Lower Fraser River Sockeye Recreational Hook and Release Mortality Study

Preliminary Investigations into Short-term Hooking Mortality of Sockeye Caught and Released at Grassy Bar, Fraser River, British Columbia, 2008

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

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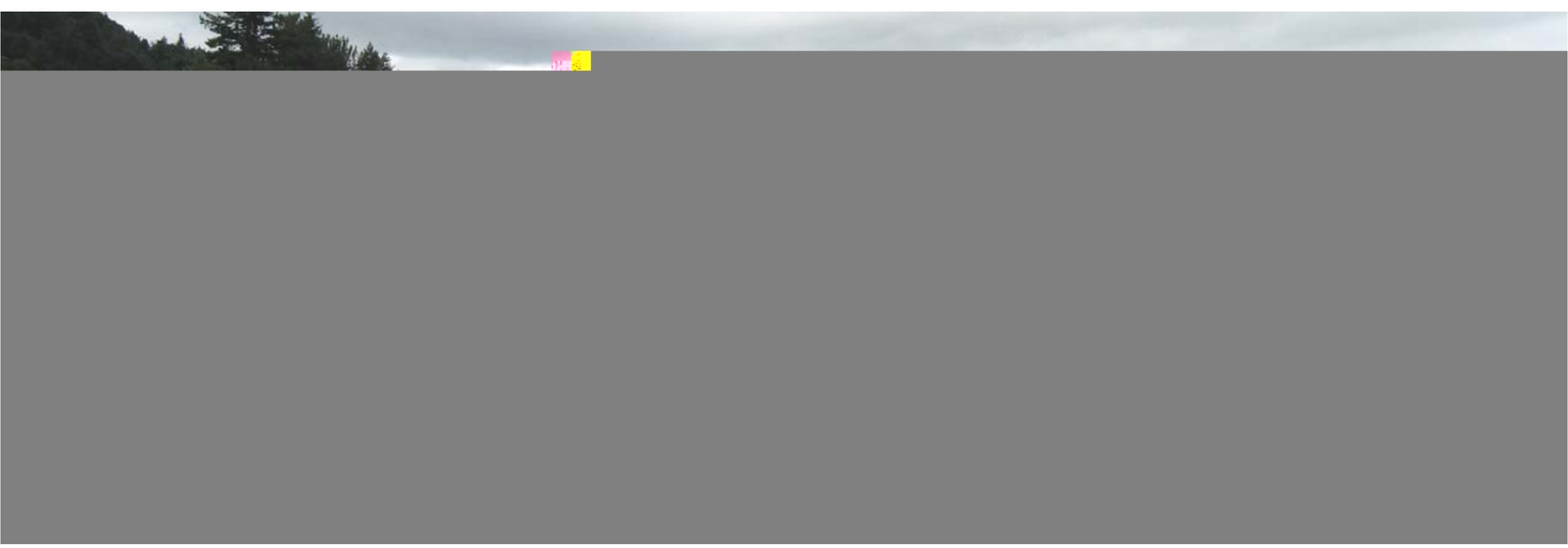
February 2009



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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*) and sockeye (*O. nerka*) are migrating upstream. In particular, the greatest fishing effort occurs during periods when sockeye retention is permitted. Sockeye retention periods vary inter-annually and range from under one week to several weeks, depending on sockeye abundance and co-migrating stocks of concern. Bottom bouncing is the predominant angling technique for sockeye in the Fraser River. To date, no data has been collected or analyzed to quantify catch-and-release (CR) mortality rates for this fishery.

The purpose of this pilot year study was to quantify short-term (24-h) mortality rates of sockeye salmon in specific angling locations, environmental conditions and sockeye stock assemblages encountered in 2008. A preliminary investigation of angling-related variables and their influence on mortality was also conducted.

The study was conducted using volunteer anglers over 15 days between August 5 and September 2, 2008 at Grassy Bar in the Fraser River. In total, the study collected and analyzed data from 173 hooked and landed sockeye and 103 sockeye captured by beach seine as a reference ("control") group. All sockeye were 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 or body (88% of all landed sockeye). Of this group, most were specifically hooked in the left maxillary bone (75%). Some fish exhibited bleeding at the time of capture (18%). However, all the fish that were released alive after 24-h showed no signs of bleeding and all but two fish 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 total mortality rate observed in the hooked group of sockeye and the mortality rate observed in the reference group. Only two mortalities were witnessed in the study and catch-and-release mortality was estimated to be 1.2% (95% confidence interval of 0%-4.1%). The two fish that died were hooked in the dorsal and ventral surface of the body posterior to the head, respectively. No mortalities were observed in the reference group.

Despite the low mortality estimates, it should be noted that this study was conducted at a single fishing location where abundances of sockeye were low, sample sizes were small, and in-river environmental conditions were relatively favourable for adult sockeye migration. Issues surrounding longer-term mortality or ultimate survivability of the hooked or reference fish to the successful completion of spawning were not addressed in this study. Additional studies may be required to further investigate angling-related variables, and any long-term or cumulative effects of catch-and-release on mortality.

It is also recommended that this study be conducted over the full 4-year Fraser sockeye cycle to help determine if there are inter-annual variations in short-term mortality under differing stock compositions and abundances.

1.0 INTRODUCTION

The non-tidal portion of the Lower Fraser River (from Chilliwack to Hope, B.C.) supports a substantial recreational fishery during the summer when chinook (*Oncorhynchus tschawytscha*) and sockeye (*O. nerka*) are migrating upstream (Mahoney 2005, 2006, 2007). In particular, the greatest fishing effort occurs during periods when sockeye retention is permitted. Sockeye retention periods vary inter-annually and range from under one week to several weeks, depending on sockeye abundance.

Harvest opportunities are dependent upon in-season abundance determined through test fisheries. If abundance permits, the regulations have generally allowed the daily harvest of two (2) sockeye. While the sockeye recreational fishery is traditionally a "catch-and-keep" (CK) fishery, the "catch-and-release" (CR) of fish is common for anglers that have either reached their daily limit or choose to release undersized fish, fish that are beginning to display secondary sexual characteristics, or non-target species (Kristianson and Strongitharm 2006). Substantive numbers of sockeye can be released in this fishery. Between 2004 and 2006, DFO creel surveys estimated the harvest of over 227,000 sockeye but also the release of over 102,000 sockeye (this includes sockeye hooked during directed chinook fisheries) (Mahoney 2005, 2006, 2007).

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 ("flosses") through the mouth or across the body of resting or swimming salmon causing the line to stop or hesitate. The angler reacts to this interruption in the line drift by abruptly dragging back on the line causing the hook to embed primarily into the outside of the salmon's jaw (maxillary bone), mouth, or head. Other hooking locations have also been noted, to a lesser extent, using this method. Bottom bouncing is successful for angling sockeye because they do not readily bite on lures or bait. Often, other salmon species such as chinook and coho, are also caught using this method.

A secondary method of fishing for sockeye, called bar fishing, uses a weight system that stabilizes a lure (spin and glow) close to the river bottom. The river current activates the lure and salmon willingly strike at the lure. This technique focuses primarily on catching chinook given they do actively bite on lures (unlike sockeye), but other species including sockeye, can be caught incidentally. Salmon that strike bar fishing lures are primarily hooked on the inside of the mouth.

Capture by recreational fisheries gear can result in a number of consequences on 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. While there has been speculation that the location and degree of the hooking injuries originating from bottom bouncing results in low mortality rates, this issue has not been quantified.

The main objective of this preliminary study was to estimate short-term (24-h) sockeye mortality representative of recreational catch and release practices incorporating typical bottom bounce fishing gear and techniques that commonly occur in the Fraser River mainstem bar fisheries from August to September. A secondary objective was to assess the influence of selected angling-related variables on hooking mortality rates. This would include as the response (dependent) variable, dead or alive at the end of the 24-hour holding period, and various predictor (independent) variables such as; hooking location, presence of bleeding, angler playing time, leader length, hook size, beaching, and scale loss.

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 in this year's study. Mortality rates are short-term (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.

2.0 METHODS

2.1 Study Area

The site chosen for this study was at Grassy Bar (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 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 close to shore. Our study focused on sockeye salmon caught by anglers using bottom bounce gear only and fishing either from shore or from boats near shore and situated in water less than 1m deep and with relatively slow river current (< 1.0m/s).

2.2 Determination of Sample Size

An a priori analysis was conducted to determine adequate sample sizes needed to provide 95% confidence limits around mortality rates (assuming a worst case scenario proportion of p = 0.5 (widest variance)) for the CR mortality and several margins of error (d=0.08 to 0.03). Figure 1 illustrates the results of determination of sample size *(n)* for each margin of error *(d)* at a 95% confidence interval (where z = 1.96) using the following formula (Fleiss 1981, Gerstman 2003):

$$n = \frac{z^2 p(1-p)}{d^2}$$

The analysis suggests that a minimum sample size of 150 fish (angled or reference group) would be sufficient to achieve a margin of error of 0.08 around the mortality estimate, 95% of the time. Sample sizes of approximately 400 fish were set as individual goals for the reference group and the CR sample to provide more precise margins of error in the range of 0.05. These goals were highly dependent on fish abundance and catch success.

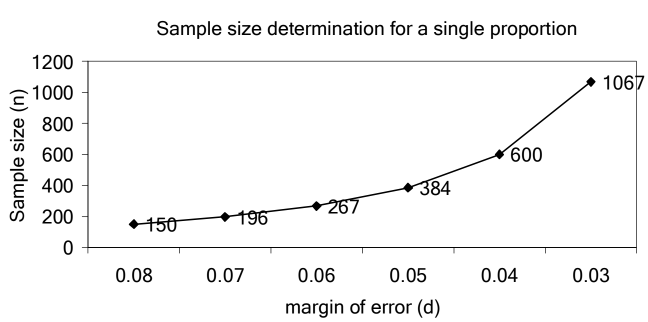

Figure 1. A priori determination of sample size *(n)* needed for estimating a single proportion (mortality rate) and provide a 95% confidence interval with varying margins of error *(d).*

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 data and handle released sockeye. 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.

Holding and Release

Sockeye were held for 24-h observation in holding pens comprised of a floating square frame (4m x 4m) with an attached net of similar length-width dimensions and a maximum hanging depth of 3m. The four bottom corners of the net were secured to the river bottom with 14kg anchors. The floating frames were constructed of 125mm diameter PVC piping, filled with urethane foam at the connection joints to enhance strength and flotation. The netting was comprised of 25mm mesh knotless seine webbing. Floating Styrofoam® sheets were placed on the water surface of the pen to ensure sockeye would not jump out of the pen. In addition, the primary net pen was surrounded by an anchored and floated predator net measuring 30m long x 6m deep.

Given the dimensions of the net, the maximum volume of the holding pen is $48m^3$. 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. Assuming a maximum fish holding density of $10kg/m^3$, the holding capacity of the net pen when situated in 2m uniform depth was estimated to be approximately 128 adult sockeye (average weight/sockeye = 2.5kg). To insure minimum negative effects associated with crowding, holding capacities were set at a maximum of 100 fish per net pen (i.e. approximately 1 sockeye per 500 liters of water).

Net pens were located in a low flow (<0.5 m/sec) side channel 40m south of the primary angling site on Grassy Bar (see Appendix 1 - Figure 2). This location was within close in-river walking distance from the angling 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.

Fish bags containing sockeye were slowly walked in-river from the point of landing to the holding net pen site. All sockeye delivered to the net pens were liberated 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-hour 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 measured for fork length and biological tissue samples taken for DNA analysis. Live sockeye were released directly into the river to continue their migration. All dead sockeye were examined to determine the cause of death. Appendix 6 - Figure 6 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 two technicians provided around-the-clock (24-h) monitoring and security.

2.3.3 Reference ("Control") Group

Experimental handling and holding of fish for observation can potentially introduce additional or unknown biases in hooking mortality estimates. While the magnitude of these biases may be unknown, our study followed similar studies and analyses (Nelson 1998, Millard et al. 2003, 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 without being hooked and 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 hooked (treatment) fish and the finite mortality rate observed in the non-hooked reference (control) group of fish.

Sockeye for the reference group were captured using a 123m (L) x 5.5m (D) beach seine with 5cm mesh webbing. Beach seining was conducted immediately upstream of the primary Grassy Bar angling site in an effort to eliminate disruption of 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 and released all non-sockeye species and then placed sockeye in the handling/transport bags. Sockeye were then walked in-river to the net pen, where they were tagged, recorded and released into the pen. 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 hooked fish. 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. Appendix 6 - Figure 7 documents the beach seining crew hauling in the net for collection of sockeye for the reference group.

2.3.4 Necropsies

All sockeye mortalities were examined externally and internally in an effort to quantify the cause of death (Necropsy Form - Appendix 2 - Figure 4). External observation focused on scale abundance/loss, the location and degree of wounds or bleeding, number of sea lice and condition of fins. The internal examination looked for 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 mucus. The gut cavity was examined to determine internal bleeding, damage to organs, tissue bruising or gaping and identify sex and gonad maturity. Each mortality was measured for fork length and tissue sampled for DNA analysis.

2.3.5 Physiological Sampling

Physiological sampling was conducted on a number of sockeye caught and released in the study in order to assess post-angling recovery rates and other physiological effects on short-term survival. A variety of non-invasive (blood samples, scale samples, length, weight, gill biopsy, fat probe reading, muscle biopsy) and invasive samples (liver, kidney, muscle, reproductive tissues) were collected for assessment from both the hooked (treatment group) fish and fish captured by beach seine (reference group). The detailed methodology and results from this sampling are to be documented in a separate report.

Appendix 6 - Figure 4 shows technicians performing a typical non-invasive physiological sample for blood on a recently hooked and landed sockeye.

2.3.6 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 3 minutes.

Dissolved oxygen levels were measured at 0700h and 1800h daily. Measurements were taken in the Fraser River just north and adjacent to the angling site at Grassy Bar in a water depth of approximately 1m and immediately upstream of the net pens in a depth of approximately 1.5m using a Hanna® Instruments Oxy-Check dissolved oxygen meter.

2.4 Analysis of Mortality Data

2.4.1 Hooking Mortality Rate

The primary objective of our study was to evaluate the short-term (24-h) mortality rate of hooked sockeye using gear common to the non-tidal Fraser River 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 observed in the hooked fish and the total mortality rate observed in the reference fish. In our study, confidence limits for *d*, the simple difference between two proportions, were generated using the Newcombe-Wilson Hybrid Score method (Newcombe 1998). The Wald-type "classical" asymptotic methods were not used because they can yield nonsensical upper confidence intervals that are greater than 1.0. This type of aberrancy is referred to as "overshoot" and is one of several problems seen with the classical methods when sample size is small or observed probabilities are near one or zero. Appendix 8 details the derivation of the Newcombe-Wilson hybrid score confidence intervals.

2.4.2 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 ($P < 0.1$) in mortality rates are further evaluated to provide odds ratios and other associated logistic regression parameters.

In our study, Pearson chi-square, Fisher’s exact tests, and logistic regressions (where applicable) were performed using software developed by John C. Pezzullo (see References: Other resources).

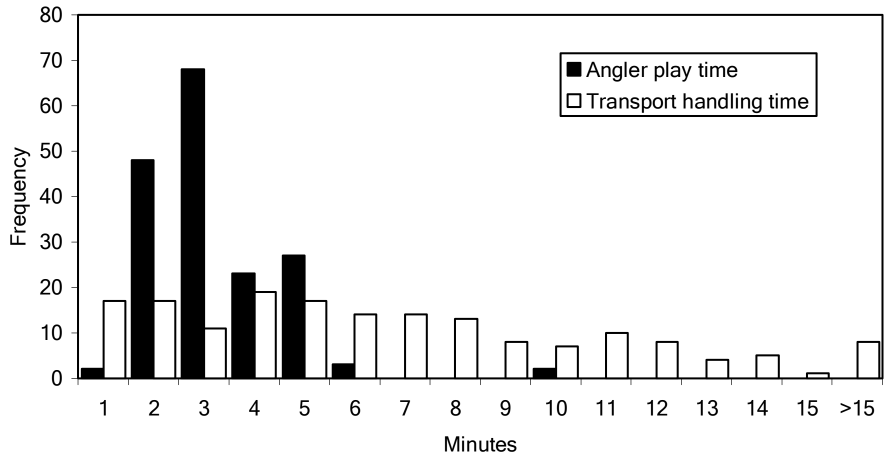

Figure 2. Frequency distribution of angler play time and transport handling time to holding pens for sockeye hooked in a bottom bounce hook-and-release study at Grassy Bar in the Fraser River.

Table 1. Descriptive statistics for catch and mortality of sockeye caught by bottom bounce gear at Grassy Bar in the Fraser River by primary hooking location.

Variable	Hooking location: Inside mouth	Maxillary bone	All other outside	Total
Total number caught	21	114	38	173
Mortality (%)	0	0	5.3	1.2
Mean playing time (minutes)	2.8	3.4	3.1	3.3
Beached (%)	38.1	39.5	50.0	41.6
Bleeding observed (%)	9.5	13.2	36.8	17.9
Vigorous condition at capture (%)	100	97.4	97.4	97.7
Mean transport handling time (minutes)	4.5	7.1	7.3	6.8
Predominant hook size (type: %)	3/0: 85.7	3/0: 75.4	3/0: 78.9	3/0: 77.5
Predominant leader lengths (range ft: %)	10-12: 88.9	10-12: 73.2	10-12: 83.8	10-12: 77.2

The physical condition of hooked and reference group fish 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 (97.6%) of hooked fish were in a vigorous condition at time of capture (80.3% not bleeding, 17.3% bleeding) (Table 2). Only 2.3% of the hooked fish were reported as lethargic (1.7% not bleeding, 0.6% bleeding). None of the beach seined sockeye exhibited any bleeding at the time of capture with 96.1% being reported as vigorous and 3.9% 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 two mortalities noted in the hooked group, 97.7% were released after 24-h as vigorous with no bleeding and 1.2% as lethargic with no bleeding. All of the beach seined fish were released after 24-h alive and in vigorous condition.

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

A. Condition at time of capture:

Study Group	Vigorous, not bleeding	Vigorous, bleeding	Lethargic, not bleeding	Lethargic, bleeding	Dead	Total
Hooked	139	30	3	1	0	173
Percent of total	80.3%	17.3%	1.7%	0.6%	0%	100.0%
Reference	99	0	4	0	0	103
Percent of total	96.1%	0%	3.9%	0%	0%	100.0%

B. Condition at time of release:

Study Group	Vigorous, not bleeding	Vigorous, bleeding	Lethargic, not bleeding	Lethargic, bleeding	Dead	Total
Hooked	169	0	2	0	2	173
Percent of total	97.7%	0%	1.2%	0%	1.2%	100.0%
Reference	103	0	0	0	0	103
Percent of total	100.0%	0%	0%	0%	0%	100.0%

Other species, particularly chinook, were also hooked and landed using bottom bounce gear during the study. Aside from noting the total number hooked and landed, no other angling statistics were collected and no mortality estimates were made for these fish.

3.2 Hooking Mortality Estimates

No mortalities were observed in any sockeye that were subjected to non-invasive 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 non-invasive physiologically sampled sockeye was estimated to be 1.2% with lower and upper 95% confidence intervals of zero to 4.1%, respectively. Excluding the physiological samples resulted in a short-term mortality estimate of 1.4% with lower and upper 95% confidence intervals of zero to 4.8%, 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 reference group. Confidence intervals reflect the range of possible mortality rates adjusted for the reference group sample.

For added comparison, adjusted mortality estimates and 95% confidence intervals associated with individual angling-related factors are presented in Appendix 4. These estimates include fish sampled non-invasively for physiological studies. Due to the limited number of mortalities and small sample sizes associated with each individual angling variable, caution should be taken when assessing these estimates. Also, individual angling variables may not act independently on mortality. Large confidence intervals for some mortality estimates are a testament to this uncertainty.

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

Gear	Total caught (*N*)	Mortalities		Adjusted catch-and-release mortality estimate (%) (95% CI)
		n	Percent	
A. Including non-destructive physiological samples:				
Bottom bounce	173	2	1.2	1.2 (0-4.1)
Beach seine (reference group)	103	0	0	
B. Excluding non-destructive physiological samples:				
Bottom-bounce	148	2	1.4	1.4 (0-4.8)
Beach seine (reference group)	86	0	0	

3.3 Factors Influencing Mortality

Angling-related variables, fish holding densities, and temporal biases were evaluated individually for significance on mortality ($P < 0.1$) using maximum-likelihood estimates (Pearson's chi-square, Fisher's exact test) (Table 4). The only variables that exhibited significant influence on mortality were hooking location and the occurrence of bleeding at time of capture. Due to the variety of possible hooking locations noted in the study (15 in total), and very low mortalities observed, assessment of this variable on mortality can be somewhat difficult to quantify. Based on the hooking locations observed in this year's data and in order to simplify this assessment, hooking categories were grouped into two major categories as follows:

Table 4. Maximum likelihood (Pearson's chi-square) and Fisher's exact test (for small sample sizes) results assessing various angling-related factors, fish holding densities, and temporal biases influencing the short-term (24-h) mortality of sockeye caught with bottom bounce gear at Grassy Bar, Fraser River. Coding for variables is shown in parentheses.

Variable	Chi-square test	p-value	Fisher's exact test
Hook location 1 (body snag=0, all other locations=1)	21.31	<0.001	0.01
Hook location 2 (all outside locations=0, maxillary bone=1)	6.08	0.014	0.06
Bleeding at capture (no=0, yes=1)	9.27	0.002	0.03
Angler play time (<5 min=0, >5 min=1)	0.46	0.498	1.00
Condition at capture (vigorous=0, lethargic=1)	0.05	0.827	1.00
Beaching (no=0, yes=1)	0.06	0.809	1.00
Air Exposure (less than 15 sec=0, greater than 15 sec=1)	0.15	0.698	1.00
Leader Length (9 leader lengths ranging from 8 to 16 feet)	1.69	0.975	--
Hook Size (4 hook sizes ranging from 1/0 to 4/0)	0.59	0.899	--
Scale loss (none=0, light to moderate=1)	0.25	0.617	1.00
Fish densities in the holding pen[a] (less than 20 fish/day=0, greater than 20 fish/day=1)	1.38	0.241	0.35
Temporal bias (hook location by study week) (0=Snags, 1=all other locations)	0.66	0.719	--
Temporal bias (mortalities by study week) (0=Alive, 1=Dead)	0.80	0.670	--

a. includes both hooked and reference group fish.

Hook location 1 which compared fish hooked inside or outside the mouth versus those snagged in the body (dorsally or ventrally) and Hook location 2 which grouped those fish hooked in the maxillary bone versus all other outside the mouth hooking locations. Dorsal or ventral body hooking locations (snags) had a significant influence on mortality (chi-square=21.31, 1 d.f., $p<0.001$). Only 15 sockeye (8.7%)

were hooked in these locations, however they were the only hooking locations associated with observed mortalities in this study. Hooking locations outside the mouth or on the body also had a significant influence on hooking mortality when compared to fish hooked in the maxillary bone (chi-square=6.08, 1 d.f., p=0.014). The presence of bleeding at the time of capture was also found to be a significant factor in the mortality of hooked sockeye (chi-square=9.27, 1 d.f., p=0.002). All other angling-related variables collected in this study (angler play time, condition at capture, beaching, air exposure, leader length, hook size, and scale loss) did not individually exhibit any significant influence on the probability of mortality.

No significant influence on mortality was found when comparing observed to expected mortalities of fish when densities of fish were greater than or less than 20fish/day in the holding pen (chi-square=1.38, 1 d.f., p=0.241).

Hooking locations were also evaluated by study week to determine if there were any significant temporal biases. No significant differences were found between weeks when snagging locations were compared to all other hooking locations (chi-square=0.66, 2 d.f., P=0.719). Temporal biases in mortality were also evaluated by comparing observed to expected mortalities by study week. No significant biases in mortality were noted between weeks (chi-square=0.80, 2 d.f., p=0.670).

Due to the lack of any observed mortalities for the majority of the explanatory variables, further assessment of the relationship between mortality and most of the angling variables in our study using odds ratios and logistic regression analysis was inappropriate, even for those exhibiting significant influence (hook location and bleeding at capture). This methodology requires at least one mortality (and preferably more) to be present in both variables being assessed. Otherwise, odd ratios approach zero or infinity and are meaningless for comparing the odds or probabilities of death associated with the angler-related variable in question. Only one variable (beaching) exhibited a single mortality in both categories (i.e. beached or not beached) being assessed. However, chi-squared and Fisher's exact tests did not show a significant difference in observed and expected mortality between fish that were beached or not beached.

Water temperatures were continuously monitored in the Fraser River near the angling site and in the holding pen throughout the study. Hourly temperatures for the two sites are presented in Appendix 6 – Figure 1. The average daily water temperature in the river was relatively steady from August 5 to August 23 varying between a high of 19.5°C on August 8 to a low of 18.2°C on August 23. Temperatures dropped steadily in the third study period from 15.8°C on August 29 to 14.4°C on September 2. Hourly water temperatures in the holding pen were not significantly different from those recorded in the river near the angling site (t=11.24, 6802 d.f., P<=0.001). Temperatures in the holding pen deviated anywhere from 1.5°C below to 0.5°C above water temperatures at the angling site (Appendix 5 – Figure 1). Due to the similarity in water temperatures observed in the river near the angling site and in the holding pen, it is unlikely that water temperature had a significant influence on mortality. The two mortalities both occurred sometime between August 6 and August 7 when the water temperature in the holding pen ranged between 18.2°C and 19.1°C. Eight other study days had temperatures within this range and five days had temperatures above 19.1°C when fish were held for observation and no mortalities occurred.

Dissolved oxygen (DO) levels were also significantly different between the two sites (t=3.5, 58 d.f., P<=0.001). DO concentrations averaged 9.4mg/l in the river near the angling site and 8.9mg/l in the net pen. Minimum levels of DO were recorded at 8.0mg/l in the net pen on August 6, 0700h. Despite the differences noted between the two sites, concentrations in the net pen were well within suitable ranges (> 5mg/l) to support the health of migrating adult salmonids (Bjorn and Reiser 1991).

The daily number of sockeye held in the net pens varied from zero on August 23 and September 2 to a high of 60 (53 reference, seven hooked) on August 21 (Figure 3). The average daily number of sockeye that were held for observation was 21. The average number of reference sockeye in the holding pen was 26 per day, and average number of hooked sockeye was 14 per day. The two mortalities were observed on a single day when the number of fish being held was higher (32) than the overall average (21). However, no significant biases were noted when comparing mortalities when fish densities were less than or greater than 20 fish/day (Table 3).

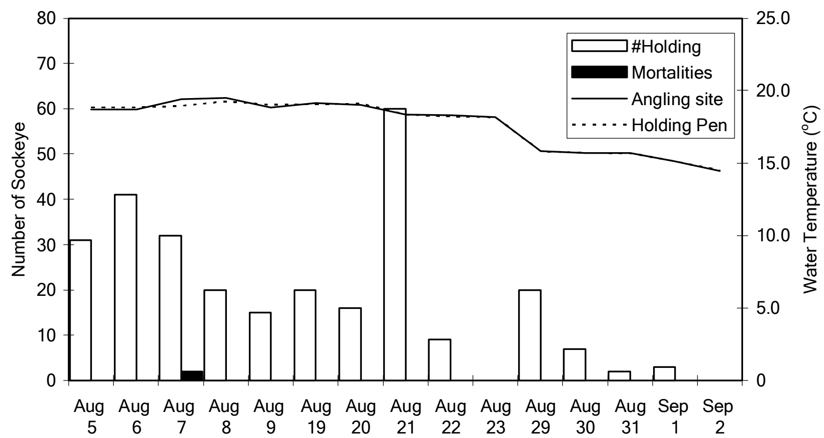

Figure 3. Daily number of fish held for 24-h observation in the net pens and observed mortalities (bars) compared to average daily water temperatures from in-situ data loggers located in-river near the angling site and the holding net pen (lines) at Grassy Bar in the Fraser River.

Visual observations and post-mortem assessment concluded that one of the two mortalities in this study was directly attributable to hooking by an anterior ventral snag. This type of hooking event was relatively infrequent in the study (6% of the hooked fish). In this particular case, internal hemorrhaging noted in the necropsy suggested that the hook had punctured or lacerated the heart or liver leading to the probable cause of death. The other mortality noted in the study was associated with a dorsal snag hooking location (2% of the hooked fish). This fish was also a victim of a severe seal bite injury on its posterior dorsal surface. No sign of internal bleeding was noted during the necropsy, which suggests the seal bite may have been a contributing cause of death.

4.0 DISCUSSION

Abundances of sockeye in the Fraser River were anticipated to be low in 2008. Preseason run size estimates ranged from 1.85 to 2.90 million sockeye (75 and 50% probability levels, respectively) compared to the cycle average of 4.4 million sockeye. Actual inseason estimates totalled approximately 1.16 million sockeye escaping past the Fraser River hydroacoustic station at the Mission bridge by the end of August (Pacific Salmon Commission, August 26, 2008 News Release). In addition, migration timing of Summer stocks into the river was approximately one week earlier than expected and most peaks were observed prior to start of the study (see Appendix 7 - Figure 1). The targeted sampling goal of approximately 400 sockeye in each of the hooking and reference groups was not achieved in this year's study. Overall catches were lower than anticipated, particularly during the latter two weeks of the study and coinciding with significantly reduced in-river sockeye abundances. Estimates of sockeye in the Grassy Bar area of the Fraser River declined from almost 200,000 in the first study week to less than 20,000 by week 3 (Appendix 7 – Table 1). Despite the lower than expected sample sizes attained, maximum margins of error at 95% confidence are estimated to be in the range of 7 to 10% for the hooked and reference group samples sizes attained, respectively.

This preliminary study was conducted at a single fishing bar location and during relatively good environmental conditions for in-river sockeye migration. It provides a good framework for future studies to assess catch-and-release mortalities over a wider range of angling locations, environmental conditions, and stock groups. Under the conditions for this year's study, short-term (24-h) mortality estimates of hooked sockeye was low (1.2% mortality with a 95% confidence interval of zero to 4%). The data collected in this study showed that the majority of sockeye caught by anglers were hooked in or near the maxillary bone with little to no bleeding. Although only two mortalities were observed, evaluation of angling-related variables suggests that fish hooked by snagging, particularly in the ventral surface, have a relatively high probability of dying as a result of puncture wounds or laceration of vital internal organs compared to other methods of hooking. However, during this study only 6.4% of the angled fish were hooked in this location. The presence of bleeding at the time of capture that resulted from hooking was also a variable that exhibited a strong likelihood of death. Again, a small percentage (18%) of the fish hooked in this study showed signs of bleeding at the time of capture. Excluding the two fish that died, all of the fish that exhibited light to moderate bleeding at the time of capture were later released alive and vigorous after 24 hours with no signs of bleeding. No appreciable influences on mortality were found for the remainder of angling-related variables assessed in our study. Additional work with larger sample sizes, and under a variety of conditions, would be of interest to explore the angling (or capture) related influences further.

5.0 RECOMMENDATIONS AND LIMITATIONS

For our study, we assumed that the effects of handling, transport and holding worked independently between the angled (hooked) fish and the reference (control) group. We also assumed that the beach seine method of capture for the reference group had no measurable effect on short-term mortality. Based on our results, and particularly the lack of any mortalities in the reference group, our assumptions appear to be reasonable. A simple adjusted method was therefore used to provide an estimate of 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. It is important to note that the beach seine method used in this year's study met these standards and proved to be a practical, effective and reliable method for capturing reference group fish with minimal harm.

We only produced a single short-term 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 only be indicative of the study group. Further studies along with comparisons to techniques and angling statistics from angler surveys with similar characteristics would be useful. DFO reports from this year's limited sockeye fishery were unavailable for comparison at the time of this report.

No sockeye were observed during our study that were caught by other bar fishing techniques (for example, spin and glow lures). Therefore, the results from our study can only be related to the bottom bounce fishery and may not be indicative of all bar fishing techniques that might capture sockeye. This mortality estimate also only applies to sockeye salmon, since observations and analysis of other species caught using bottom bounce gear may be different and were not included in the study.

Our mortality estimates are based on a short-term holding period of 24 hours. Although some fish health variables were incorporated in the study, no other endpoints, besides 24-h mortality were evaluated. Therefore, we cannot quantify the post-release mortality beyond the 24-h period, nor estimate actual spawner success of the hooked or reference sockeye. It is possible for example, that fish 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. Alternatively, sockeye held for observation in net pens could be afforded sufficient time and protection from predators to heal from injuries or recover from stress associated with hooking or capture. These fish may actually have a greater chance at survival than those fish released back into the river immediately after hooking (or capture).

Comments regarding seal bites were noted for approximately seven sockeye in the study, however this data was not consistently collected or analyzed. A severe seal bite was noted as a possible contributing factor in one of the two observed mortalities. The prevalence and severity of seal bites in the hooking and reference group could be a significant contributing factor in mortality and needs to be consistently adjudicated and documented and further analyzed in future studies.

Additional data regarding handling and transfer times for fish in the reference group would also be useful. This data was not formally recorded for each individual fish in the reference group and could not be fully evaluated in this year's data.

Additional comparisons between angler-related variables and their influence on mortality may also be of importance if mortality rates in future years are higher (or different) than those witnessed in the pilot year. It would be very interesting to see if relative hooking location data changes and whether these changes affect mortality between years. Different sizes of weights used by anglers in this fishery may also have an influence on hooking location as a result of differing behaviour of the gear. This data should be recorded and analyzed in future studies.

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. Future studies should attempt to collect and quantify sex and sexual maturity (or at least, sexual dimorphism) of captured sockeye and the possible influence of this on mortality.

Since this study was only conducted at one gravel bar, it may not be universally representative of all bars or fishing sites on the Fraser River. There may be different physical or environmental conditions between bars that could ultimately affect mortality rates. Although our study site was conducted at a popular bar fishing location and is believed to be typical, given its limited spatial and temporal scope, the results may not necessarily be representative of the wider range of environmental conditions and locations that are available in the Fraser River for these fisheries. Studies and comparisons of angling characteristics, gear and techniques at other sites may help to determine if differences exist.

This study also was conducted in a year with low angler effort 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 near where angling starts during the summer months, with further angling opportunities existing upstream approximately 50 km to Hope. Therefore, the estimates at Grassy Bar may underestimate the longer-term mortality for fish that are hooked and released multiple times. 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 four-year cycle period. A single year study, particularly during a year of low sockeye abundance when environmental conditions are favourable, may not necessarily be representative of mortality rates witnessed in a year when abundances are higher or conditions are less favourable. Angler-related variables may also have significantly different influences on mortality in relation to annual changes in environmental, regulatory, biological, or abundance-based components. 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.

Substantive numbers of chinook were caught in this study by the beach seine. No data on stock origin was collected except to note that all fish had intact adipose fins. Future studies should include plans to collect biological and tissue samples from chinook caught in the beach seine for DNA stock analysis.

The on-site study team observed and encountered numerous instances of illegal nighttime activity during the study. Drift gillnetting was observed in the mainstem Fraser and the side channel of Grassy Bar, along with heavy caliber weapons fire, and vessel movements related to a proximate drug grow operation. These occurrences resulted in the need for constant vigilance and raised concerns for the safety of staff, equipment and sockeye that were being held in the net pens. Future studies need to review site security measures and implement communication protocols with criminal enforcement and emergency services agencies.

6.0 ACKNOWLEDGMENTS

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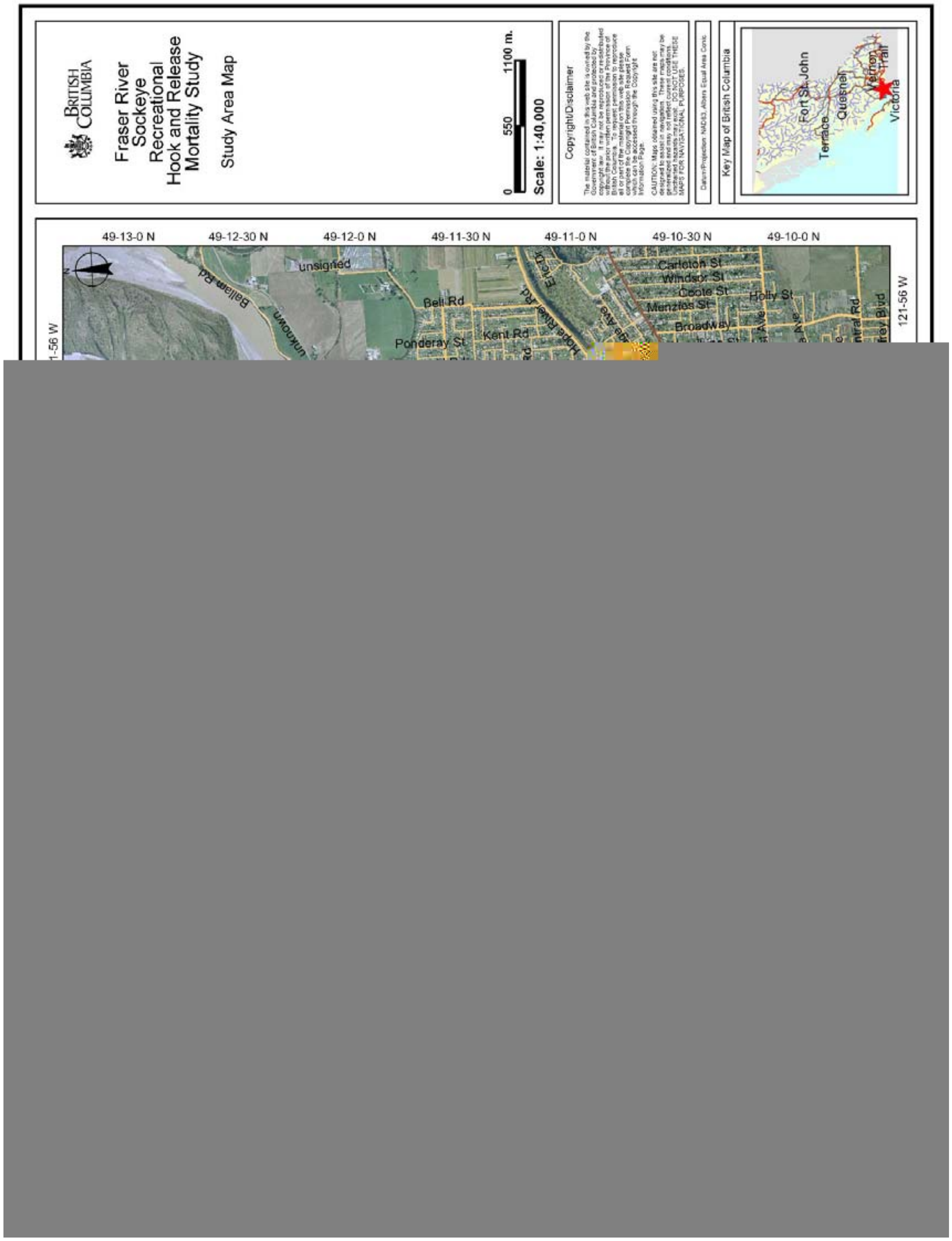
Appendix 1 - Figure 1. Detailed ortho photo mosaic map of the general location of the lower Fraser River Sockeye Recreational Hook and Release Mortality Study showing boat access at Island 22 Park, the Grassy Bar study site and alternate net pen site at Calamity Bar.



Appendix 2 - Figure 1. Daily Encounter Form.

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

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

Shift (AM/PM): ______
Water Temp (^oC): ______
Air Temp (^oC): ______

HOUR	ANGLER COUNT	WEATHER	STRIKES	HOOKUPS	LOSSES	LANDINGS
1						
2						
3						
4						
5						
6						
7						
8						

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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.

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

IDENTIFICATION

Date: ________ (dd-mmm-yyyy) **Location:** ________

Observer ID: ________ **Angler:** boat shore

Fish Bagged?: Y N **Bag #:** ____ **Tag #:** ______ **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

GEAR DESCRIPTION (circle one)

Gear Type: bottom bouncing bar fishing beach seine (control)

Hook Size: 0 1 1/0 2/0 other: ____ **Leader Length (ft.):** ____

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:

Dorsal 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)	

COMMENTS: ________

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Appendix 2 - Figure 3. Holding Form.

...aser River Sockeye Recreational Hook & Release M... ...ty Study

Holding Form

Initial Condition (circle one)	Date Released (dd-mmm-yyyy)	Time Released (24 h clock) (hh:mm)	Fork Length (mm)	Scale No.	DNA Vial No.	...ase Condition (circle one)	Comments
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
VNB VB LNB LB D						B LNB LB D	
NB VB LNB LB D						B LNB LB D	

Bleeding LNB=Lethargic,Not Bleeding LB=Lethargic,Bleeding D=Dead

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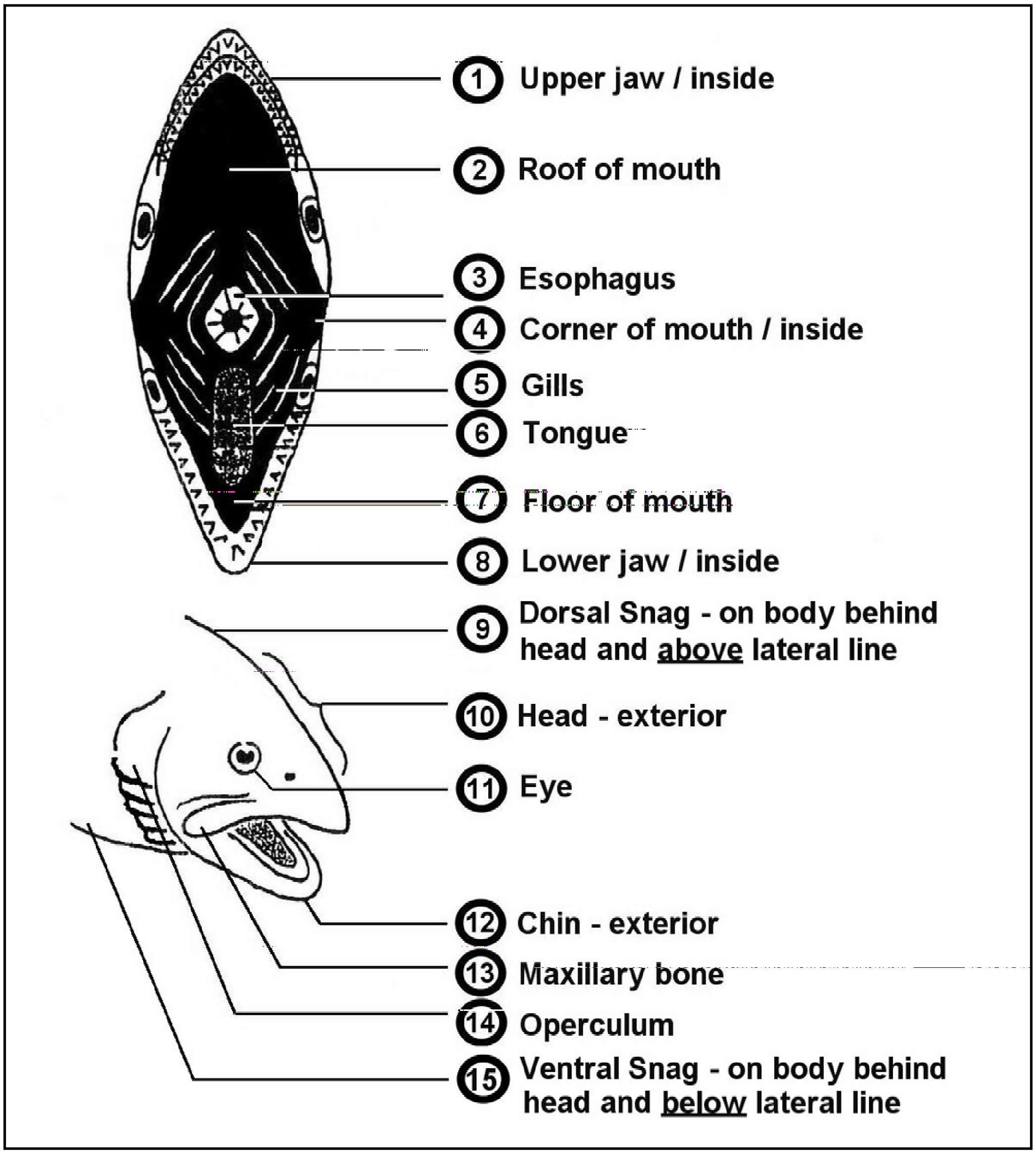
Appendix 2 - Figure 5. Diagrammatic view of a salmonid head illustrating hook injury locations adapted from Mongillo (1984).



Appendix 3 - Table 1. Angling catch summary by date, study week and species at Grassy Bar, Fraser River.

Date	Average number of anglers	Number of hookups	----- Number of losses -----			----- Number of landings -----		
			Sockeye	Chinook	Coho	Sockeye[a]	Chinook	Coho
5-Aug	17	35	3	0	0	32	0	0
6-Aug	7	58	14	0	0	43	1	0
7-Aug	9	31	10	3	0	17	1	0
8-Aug	10	39	14	3	0	20	2	0
9-Aug	13	30	8	2	0	15	5	0
Week 1	**11**	**193**	**49**	**8**	**0**	**127**	**9**	**0**
19-Aug	12	37	7	3	0	22	5	0
20-Aug	6	17	6	4	0	1	6	0
21-Aug	6	15	1	4	0	7	3	0
22-Aug	10	30	7	5	0	9	7	2
23-Aug	6	9	1	3	0	0	5	0
Week 2	**8**	**108**	**22**	**19**	**0**	**39**	**26**	**2**
29-Aug	11	7	0	0	0	0	6	1
30-Aug	10	14	0	4	0	7	2	1
31-Aug	20	14	1	3	0	2	7	1
1-Sep	11	18	2	7	2	3	1	3
2-Sep	4	11	0	3	0	0	8	0
Week 3	**11**	**64**	**3**	**17**	**2**	**12**	**24**	**6**
Total	**10**	**365**	**74**	**44**	**2**	**178**	**59**	**8**

a. Totals include 5 sockeye that were removed from the study due to incomplete data records. None of these 5 fish died. Of the 173 remaining sockeye, 25 were non-destructively sampled for physiology studies. All 25 sockeye were held for 24-h observation and none died during the study.

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

	Number of sets	Socke4 TcD Sim		Chinook Jack	Chinook Adult	Chum	Sturgeon
7-Aug	7	21	1	29	1	0	0
20-Aug	8	20	0	60	5	0	0
21-Aug	8	60	0	165	30	0	3
29-Aug	7	19	8	124	17	0	2

a. Totals include 17 sockeye that were were removed from the mortality study for destructive physiological samples. An additional 17 of the remaining 103 fish were non-destructively sampled. None of the non-destructively sampled fish died during the study.

Appendix 4 - Table 1. Adjusted estimates of short-term (24-h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River, 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	1	0	3	0	1.7	0
	Roof of mouth	2	0	0	2	0	1.2	0
	Esophagus	0	0	0	0	--	0	0
	Corner of mouth	6	0	0	6	0	3.5	0
	Gills	1	0	0	1	0	0.6	0
	Tongue	0	0	0	0	--	0	0
	Floor of mouth	3	0	0	3	0	1.7	0
	Lower jaw	5	0	0	5	0	2.9	0
	Other	1	0	0	1	0	0.6	0
Inside mouth total		20	1	0	21	0	12.1	0
Maxillary bone total		113	1	0	114	0	65.9	0
Other outside mouth	Dorsal snag	3	0	1	4	25.0	2.3	25.0 (4.2-69.9)
	Head	1	0	0	1	0	0.6	0
	Eye	1	0	0	1	0	0.6	0
	Chin	20	0	0	20	0	11.6	0
	Operculum	0	0	0	0	--	0	0
	Ventral snag	10	0	1	11	9.1	6.4	9.1 (0.8-37.7)
	Other	1	0	0	1	0	0.6	0
Other outside mouth total		36	0	2	38	5.3	22.0	5.3 (0-17.3)
Grand total		169	2	2	173	1.2	100.0	1.2 (0-4.1)

Appendix 4 - Table 2. Adjusted estimates of short-term (24-h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River, 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	10	1	0	0	1	0	0.6	0
	12	14	1	0	15	0	8.7	0
	14	1	0	0	1	0	0.6	0
	15	1	0	0	1	0	0.6	0
	unknown	3	0	0	3	0	1.7	0
Inside mouth total		20	1	0	21	0	12.1	0
Maxillary bone	8	6	0	0	6	0	3.5	0
	9	7	0	0	7	0	4.0	0
	10	32	0	0	32	0	18.5	0
	11	1	1	0	2	0	1.2	0
	12	48	0	0	48	0	27.7	0
	14	4	0	0	4	0	2.3	0
	15	11	0	0	11	0	6.4	0
	16	2	0	0	2	0	1.2	0
	unknown	2	0	0	2	0	1.2	0
Maxillary bone total		113	1	0	114	0	65.9	0
Other outside mouth	8	2	0	0	2	0	1.2	0
	10	2	0	0	2	0	1.2	0
	11	1	0	0	1	0	0.6	0
	12	26	0	2	28	7.1	16.2	7.1 (0.9-22.7)
	15	3	0	0	3	0	1.7	
	16	1	0	0	1	0	0.6	0
	unknown	1	0	0	1	0	0.6	0
Other outside mouth total		36	0	2	38	5.3	22.0	5.3 (0-17.3)
Grand total		169	2	2	173	1.2	100.0	1.2 (0-4.1)

Appendix 4 - Table 3. Adjusted estimates of short-term (24-h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River, 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	2/0	3	0	0	3	0	1.7	0
	3/0	17	1	0	18	0	10.4	0
Inside mouth total		20	1	0	21	0	12.1	0
Maxillary bone	1/0	2	0	0	2	0	1.2	0
	2/0	23	0	0	23	0	13.3	0
	3/0	85	1	0	86	0	49.7	0
	4/0	3	0	0	3	0	1.7	0
Maxillary bone total		113	1	0	114	0	65.9	0
Other outside mouth	2/0	8	0	0	8	0	4.6	0
	3/0	28	0	2	30	6.7	17.3	6.7 (0.7-21.3)
Other outside mouth total		36	0	2	38	5.3	22.0	5.3 (0-17.3)
Grand total		169	2	2	173	1.2	100.0	1.2 (0-4.1)

Appendix 4 - Table 4. Adjusted estimates of short-term (24-h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River, 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	1	0	19	0	11.0	0
	Light	2	0	0	2	0	1.2	0
	Moderate	0	0	0	0	--	0	--
Inside mouth total		20	1	0	21	0	12.1	0
Maxillary bone	None	98	1	0	99	0	57.2	0
	Light	13	0	0	13	0	7.5	0
	Moderate	2	0	0	2	0	1.2	0
Maxillary bone total		113	1	0	114	0	65.9	0
Other outside mouth	None	24	0	0	24	0	13.9	0
	Light	11	0	2	13	15.4	7.5	15.4 (3.8-42.2)
	Moderate	1	0	0	1	0	0.6	0
Other outside mouth total		36	0	2	38	5.3	22.0	5.3 (0-17.3)
Grand total		169	2	2	173	1.2	100.0	1.2 (0-4.1)

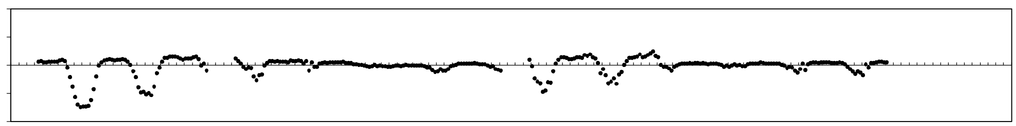
Appendix 4 - Table 5. Adjusted estimates of short-term (24-h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River, using bottom bounce gear, corrected for handling mortality. The number of fish hooked, the release condition after the 24-h holding period and the 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						
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	19	1	0	20	0	11.6	0
	Light	0	0	0	0	--	0	0
	Moderate	1	0	0	1	0	0.6	0
Inside mouth total		20	1	0	21	0	12.1	0
Maxillary bone	None	101	1	0	102	0	59.0	0
	Light	9	0	0	9	0	5.2	0
	Moderate	3	0	0	3	0	1.7	0
Maxillary bone total		113	1	0	114	0	65.9	0
Other outside mouth	None	30	0	2	32	6.3	18.5	6.3 (0.5-20.2)
	Light	5	0	0	5	0	2.9	0
	Moderate	1	0	0	1	0	0.6	0
Other outside mouth total		36	0	2	38	5.3	22.0	5.3 (0-17.3)
Grand total		169	2	2	173	1.2	100.0	1.2 (0-4.1)

Appendix 4 - Table 6. Adjusted estimates of short-term (24-h) catch-and-release hooking mortality rates of sockeye salmon at Grassy Bar in the Fraser River, 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	69	2	1	72	1.4	41.6	1.4 (0-7.5)
No	100	0	1	101	1.0	58.4	1.0 (0-5.4)
Grand total	169	2	2	173	1.2	100.0	1.2 (0-4.1)

Appendix 5 - Figure 1. Comparison of hourly holding pen (dashed) and angling site (solid) water temperatures 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 - Figure 3. Typical hooking location (left maxillary) observed in the recreational sockeye bottom bounce fishery (photograph by Bill Otway).

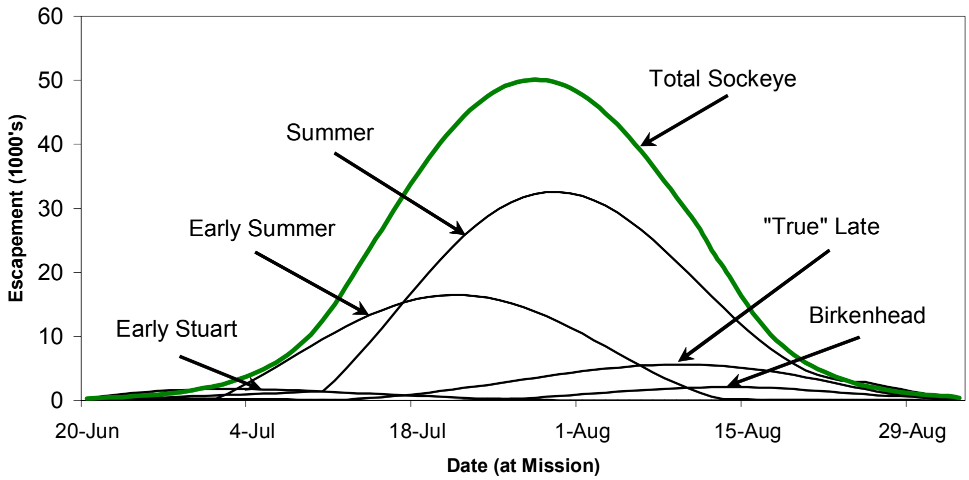
Appendix 6 - Figure 4. Non-destructive physiological sampling of a hooked and landed sockeye (photograph by Cathy Ball).

Appendix 6 - Figure 5. Holding pens and predator net configuration in the side channel situated at the southern (tail) end of Grassy Bar, Fraser River (photograph by Jim Thomas).

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

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

Appendix 7 - Figure 1. Fraser River sockeye timing and daily escapement estimates (smoothed) past Mission, British Columbia, by major stock group (June 20 to September 2, 2008).



Source: Pacific Salmon Commission

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 3 to August 31, 2008. (Source: Pacific Salmon Commission, August 26, 2008). 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
3-Aug	5-Aug	0	3,219	12,277	634	2,086	18,216	32	0.18%
4-Aug	6-Aug	0	7,170	35,777	1,310	4,288	48,545	43	0.09%
5-Aug	7-Aug	0	7,215	35,998	1,318	4,315	48,846	17	0.03%
6-Aug	8-Aug	0	6,251	30,757	1,120	10,790	48,918	20	0.04%
7-Aug	9-Aug	0	4,419	21,741	791	7,627	34,578	15	0.04%
Study Week 1		**0**	**28,274**	**136,549**	**5,173**	**29,107**	**199,103**	**127**	**0.06%**
17-Aug	19-Aug	0	1,807	7,228	1,946	2,919	13,900	22	0.16%
18-Aug	20-Aug	0	2,238	10,561	2,506	2,596	17,900	1	0.01%
19-Aug	21-Aug	0	1,208	7,059	1,548	5,285	15,100	7	0.05%
20-Aug	22-Aug	0	704	4,114	902	3,080	8,800	9	0.10%
21-Aug	23-Aug	0	840	5,486	919	3,255	10,500	0	0.00%
Study Week 2		**0**	**6,797**	**34,449**	**7,821**	**17,135**	**66,200**	**39**	**0.06%**
27-Aug	29-Aug	0	155	1,550	837	558	3,100	0	0.00%
28-Aug	30-Aug	0	420	4,200	2,268	1,512	8,400	7	0.08%
29-Aug	31-Aug	0	205	2,050	1,107	738	4,100	2	0.05%
30-Aug	1-Sep	0	110	1,100	594	396	2,200	3	0.14%
31-Aug	2-Sep	0	170	1,700	918	612	3,400	0	0.00%
Study Week 3		**0**	**1,060**	**10,600**	**5,724**	**3,816**	**21,200**	**12**	**0.06%**

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 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

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

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

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

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

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

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

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

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 scop8.b((0.3342)-12(on sco0.3342)-12