2009
Lower Fraser River Sockeye Recreational Hook and Release Mortality Study

Further Investigations into Short-term (0 to 24 h) Hooking Mortality of Sockeye Caught and Released at Grassy Bar, Fraser River, British Columbia, 2009

Prepared for:
Fraser Salmon and Watersheds Program
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Fraser Salmon & Watersheds Program

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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*) and sockeye (*O. nerka*) 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 508,000 sockeye have been harvested in the Fraser River recreational fishery over the last 10 years. Although this fishery is primarily a catch-and-keep (CK) fishery, an additional 344,000 sockeye have been estimated to have been released over the same time period (Fisheries and Oceans Canada website - Pacific Region - Fraser River Area - Recreational Fisheries - Fraser River Creel Survey Results). Until 2008, no studies had been conducted to estimate catch-and-release (CR) mortality in this fishery. The ability to estimate the impacts of catch-and-release of sockeye in the Fraser River recreational fishery is important to the successful management and conservation of these stocks.

This report details the methods and results from the second year of a proposed 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 was also conducted.

This year's study was conducted using volunteer anglers over 15 days between 10 August and 28 August, 2009 at Grassy Bar in the Fraser River. In total, the study collected and analyzed data from 291 hooked and landed sockeye (angled treatment group) and 63 sockeye captured by beach seine (reference treatment group). All captured sockeye were floy-tagged and held in net pens for 24 h observation prior to release back into the river. Net pens were situated in a side channel close to the angling site.

Primary hooking locations were observed to be on the outside of the mouth (head or body) (90% of all landed sockeye). Of this group, most were specifically hooked in the left maxillary bone (80%). Approximately 25% of the hooked fish exhibited bleeding at the time of capture. However, all the sockeye that were hooked, held and released alive after 24 h in the net pens showed no signs of bleeding and all but six (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). Only five mortalities were witnessed in the study in 2009 and short-term (0 to 24 h) catch-and-release mortality was estimated to be 1.7% with 95% confidence intervals of 0% - 4.0%. The five fish that died were all initially hooked through the left maxillary bone followed by the hook either puncturing or

lacerating major arteries in the gills or under the tongue. No mortalities were observed in the reference group.

Adjunct physiological sampling and radio-tagging of individual sockeye was undertaken concurrently with the primary short-term CR study. Nondestructive and destructive physiological samples were collected from individual sockeye to investigate physiological stressors related to angling (hooked) or capture by beach seine and post-capture holding of sockeye in net pens for 24 h. Tissue samples were also collected for DNA stock composition analysis. Tracking and analysis of radio-tagged sockeye will provide insights into migration routes and timing, survival and corroboration of DNA samples for stock composition. Preliminary results from physiological samples taken during the 2008 study and radio-tagging in 2009 are presented here primarily for interest. Complete documentation and final analysis of this data is pending and be reported under a separate contract.

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 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 chinook (*Oncorhynchus tschawytscha*) and sockeye (*O. nerka*) are migrating upstream. 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, 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). Substantive numbers of sockeye can be released in this fishery. Between 2000 and 2009, DFO creel surveys have estimated a total harvest of close to 508,000 sockeye in the Fraser River summer recreational fishery and an additional release of almost 344,000 sockeye (this includes sockeye hooked during directed chinook fisheries) (Source: Fisheries and Oceans Canada website).

Fraser River sockeye do not 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 to 3/0. Often the hook is "baited" with wool and/or a brightly coloured corkie. The gear is cast into the river with a weight 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 the outside of the salmon's jaw (maxillary bone), mouth, or head (J. O. Thomas and Associates 2009). Other hooking locations are possible and have also been noted, to a lesser extent. Other salmon species such as chinook and coho are also caught using this method.

Capture in any recreational fishery can result in a number of consequences to the physical 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. It has been speculated 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 originating from bottom bouncing results in very low short-term mortality rates of 1.2% with 95% confidence intervals of between 0 and 4.1% (J. O. Thomas and Associates 2009).

A second study was repeated during the summer of 2009 using similar methodology and procedures as described in the 2008 report. In addition to collecting basic CR data and estimating short-term mortality rates, physiological sampling and radio-tagging was also conducted separately on a cross-section of sockeye captured during the study. Both of these added components were coordinated by Michael R. Donaldson and his research team at the Centre for Applied Conservation Research, Forest Sciences Centre, University of British Columbia. Nondestructive 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 are presented. A more complete reporting of these components is pending in a separate report.

The following report details the methodology and results of the CR component of the 2009 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.

METHODS

STUDY AREA

Grassy Bar was chosen again in 2009 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 (in water less than 1 m deep and with relatively slow river current ($< 1.0\ m{\cdot}s^{-1}$)).

Appendix 7 - Figure 1 shows a typical alignment of shore-based anglers fishing just off the beach on the mainstem side of Grassy Bar.

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 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 7 - Figure 2.

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 and tagged. 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 system. 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 adjacent to the dorsal fin. Data related to fish capture, hooking location, fish condition and numbered identification tag were recorded for each fish (Individual Sockeye Landing Form and Hooking Location diagram - Appendix 2 - Figures 2 and 6). Holding/transport bags containing sockeye were then slowly walked in-river from the point of landing to the holding net pen site.

Appendix 7 - Figure 3 shows a typically hooked and landed sockeye being assessed and prepared for transport to the holding pen.

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 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.

Sockeye Holding and Release

Angled sockeye were held for 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. A total of three net pens were used in the 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 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 restricted to a maximum of 35 fish per net pen (i.e. approximately 1 sockeye per 900 liters (0.9 m^3) of water).

Net pens were located in a low flow (<0.5 $m \cdot sec^{-1}$) side channel approximately 40 m south of the primary angling site on Grassy Bar (see Appendix 1 - Figure 2 and

Appendix 7 - Figure 4). 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. 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 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 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. As part of this year's study, some of the angled sockeye that were held for 24 h were fitted with micro-coded 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 determine the cause of death.

Appendix 7 - Figure 5 shows a typical release of a live and vigorous sockeye after the 24 h holding period.

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.

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 by species, adipose fin-clip mark status for chinook and coho, and which sockeye were taken for physiological samples or radio-tagging. All daily beach seine catch and effort data was recorded on individual forms (Beach Seine Summary Form - Appendix 2 - Figure 4).

Appendix 7 - Figure 6 documents 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. 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.

A number of sockeye were taken for physiological samples or for radio-tagging and immediate release.

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. At the completion of the 24 h holding period, all sockeye in the pen were individually caught by a long-handled knotless mesh net. To assist in identifying beach seined from angled sockeye, different number sequences of floy tags were used for each treatment group. 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. Fork lengths were obtained on a random sample of sockeye, as time permitted. 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 or bleeding, 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 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 mortality was measured for fork length and tissue sampled for DNA analysis.

Physiological Sampling and Radio-tagging

Physiological sampling was conducted on a number of sockeye caught and released in the study in order to assess post-capture recovery rates and other physiological effects during the 0 to 24 h holding period. A variety of nondestructive (blood samples, scale samples, length, weight, gill biopsy, fat probe reading, muscle biopsy) and destructive samples (liver, kidney, muscle, otoliths, reproductive tissues) were collected from sockeye in three treatment groups: 1) captured by angling and immediately released, 2) captured by beach seine and immediately released, and 3) captured by angling and held 24 h in the net pens, then released.

A cross-section of individual sockeye that were captured from each of the treatment groups were also fitted with LOTEK® model MCFT-3A micro-coded radio tags. A total of 100 radio tags were available and distributed approximately equally (~33) in each treatment group. For sockeye in treatment groups 1 and 2 (above), radio tags were inserted shortly after landing and sockeye were released immediately back into the river. For angled sockeye that were held in net pens for 24 h (treatment group 3 above), fitting of radio tags was done after the 24 h hour holding period, and then fish were immediately released back into the river. Angled sockeye that were held for 24 h in net pens and fitted with radio tags were also floy tagged at the time of capture as part of the short-term mortality study. Sockeye that were fitted with radio tags and released immediately back into the river were not floy tagged.

Analysis and reporting of the physiological sampling and radio-tagging component of the study is being coordinated by Michael R. Donaldson, Ph. D. student, at the Centre for Applied Conservation Research, Forest Sciences Centre, University of British Columbia. Preliminary summarized results only are presented in this report.

Appendix 7 - Figure 7 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 documented in Appendix 7 - Figures 8 and 9.

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” (Nelson 1998), the “simple model” (Wilde et al. 2003; Wilde and Pope 2008), and the “additive finite mortality rate” (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.). Maximum likelihood 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, Fisher’s exact tests, and logistic regressions were performed (where applicable) using 2xn 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 10 to 14, August 17 to 22, and August 24 to 28, 2009. Due to very low mortality rates witnessed in the study and no significant differences noted between hooking mortality (Pearson's chi-square = 1.62, 2 d.f., P = 0.44) or hooking locations (Pearson's chi-square = 0.31, 2 d.f., P = 0.86) between weeks, data from all three weeks were combined and analyzed collectively for this report.

SUMMARY BY TREATMENT GROUP

Angled (Experimental) Group

Catch, Fishing Effort and Mortality

Participating anglers hooked and landed 328 sockeye during the 15 study days between 10 August and 28 August (Appendix 3 - Table 1). Nondestructive physiological samples (blood, length, scale samples) were taken randomly from 10 of the angled sockeye immediately after landing and prior to release into the holding pens. Thirty-seven of the angled and landed sockeye were fitted with radio tags and released immediately back into the river, leaving 291 angled sockeye for 24 h holding in the net pens.

Based on hourly angler counts taken each day, mean daily angler effort during the study ranged from a low of 8 anglers on 11 August to a high of 26 anglers on 17 August (Appendix 3 - Table 1). The mean number of anglers for the study was approximately 17 per day and the mean daily sockeye catch ranged from 0.25 to 3.43 per angler·day. Hourly catch rates ranged from 0.04 to 0.49 sockeye per angler·hour. Angler success in our study was slightly higher than 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 was 0.19 sockeye per angler·hour for our study (10 August to 28 August) compared to 0.12 sockeye (released) per angler·hour (1 August to 3 September) from angler creel surveys (Fisheries and Oceans Canada website, 2009 Fraser River Recreational Fishery Preliminary In-season Summary).

Of the 291 angled sockeye that were caught and held, only five (1.7%) died within the 24 h holding period. In addition to sockeye, anglers in the study also caught and landed a total of 36 chinook, 1 coho and 27 pink. Aside from noting the total number hooked and landed, no other angling statistics were collected and no mortality estimates were made for these other species.

Sockeye Handling and Transport

Angler playing times ranged anywhere from 1 to 12 minutes with a mean angler play time of 2 min 12 sec. (SD < 0.001) (Figure 1). Handling/transport times were more variable, ranging anywhere from 1 minute up to 15 or more minutes with an overall average of 11 min 39 sec (SD = 0.007). Of the five mortalities observed, angler playing times for these fish ranged from 2 and 4 minutes, and handling/transport times were all recorded as 5 minutes. Overall handling time (angler play time plus handling/transport time) for the hooked sockeye averaged 13 min 51 sec (SD = 0.007). Four of the five observed mortalities occurred in hooked fish that had overall handling times less than 14 minutes. 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 of 14 minutes (Pearson's chi-square = 0.22, 1 d.f., P = 0.637).

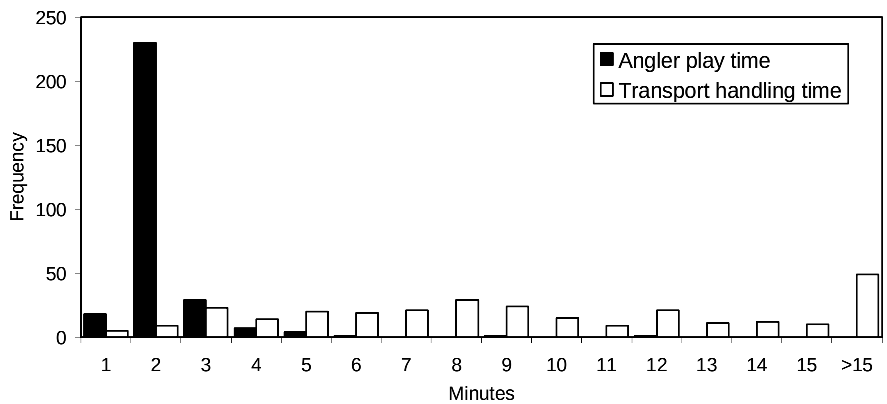


Figure 1. Frequency distribution of angler play time and handling/transport time to holding pens for sockeye hooked in a bottom bounce hook-and-release study at Grassy Bar in the Fraser River in 2009.

Hooking Locations and Angling-related Factors

Of the 291 sockeye landed and held, 218 (75%) were hooked in the maxillary bone, 43 (15%) were hooked in other outside locations, and 30 (10%) 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 11%. For sockeye dragged onto dry ground, the substrate comprised a mix of gravel (70%) and fine sand (30%). The remainder (89%) of landed sockeye were netted or transferred directly to handling/transport bags in shallow water without being brought ashore. The majority of hooks (99%) were removed from sockeye by technicians using their hands, or pliers when necessary. Four fish (1%) had hooks that could not be removed easily. In three of these fish, the line was cut and the hook was left in place for the 24 h holding period. In the other one, the technician was able to cut the hook and remove it. Approximately 25% of the hooked fish exhibited some bleeding (light to moderate) at the time of landing and after hook removal. Fish that were hooked inside the mouth exhibited the most amount of bleeding (40%) compared to those hooked in the maxillary bone (21%) or other outside locations (35%). The majority (99%) of hooked sockeye were evaluated as being in a vigorous condition at the time of landing.

There were a variety of hook sizes and leader lengths among the anglers in the study. Hook sizes ranged from 1 to 5/0, with the majority of anglers choosing the 2/0 (40%) or 3/0 size (52%). Leader lengths in the study ranged anywhere from 5 to 25 feet. The predominant leader lengths were between 10 and 14 feet (68%).

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 2009, by primary hooking location.

	Hooking location			
Variable	Inside mouth	Maxillary bone	All other outside	Total
Total number caught	30	218	43	291
Mortality (%)	0	2.3	0	1.7
Mean Playing Time (min:sec)	2:00	2:12	2:22	2:18
Beached (%)	26.7	9.2	9.3	11.0
Bleeding observed (%)	40.0	21.1	34.9	25.1
Vigorous condition at capture (%)	96.7	99.1	100	99.0
Mean transport handling time (min:sec)	12:00	11:35	11:43	11:51
Predominant hook size (type: %)	3/0: 60.0	3/0: 50.0	3/0: 58.1	3/0: 52.2
Predominant leader lengths (range ft: %)	10-14: 60.0	10-14: 71.5	10-14: 60.5	10-14: 68.6

Beach Seine (Reference) Group

Catch, Effort and Mortality

A total of 113 sockeye were caught using a beach seine over four days (August 13, 18, 20, and 27) (Appendix 3 - Table 2). Eighteen sockeye were removed immediately from the beach seine for destructive physiological samples. Radio tags were gastrically inserted in 26 of the beach seined sockeye, after which they were released immediately back into the river. Six additional sockeye escaped from the seine or were released immediately without tagging, leaving a total 63 reference group sockeye for holding 24 h in the net pens. Beach seining also caught 112 chinook jacks, 48 chinook adults, 995 pink, 2 coho, 5 sturgeon and 10 suckers. Radio tags were inserted into two of the sturgeon and released. All other fish caught in the seine other than sockeye were recorded and released into the river as soon as they were discovered.

Of the 63 sockeye retained for the beach seined group, none died during handling or within the 24 h holding period.

Sockeye Handling and Transport

Handling/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 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 (99%) of angled sockeye were in a vigorous condition at time of capture (75% not bleeding, 25% bleeding) (Table 2). Only 1% of the angled sockeye were reported as lethargic (0.3% not bleeding, 0.7% bleeding). None of the beach seined sockeye exhibited any bleeding at the time of capture with 97% being reported as vigorous and 3% as lethargic. No fish died during initial capture, handling or transport either by angling or by beach seining. At the time of release, no fish were reported as bleeding in either study group. Except for the five mortalities noted in the angled group, 96% were released after 24 h as vigorous with no bleeding and 2% as lethargic with no bleeding. All of the beach seined fish were released after 24 h alive, of which 95% were in vigorous and 5% 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 2009.

A. Condition at time of capture:

Study Group	Vigorous, not bleeding	Vigorous, bleeding	Lethargic, not bleeding	Lethargic, bleeding	Dead	Total
Angled	217	71	1	2	0	291
Percent of total	74.6%	24.4%	0.3%	0.7%	0%	100.0%
Beach Seine	61	0	2	0	0	63
Percent of total	96.8%	0%	3.2%	0%	0%	100.0%

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

Study Group	Vigorous, not bleeding	Vigorous, bleeding	Lethargic, not bleeding	Lethargic, bleeding	Dead	Total
Angled	280	0	6	0	5	291
Percent of total	96.2%	0%	2.1%	0%	1.7%	100.0%
Beach Seine	60	0	3	0	0	63
Percent of total	95.2%	0%	4.8%	0%	0%	100.0%

FISH SIZE

The mean fork length was 58.9 cm for angled sockeye and 53.4 cm for beach seined sockeye. A significant difference was noted between the two groups ($t = 3.84$, 178 d.f., $P < 0.001$). However, the sample size for lengths from the beach seine was small (n=10).

HOOKING MORTALITY ESTIMATES

No mortalities were observed in any sockeye that were subjected to nondestructive physiological sampling at time of capture or after the 24 h holding period. However, for completeness, mortality estimates are presented inclusive and exclusive of these samples (Table 3). The short-term hooking mortality rate using the adjusted (additive) model and including nondestructive physiologically sampled sockeye was estimated to be 1.7% with lower and upper 95% confidence intervals of zero to 4.0%, respectively. Excluding the physiological samples resulted in a short-term mortality estimate of 1.8% with lower and upper 95% confidence intervals of zero to 4.1%, 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.

Table 3. Estimates of short-term (0 to 24 h) catch-and-release mortality of sockeye salmon at Grassy Bar in the Fraser River in 2009, 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. Nondestructive physiological samples are included (A) and excluded (B) from estimates for comparison.

Treatment group	Total caught (*N*)	Mortalities		Adjusted catch-and-release mortality estimate (%) (95% CI)
		n	Percent	
A. Including nondestructive physiological samples:				
Angled (experimental group)	291	5	1.7	1.7 (0-4.0)
Beach seine (reference group)	63	0	0	
B. Excluding nondestructive physiological samples:				
Angled (experimental group)	281	5	1.8	1.8 (0-4.1)
Beach seine (reference group)	63	0	0	

For added comparison, adjusted mortality estimates and 95% confidence intervals associated with individual angling-related factors are presented in Appendix 4. These estimates include the 10 nondestructive physiologically sampled sockeye. Caution should be taken when assessing the mortality estimates associated with each individual angling related factor. High mortality rates and large confidence intervals for some variables result from small sample sizes for some factors that have many individual variables.

FACTORS INFLUENCING MORTALITY

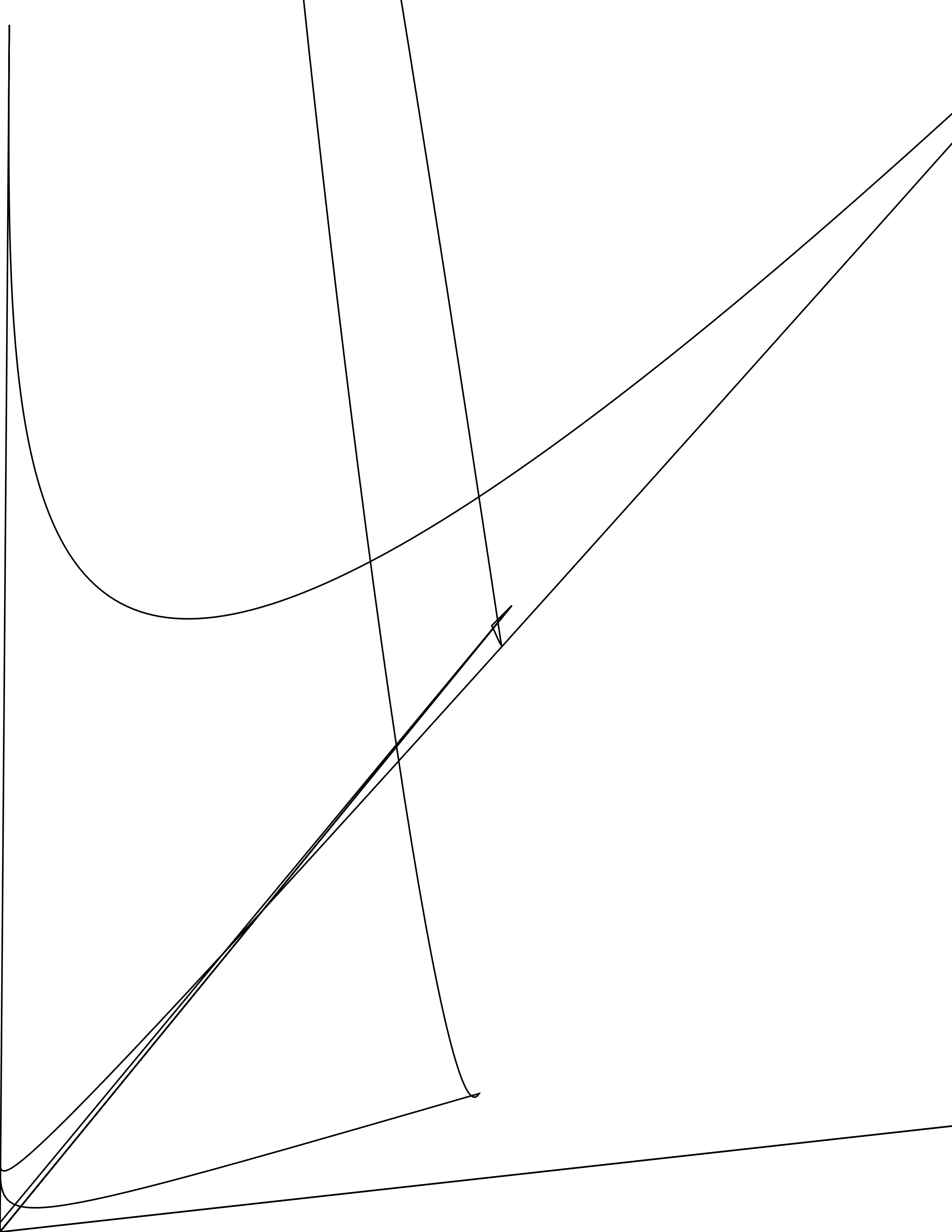
Angling-related factors, fish holding densities, and temporal and environmental factors were evaluated for significance on short-term (0 to 24 h) mortality ($P < 0.05$) using 2 by 2, or in some cases, 2 by 3 contingency tables. Factors influencing mortality were grouped into categories and assessed for the ultimate condition at release (alive or dead). Significance was evaluated using Pearson's chi-square. Due to relatively small sample sizes in some categories, Fisher's exact tests (sum of small p's) were also calculated as a comparative test of significance. Logistic regressions were performed in cases where mortalities were present in both independent variable categories. Odds ratios (OR) and relative risk ratios (RR) were calculated as a means of further assessing likelihood of mortality associated with each variable. 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. Visual observations and post-mortem assessment concluded that all five mortalities in this study were directly attributable to injuries from hooks that initially pierced through the left maxillary and further penetrated into the gill area. Necropsies indicated lacerations or tearing of gill arches and all had white gills indicating these fish most likely bled out and died relatively quickly after being hooked. Hooking in the maxillary bone was also the most frequently observed hooking location (75% of all hooking events). However, hooking in the maxillary bone that subsequently penetrated into the mouth or gills was rarely observed (less than 4% of maxillary bone hooking events).

Hooking in the outside of the body (particularly ventral snags near the pectoral fin) had a very significant influence on short-term (0 - 24 h) mortality in the preliminary 2008 study (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, there were no mortalities observed in sockeye hooked in these locations. Ventral surface hooking can be fatal due to piercing of vulnerable organs such as the heart or liver or severing of major blood vessels. In both years, the frequency of dorsal or ventral hooking in the outside of the body (including the head and eye) was observed to be very low (8.7% in 2008 and 5.8% in 2009).

Based on the small number of hooking locations associated with mortalities observed both in 2008 and 2009, and to further compare the results observed between the two 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, which compares those fish hooked in the maxillary bone versus all other outside the mouth or body hooking locations.



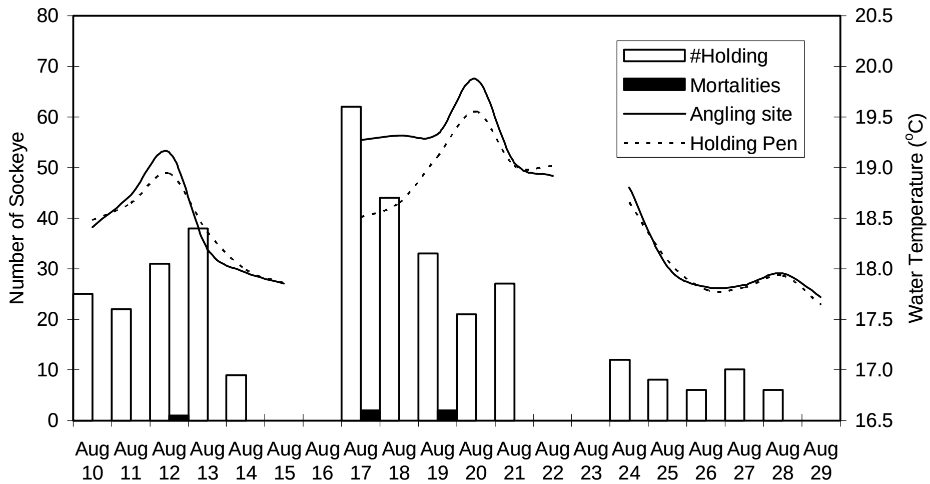


Figure 2. Daily number of fish held for 24 h observation in the net pens and observed mortalities (bars) compared to average daily water temperatures from in-situ data loggers located in-river near the angling site and the holding net pen (lines) at Grassy Bar in the Fraser River in 2009.

Temporal Factors

Hooking locations were also evaluated by study week to determine if there were any significant temporal biases in the observed hooking locations or to short-term (0 to 24 hr) mortalities. There were no significant biases found between weeks when comparing the number of sockeye hooked in the maxillary bone compared to all other hooking locations (Pearson's chi-square = 0.31, 2 d.f., P = 0.86) or when comparing the observed to expected number of short-term hooking mortalities by study week (Pearson's chi-square = 1.62, 2 d.f., P = 0.45).

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. The average daily water temperature in the river ranged from a high of 19.9 °C near the angling site during the second study week (20 August) to a low of 17.6 °C in the net pen on the last day of the study (29 August). In general, temperatures increased steadily from the start of the study to 20 August, then decreased steadily until the end of the study. Hourly water temperatures in the holding pen were not significantly different from those recorded in the river near the angling site during the first study week (t = 0.45, 129 d.f., P = 0.65), significantly different in the second week (t = 5.03, 130 d.f., P < 0.0001) and marginally different in the third study week (t = 1.53, 124 d.f., P = 0.01). Temperatures in the holding pen deviated anywhere from 2.7°C below to 0.4°C above water temperatures at the angling site (Appendix 5 - Figure 1). It is believed that the significant differences noted in water temperatures between the two sites during the second week is due to the partial exposure of the temperature gauge to the upper surface waters near the angling site during some low water periods. Daily average water temperatures between the two sites were consistently within 0.1^{o}C over the course of the study, therefore it is unlikely that the differences observed in water temperature between the two sites had a significant influence on short-term (0 - 24 h) mortality.

The five observed hooking mortalities occurred during average daily water temperatures of between 18.5^{o}C to 19.1^{o}C in the net pen. These temperatures were among the highest seen throughout the study period (only one other day was higher at 19.6^{o}C). Decreased swimming performance and early signs of physiological stress as well as slowed migration have been noted in Fraser River sockeye migrating in this freshwater temperature range (Fraser River Environmental Watch Report, August 16th, 2009, Lee et al. 2003). However, no significant difference was noted when comparing alive or dead sockeye after 24 hour holding when average daily water temperatures were below 18.5^{o}C or above or equal to 18.5^{o}C in the net pen (Pearson's chi-square = 1.38, 1 d.f., P = 0.24).

PHYSIOLOGY

Results of the physiological sampling component of this year's study were unavailable at the time of this report. However, summarized results of physiological sampling from 2008 are presented in Appendix 6 - Figure 1 (Michael R. Donaldson, pers. comm.). Plasma concentrations of various stress indicators in blood samples were analyzed by treatment group (immediately after capture by angling, immediately after capture in the beach seine, and from angled sockeye held 24 h in the net pen). Plasma cortisol and glucose levels were found to be significantly elevated (~ 4 fold and ~2 fold increase, respectively) in the angled sockeye after being held for 24 h in the net pen compared to those taken at time of capture either by angling or beach seine (cortisol: ANOVA, $F_{2,106}$=99.0, $P < 0.001$; Tukey-Kramer HSD test, $P<0.05$, and glucose: ANOVA, $F_{2,105}$=16.2, $P < 0.001$; Tukey-Kramer HSD test, $P<0.05$). Mean plasma lactate concentrations were slightly higher in the beach seine and net pen groups compared to the angling group, however these differences were not found to be significant (ANOVA, $F_{2,105}$=3.0, P = 0.051). Mean plasma sodium and chloride ions and osmolality concentrations were similar in both the capture groups (angling, beach seine) and were found to be significantly depressed in the angled sockeye that were held 24 h in the net pens (sodium: ANOVA, $F_{2,106}$=16.3, $P < 0.001$; Tukey-Kramer HSD test, $P<0.05$, chloride: ANOVA, $F_{2,105}$=37.3, $P < 0.001$; Tukey-Kramer HSD test, $P<0.05$, and osmolality: ANOVA, $F_{2,105}$=10.3, $P < 0.001$; Tukey-Kramer HSD test, $P<0.05$).

RADIO-TAGGING

Preliminary results of the fate of radio-tagged and released sockeye in 2009 for each of the treatment groups; angled and immediately released after tagging, beach seined and immediately released after tagging, and angled and held for 24 h in the net pen, then tagged and immediately released are presented in Appendix 6 - Tables 1 and 2. These summaries have not been adjusted to reflect unreported fisheries harvest or effects from tagging and handling. A total of 99 sockeye were radio-tagged and released; 36 from the angled group, 26 from those captured in the beach seine, and 37 from the angled group that were held 24 h in the net pens.

Estimated survival to the spawning grounds (last detection near the natal subwatershed) was highest in sockeye that were tagged and immediately released after capture in the beach seine (52.2%), followed by sockeye that were tagged and immediately released after hooking (angled) (36.3%). Survival of sockeye that were angled and held 24 h in the net pen, then tagged and released was 2.9% (Appendix 6 - Table 1).

The number of individuals and their final detection location is presented in Appendix 6 - Table 2. Although last detections may not be an ultimate measure of survival success to the spawning grounds, it is interesting to note that almost half (45%) of the radio-tagged sockeye from all treatment groups combined, survived migration distances at least to Qualark, approximately 66 km upstream and some individuals (6) even survived to be last detected as far north as the confluence of the Nechako and Stuart Rivers, a distance of over 800 km from the study site.

DISCUSSION

Abundances of sockeye in the Fraser River were anticipated to be high in 2009. Preseason run size estimates forecasted approximately 9.9 – 10.5 million returning sockeye (75% probability level for Early Stuart and 50% probability levels for Early Summer-run, Summer-run, Birkenhead and True Late-run). However, actual inseason estimates only totalled approximately 1.31 million sockeye escaping past the Mission bridge (Pacific Salmon Commission, September 11, 2009, News Release No. 10) (Appendix 8 – Figure 1). Despite the lower than expected returns of Fraser sockeye in 2009, abundances and the total number of hooked sockeye that were observed were higher in 2009 (328 hooked and landed sockeye) compared to 2008 (178 hooked sockeye). Migration timing of sockeye through the study area in 2008 was approximately one week earlier than forecasted and estimated abundances were considerably lower during the 2nd and 3rd week of the study (estimated 87,400 sockeye - J. O. Thomas and Associates 2009) when compared to the same time period in 2009. Estimated abundance in 2009 for week 2 and 3 was 245,400 sockeye (Appendix 8 – Table 1).

Under the conditions for this year's study, short-term (0 to 24 h) mortality estimates of hooked sockeye was low (1.7% mortality with a 95% confidence interval of zero to 4.0%). This was slightly higher than the 1.2% mortality rate seen in 2008, however the 95% confidence interval was virtually identical (zero to 4.1%).

Similar to results seen in 2008, the data collected in this year's study also showed that the majority of sockeye caught by anglers were hooked in or near the maxillary bone with little to no bleeding. However, unlike the results in 2008 where sockeye that were snagged in the body were associated with the only observed mortalities, the five mortalities observed in 2009 were all hooked initially in the maxillary bone. Further 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 2009. In fact, of all the angling-related factors assessed, only bleeding at time of capture came close to being a significant factor.

Physiological samples collected concurrently during this study in 2008 and 2009 provide 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 suggest 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.

Preliminary results from the radio tagged sockeye also suggest that sockeye released immediately after capture either by hooking or by beach seine may have better longer-term survival rates than those that were hooked and held for 24 h after capture. It is important to note however, that the results of the radio tagging are preliminary and require more detailed analysis, discussion and reporting. Aside from the effects of capture and holding witnessed in our study, there are many additional and often unknown factors that can affect the fate of or loss of radio tag signal from individual radio-tagged sockeye after their release and during their subsequent freshwater migration. These factors are often difficult or impossible to isolate and measure and may confound or compound the effects associated with the capture, handling and holding experienced by individual sockeye in our study. Factors that may affect survival or tracking of radio-tagged sockeye after release include such things as tag regurgitation/expulsion, tag malfunction (failure/battery discharge), unreported fishing harvest, stress or injury associated with the handling during radio-tag implantation, and a myriad of other manmade (river blockages, pollution) or natural (elevated water temperatures and other environmental stressors, animal predation) causes encountered during migration.

RECOMMENDATIONS AND LIMITATIONS

For this study, we assumed that the effects of handling, transport and holding worked independently 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 reference group both in 2008 and 2009, our assumptions appear 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. Their model 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 (or control) 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 properly 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 was less than anticipated in 2009, it is important to note that the beach seine method continued to be a practical method for capturing a reference group of sockeye with minimal harm.

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. The similarity in predominant hooking locations observed in 2008 and 2009 coupled with low mortality rates suggests that angling techniques were similar between years. Comparisons with preliminary creel survey estimates from DFO also suggest that mean angler catch success was similar (slightly higher in our study) for a similar time period but throughout a greater study area (Mission to Hope).

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 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 (scale or slime loss, abrasions). Ultimately, this could lead to reduced spawner success (percent spawn), 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 data 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 regarding predator wounds. Twenty-seven hooked sockeye exhibited minor wounds and three exhibited major wounds. None of these fish died during the study and therefore the presence or absence of predator wounds was not found to have a significant influence on short-term mortality. Despite this, assessment of this data may be important in the overall assessment of mortality and it is recommended that it be collected and analyzed in future studies.

We also collected data regarding casting weights used by anglers in this year's study. Similar to most angling-related factors, no significant influence was noted for this variable on short-term (0 - 24 h) hooking mortality. Despite this, casting weight is believed to be an integral factor associated with the behaviour of the angling gear and may have a measurable effect on hooking success. It is therefore of interest to continue collection and analysis of this data.

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 dimorphism 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) and it may not be universally representative of all bars or fishing sites on the Fraser River. 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. 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 study also was conducted in a year when no other targeted angler effort was conducted on sockeye throughout the Fraser River. As a result, individual sockeye likely had few, if any, multiple captures by recreational anglers. In years when sockeye retention is permitted and angler effort is considerably greater, multiple captures might be more common, particularly at bars further upstream from our study location. In fact, our study location is the closest freshwater location available to anglers during the upstream migration of Fraser River sockeye. Therefore, the results at Grassy Bar may not be 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, we recommend conducting this study over a full four-year cycle period. Timing of the study should be 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) mortality rates for 2008 and 2009 were similar. However, these results were conducted during periods of relatively low sockeye abundance when environmental conditions were considered favourable and therefore may not necessarily be representative of mortality rates witnessed in a year when abundances are higher or in-river migratory conditions are considered poor. Angler-related variables may also have significantly different influences on mortality in relation to annual changes in 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 (primarily pinks). Initial plans for the 2009 study were to include collection of biological and tissue samples from chinook for DNA stock analysis. However, the large numbers of pink salmon that were caught in 2009 required increased handling time and ultimately precluded additional DNA sampling.

The physiological sampling and results from radio-tagging of individual sockeye may shed additional light on the fate of sockeye encountered in bottom bounce fisheries. However, care should be taken when interpreting the results presented in this report. Individual sockeye are exposed to many other factors during their freshwater migration that may affect their fate in addition to the capture, 24 h holding, and release experienced in a study like ours. The summaries presented here are preliminary. A more complete analysis and discussion of the physiological and radio-tagging data is pending.

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http://www.quantitativeskills.com/sisa/statistics/twoby2.htm
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APPENDICES

Appendix 1 - Study location maps.

Appendix 2 - Data forms.

Appendix 3 - Catch summaries.

Appendix 4 - Adjusted mortality rate estimates by hooking location and individual angling-related factor.

Appendix 5 - Water temperature profiles.

Appendix 6 - Physiology and radio-tagging summaries.

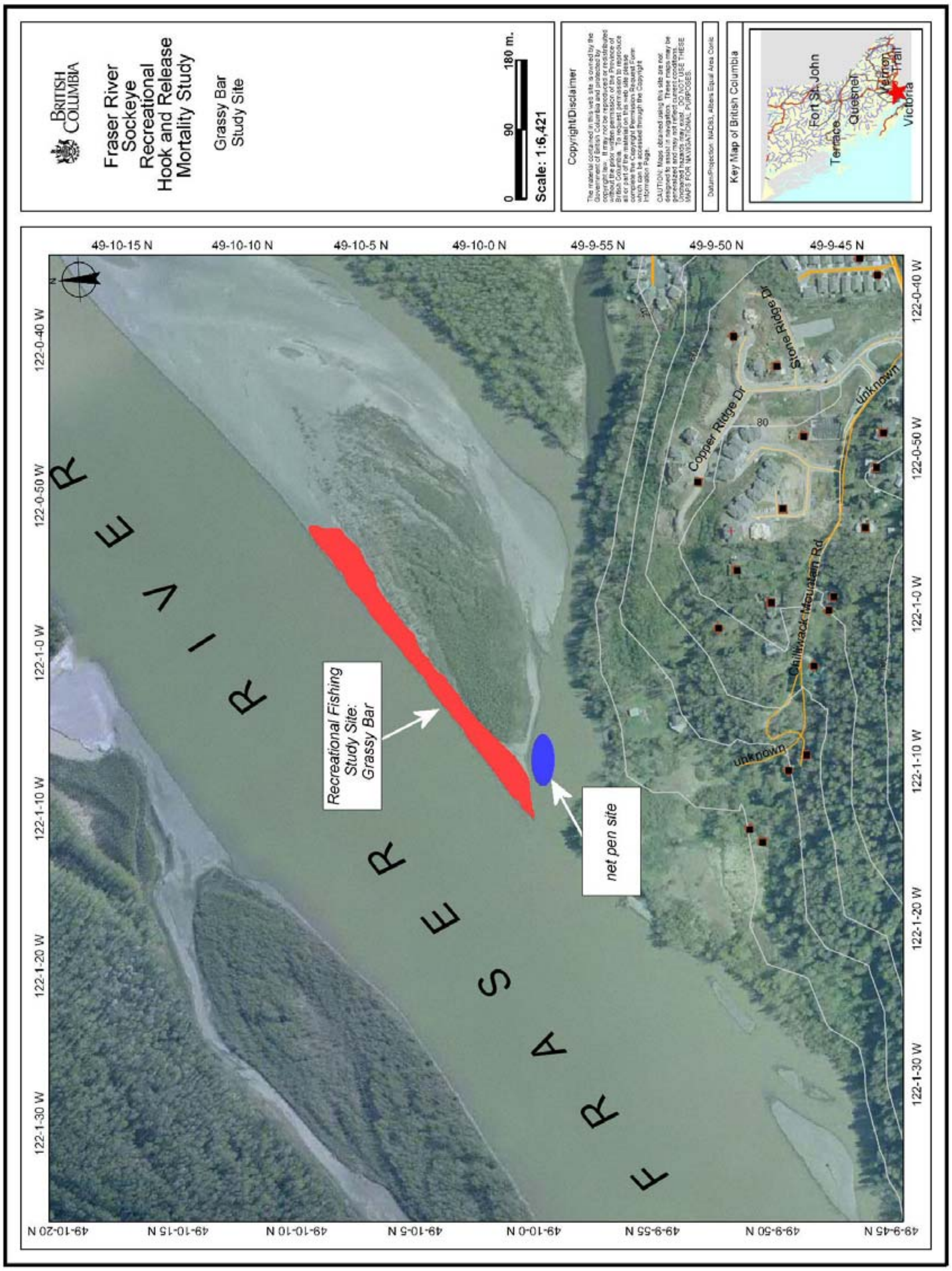
Appendix 7 - Study photos.

Appendix 8 - Fraser River sockeye escapement and abundance estimates.

Appendix 9 - 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 and alternate net pen site at Calamity Bar. 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			

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 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:

Appendix 2 - Figure 5. Necropsy Form.

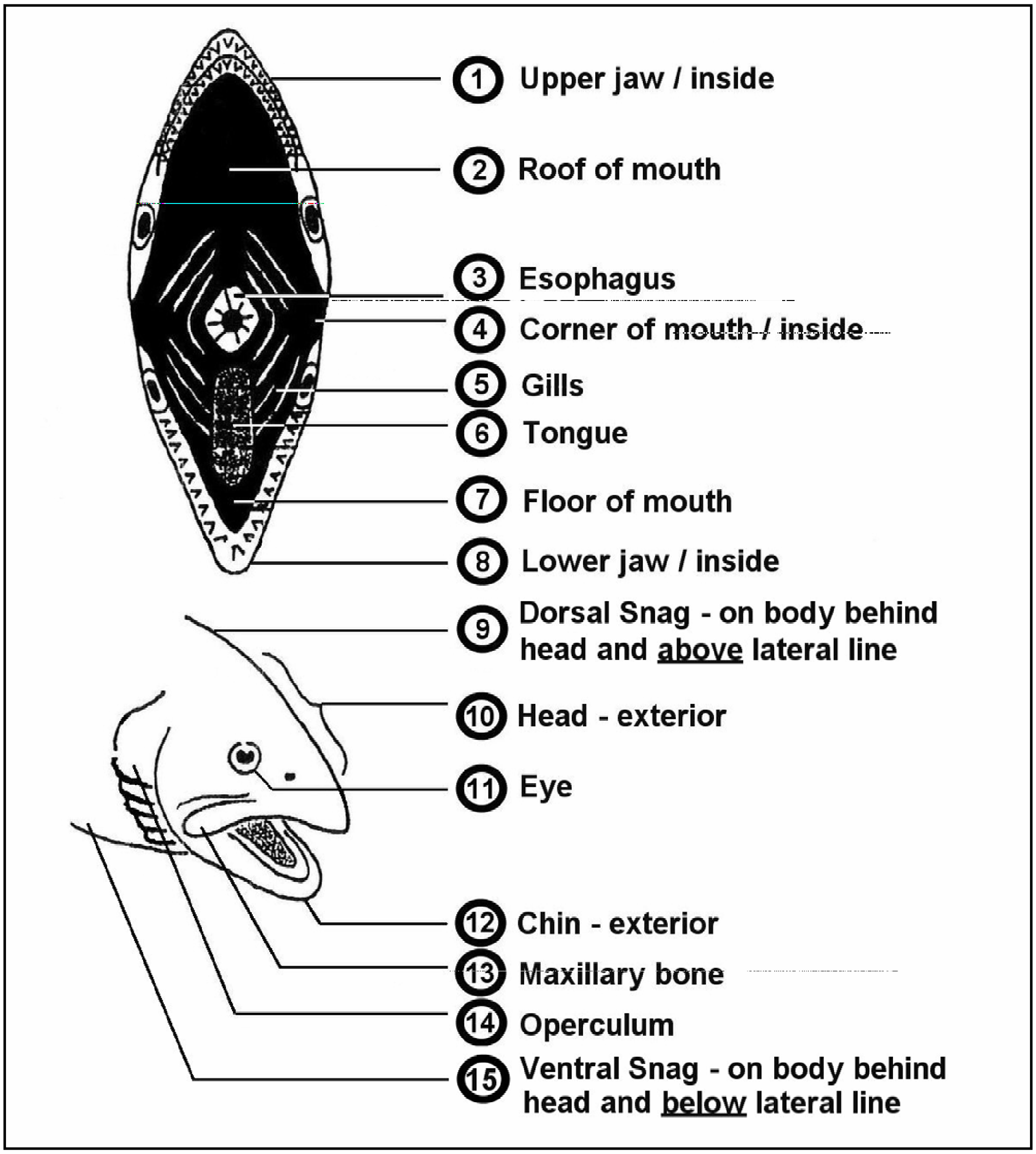
Fraser River Sockeye Recreational Hook & Release Mortality Study

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%

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, 2009.

Date	Average number of anglers	Number of sockeye landed	Angler effort (angler·hrs)	Mean Catch per angler·hr
10-Aug	11	25	76	0.33
11-Aug	8	26	53	0.49
12-Aug	14	31	101	0.31
13-Aug	12	17	85	0.20
14-Aug	21	13	123	0.11
Week 1	**13**	**112**	**438**	**0.26**
17-Aug	26	62	185	0.34
18-Aug	17	26	120	0.22
19-Aug	18	33	129	0.26
20-Aug	18	16	129	0.12
21-Aug	23	27	164	0.16
Week 2	**21**	**164**	**727**	**0.23**
24-Aug	17	18	120	0.15
25-Aug	13	11	92	0.12
26-Aug	15	10	106	0.09
27-Aug	16	4	97	0.04
28-Aug	19	9	136	0.07
Week 3	**16**	**52**	**551**	**0.09**
Total	**17**	**328**	**1716**	**0.19**

a. Number of landings include 37 sockeye radio tagged and released immediately and 10 sockeye that were sampled nondestructively for physiology.

Appendix 3 - Table 2. Beach seine (reference group) catch summary by date, study week and species at Grassy Bar, Fraser River, 2009.

						Released						
Date	Number of sets	Kept Sockeye	Sockeye (Destruct-Physio)	Sockeye (Radio-tag)	Sockeye (Other)	Coho	Chinook Adult	Chinook Jack	Pink	Chum	Sturgeon	Other[a]
13-Aug	5	25	9	8	0	0	7	14	23	0	1	5
Week 1	**5**	**25**	**9**	**8**	**0**	**0**	**7**	**14**	**23**	**0**	**1**	**5**
18-Aug	6	23	9	12	1	0	24	39	247	0	3	1
20-Aug	4	9	0	3	4	0	9	13	174	0	0	1
Week 2	**10**	**32**	**9**	**15**	**5**	**0**	**33**	**52**	**421**	**0**	**3**	**2**
27-Aug[b]	7	6	0	3	1	2	8	46	551	0	1	3
Week 3	**7**	**6**	**0**	**3**	**1**	**2**	**8**	**46**	**551**	**0**	**1**	**3**
Total	**22**	**63**	**18**	**26**	**6**	**2**	**48**	**112**	**995**	**0**	**5**	**10**

a. All other fish caught were suckers.
b. Three additional chinook jack and 9 pink were removed for destructive physiological samples.

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 2009, 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 specific hooking location. 95% confidence intervals (95% CI) are provided.

		Release condition						
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	2	0	0	2	0	0.7	0
	Roof of mouth	4	0	0	4	0	1.4	0
	Esophagus	0	0	0	0	--	0	0
	Corner of mouth	5	0	0	5	0	1.7	0
	Gills	3	0	0	3	0	1.0	0
	Tongue	1	0	0	1	--	0.3	0
	Floor of mouth	13	0	0	13	0	4.5	0
	Lower jaw	2	0	0	2	0	0.7	0
	Other	0	0	0	0	--	0	0
Inside mouth total		30	0	0	30	0	10.3	0
Maxillary bone total		210	3	5	218	2.3	74.9	2.3 (0-5.3)
Other outside mouth	Dorsal snag	4	0	0	4	0	1.4	0
	Head	1	0	0	1	0	0.3	0
	Eye	2	0	0	2	0	0.7	0
	Chin	19	2	0	21	0	7.2	0
	Operculum	2	0	0	2	--	0.7	0
	Ventral snag	10	1	0	11	0	3.8	0
	Other	2	0	0	2	0	0.7	0
Other outside mouth total		40	3	0	43	0	14.8	0
Grand total		280	6	5	291	1.7	100.0	1.7 (0-4.0)

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 2009, 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						
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	1	0	0	1	0	0.3	0
	12	13	0	0	13	0	4.5	0
	14	4	0	0	4	0	1.4	0
	15	5	0	0	5	0	1.7	0
	16	2	0	0	2	0	0.7	0
	18	1	0	0	1	0	0.3	0
	20	4	0	0	4	0	1.4	0
Inside mouth total		30	0	0	30	0	10.3	0
Maxillary bone	5	1	0	0	1	0	0.3	0
	7	1	1	0	2	0	0.7	0
	8	2	0	0	2	0	0.7	0
	9	1	0	0	1	0	0.3	0
	10	13	0	2	15	13.3	5.2	13.3 (2.1-37.9)
	11	1	0	0	1	0	0.3	0
	12	114	2	2	118	1.7	40.5	1.7 (0-6.0)
	13	2	0	0	2	0	0.7	0
	14	17	0	0	17	0	5.8	0
	15	9	0	0	9	0	3.1	0
	16	4	0	0	4	0	1.4	0
	17	5	0	0	5	0	1.7	0
	18	3	0	0	3	0	1.0	0
	20	33	0	1	34	2.9	11.7	2.9 (0-14.9)
	unknown	4	0	0	4	0	1.4	0
Maxillary bone total		210	3	5	218	2.3	74.9	2.3 (0-5.3)
Other outside mouth	10	3	0	0	3	0	1.0	0
	11	1	0	0	1	0	0.3	0
	12	21	0	0	21	0	7.2	0
	14	1	0	0	1	0	0.3	0
	15	6	0	0	6	0	2.1	0
	16	1	0	0	1	0	0.3	0
	18	1	1	0	2	0	0.7	0
	20	5	2	0	7	0	2.4	0
	25	1	0	0	1	0	0.3	0
Other outside mouth total		40	3	0	43	0	14.8	0
Grand total		280	6	5	291	1.7	100.0	1.7 (0-4.0)

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 2009, 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						
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	1	0	0	1	0	0.3	0
	2/0	10	0	0	10	0	3.4	0
	3/0	18	0	0	18	0	6.2	0
	4/0	1	0	0	1	0	0.3	0
Inside mouth total		30	0	0	30	0	10.3	0
Maxillary bone	1	1	0	0	1	0	0.3	0
	2/0	86	2	3	91	3.3	31.3	3.3 (0-9.2)
	3/0	106	1	2	109	1.8	37.5	1.8 (0-6.4)
	4/0	12	0	0	12	0	4.1	0
	5/0	5	0	0	5	0	1.7	0
Maxillary bone total		210	3	5	218	2.3	74.9	2.3 (0-5.3)
Other outside mouth	2/0	16	0	0	16	0	5.5	0
	3/0	22	3	0	25	0	8.6	0
	4/0	1	0	0	1	0	0.3	0
	5/0	1	0	0	1	0	0.3	0
Other outside mouth total		40	3	0	43	0	14.8	0
Grand total		280	6	5	291	1.7	100.0	1.7 (0-4.0)

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 2009, 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						
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	18	0	0	18	0	6.2	0
	Light	10	0	0	10	0	3.4	0
	Moderate	2	0	0	2	0	0.7	0
Inside mouth total		30	0	0	30	0	10.3	0
Maxillary bone	None	168	2	2	172	1.2	59.1	1.2 (0-4.1)
	Light	37	1	2	40	5.0	13.7	5.0 (0-16.5)
	Moderate	5	0	1	6	16.7	2.1	16.7 (1.8-56.4)
Maxillary bone total		210	3	5	218	2.3	74.9	2.3 (0-5.3)
Other outside mouth	None	26	2	0	28	0	9.6	0
	Light	13	1	0	14	0	4.8	0
	Moderate	1	0	0	1	0	0.3	0
Other outside mouth total		40	3	0	43	0	14.8	0
Grand total		280	6	5	291	1.7	100.0	1.7 (0-4.0)

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 2009, 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						
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	1.5	6	0	0	6	0	2.1	0
	2	12	0	0	12	0	4.1	0
	2.5	3	0	0	3	0	1.0	0
	3	8	0	0	8	0	2.7	0
	unknown	1	0	0	1	0	0.3	0
Inside mouth total		30	0	0	30	0	10.3	0
Maxillary bone	1.5	21	0	0	21	0	7.2	0
	2	62	1	2	65	3.1	22.3	3.1 (0-10.5)
	2.5	26	0	0	26	0	8.9	0
	3	84	2	3	89	3.4	30.6	3.4 (0-9.4)
	4	11	0	0	11	0	3.8	0
	unknown	6	0	0	6	0	2.1	0
Maxillary bone total		210	3	5	218	2.3	74.9	2.3 (0-5.3)
Other outside mouth	1.5	7	0	0	7	0	2.4	0
	2	7	3	0	10	0	3.4	0
	2.5	5	0	0	5	0	1.7	0
	3	17	0	0	17	0	5.8	0
	4	2	0	0	2	0	0.7	0
	unknown	2	0	0	2	0	0.7	0
Other outside mouth total		40	3	0	43	0	14.8	0
Grand total		280	6	5	291	1.7	100.0	1.7 (0-4.0)

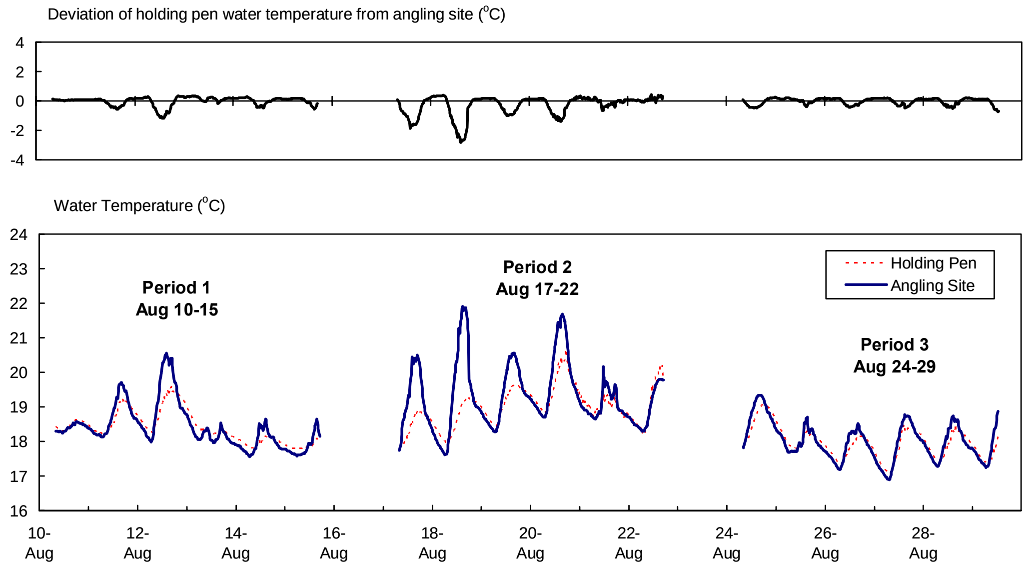
Appendix 4 - Table 7. Adjusted estimates of short-term (0 to 24 h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River in 2009, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24 h holding 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	31	0	1	32	3.1	11.0	3.1 (0-15.7)
No	249	6	4	259	1.5	89.0	1.5 (0-3.9)
Grand total	280	6	5	291	1.7	100.0	1.7 (0-4.0)

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 2009, 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	252	4	5	261	1.9	89.7	1.9 (0-4.4)
Minor	25	2	0	27	0	9.3	0
Major	3	0	0	3	0	1.0	0
Grand total	280	6	5	291	1.7	100.0	1.7 (0-4.0)

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



Appendix 6 - Table 1. Survival[a] of sockeye salmon captured by beach seine or angling and released immediately or fish that were captured by angling and held in a net pen to recover for 24 h. Preliminary summary from Michael R. Donaldson.

Capture method	Survived[b] > 24 h	Survived[b] > 48 h	Survived[b] > 96 h	Reached natal subwatershed[c]
Beach seine (immediate release)	21 of 22 (95.5 %)	20 of 22 (90.9 %)	16 of 22 (72.7 %)	12 of 23 (52.2 %)
Angling (immediate release)	31 of 32 (96.9 %)	25 of 32 (78.1 %)	19 of 32 (59.4 %)	12 of 33 (36.3 %)
Angling (net pen for 24 h)	29 of 36 (80.6 %)	22 of 36 (61.1 %)	12 of 36 (33.3 %)	1 of 35 (2.9 %)

a. Total numbers have not been adjusted to reflect unreported fisheries harvest or tagging and handling effects.

b. Note that this value may under-represent true survival time as it only reflects the duration from release to when an individual was detected at its last receiver site and does not account for travel between receivers.

c. Total number of tagged and released fish exclude individuals for which stock identification has not yet been confirmed by DNA analysis. Survival to reach natal subwatersheds represents only individuals that were detected by fixed station receivers at terminal areas.

Appendix 6 - Table 2. Final receiver detection location[a,b] of individuals from each treatment group (based on fixed station and mobile tracking). Preliminary summary from Michael R. Donaldson.

Last Detection Location	Angling	Beach seine	Angled held 24h in net pen
Release Site	1	0	3
Crescent Island	0	0	3
Mission	0	1	1
Mission to Harrison	1	2	1
Harrison confluence	0	1	0
Harrison River/Weaver Creek	5	3	7
Rosedale	2	1	4
Rosedale to Hope	4	1	4
Hope	1	0	5
Qualark	2	1	4
Sawmill	1	0	0
Hell's Gate	1	1	1
Thompson confluence	1	0	3
Spence's Bridge	3	0	0
Seton confluence	5	3	0
Chilcotin confluence	2	2	0
Chilko	0	1	0
Quesnel confluence	2	1	0
Quesnel - Likely	3	1	1
Nechako - Stuart confluence	1	5	0
Fisheries capture	2	1	0

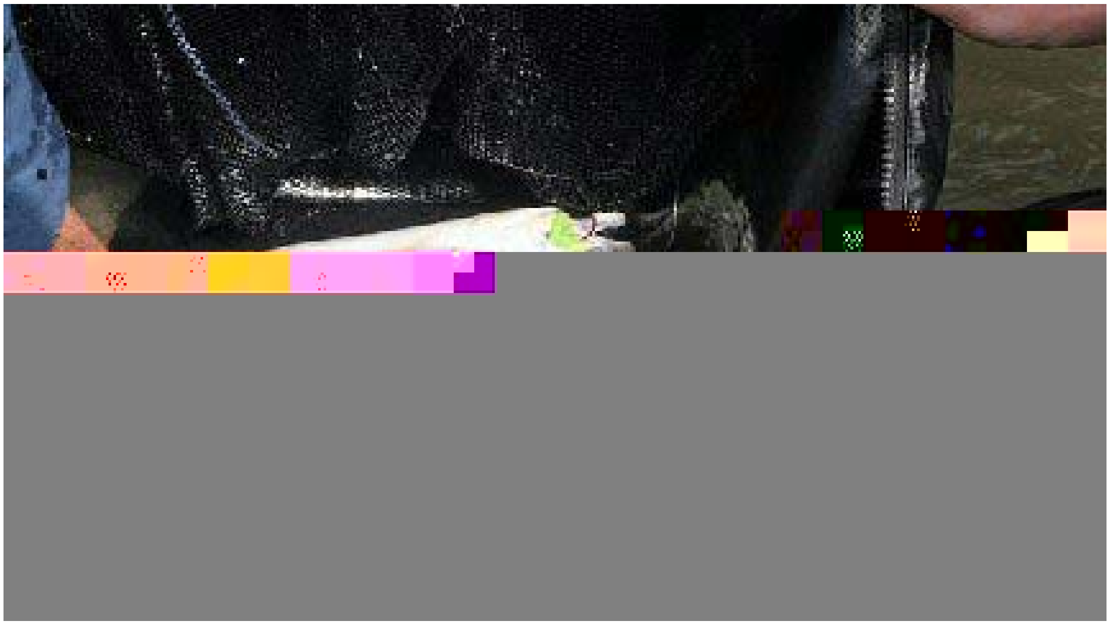
a. Total number of tagged and released fish exclude individuals for which stock identification has not yet been confirmed by DNA analysis.

b. Total numbers have not been adjusted to reflect unreported fisheries harvest or tagging and handling effects.

Appendix 7 - Figure 1. Volunteer anglers fishing with bottom bounce gear at Grassy Bar, Fraser River (photograph: Cathy Ball).

Appendix 7 - Figure 2. Typical bottom bounce gear (photograph:Cathy Ball).

Appendix 7 - Figure 3. Typical hooking location (left maxillary) observed in the recreational sockeye bottom bounce fishery at Grassy Bar, Fraser River (photograph: Bill Otway).



Appendix 7 - Figure 4. Holding pens and predator net configuration in the side channel situated at the southern (downstream) end of Grassy Bar, Fraser River (photograph: Jim Thomas).

Appendix 7 - Figure 5. Release of a live, vigorous sockeye after the 24 h holding period (photograph: Cathy Ball).

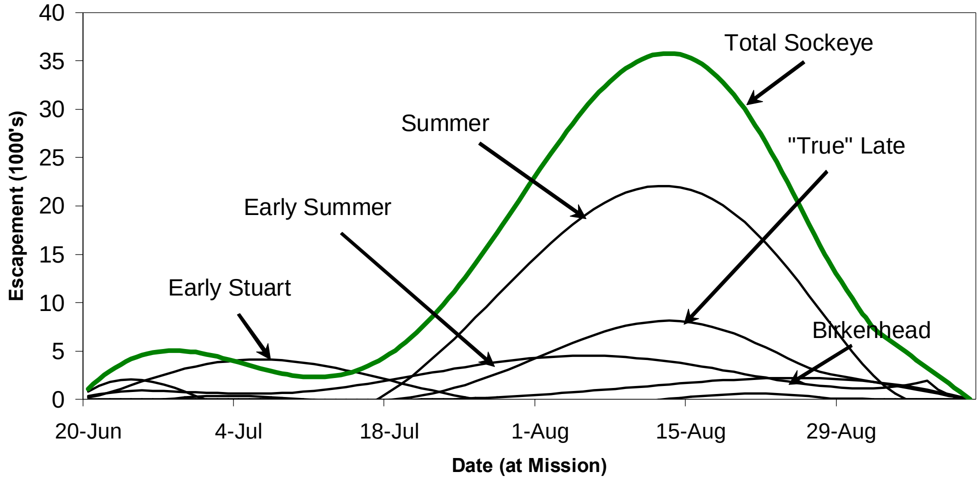
Appendix 7 - Figure 6. Beach seining for reference group fish (photograph: Cathy Ball).

Appendix 7 - Figure 7. Nondestructive physiological sampling of a hooked and landed sockeye (photograph: Cathy Ball).

Appendix 7 - Figure 8. Insertion of a micro-coded radio tag into the stomach of a captured sockeye. (photograph: Jim Thomas).

Appendix 7 - Figure 9. Mobile tracking of a radio-tagged and released sockeye (photograph: Jim Thomas).

Appendix 8 - Figure 1. Fraser River sockeye timing and daily escapement estimates (smoothed) past Mission, British Columbia, by major stock group (June 20 to September 10, 2009).



Source: Pacific Salmon Commission

Appendix 8 - 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 8 to August 26, 2009. (Source: Pacific Salmon Commission, September 11, 2009). 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
8-Aug	10-Aug	410	7,837	43,507	1,604	10,873	64,230	25	0.04%
9-Aug	11-Aug	281	5,235	29,872	1,101	7,466	43,955	26	0.06%
10-Aug	12-Aug	105	3,566	19,150	622	9,224	32,668	31	0.09%
11-Aug	13-Aug	0	4,025	19,719	520	15,913	40,178	17	0.04%
12-Aug	14-Aug	0	3,697	18,875	498	15,232	38,302	13	0.03%
Study Week 1		**796**	**24,361**	**131,122**	**4,345**	**58,708**	**219,333**	**112**	**0.05%**
15-Aug	17-Aug	0	982	21,138	1,664	6,125	29,909	62	0.21%
16-Aug	18-Aug	0	1,299	27,976	2,202	8,106	39,584	26	0.07%
17-Aug	19-Aug	4	4,689	22,130	4,147	9,884	40,854	33	0.08%
18-Aug	20-Aug	4	5,569	26,098	4,891	11,657	48,218	16	0.03%
19-Aug	21-Aug	0	1,894	7,521	1,333	8,727	19,474	27	0.14%
Study Week 2		**8**	**14,432**	**104,863**	**14,237**	**44,499**	**178,039**	**164**	**0.09%**
22-Aug	24-Aug	0	1,985	11,973	1,249	3,638	18,846	18	0.10%
23-Aug	25-Aug	0	1,404	9,277	968	2,819	14,466	11	0.08%
24-Aug	26-Aug	0	492	6,848	1,272	4,432	13,044	10	0.08%
25-Aug	27-Aug	0	415	5,591	1,038	3,619	10,663	4	0.04%
26-Aug	28-Aug	0	363	5,465	1,015	3,537	10,380	9	0.09%
Study Week 3		**0**	**4,658**	**39,154**	**5,542**	**18,045**	**67,399**	**52**	**0.08%**

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

Appendix 9 - 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 score test 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

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

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

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

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

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