald-type hypothesis test uses a standard error of π estimate (the square root term) calculated at the maximum likelihood estimate, $\hat{p}$:

$$z_{\alpha/2} < |\hat{p}-\pi| / \sqrt{\hat{p}(1-\hat{p})/n} \qquad \text{[Equation 1]}$$

A $100(1-\alpha)\%$ confidence interval for π may be calculated by solving this inequality for π .

$$\hat{p}-z_{\alpha/2}\sqrt{\hat{p}(1-\hat{p})/n} < \pi < \hat{p}+z_{\alpha/2}\sqrt{\hat{p}(1-\hat{p})/n} \qquad \text{[Equation 2]}$$

(For clarity, from this point on we will drop the subscript from $z_{\alpha/2}$.) By a similar inversion of the Wald-type test for the difference between two independent binomial proportions, $\pi_1-\pi_2$, a $100(1-\alpha)\%$ confidence interval may then be calculated as:

$$(\hat{p}_1-\hat{p}_2)-z\sqrt{\hat{p}_1(1-\hat{p}_1)/n_1+\hat{p}_2(1-\hat{p}_2)/n_2} < \pi_1-\pi_2 < (\hat{p}_1-\hat{p}_2)+z\sqrt{\hat{p}_1(1-\hat{p}_1)/n_1+\hat{p}_2(1-\hat{p}_2)/n_2}$$

[Equation 3]

where the subscripts indicate the first and second binomial proportions. These are methods most often presented in introductory textbooks of statistics and most often made available in software.

II. Derivation of Wilson score confidence interval for a single binomial proportion.

Let X equal the number of mortalities out of a sample of n trials. Let $\hat{p}$ equal the observed mortality rate, X/n. Let π equal the true population mortality rate. Let z_α equal the $1-\alpha$ quantile of the standard normal distribution, with α being the type I error rate. The Wilson-type hypothesis test estimates the standard error of π estimate (the square root term) at the null hypothesis. This is the <u>score test</u> approach to hypothesis testing.

$$z < |\hat{p}-\pi| / \sqrt{\pi(1-\pi)/n} \qquad \text{[Equation 4. Compare this to Equation 1.]}$$

To calculate confidence limits we will set z equal to the right side of the inequality. After squaring both sides, we can put this into the standard quadratic form and solve for π .

$$z = |\hat{p}-\pi| / \sqrt{\pi(1-\pi)/n}$$

Squaring both sides

$z^2 = (\hat{p}^2 - 2\hat{p}\pi + \pi^2)/(\pi(1-\pi)/n)$
Then simplifying

$$z^2(\pi(1-\pi)/n) = (\hat{p}^2 - 2\hat{p}\pi + \pi^2)$$

$$z^2\pi/n - z^2\pi^2/n = \hat{p}^2 - 2\hat{p}\pi + \pi^2$$

$$\hat{p}^2 - 2\hat{p}\pi + \pi^2 - z^2\pi/n + z^2\pi^2/n = 0$$

Putting this into quadratic form, $\mathrm{a}\pi^2 + \mathrm{b}\pi + \mathrm{c} = 0$, yields

$$((n+z^2)/n)\pi^2 - (2\hat{p} + z^2\pi/n)\pi + \hat{p}^2 = 0$$

Now solve for π, using the quadratic formula

$$\pi = \frac{-(-(2\hat{p} + \frac{z^2}{n})) \pm \sqrt{(-(2\hat{p} + \frac{z^2}{n}))^2 - 4(1 + \frac{z^2}{n})\hat{p}^2}}{2\frac{(n+z^2)}{n}}$$

This simplifies by algebra

$$\pi = \frac{2\hat{p} + \frac{z^2}{n} \pm \sqrt{4\hat{p}^2 + \frac{4\hat{p}z^2}{n} + \frac{z^4}{n^2} - 4\hat{p}^2 - \frac{4\hat{p}^2z^2}{n}}}{2\frac{(n+z^2)}{n}}$$

$$\pi = \frac{2\hat{p} + \frac{z^2}{n} \pm \sqrt{\frac{4\hat{p}z^2}{n} + \frac{z^4}{n^2} - \frac{4\hat{p}^2z^2}{n}}}{2\frac{(n+z^2)}{n}}$$

$$\pi = \frac{2\hat{p} + \frac{z^2}{n} \pm \sqrt{\frac{z^4}{n^2} + \frac{4z^2}{n}(\hat{p}(1-\hat{p}))}}{2\frac{(n+z^2)}{n}}$$

$$\pi = \frac{2n\hat{p} + z^2 \pm z\sqrt{z^2 + 4n(\hat{p}(1-\hat{p}))}}{2(n+z^2)}$$

These two roots provide score type upper and lower $100(1-\alpha)\%$ confidence limits for π.

$$U = \frac{2n\hat{p} + z^2 + z\sqrt{z^2 + 4n(\hat{p}(1-\hat{p}))}}{2(n+z^2)}$$ [Equation 5]

$$L = \frac{2n\hat{p} + z^2 - z\sqrt{z^2 + 4n(\hat{p}(1-\hat{p}))}}{2(n+z^2)}$$ [Equation 6]

III. Derivation of Newcombe-Wilson hybrid score confidence limits for the difference between two binomial proportions.

These are formed by calculating the Wilson score intervals [Equations 5,6] for each of the two independent binomial proportion estimates, $\hat{p}_1$ and $\hat{p}_2$. The first proportion, $\hat{p}_1$, with sample size n_1, has score intervals of L_1 and U_1. The second proportion, $\hat{p}_2$, with sample size n_2 has score intervals of L_2 and U_2. These are then substituted into the standard error terms of the inequality for Wald-type confidence intervals for the difference in two proportions. Starting with Equation 3 from above, we have

$$(\hat{p}_1 - \hat{p}_2) - z\sqrt{\hat{p}_1(1-\hat{p}_1)/n_1 + \hat{p}_2(1-\hat{p}_2)/n_2} < \pi_1 - \pi_2 < (\hat{p}_1 - \hat{p}_2) + z\sqrt{\hat{p}_1(1-\hat{p}_1)/n_1 + \hat{p}_2(1-\hat{p}_2)/n_2}$$

Replacing the observed proportions in each standard error term (the square root terms) with their corresponding score interval estimates gives us

$$(\hat{p}_1 - \hat{p}_2) - z\sqrt{L_1(1-L_1)/n_1 + U_2(1-U_2)/n_2} < \pi_1 - \pi_2 < (\hat{p}_1 - \hat{p}_2) + z\sqrt{U_1(1-U_1)/n_1 + L_2(1-L_2)/n_2}$$

[Equation 7]

where the subscripts indicate the first and second proportions. Notice that the standard error term for the lower limit is calculated from the lower score limit for the first proportion and the upper score limit for the second proportion. The standard error term for the upper limit is calculated from the upper score limit for the first proportion and the lower score limit for the second proportion. This provides upper and lower Newcombe-Wilson hybrid score $100(1-\alpha)\%$ confidence limits for $\pi_1 - \pi_2$.

Upper Limit = $(\hat{p}_1 - \hat{p}_2) + z_{\alpha/2}\sqrt{U_1(1-U_1)/n_1 + L_2(1-L_2)/n_2}$

Lower Limit = $(\hat{p}_1 - \hat{p}_2) - z_{\alpha/2}\sqrt{U_2(1-U_2)/n_2 + L_1(1-L_1)/n_1}$