Direct and delayed mortality of white sturgeon caught in three gear-types in the lower Fraser River

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EXECUTIVE SUMMARY

Direct and post-release mortality rates were assessed for white sturgeon (*Acipenser transmontanus*) caught by anglers, and incidentally in First Nations set and drift gillnets during sockeye salmon food, social and ceremonial fishery openings. Duration of set gillnet fishing intervals was significantly longer than that for drift gillnets. Direct mortality rates, assessed from catch interviews, did not differ significantly between drift and set gillnets. This study found that of the limited interviews conducted, 4.8% of sturgeon caught in drift gillnets at Canoe Passage, and 6.2% of sturgeon caught in set gillnets at Hatzic, were dead at the time of net retrieval. Direct mortality in set gillnets occurred disproportionately in the 70 to 100 cm fork length range. Direct mortality of angled fish was less than 0.012%. Post-release mortality rates were based on survival of 172 sturgeon (32 caught in drift gillnets, 76 angled and 64 from set gillnets) held for three days in surface net pens situated in the river near the capture sites. After three days of holding, mortality rates of angling (2.6%) and drift gillnet (0%) caught sturgeon were significantly lower than those caught in set gillnets (46.9%). Mortality was related to stocking density and holding time, indicating a possible holding effect (the stresses associated with being held in unnatural elevated densities in surface waters may have contributed to the mortality observed). However, when density and time were factored out, post-release mortality was nevertheless a statistically (ANCOVA) significant function of gear type. Of the three gear types examined, set gillnets posed the biggest threat to the recovery of endangered sturgeon populations. Further attention should be given to this problem.

Fishing effort data were combined with CPE data and direct and post-release mortality rates to estimate total sturgeon mortality for the study period in portions of the river where CPE estimates were applied. Mortality was variable among the river zones studied and was significantly higher in the Hatzic set gillnet zone than in the adjacent Sumas set gillnet zone, revealing significant variation within DFO statistical divisions. Further stratification of management zones would result in more accurate and precise catch and mortality estimates).

Results of this study are of interest to lower Fraser River fisheries managers from federal, provincial, and First Nations governments, and may assist in the decision-making processes regarding allowable harm provisions under SARA.

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1 INTRODUCTION

White sturgeon (*Acipenser transmontanus*) are long-lived, late-maturing species (Semakula and Larkin 1968) with a generation time of 30-40 years (Ptolemy and Vennesland 2003). White sturgeon populations have not recovered from overfishing that resulted in great declines at the turn of the last century (Echols 1995; Ptolemy and Vennesland 2003). In November 2003, the status of white sturgeon was examined by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and the species was given a designation of "Endangered" (COSEWIC 2003). The COSEWIC evaluation of white sturgeon in Canada included the separate consideration of six stocks of white sturgeon, all of which occur in BC; these stocks are: lower Fraser River; middle Fraser River; upper Fraser River; Nechako River; Columbia River; and Kootenay River. The main reasons for the designation included habitat degradation and loss through impoundments, channelization, dyking and pollution. Incidental catches and illegal fishing were also noted as being potentially limiting to population recovery (COSEWIC 2003). To date, there have been no direct studies of injury or latent mortality levels for Fraser River white sturgeon released from recreational, commercial, and aboriginal fisheries.

Currently, white sturgeon are being considered for listing under the Canadian Species At Risk Act (SARA). Resource-users potentially affected by that listing include First Nations gill-netters and recreational anglers. White sturgeon are caught incidentally in First Nations in-river fisheries in the lower Fraser that target migrating runs of Pacific salmon (no direct targeting of white sturgeon has occurred since 1994; COSEWIC 2003). White sturgeon are also targeted by anglers in a catch-and-release recreational fishery in the lower Fraser.

In the lower Fraser River, aboriginal fisheries associated with food, social, and ceremonial purposes primarily use drift and set gillnets. Drifted gillnets likely have lower sturgeon mortalities because of shorter soak times, whereas set gillnets, typically left fishing overnight, may cause higher levels of mortality. Most sturgeon intercepted in aboriginal gillnet fisheries are released, especially if the fish are in good condition. Sturgeon catch data from the DFO First Nations monitoring program (that focuses on salmon fisheries) for the lower Fraser River from 2001 to 2005 showed that between 92.6% and 99.8% of the sturgeon reported as First Nations gillnet bycatch were released, presumably alive (E. Miyagi, unpublished data). Some fish are retained when they are found dead or in very poor condition. A preliminary study on the First Nations' set gillnet fishery suggested a mortality rate of 7 to 13% on gilled sturgeon held in enclosures for 5-12 hours (as cited in Walters and Korman 2005).

The recreational fishery for white sturgeon is a non-retention fishery. By regulation, all sturgeon must be released following capture. The levels of serious injury and latent mortality directly associated with the catch-and-release fishery have not been thoroughly studied. In an ongoing mark-recapture study in the lower Fraser River, the relatively high recapture rate of tagged sturgeon that were originally captured by angling (Nelson et al. 2004) is consistent with the notion that catch-and-release mortality is relatively low. However, mortality rates estimated from mark-recapture data are typically biased because mortalities cannot be recaptured, and because some individual fish may be "trap-happy" (Walters and Korman 2005).

In this report, we assessed the direct and delayed mortality rates of sturgeon caught by anglers, and incidentally in both set and drifted gillnets during mid-summer First Nations food, social, and ceremonial salmon fisheries that were targeting sockeye (*Oncorhynchus nerka*). Direct mortality rates were assessed using First Nations catch monitoring interviews and data collected under the Fraser River Sturgeon Conservation Society (FRSCS) Lower Fraser River First Nations Sturgeon Stewardship Program. Delayed mortality was estimated by monitoring the condition of sturgeon that were collected from each of the three gear types and held in-river for three days in holding tanks. The study was conducted for the Tsawwassen First Nation with funding provided by Fisheries and Oceans Canada, BC Ministry of Environment, and the FRSCS. Results of this study are of interest to lower Fraser River managers from federal, provincial, and First Nations governments, and may assist in the decision-making processes regarding allowable harm provisions under SARA.

2 METHODS

2.1 Study Area

The study took place in the lower Fraser River between the river mouth and Hope (see Figure 1). The area was divided into three strata, and into five zones[1]. The three strata included the area near Westham Island (downstream of Deas Island at rkm 12), the area near Hatzic Slough (rkm 80 to 85), and the area upstream of Dewdney Park (rkm 92 to 155). Within the Westham Island stratum, there were two zones: Ladner Reach[2] and Canoe Passage. There were also two zones within the Dewdney Stratum: the Sumas area (rkm 92 to 99) and the zone upstream of rkm 105. The final zone, the Hatzic area, was the same as the Hatzic Slough stratum (Figure 1).

Drift gillnet fishing was monitored in the Westham Island stratum. Fishing (and hence collection) occurred throughout the stratum, but the areas in which sturgeon were most likely to be caught were Ladner Reach and Canoe Passage. Catch monitoring was restricted to these two zones. The holding pens for post-release mortality assessment were located in Sea Reach, and were attached to a private dock in a tidally influenced area of sufficient river flow (Figure 1).

Set gillnet fishing was monitored in the Hatzic and Dewdney strata. Monitoring interviews occurred throughout the river from the Mission Bridge to Hope, but the majority of interviews and all sturgeon collection occurred in the Hatzic and Sumas zones. The collection restriction was based on a desire to minimize sturgeon transport time, as the holding pens were tied to a log boom near the mouth of Hatzic Slough (Figure 1).

2.2 Holding Study

The basic study design was to collect a representative sample of sturgeon less than 135 cm (fork length) from fishermen (drift gillnets, set gillnets and anglers), transfer these fish into holding pens, and monitor the condition and survival of these fish for three days. The maximum

[1] River kilometer (rkm) designations were based on those used in FRSCS monitoring studies, with rkm 0 being the mouth of the Fraser River at Garry Point (Steveston).
[2] The Ladner Reach is known locally as "the S and M".

size limit of 135 cm fork length was set because most of the sturgeon caught by First Nations fisheries tend to be less than 135 cm (FRSCS, unpublished data) and because of concerns regarding the transport and holding of larger sturgeon.

Sturgeon were collected during four weekend-long First Nation fishery openings and from recreational anglers targeting sturgeon during these same weekends. In the First Nation fisheries, sturgeon were collected from drift gillnets and set gillnets. Collection effort was concentrated at two main locations: Westham Island and Hatzic Slough (see Figure 1). Collection at Westham was restricted to drift gillnets, while at Hatzic sturgeon were collected from set gillnets and anglers. The goal, to collect 100 sturgeon from each gear type over the course of the four week study, was based on statistical considerations and the capacity of the holding pens (about 15 sturgeon per pen).

All collected sturgeon were measured (girth and fork length), checked for injuries and deformities, scanned for PIT tags (and tagged if none was present)[3], and assigned a pre-holding condition code (see below). Sturgeon less than or equal to 135 cm fork length were gently placed in a holding pen; and larger fish were released back into the river. Five benchmark times were noted during the collection process: the start of the fishing interval; the end of the fishing interval; the time when the fish was removed from the water; the time when the fish was transferred from the fishing boat to the collection biologists; and the time of placement into the holding pens. Capture location (in rkm) was also recorded.

"Condition codes" were used to categorize sturgeon health. The codes were previously developed and used by the FRSCS for their sturgeon stewardship programs. In order to have standardized data, we adopted the same scale. The five conditions codes were: 1) vigorous, no bleeding; 2) vigorous but bleeding; 3) lethargic, no bleeding; 4) lethargic and bleeding; and 5) dead. Injuries and deformities were noted in a standardized format, where categories included: cut (which included split and tattered fins); net marks (which included redness from net-rubbing); and deformity (which included misshapen fins, crooked backs, etc).

Six holding pens, similar to those described by Nelson et al. (2004), were installed in-river, two at Westham, and four at Hatzic (Figure 1). The holding pens had a 2718 L volume, and measured 2.43 m × 1.22 m × 0.91 m (Photo 1). The aluminum frame of the pens housed several Styrofoam floats to provide buoyancy. In the river, the pens sat nearly submerged, with only 5 cm protruding above the water surface. Attached to the frames were vinyl pouches, which formed the rear wall, bottom and front wall. Mesh panels (38 mm mesh) made up the left and right sides, allowing river water to freely flow through the holding pens. The top of the pens were sheet plywood, attached by hinges to the frame, allowing the pen to be widely opened during pen-checks, and for sturgeon placement and removal.

Sturgeon were held for three days in the pens. The holding pens were checked for mortalities twice daily (in the morning and early evening). On each pen-check, a dip net was

[3] Sturgeon in the lower Fraser River have been tagged with PIT tags since 1995 (RL&L 2000). Any untagged sturgeon were tagged as part of this study. PIT tags were inserted into sturgeon at a location just posterior to the bony head plate, left of the dorsal line, near the first dorsal scute, as per the standardized procedure for sturgeon studies in the lower Fraser River (Nelson et al. 2004).

used to carefully "sweep" the bottom of the pen where the sturgeon tended to spend most time. The PIT tags of the dead sturgeon were recorded, along with the date and time when each fish was found dead. Dead sturgeon were removed immediately from the pens.

At the end of the third day (or earlier for dead fish), each sturgeon was removed and identified using the PIT tag scanner, assigned a post-holding condition code, and released. The time of release for each fish was recorded. Analysis of variance was used to determine if sturgeon fork length affected the probability of dying.

During the holding period, temperatures and dissolved oxygen (DO) were measured twice daily. Measurements were made inside the holding pens, and in the surrounding river water. Once a day, in-river temperature and DO were measured at a location closer to the centre of the river-channel.

At the start of the study, sturgeon collected from different gear-types were kept in segregated holding pens. Since target collection numbers were not always attainable, we faced the problem of having differing stocking densities for each gear-type. In order to minimize the potential for bias, segregation was discontinued. Sturgeon of unknown origin were sometimes stocked into the pens to achieve desired densities (i.e., to act as "filler").

The unit of replication for statistical analyses was the "day-gear-pen cohort". That is, all sturgeon caught on the same day, from the same gear-type and held in the same pen were considered to be one "unit of replication." The proportion of fish from that unit that died was the value used in statistical tests. When the sample size for a given unit was less than three fish, it was ignored, as accurate mortality estimation was very unlikely. Analysis of variance (ANOVA) was used to compare mortality rates among gear types.

Pen stocking density was considered as a covariate. Stocking density was measured in two ways: 1) the number of sturgeon in the pen; and 2) the sum of the fork lengths of all the fish in the pen. The latter method accounted for variation in the size of sturgeon collected (e.g., a large fish counted for "more density" than a small fish). Analysis of covariance (ANCOVA) was used to factor-out the effect of stocking density when assessing the effects of gear-type on sturgeon mortality.

Although the proportion of sturgeon alive at the end of the third day made up the bulk of the data in this study, the proportions at the end of the first and second days were also considered. For each unit of replication, mortality rates after one day, two days and three days were known. Differences between days were compared using a paired *t*-test, and similarities among cohorts were examined using correlation analysis.

2.3 First Nation Catch Interviews

Catch interviews were conducted during the four weekend-long First Nation fishery openings during the summer of 2005. Interviews were made opportunistically. At times, fishermen were asked a few quick questions (or their catch was estimated visually) while the sturgeon they had caught were being collected for the holding study. Other times, fishermen were approached solely for the purpose of the interview. Many "interviews" were conducted by observing the fishing activity from a distance, without contact with the fishermen.

Data collected during interviews (or by observation) consisted of a few metrics of effort and catch. Effort was estimated by noting the start and end time of the fishing intervals, the number of gillnets in the water, as well as the length, depth, and mesh size of the gillnets used. The location of the fishing activity (rkm) was also recorded. The main catch statistics of interest were the number of sturgeon captured and the number of those that were dead. The few interviews where the First Nations fishermen were targeting Chinook were ignored (since their mesh size differed notably from the majority of the other interviews). Drift gillnet fishing outside of the Canoe Pass and Ladner Reach areas around Westham Island was also ignored because of an overall low sample size, and a lack of replication. Throughout the field sessions, attempts were made to conduct interviews in the South Arm and North Arm of the main river channel. Although sturgeon were occasionally caught in these deep water areas, sturgeon interceptions were more infrequent. Drift-net interviewers found it most effective to intercept sturgeon by watching each of the individual boats as they pulled their nets, thus interview efforts were concentrated in the shallower waters of Canoe Pass and Ladner Reach. However, the Westham fishing area outside of Canoe Pass and Ladner Reach is large and at times, the majority of the fleet was fishing in those outside areas.

Upstream of the Mission Bridge, fishing effort was monitored by counting set gillnets. Net counts were performed by an individual while driving a boat from the Mission Bridge upstream through the study area. Over the study period, six net counts were made in each of two study zones (Hatzic and Sumas). A single net count was made per zone during each of the first and last fishery openings (31 July to 1 Aug; 19 to 20 Aug). During each of the other two fishery openings (5 to 6 Aug; 12 to 13 Aug), two net-counts were made in each zone.

Catch per effort (measured as *catch per gillnet-hour* – i.e., the number of sturgeon caught per hour per gillnet) data were stratified by location and by week. Geographically, interviews fell into one of three strata: the Westham Island area, the Hatzic Slough area, and the areas upstream of Dewdney. These large-scale strata could be split into smaller zones. Most interviews in the Westham Island area occurred either in the Ladner Reach or Canoe Passage areas (see Figure 1). Interviews that occurred upstream of the Dewdney area were split into two zones: those near the Sumas confluence (rkm 92 to 99); and those farther upstream (rkm 105 to 155). Interviews in the Hatzic Slough area were not further subdivided.

Direct mortality rates, stratified by week and zone, were assessed from the interview data as a percentage of the total sturgeon catch that was caught dead. The precision of mortality rates was determined from the number of sturgeon collected, n, as half of the smallest measurable mortality increment, or 0.5 ($1/n$). When no dead sturgeon were collected, the minimum detectible mortality rate (assuming 95% confidence) was calculated from the sample size as:

$$1\text{-}10^{\log_{10}(1\ -\ 95\%)/n}.$$

This equation stems from a theoretical framework built around the probability of observing rare events. When events are rare, the probability of observing an event increases as the number of observations increases. Hence, for a given number of eventless observations, the maximum rate of occurrence of the rare event can be inferred.

2.3.1 Calculating Catch

Because of gear differences among strata (drift gillnets near Westham and set gillnets above Mission Bridge), and differences in the way that effort was tabulated, the methods used to calculate catch were different upstream and downstream of Mission Bridge.

2.3.1.1 Upstream of Mission Bridge (Set gillnets)

Catch per effort was calculated for each of the i interviews conducted during each of the o openings within each of the z zones as

$$cpe_{z,o,i} = S_{z,o,i} / G_{z,o,i}$$

where $S_{z,o,i}$ was the catch of sturgeon reported in each interview, and where $G_{z,o,i}$ was the fishing effort reported in each interview (in units of "gillnet·hours", or the number of gillnets used multiplied by the fishing duration for each net sampled). Zone-specific catch per effort, $\overline{cpe}_z$, was calculated as

$$\overline{cpe}_z = \sum_{o=1}^{4} \sum_{i=1}^{n_{z,o}} S_{z,o,i} \Big/ \sum_{o=1}^{4} \sum_{i=1}^{n_{z,o}} G_{z,o,i}$$

where $n_{z,o}$ was the number of interviews conducted in zone z during opening o, and where there were 4 fishery openings during the study period. Variance in $\overline{cpe}_z$ was calculated as the square of the standard error, using the formula

$$VAR\left\{\overline{cpe}_z\right\} = \frac{\sum_{o=1}^{4} \sum_{i=1}^{n_{z,o}} \left(cpe_{z,o,i} - \overline{cpe}_z\right)^2}{\left(\sum_{o=1}^{4} n_{z,o}\right)\left(\left(\sum_{o=1}^{4} n_{z,o}\right) - 1\right)}.$$

Effort was measured in the areas upstream of Mission using net-count data. Over the study period, six net counts (nc_j; j=1..6) were made. During the first and last fishery opening, a single net-count was made, requiring an assumption that this level of effort applied for the duration of the 48 hour fishery opening. Effort was expressed in units of "gillnet·hours",

$$E_{z,j} = nc_{z,j} d_j$$

where d_j was the duration of fishery opening (48 hours). During each of the other two fishery openings, two net-counts were made. In these cases, the duration of the opening was split into two periods, and effort (in "gillnet·hours") was calculated for each 24 hour period (d_j = 24 h). Variance around period- and zone-specific effort estimates was derived from the six observed net counts as

$$VAR\left\{\overline{E}_{z,j}\right\} = \frac{\sum_{j=1}^{6} \left(d_j \bullet nc_{z,j} - d_j \bullet \overline{nc}_z\right)^2}{(6)(6-1)}.$$

Catch associated with each of the j net-monitoring periods in each of the z zones was calculated as the product of effort and catch per effort,

$$\overline{C}_{z,j} = \overline{cpe}_z \overline{E}_{z,j} ,$$

and overall catch in each zone was the sum of the periods,

$$\overline{C}_z = \sum_{j=1}^{6} \overline{C}_{z,j} .$$

Variance around $\overline{C}_{z,j}$ was calculated using the Taylor series expansion

$$VAR\left\{\overline{C}_{z,j}\right\} = VAR\left\{\overline{cpe}_z\right\}\overline{E}^2_{z,j} + VAR\left\{\overline{E}_{z,j}\right\}\overline{cpe}^2_z + VAR\left\{\overline{cpe}_z\right\}VAR\left\{\overline{E}_{z,j}\right\}$$

and that around the overall catch was

$$VAR\left\{\overline{C}_z\right\} = \sum_{j=1}^{6} VAR\left\{\overline{C}_{z,j}\right\} .$$

The standard error of the overall catch for each zone was simply the square root of the variance,

$$SE\left\{\overline{C}_z\right\} = \sqrt{VAR\left\{\overline{C}_z\right\}} .$$

2.3.1.2 Westham Area (Drift gillnets)

Catch per effort during each of the o openings within each of the z zones in the Westham area was calculated as

$$cpe_{z,o} = S_{z,o} / M_{z,o} ,$$

where $S_{z,o}$ was the number of sturgeon collected from drift fishermen during the collection portions of the holding study, and $M_{z,o}$ was the duration of the collection efforts. Catch per effort was in units of "sturgeon per hour," and all boats in the monitoring zone were assumed to be fully sampled (i.e., no sturgeon were caught in the monitoring zone during collection periods that were not accounted for). With regard to this assumption, it should be noted that it was not possible to fully cover the entire fishing area near Westham Island, and sturgeon may have been caught outside of the two monitoring zones (Canoe Passage and the Ladner Reach) without being recorded.

Effort (in hours) was based on the duration of the fishery opening. Openings were 30 hours long. "Full" effort was assumed during 18 monitoring (i.e., daylight) hours, and half effort was assumed to occur during the 12 nighttime hours (8 PM to 8 AM). The total effort, in hours was therefore 18 + (0.5)(12) = 24. Note that the assumed differences between day and night were not based on data, but on subjective observations of field personnel, and are therefore a potential source of bias in the results. Note also that total effort likely varied among fishery openings (depending on tidal movements), but we cannot account for such differences.

Catch associated with each opening in each zone was calculated as the product of effort and catch per effort,

$$\overline{C}_{z,o} = 24\overline{cpe}_{z,o} ,$$

and overall catch in each zone was the sum of the periods,

$$\overline{C}_z = \sum_{o=1}^{3} \overline{C}_{z,o} .$$

Note that monitoring effort occurred in the Westham area during only three of the four fishery openings. Standard error could not be estimated using this methodology.

2.4 FRSCS Sturgeon Stewardship Programs

Two of the sturgeon stewardship programs managed by the Fraser River Sturgeon Conservation Society provided key information for the mortality study. The FRSCS Lower Fraser River White Sturgeon Monitoring and Assessment Program provided angler CPE data and a sturgeon length frequency distribution. In addition, the FRSCS Lower Fraser River First Nations Sturgeon Stewardship Program provided set gillnet sturgeon capture rates. Details of the FRSCS' Program methodologies can be found in Nelson et al. (2004). A summary of the methods, as they apply to the present study, are supplied below.

As part of the Lower Fraser River White Sturgeon Monitoring and Assessment Program, many volunteer recreational anglers and angling guides have been trained to collect biological information on sturgeon that they (or their clients) bring to the boat. Each sturgeon is measured (girth and fork length), assigned a condition code, and scanned for the presence of PIT tags (and, in most cases, tagged if none is present). In addition to catch, effort data (rod hours) is recorded (number of rods fished and the duration of the fishing trip); these data are recorded even if no fish are captured

The Lower Fraser River First Nations Sturgeon Stewardship Program is active in several locations in the lower Fraser, from Tsawwassen to Hope. The program increases sturgeon tag-application rates, and monitors catch rates and mortality. In select locations, participating fishermen are asked to put all caught sturgeon (alive and dead) into a "First Nations stewardship" pen similar to the pens used in our holding study. At least once daily, a technician visits the pen and inspects/samples each fish (live and dead) prior to release (all fish are scanned for the presence of a PIT tag, measured (fork length and girth), inspected for wounds and injuries, and assigned a condition code). The proportion of dead sturgeon in the First Nations stewardship pens provides additional data on direct capture-related mortality. The length distribution of sturgeon in the First Nations stewardship pens provides information about gear selectivity. For this report, the set gillnet data from the FRSCS First Nations sturgeon stewardship program was limited to those collected after June from 2002 to 2005 by Leq'aimel/Lakahahmen and Hatzic bands. Before July, water temperatures were cooler, and fishing activity targeted Chinook, thus nets had larger mesh sizes, and fishing behaviour may have differed relative to the sockeye-targeted fishing considered in this report. Data from previous years were considered unreliable for this study as the operational details of the First Nations stewardship program were still being communicated to the participants. For this study, fish from these First Nations stewardship pens were sometimes transferred to the holding pens to act as "filler" when desired stocking densities for the holding study were not otherwise reached.

3 RESULTS

3.1 Holding Study

From 23 July to 20 August, 2005, a total of 208 sturgeon were collected from three Fraser River locations. Initially, cooperation amongst fishermen varied, but improved markedly over time as they became more aware of the study. A total of 32 sturgeon were collected from drift gillnets near Westham Island (rkm 3.5 to 12). Of the 170 sturgeon collected near the Hatzic Slough (rkm 80 to 85), 94 were collected from anglers, and 76 from set gillnets. An additional six sturgeon were collected from set gillnets near the Sumas River confluence (rkm 95 to 96). There were significant differences among gear types in the proportion of fish exhibiting gillnet-rubbing marks, "net rash," split fins, and/or cuts (χ^2_2 = 79.6; P < 0.0001; Figure 2). It should be noted that major versus minor net-rashes and fin-splits were scored identically, thus the true magnitude of differences among gear types is muted in Figure 2 (i.e., real differences among gear types were likely more marked than presented in these analyses).

The sturgeon held in this study ranged from 28.5 to 134 cm fork length (Table 1). Although there were no significant differences in mean length among gear types ($F_{2,201}$ = 1.9; P = 0.15), visual inspection of data (Figure 3) suggested differences in the relative size distributions (because of the small sample sizes and the range in size classes, a chi square test for goodness of fit would be suspect). Specifically, the smallest size classes were only caught by set gillnets; the largest size class was only caught by angling; and drift gillnets did not catch any of the smallest or largest fish (Table 1); these differences may be related to regional differences in sturgeon size distribution rather than to gear selectivity.

The results presented in this report apply only to the size range of sturgeon that were collected during the study period. Although no sturgeon caught in drift or set gillnets were too large for the holding pens, several angler-caught fish were too large to be held. Six years of fork length data from the FRSCS (Figure 4) revealed that our results apply to 75% of the overall population of angler-caught fish (i.e., to those with fork length less than or equal to 135 cm).

3.1.1 Mortality Analysis

3.1.1.1 Three-day Holding Period

Ideally, all 208 sturgeon would have been monitored and released after a three-day holding period. However, 32 angled and set gillnet-caught fish were accidentally released early, and two fish escaped before the end of the holding period. Also, in efforts to control stocking densities in the holding pens, two fish were moved from one pen to another, and were therefore censored from the study. In all, 172 sturgeon were included in the three-day mortality analyses (32 drift gillnet, 76 angled and 64 set gillnet fish). Note that seven additional sturgeon, which were not included in the mortality analyses, were taken from a First Nations stewardship pen and placed in Holding Pen B on 20 August in order to increase stocking densities (Table 2).

The mortality rates for the three-day holding periods were significantly different among gear types (Table 2; $F_{2,15}$ = 9.8; P = 0.0019). Specifically, the overall three-day mortality rates of angling (2.6%) and drift gillnet (0%) fish were significantly lower than those of set gillnet fish (46.9%; Table 3). Due to the availability of sturgeon at the time of sampling, the stocking density, either in terms of number of fish, or of the total fork length of the fish in each pen, could not always be controlled. A Spearman's rank-order correlation between density and mortality was highly statistically significant (r_s = 1, P = 0). As such, density had to be factored out of analyses of the effect of gear type on post-release mortality.

In order to factor density out of the analysis, a mortality vs. gear-type ANCOVA was performed using density as the covariate. The ANCOVA showed that when density was factored out, mortality was nevertheless a significant function of gear type ($F_{2,12}$ = 6.5; P = 0.012). Neither density ($F_{1,12}$ = 0.2; P = 0.68) or the interaction term ($F_{2,12}$ = 0.08; P = 0.92) were statistically significant in the ANCOVA. Figure 5 shows that the slopes of the mortality-density lines did not differ significantly among gear types. Reading mortality values off the trend lines shows that at any given density level, predicted mortality is higher for set gillnet than for angling or drift gillnet sturgeon.

There was no statistical difference in fork length between sturgeon that survived the 3 day holding period vs. those that died ($F_{1,170} = 1.7$; $P = 0.19$). There was also no difference in condition upon capture ($\chi^2_2 = 1.7$; $P = 0.42$).

3.1.1.2 Two-day Holding Period

In order to explore the effects of holding time on mortality, we performed the same analyses using the mortality status of the sturgeon after 2 days, instead of after three. In the two-day mortality analyses, we were able to include the 32 fish that were accidentally released a day early (Table 4). In all, 204 sturgeon were included in the two-day mortality analyses (32 drift gillnet, 94 angled and 78 set gillnet fish).

Mortality rates after two days of holding were correlated to those after three days ($r = 0.77$; $P = 0.0002$), but significantly lower (paired $t_{18} = -2.6$; $P = 0.010$). The two-day mortality rates of angling and drift gillnet fish were both 0%, whereas that for set gillnet fish was 11.5% (Table 5). There were no significant differences in two-day mortality rates among gear types ($F_{2,19} = 2.6$; $P = 0.10$). The ANCOVA showed no significant factors ($P \geq 0.14$).

3.1.1.3 Single-day Holding Period

Mortality after a single day of holding was inconsequential. The only sturgeon that died was collected 12 Aug from a set gillnet, and was being held with eight other fish. It was 77 cm long. Though it had tail and dorsal splits when it was placed in the pen, it was in no worse shape than many other set gillnet fish collected throughout the study period (pers. obs.).

3.1.2 Water Quality Analysis

Dissolved oxygen values measured in a given Hatzic holding pen were correlated to those in other Hatzic area pens, and to those measured mid-channel (Appendix Table A1). Similarly, DO values measured inside the Westham holding pens were correlated to those from immediately outside of the pens, and to those measured about 4 m towards mid-channel (Appendix Table A2). Temperatures were similarly correlated (Appendix Tables A3 and A4). Paired t-tests showed that there were no significant differences among pens in the daily DO or temperature values (Appendix Tables A5 and A6). Similarly, there were no significant differences between values measured inside versus outside of the pens (Appendix Tables A7 and A8).

Differences between pens and the mid-channel were more marked than those among pens. In Hatzic and Westham holding pens, daily temperatures peaked higher, and DO values fell lower than those observed mid-channel (Appendix Figure A1). Paired t-tests showed that DO values in pen A and C, and temperature values in all six holding pens differed significantly from those measured mid-channel (Appendix Tables A5 and A6) or those measured 4 m towards mid-channel (Appendix Tables A7 and A8).

Since the pens were tied either to a dock or to a log-boom, they were in relatively shallow water, at the surface, and near river banks where water flows were less than mid channel. It is unlikely that holding sturgeon in the pens resulted in the increases in temperature or the deceases in DO. Rather, the differences between mid-channel DO/temperature readings and those in the pens were likely a function of current and depth.

3.2 First Nation Catch Interviews

In total, 127 First Nation catch interviews were included in the analysis (Table 6). Of these, 64 were from drift gillnet fishermen near Westham Island (rkm 3.5 to 12). These included 48 interviews in Canoe Passage and 16 in Ladner Reach. Near Hatzic Slough (rkm 80 to 85), 33 interviews with set gillnet fishermen were conducted. Upstream of Dewdney, another 30 set gillnet interviews were conducted. Of these, 22 occurred near the Sumas confluence (rkm 92 to 99) and eight farther upstream (rkm 105 to 155). Summary statistics for catch interviews and fishing effort are shown by zone and by week in Table 7.

Duration of fishing intervals varied significantly among zones (Table 6; $F_{4,122} = 43.6$; $P < 0.0001$). There was no significant difference between the duration of set gillnet fishing intervals near Hatzic (average 11.1 hours) vs. Sumas (average 9.9 hours). Hatzic and Sumas set gillnet fishing durations were significantly longer than those upstream of rkm 105 (average 5.8 hours). Fishing durations for set gillnets were significantly longer than those for drift gillnets. There were no significant differences in fishing duration among drift gillnet locations (average durations: Canoe Passage: 1.1 hours; Ladner reach: 0.9 hours).

3.2.1 <u>Catch Estimates</u>

Catch estimation was possible for four of the five study zones. A lack of effort data precluded catch estimation in the zone upstream of rkm 105. Elsewhere, catch was estimated as the product of CPE and effort.

In the Westham Island stratum, total sturgeon catch was estimated for three fishery openings (31 July to 1 Aug; 5 to 6 Aug; and 12 to 13 Aug) in two zones (Canoe Passage and Ladner Reach). No monitoring was included in the remaining parts of the Westham Island fishing area due to the lower chance of collecting sturgeon from fishermen elsewhere. In Canoe Passage, each of the three fishery openings were monitored for 18 hours, during which 5, 9 and 7 sturgeon were collected, respectively. Assuming 24 hours of equivalent fishing effort, the catch per opening for Canoe Passage was estimated to be 6.7, 12 and 9.3 sturgeon (Table 8), which sum up to 28 sturgeon. In the Ladner Reach, the three fishery openings were monitored for six, nine and six hours, during which sturgeon catches were 1, 2 and 6, respectively,. Assuming 24 hours of equivalent fishing effort, the catch per opening for the Ladner Reach was estimated to be 4, 5.3 and 24 sturgeon (Table 8), which sum up to 33.3 sturgeon. Note that the assumption of 24 hours of equivalent effort is not based on data, and may have biased the results.

At Hatzic, total sturgeon catch was estimated for all four fishery openings during the study period. Total catch was estimated to be between 306.6 and 644.8 sturgeon, with a point estimate at 475.7 sturgeon (Table 9). Catch per effort in the Hatzic area was estimated to be 0.17 sturgeon per gillnet hour. Net counts in the Hatzic area ranged from 12 to 22 nets. Within fishery openings, Hatzic catches ranged from 98.4 (during the 31 July to 1 Aug opening) to 155.8 sturgeon (during the opening from 5 to 6 Aug). Note that for two of the four fishery openings, a single net count was applied to the entire duration of the opening, which could have biased results.

In the Sumas zone, total sturgeon catch was estimated for all four fishery openings during the study period. Total catch was estimated to be between 36.1 and 92.4 sturgeon, with a point estimate at 64.2 sturgeon (Table 9). Catch per effort in the Sumas area was estimated to be 0.061 sturgeon per gillnet hour. There was no fishing effort observed near Sumas in the opening from 19 to 20 Aug. During other openings, net counts ranged from 4 to 10 nets. During the three openings with observed fishing effort, Sumas catches ranged from 14.6 (during the opening from 12 to 13 Aug) to 29.2 sturgeon (during the 31 July to 1 Aug opening).

3.2.2 Direct Mortality Estimates

The overall proportion of sturgeon that was dead at the time of net picking was 4.5%. Specifically, 4.8% of the sturgeon were dead in Canoe Passage, 0% in Ladner Reach (3.3% overall for Westham drift gillnets) and 6.2% at Hatzic (Table 6). The direct mortality rate did not differ significantly among zones ($F_{1,72}$ =0.92; P = 0.45; Table 6). According to the interviews conducted upstream of Dewdney, no sturgeon were dead in the nets. Although the direct mortality rate may be low, it is unlikely that our sampling effort was great enough to be confident in zero as the true value for these fisheries. Since the sample sizes for Ladner Reach, Sumas and the area Upstream of rkm 105 were 9, 24 and 22, respectively, we can say with 95% confidence that the direct mortality rates in these three areas were less than 28.3%, 11.7% and 12.7%, respectively (Table 6).

3.3 FRSCS Sturgeon Stewardship Programs

Six years of First Nations stewardship data were available for analysis of angling (2000 to 2005). For set gillnets, data were limited to those collected after June from 2002 to 2005 by Leq'aimel, Lakahahmen and Hatzic area bands. First Nations stewardship data included estimates of direct mortality of sturgeon caught by anglers and set gillnets; and length frequencies for 25,000 angled sturgeon and 1663 sturgeon caught in set gillnets.

The relative length frequency distribution of angled and set gillnet fish is shown in Figure 4. The length distribution of sturgeon captured by angling was wide, with a broad peak (representing 44% of the fish) between 70 and 110 cm fork length. In contrast, the length distribution of set gillnet fish was more skewed, and strongly peaked in the 60 to 70 cm fork length size range (and 74% of the fish were between 50 and 80 cm). The difference between gear types in size distribution indicates that some degree of gear selectivity must be occurring.

The *estimated* direct capture-related mortality for sturgeon captured by angling in the recreational fishery was 0% (no reported deaths of 25,219 sampled sturgeon captured by angling). From theoretical frameworks developed around the probability of observing rare events (see Methods), we calculated with 95% confidence, that the *actual* direct mortality rate of angled sturgeon is *less than* 0.012% (or about 1.2 mortalities per 10,000 angled sturgeon). From the FRSCS stewardship data, the angling CPE for the 2005 study period was estimated to be 1.07

sturgeon per boat trip (or 0.32 sturgeon per rod per trip). This translates into a maximum rate of one sturgeon mortality per 7881 boat trips (or per 25,961 rod trips).

The estimated direct capture-related mortality for set gillnet fish was 11.7% (or 194 reported deaths of 1663 sturgeon captured). The direct mortality rate varied among years, and was 10.4%, 14.3%, 11.6% and 9.0% in 2002, 2003, 2004 and 2005, respectively[4]. A comparison of the relative length distribution of live and dead set gillnet fish revealed disproportionate mortality in the 70 to 100 cm fork length range, and concomitantly, disproportionate survival in the 50 to 70 cm fork length range (Figure 6).

4 DISCUSSION

The potential listing of white sturgeon as endangered under SARA could affect the First Nations' drift and set gillnet salmon fisheries, which catch sturgeon incidentally, and could also impact the directed recreational fishery for sturgeon. User groups were interested in proactive research to determine the extent of direct and post-release mortality of the sturgeon caught in the respective fisheries, as a demonstrated effect (or lack of effect) could be of interest with regard to allowable harm provisions in the SARA legislation. Direct and post-release mortalities are discussed separately below.

4.1 Direct Mortality

Sturgeon mortality at the time of capture was 6.2% in Hatzic area set gillnets (Table 6). This estimate was lower than the 2005 estimate of lower Fraser set gillnet mortality from the FRSCS First Nations stewardship data (9.0%; see Section 3.3). This may have been due to the differences in data collection methods or fish handling. The direct mortality measured from study interviews included moribund fish as being alive, whereas those fish may have died after being released. In contrast, moribund fish that died shortly after being placed in the First Nations stewardship pens could be counted as dead in the stewardship data.

The First Nations stewardship data revealed a trend in the size-distribution of sturgeon mortality, with disproportionate mortality in the 70 to 100 cm fork length range (Figure 6). Observations of set gillnet mortalities (T. Nelson, unpublished data) revealed that the disproportionate mortality occurred in the size range where capture in gillnets can result in the sturgeons' gills being cut or its opercula being held tightly closed; without opercular movements, water does not move over the gills, and the sturgeon suffocates. Cut gills result in an excessive loss of blood. Fish of any size can get wrapped up in the gillnet mesh, but only those within a certain size range can be gilled or suffocated. The larger sturgeon tend to get caught around their snout and then "wrapped" in the gillnet mesh as they try to escape. Smaller sturgeon can pass through the mesh until it becomes wrapped around their bodies anterior to their opercula. Note that, aside from shorter soak times, drift gillnet mortality rates may be small relative to set

[4] Note that since 2002, one of the objectives of the FRSCS Lower Fraser River First Nations Sturgeon Stewardship Program has been to reduce sturgeon interception and mortality rates, and to improve the condition of release of live sturgeon removed from First Nation gill nets. The reduction in the overall direct mortality rates since 2003 may be due to increasing success of the FRSCS First Nations Sturgeon Stewardship program in meeting that objective.

gillnets because drift gillnets do not hang taught, therefore sturgeon intercepted in drift gillnets cannot readily "push" into the net (as they can with a set gillnet) and get the mesh stretched tightly around their opercula.

For some set and drift gillnet fisheries, direct mortality rates of 0% were observed, however, these cannot be confirmed through this preliminary study. Too few sturgeon were observed in First Nations catches, especially in areas outside of Hatzic, to make accurate assessment of direct mortality rates for these fisheries. In a hypothetical case (presented to clarify this point), say the actual mortality rate resulting from capture was 5% (or 1 out of 20). If only 4 sturgeon were collected, the chance of all of them being alive upon capture would be 81.5% [where 81.5% = $(1 - 5\%)^4$]. Even if you collected 20 sturgeon, there would still be a 35.8% [where 35.8% = $(1 - 5\%)^{20}$] chance of having them all be alive. To be 95% sure of observing a dead fish, a total of 59 sturgeon would need to be collected. Using similar logic, one can say that if 20 sturgeon were collected, and all were alive, we would be 95% confident that the actual mortality rate was less than 13.9%. In this study, the small sample sizes for Ladner Reach, Sumas and the area upstream of rkm 105 were such that we could only say with 95% confidence that the mortality rates in these three areas were less than 28.3%, 11.7% and 12.7%, respectively. In reality, it is likely that these direct mortality rates were much lower, and close to those for similar gear types in other zones (e.g., 4.8% for drift gillnets, and 6.2% for set gillnets).

Although some sturgeon captured by angling in the recreational fishery were injured upon capture (Figure 2), there were no reported deaths among the 25,219 sampled sturgeon. Using the methodology described above, we calculated with 95% confidence, that the *maximum actual* direct mortality rate of angled sturgeon was 0.012%. A maximum rate of mortality is presented because a point estimate cannot be calculated without observing an actual mortality event. Note that the collection of additional data showing survival of sturgeon caught by angling will result in decreases in the estimate of maximum mortality rate.

4.2 Post-release Mortality

In order to estimate post-release mortality, it was necessary to hold and monitor sturgeon. This methodology required that the sturgeon be subjected to unnatural conditions for the duration of the holding period. As such, the true *in situ* post-release mortality could not be accurately known. As sturgeon are bottom-dwelling fish, the stresses associated with being held in elevated densities in near-surface pens (with higher temperature and lower DO than observed mid-channel) may have contributed to the mortality observed during this study, especially during warmer water periods. With this in mind, the study was designed to provide a comparison of *relative* mortality rates among gear types. Specifically, the study was designed to determine the mortality rates in comparison to the directed catch-and-release recreational fishery, which is thought to have the smallest impact on the targeted sturgeon (FRSCS, unpublished data).

During the study, it became apparent that the sturgeon caught in drift gillnets or by anglers were in better condition than those collected from set gillnets, and in-season mortality estimates differed clearly among gear types. The results were complicated because catch rates (and hence collection rates) varied by gear-type, therefore our segregated holding design disallowed the control of stocking densities. The gear type associated with the highest mortality rates was also associated with the highest stocking densities; and no comparable densities were available for angling and drift gillnet fish to provide an adequate control. To rectify the problem, three actions were taken for the final week of angler and set gillnet sturgeon collection. First, the segregation of sturgeon by gear types was discontinued. Set gillnet and angling fish were no longer held in different pens. Second, local anglers were contacted and encouraged to come out for sturgeon angling "blitzes". Since the study occurred during a slower recreational angling period, the blitzes helped increase the sample size and stocking densities for angled fish. On the final weekend of the study, a blitz resulted in the capture of 46 sturgeon, or 60% of the total number of angler-caught sturgeon for the study period. Third, sturgeon from the FRSCS First Nations stewardship program were put into our holding pens to act as "filler" when the desired stocking densities could not otherwise be reached. The mortality of two angled sturgeon held for three days at higher pen densities amplified concerns about the holding densities affecting mortality in this study.

The *relative* post-release mortality rates presented in this study were not affected by stocking densities. An analysis of covariance showed that there was no difference among gear types in the way that mortality was affected by density (Figure 5 shows that the slopes for all gear types were nearly identical). More importantly, the ANCOVA showed that there was no demonstrable effect of density on mortality (Figure 5 shows that all slopes were nearly horizontal). This means that the issues regarding stocking density were moot with respect to the relative mortality analyses. Regardless of the stocking density, the mortality of set gillnet fish was significantly higher than that of drift gillnet or angled sturgeon. This result held regardless of the duration of the holding period (two versus three days).

The *absolute* post-release mortality rates that were generated from this study should not be taken at face value because they differed significantly depending on the duration of the holding period. One fish died after one day of holding, 9 after two days, and 32 after three days. Mortality rates in this study cannot be partitioned into portions related to capture and those related to holding. We are aware of no prior sturgeon holding studies to be used for comparison. However, holding studies for salmonids (that have different habitat requirements from sturgeon) showed that the majority of mortality occurred at the start of the holding period (e.g., Cox-Rogers 2004), suggesting an initial post-capture effect, and a minimal holding effect. In this study, we may have been observing a minimal capture effect, followed by an elevated holding effect. We cannot determine whether post-release mortality would have increased over a three day period had the fish been released into the river rather than into holding pens. However, given that the three-day mortality of the drift gillnet and angling fish was low, the assumption can be made that holding-related mortalities were limited for fish held in those conditions, and that the majority of the mortality observed for the set gillnet fish was likely related to capture. Moreover, although we cannot know the exact capture-related mortality rates, this limited study indicates that those for set gillnet fish were higher than those for other gear types.

The post-release mortality rates were significantly different among gear types, yet the differences may have been more striking than those revealed by examining mortality rates alone. Although the five-point "condition code" scale could not capture the differences, it was apparent that the health of the live sturgeon at the time of capture differed among gear types (Figure 2). Fish caught by anglers during the study tended to be clean white, with little injury other than a single puncture wound from a barbless hook, typically in the outer edge of the mouth. (More extensive injuries from angling can occur and have been observed outside this study; Erin

Stoddard, MOE Surrey, pers. comm.). Sturgeon captured by angling exhibited no redness, "rash," or bruising, even after 72 hours of holding. Set gillnet sturgeon typically had red-coloured body, "rashes" and bruising resulting from rubbing and thrashing in the net, tattered and split fins, and sometimes missing or bleeding scutes (compare Photo 2 with Photo 3). Extensive "rash" and bruising was not typically overly evident at the time that these sturgeon were removed from the net; the condition was most notable after 24 hours, and the severity of the condition increased in most cases over the entire holding period. Drift gillnet caught fish exhibited many of the same injuries as the set gillnet caught fish, but not to the same extent, likely owing to shorter soak/entanglement times. As with drift gillnet caught fish, sturgeon caught in set gillnets would likely suffer minimal injuries if they were entangled for a short time only, but injuries likely become more significant the longer they are left in the nets. The average soak time for set gillnets was as high as 11.1 hours, compared to 1.1 hours for drift gillnets.

4.3 Sturgeon Catch Rates

Caution must be used when extrapolating our catch per effort rates to larger areas or to other fisheries. Our interviews occurred only in areas where sturgeon were most likely to be caught, thus blind extrapolation of catch rates is not appropriate and would lead to overestimation of river-wide sturgeon catch (and underestimation of sturgeon impacts). Catch estimates presented in this report are therefore restricted to the First Nations food, social and ceremonial sockeye fisheries in the study sampling zones (i.e., the places where interviews were conducted).

Upstream of Mission Bridge, the estimates of total sturgeon catch were imprecise. Wide confidence bounds resulted from variation in CPE among interviews, variation in the set gillnet counts among days, and overall low sample sizes. Nevertheless, it can be clearly seen from our results that large variation in catch rates occurred within the DFO catch statistical divisions[5]. Specifically, the estimated catch in the Hatzic area was 7.5 times greater than that in the adjacent Sumas area. Therefore, it is reasonable to assume that catch rates at any given location in the river are unknown without local interview data. Further stratification of the DFO statistical divisions would result in more accurate point estimates and more precision around the estimates.

In the Westham area, we estimated total sturgeon catch to be 28 for Canoe Passage and 33.3 for Ladner Reach (total of 61.3 sturgeon for the surveyed areas over three openings). The actual reported sturgeon catch for the Tsawwassen First Nation for the three surveyed fishery openings was 59 sturgeon (Nikki Jacobs, Tsawwassen First Nation Fisheries, pers. comm.). Since our estimates represented the efforts of Tsawwassen and Musqueam First Nations combined, it appears that we may have under-estimated the total sturgeon catch. Note however, that the Tsawwassen First Nation estimate included fish caught anywhere downstream of the Port Mann Bridge, whereas our estimates were restricted to two reaches within that management area. It was our assumption that the sturgeon catch rates in areas outside of Canoe Passage and Ladner Reach would be low due to deeper water conditions. During the study period, we collected two sturgeon from Sea Reach and one off Deas Island, indicating that catch rates in the

[5] DFO catch statistical divisions are: 1) below Port Mann Bridge; 2) Port Mann to Mission; 3) Mission to Harrison; 4) Harrison to Hope; and 5) Hope to Sawmill).

un-surveyed areas were not zero[6]. Again, further stratification of the DFO statistical divisions would have helped to accurately estimate sturgeon catches.

4.4 Total Sturgeon Catch and Mortality

To estimate the total effect of fishing on sturgeon mortality, it was necessary to combine the catch estimates with the direct and post-release mortality estimates. For example, the Canoe Passage total catch was estimated at 28.0 sturgeon, of which 4.8% would be expected to be dead upon capture, and for which 0.0% would be expected to die after being held for three days. Overall, it was calculated that 1.3 sturgeon died in Canoe Passage during the study period (Table 10). Note that the confidence bounds around the estimates of total mortality were derived entirely from the error associated with the estimates of direct and delayed mortality rates, and not from Westham area catch rates (for which confidence limits could not be computed).

Using the 94 sturgeon collected from anglers during the study as an estimate of the total number of sturgeon captured by the recreational fishery at Hatzic, we calculated the total number of mortalities to be either zero or 2.5 sturgeon (Table 10), depending on how the holding study results are interpreted (and whether a holding effect could be confirmed). If the three-day holding results are taken at face-value, then the total angling-related sturgeon mortality would be 2.5 fish. However, the mortality rate for angled fish held for two days was 0%. Assuming the mortality observed on day three was not the result of capture, but rather an artifact of being held in artificial conditions, then calculated total mortality for sturgeon caught by anglers in the Hatzic area during the 2005 study period would be zero.

The majority of the sturgeon mortality came from the set gillnets above Mission Bridge. Depending on how the holding study results are interpreted (and whether a holding effect is considered), either 80.8 or 238.6 sturgeon were calculated to have died from Hatzic set gillnets during the study period (Table 10). Using the lower and upper confidence bounds on the catch estimates, the range in total mortality at Hatzic was calculated to be 52.1 to 109.6 using the two-day post-release mortality rate; and 153.8 to 323.3 using the three-day post-release mortality rate. Regardless of the exact values, it is apparent that the set gillnets had significantly more impact on sturgeon populations than either drift gillnets or angling. Mortalities from set gillnets could potentially be reduced by decreasing soak times or by fishing them in areas where sturgeon bycatch is lower. For example, the total sturgeon mortality at Sumas, calculated to be either 7.4 or 30.1 (Table 10), although still larger than other gear types, was considerably lower than for Hatzic.

Our results cannot be extrapolated to calculate overall sturgeon mortality in the river in 2005, either for the First Nations food, social and ceremonial sockeye fishery, or for the recreational fishery. Firstly, it is not clear which post-release mortality estimates should be used. There is no strong evidence that the mortality after the three-day holding period was more accurate than that after two days. Secondly, the fish were collected from a few isolated locations, where fishing practices differed from other parts of the river. For example, interviews

[6] File data from the FRSCS Lower Fraser River White Sturgeon Monitoring and Assessment Program (from 2000-2005) also indicate that sturgeon interceptions occur consistently in First Nation drift gillnet fisheries in the section of river downstream of the Mission Bridge to the Strait of Georgia.

revealed that soak times upstream of rkm 105 were significantly longer than those at the Hatzic Slough. Further there are many more salmon gillnet fisheries that occur on the lower Fraser River throughout the year that use different gear types and techniques, and there are many significantly more intensive periods for recreational angling. Finally, the monitoring zones were selected because of their propensity to capture sturgeon, which were needed for the holding portion of the study. As such, the extrapolation from our zones to the rest of the river would result in an inappropriate estimation of the total sturgeon impact, and likely an overestimation of the number of sturgeon captured, and the number killed.

Sturgeon population recovery rates could be improved by promoting fishing practices that result in reduced sturgeon catch rates. For example, the likelihood of capturing a sturgeon depended on fishing technique (drift gillnetting in deeper water tended to catch fewer sturgeon) or location (fishing near the Sumas River mouth had lower sturgeon catch per effort than at Hatzic). Moreover, post-release survival of sturgeon likely depends on handling techniques. Sturgeon released immediately would be expected to survive better on average than those left on the bottom of a fishing boat for long periods before being released. Education and outreach programs such as those administered by the FRSCS should help promote improved fishing practices.

4.5 Caveats

It is important to further acknowledge three main caveats associated with this study, such that appropriate caution can be used when interpreting the results. Firstly, relatively few fish were captured and/or collected during the study period. As expected, the lower sample sizes affected the accuracy of the point estimates of direct and three-day mortality rates. The observations of 0% direct mortality (and in the case of drift fisheries, delayed mortality) are also likely artifacts of small sample sizes. As such, where 0% direct mortality was observed, a method for calculating *maximum* mortality rate was used, but even this latter method was linked to sample size. For example, many samples existed for sturgeon caught by anglers, and a relatively low maximum rate was calculated; conversely, fewer data exist for sturgeon caught in the drift gillnet fisheries, and the maximum rate that were calculated were unrealistically high.

The second main caveat is that only a single set gillnet fishery was sampled when estimating delayed mortality. The interview data showed that fishing practices varied among locations, thus it follows that differences in post-release mortality may also exist. By sampling only a single set gillnet fishery, no measure of variability among fisheries could be obtained.

Finally, it is necessary to discuss the effects of holding on survival. Fish held in near-surface pens experienced pressures different from those to which they are habituated on the riverbed. Moreover, fish held in pens experienced elevated temperatures, and decreased DO relative to mid-channel areas. Even after density was mathematically factored out of the analysis of delayed mortality rates, there was an increase in mortality rates with holding time. The inability to partition the delayed mortality into natural and holding-related factors causes bias in our estimates of total mortality by gear type (Section 4.4). Nevertheless, there is *no* holding-time bias associated with our among-gear comparisons of survival because comparisons were *relative*, and made while controlling for holding time.

5 RECOMMENDATIONS

- Of the three gear types examined, set gillnets pose the biggest threat to the recovery of endangered sturgeon populations. Further attention should be given to this problem.

- The effects of holding on survival could be explored through additional holding studies, experimentally varying density and/or temperature, and conducted at varying times of year.

- Survey and monitoring methods could be modified to provide reliable estimates of sturgeon catch (and mortality). Modifications include further subdivision of current DFO monitoring zones.

- Sturgeon population recovery rates could be improved by promoting fishing practices that result in reduced sturgeon catch rates.

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TABLES

Table 1. The mean, median, minimum and maximum fork lengths (cm) and sample size (n) of sturgeon held for three days, by collection gear type.

	Angling	Drift Gillnet	Set Gillnet
Minimum	40	55	28.5
Median	72.3	78.5	69
Mean	77.5	77	71.8
Maximum	134	104	126
n	94	32	76

Table 2. **Summary of sturgeon mortality after three days of being held in pens. Sturgeon were caught using one of three gear types. Also shown are stocking densities (number of fish) and the sum of the fork lengths of all fish in each pen. Mortality was not calculated when count was less than three.**

Gear	Date	Pen	Count	Died	Lived	Density	Sum (FL)	3 Day Post-Release Mortality
Angling	23 Jul	A	12	0	12	12	915.5	0.0%
Angling	24 Jul	B	7	0	7	7	474	0.0%
Angling	5 Aug	A	4	0	4	4	327	0.0%
Angling	6 Aug	B	2	0	2	2	156	n/a
Angling	9 Aug	C	5	0	5	5	527	0.0%
Angling	19 Aug	A	14	0	14	14	1040	0.0%
Angling	19 Aug	D	13	1	12	15	997	7.7%
Angling	20 Aug	B	7	1	6	14	1090	14.3%
Angling	20 Aug	C	12	0	12	13	1062	0.0%
Drift	31 Jul	E	1	0	1	1	84	n/a
Drift	1 Aug	F	6	0	6	6	409	0.0%
Drift	5 Aug	E	2	0	2	2	151	n/a
Drift	6 Aug	F	9	0	9	9	704	0.0%
Drift	12 Aug	E	4	0	4	4	280	0.0%
Drift	13 Aug	F	10	0	10	10	836	0.0%
Set	31 Jul	B	9	0	9	9	609	0.0%
Set	31 Jul	C	13	5	8	13	960	38.5%
Set	1 Aug	D	10	2	8	12	876	20.0%
Set	5 Aug	C	14	11	3	14	1004.7	78.6%
Set	6 Aug	D	10	9	1	10	739	90.0%
Set	12 Aug	D	6	3	3	6	471	50.0%
Set	19 Aug	D	1	0	1	15	997	n/a
Set	20 Aug	C	1	0	1	13	1062	n/a

Table 3. **Season-wide summary of sturgeon mortality after three days of being held in pens. Sturgeon were caught using one of three gear types. Also shown is average stocking density by gear type.**

Gear	Total Count	Total Died	Total Lived	Average Density	Average Total FL	3 Day Post-Release Mortality
Angling	76	2	74	9.56	732.06	2.6%
Drift	32	0	32	5.33	410.67	0.0%
Set	64	30	34	11.50	839.84	46.9%

Table 4. **Summary of sturgeon mortality after two days of being held in pens. Sturgeon were caught using one of three gear types. Also shown are stocking densities (number of fish) and the sum of the fork lengths of all fish in each pen. Mortality was not calculated when count was less than three.**

Gear	Date	Pen	Count	Died	Lived	Density	Sum (FL)	2 Day Post-Release Mortality
Angling	23 Jul	A	12	0	12	12	915.5	0.0%
Angling	24 Jul	B	7	0	7	7	474	0.0%
Angling	1 Aug	A	2	0	2	2	138	n/a
Angling	5 Aug	A	4	0	4	4	327	0.0%
Angling	6 Aug	B	2	0	2	2	156	n/a
Angling	9 Aug	C	5	0	5	5	527	0.0%
Angling	12 Aug	A	3	0	3	9	669.1	0.0%
Angling	13 Aug	C	13	0	13	13	1025.5	0.0%
Angling	19 Aug	A	14	0	14	14	1040	0.0%
Angling	19 Aug	D	13	0	13	15	997	0.0%
Angling	20 Aug	B	7	0	7	14	1090	0.0%
Angling	20 Aug	C	12	0	12	13	1062	0.0%
Drift	31 Jul	E	1	0	1	1	84	n/a
Drift	1 Aug	F	6	0	6	6	409	0.0%
Drift	5 Aug	E	2	0	2	2	151	n/a
Drift	6 Aug	F	9	0	9	9	704	0.0%
Drift	12 Aug	E	4	0	4	4	280	0.0%
Drift	13 Aug	F	10	0	10	10	836	0.0%
Set	31 Jul	B	9	0	9	9	609	0.0%
Set	31 Jul	C	13	0	13	13	960	0.0%
Set	1 Aug	D	10	0	10	12	876	0.0%
Set	5 Aug	C	14	1	13	14	1004.7	7.1%
Set	6 Aug	D	10	6	4	10	739	60.0%
Set	12 Aug	D	6	1	5	6	471	16.7%
Set	12 Aug	A	6	1	5	9	669.1	16.7%
Set	12 Aug	B	8	0	8	8	504	0.0%
Set	19 Aug	D	1	0	1	15	997	n/a
Set	20 Aug	C	1	0	1	13	1062	n/a

Table 5. Season-wide summary of sturgeon mortality after two days of being held in pens. Sturgeon were caught using one of three gear types. Also shown is average stocking density by gear type.

Gear	Total Count	Total Died	Total Lived	Average Density	Average Total FL	2 Day Post-Release Mortality
Angling	94	0	94	9.17	701.76	0.0%
Drift	32	0	32	5.33	410.67	0.0%
Set	78	9	69	10.90	789.18	11.5%

Table 6. **Season-wide summary statistics for sturgeon direct mortality from interviews with First Nation fishermen in the lower Fraser River, summer 2005. Direct mortality rates presented with measured accuracy (±). When no dead sturgeon were collected, a minimum detectible mortality rate was calculated from the sample size, and the true mortality rate was reported as being less than the detectible rate.**

Stratum Zone	Gear Type	Number of Interviews	Total Sturgeon Caught	Dead Sturgeon Caught	Direct Mortality Rate	Average Duration (hours)	cpe: Sturgeon per fishery hour	cpe: Sturgeon per gillnet hour
Westham Island	Drift	64	30	1	3.3% ± 1.7%	1.1	0.47	
Canoe Passage	Drift	48	21	1	4.8% ± 2.4%	1.1	0.44	
Ladner Reach	Drift	16	9	0	0% (< 28.3%)	0.9	0.56	
Hatzic Slough	Set	33	146	9	6.2% ± 0.3%	11.1		0.17
Up from Dewdney	Set	30	46	0	0% (< 6.3%)	7.7		0.077
Sumas	Set	22	24	0	0% (< 11.7%)	9.9		0.061
> rkm 105	Set	8	22	0	0% (< 12.7%)	5.8		0.108
Total		127	222	10	4.5% ± 0.2%			

Table 7. Weekly summary statistics for interviews with First Nation fishermen in the lower Fraser River, summer 2005.

	Zone	Gear Type	Study period: 31 Jul - 1 Aug	5 - 6 Aug	12 - 13 Aug	19 - 20 Aug
Number of Interviews	Canoe Passage	Drift	10	24	14	0
	Ladner Reach	Drift	1	7	8	0
	Hatzic	Set	12	10	5	6
	Sumas	Set	9	8	5	0
	> rkm 105	Set	0	7	1	0
Number of Sturgeon Caught	Canoe Passage	Drift	5	9	7	-
	Ladner Reach	Drift	1	2	6	-
	Hatzic	Set	64	41	20	21
	Sumas	Set	11	7	6	-
	> rkm 105	Set	-	18	4	-
Mean Net Length (m)	Canoe Passage	Drift	91.4	91.4	91.4	-
	Ladner Reach	Drift	91.4	91.4	91.4	-
	Hatzic	Set	33.0	30.5	30.5	30.5
	Sumas	Set	50.8	49.5	30.5	-
	> rkm 105	Set	-	29.6	30.5	-
Mean Net Depth (meshes)	Canoe Passage	Drift	60	60	60	-
	Ladner Reach	Drift	60	60	60	-
	Hatzic	Set	60	60	60	60
	Sumas	Set	33.3	30	30	-
	> rkm 105	Set	-	34.3	30	-
Mean Mesh Size (cm)	Canoe Passage	Drift	12.7	12.7	12.7	-
	Ladner Reach	Drift	12.7	12.7	12.7	-
	Hatzic	Set	13.0	13.1	13.0	13.0
	Sumas	Set	12.9	12.1	12.3	-
	> rkm 105	Set	-	13.4	12.7	-
Mean Number of Nets per Interview	Canoe Passage	Drift	1.0	1.0	1.0	-
	Ladner Reach	Drift	1.0	1.0	1.0	-
	Hatzic	Set	1.8	2.4	2.8	2.0
	Sumas	Set	1.3	1.5	1.0	-
	> rkm 105	Set	-	1.0	1.0	-
Mean Fishing Time per Interview (hours)	Canoe Passage	Drift	1.1	1.4	1.1	-
	Ladner Reach	Drift	0.3	1.1	0.9	-
	Hatzic	Set	12.6	10.3	12.2	8.5
	Sumas	Set	13.4	17.7	8.7	-
	> rkm 105	Set	-	23.5	39.3	-

Table 8. **Sturgeon catch estimates for Canoe Passage and Ladner Reach during three fishery openings. Catch per effort was estimated as the number of sturgeon collected over the duration of the sturgeon monitoring effort.**

	Monitoring effort (h)	Observed Catch	Catch per h	Total Effort (h)	Sturgeon Catch
Canoe Passage					
31 July - 1 Aug	18	5	0.28	24	6.7
5 - 6 Aug	18	9	0.50	24	12.0
12 - 13 Aug	18	7	0.39	24	9.3
Ladner Reach					
31 July - 1 Aug	6	1	0.17	24	4.0
5 - 6 Aug	9	2	0.22	24	5.3
12 - 13 Aug	6	6	1.00	24	24.0
Overall Catch				**Canoe Passage**	**28.0**
				Ladner Reach	**33.3**
				Total	**61.3**

Table 9. **Effort and catch estimates for Hatzic and Sumas sturgeon during six time periods (each associated with a single net-count estimate of fishing effort). Values in brackets are standard errors of the estimates.**

	Net Counts		Effort (gillnet hours)		Sturgeon Catch	
Time Period	Sumas	Hatzic	Sumas	Hatzic	Sumas	Hatzic
31 July - 1 Aug	10	12	480 (67.5)	576 (73.3)	29.2 (11.3)	98.4 (42.5)
5 Aug	6	16	144 (33.8)	384 (36.7)	8.8 (3.8)	65.6 (27.7)
6 Aug	8	22	192 (33.8)	528 (36.7)	11.7 (4.7)	90.2 (37.6)
12 Aug	4	14	96 (33.8)	336 (36.7)	5.8 (3.0)	57.4 (24.5)
13 Aug	6	12	144 (33.8)	288 (36.7)	8.8 (3.8)	49.2 (21.3)
19 - 20 Aug	0	14	0 (67.5)	672 (73.3)	0.0 (4.4)	114.8 (49.0)
Total					**64.2 (14.4)**	**475.7 (86.3)**

Table 10. Estimates of total sturgeon mortality in the surveyed zones during the survey periods, assuming that two-day and three-day holding mortality rates are meaningful estimates of *in situ* post-release mortality.

Zone	Gear	Catch	Direct Mortality	2 day post-Release Mortality	3 day post-Release Mortality	Total Dead Sturgeon After 2 days	Total Dead Sturgeon After 3 days
Canoe Passage	Drift	28	4.8%	0%	0%	1.3	1.3
Ladner Reach	Drift	33.3	0%	0%	0%	0	0
Hatzic	Angling	94	0.012%	0%	2.6%	0	2.5
Hatzic	Set	475.7	6.2%	11.5%	46.9%	80.8	238.6
Sumas	Set	64.2	0%	11.5%	46.9%	7.4	30.1

FIGURES

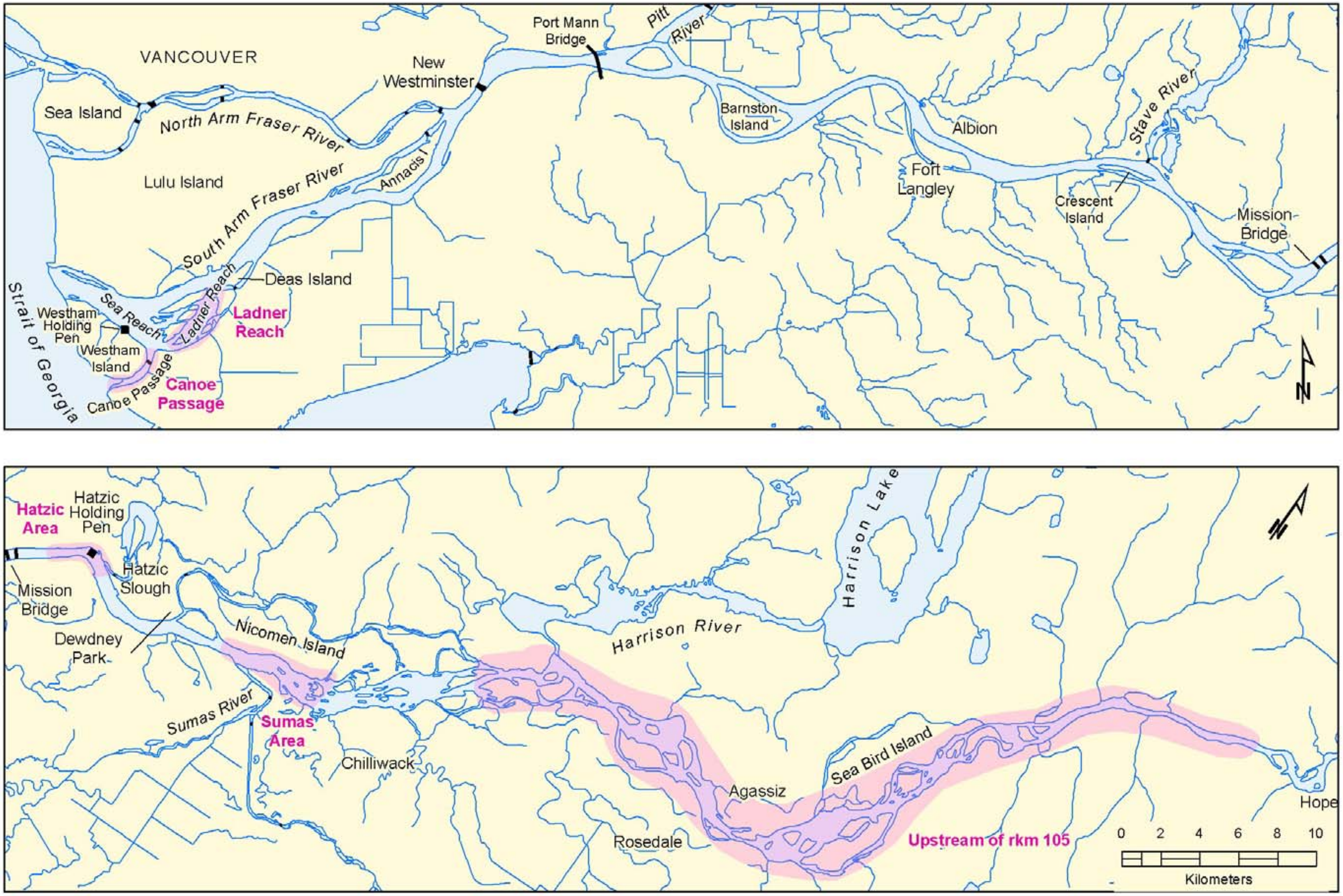


Figure 1. **Map of study area. The five study zones are shaded pink. The five zones combine to make three strata. The two down-river zones are combined into one stratum; the Hatzic zone is a stratum; and the two zones upstream of Dewdney Park make up the third stratum. The holding pen locations are indicated by black squares.**

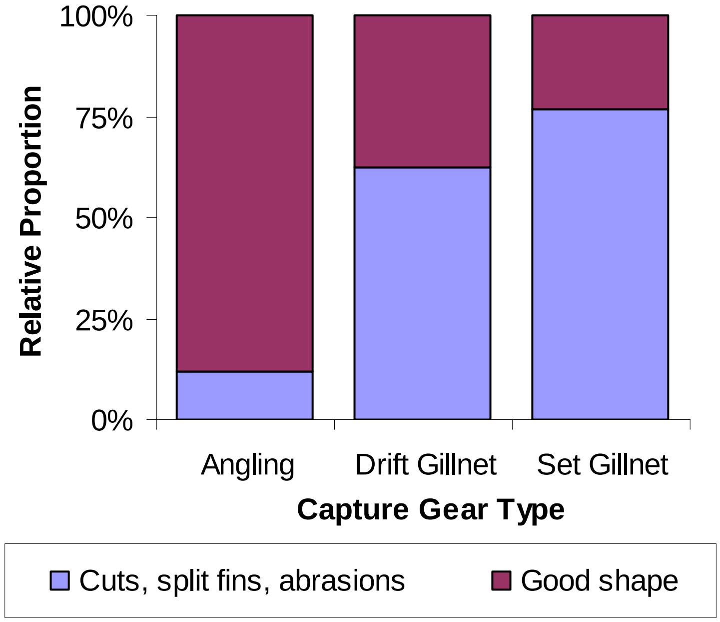


Figure 2. **The relative proportions of sturgeon showing cuts, split fins or abrasions upon collection from three gear types, summer 2005. Note that major versus minor net-rashes and fin-splits were scored identically, thus differences between set and drift gillnet fish were less apparent in these analyses.**

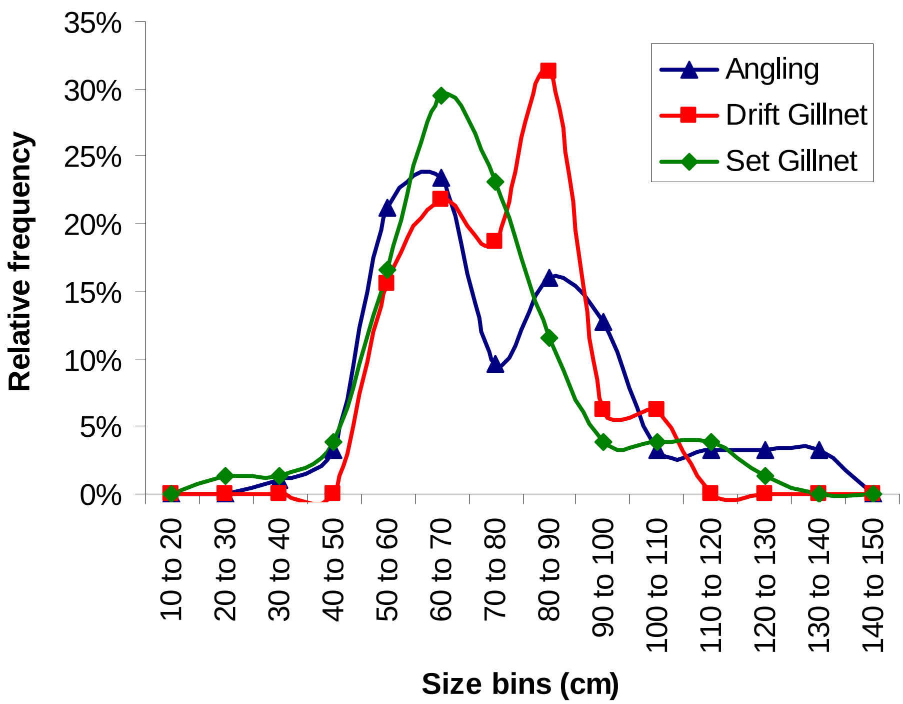


Figure 3. **The relative size distribution of sturgeon collected from three gear types, summer 2005.**

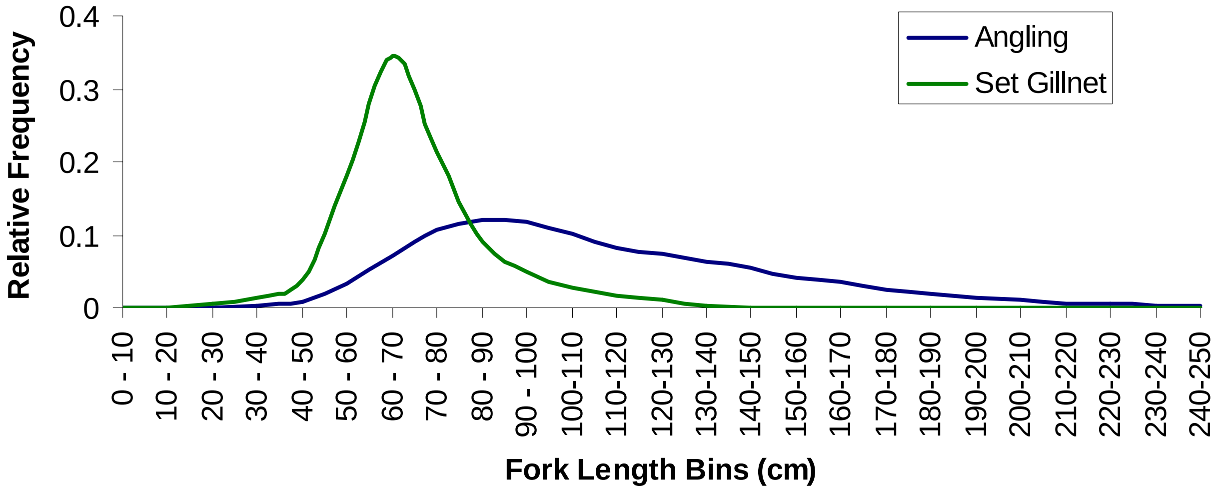


Figure 4. **The relative size distribution of sturgeon caught in two gear types from six years of angling data and four years of Leq'aimel, Lakahahmen and Hatzic set gillnet data from the FRSCS First Nations stewardship database.**

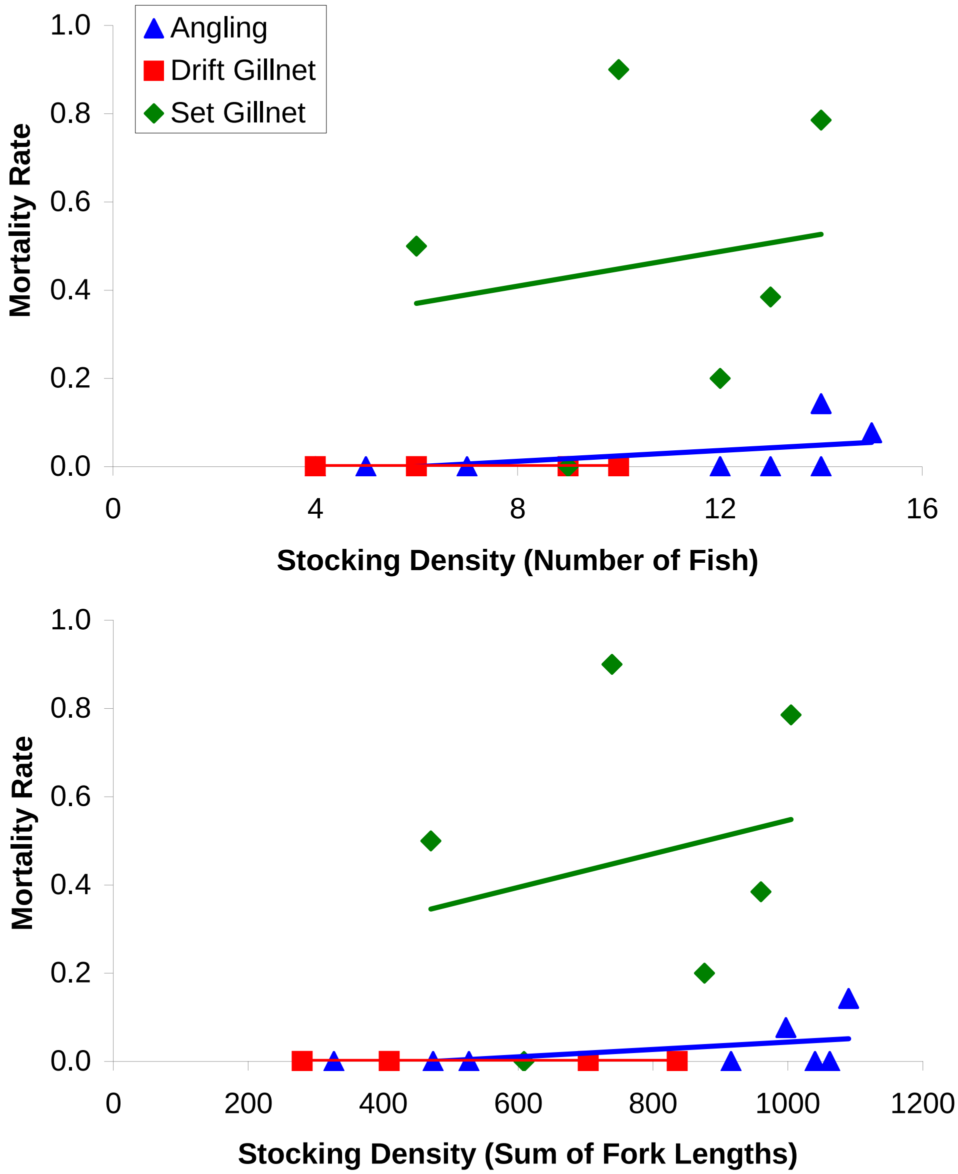


Figure 5. **The relationship between mortality and stocking density for each gear type. Holding period was three days. Upper panel: Stocking density is the number of fish in each holding pen. Lower panel: Stocking density is the sum of the fork lengths of all the fish in each pen.**

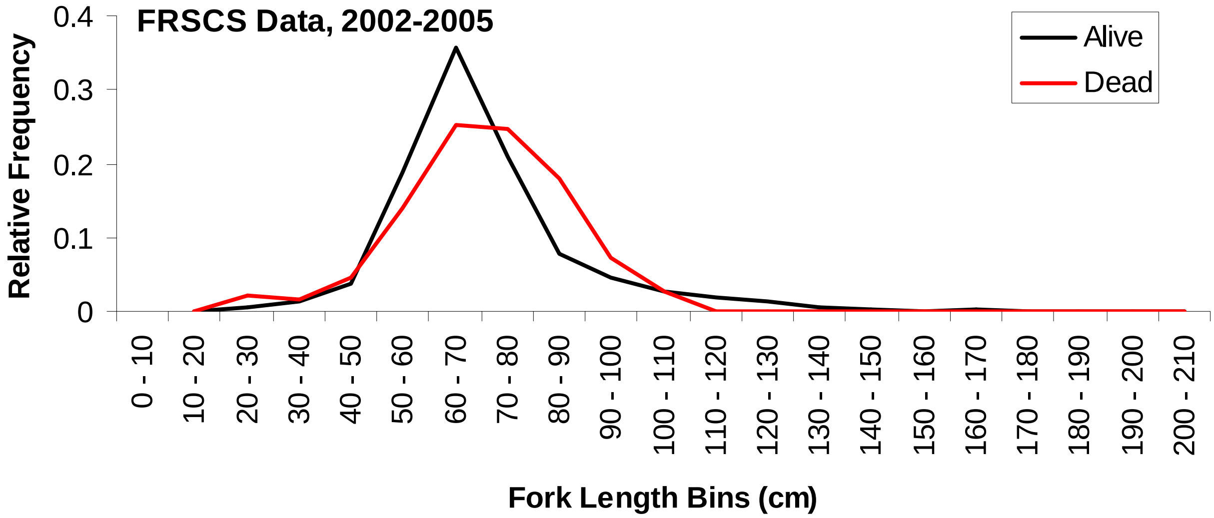


Figure 6. **The relative size distribution of set gillnet caught sturgeon, caught alive versus dead, from four years of Leq'aimel, Lakahahmen and Hatzic data from the FRSCS First Nations stewardship database.**

PHOTOS

Photo 1. **Sturgeon holding pens. Holding pen volume was 2718 L , and measured 2.43 m long, 1.22 m wide (front to back) and 0.91 m deep (top to bottom), or 8x4x3 feet.**

Photo 2. **Example of clean, white body condition of an angled sturgeon after a three-day holding period.**

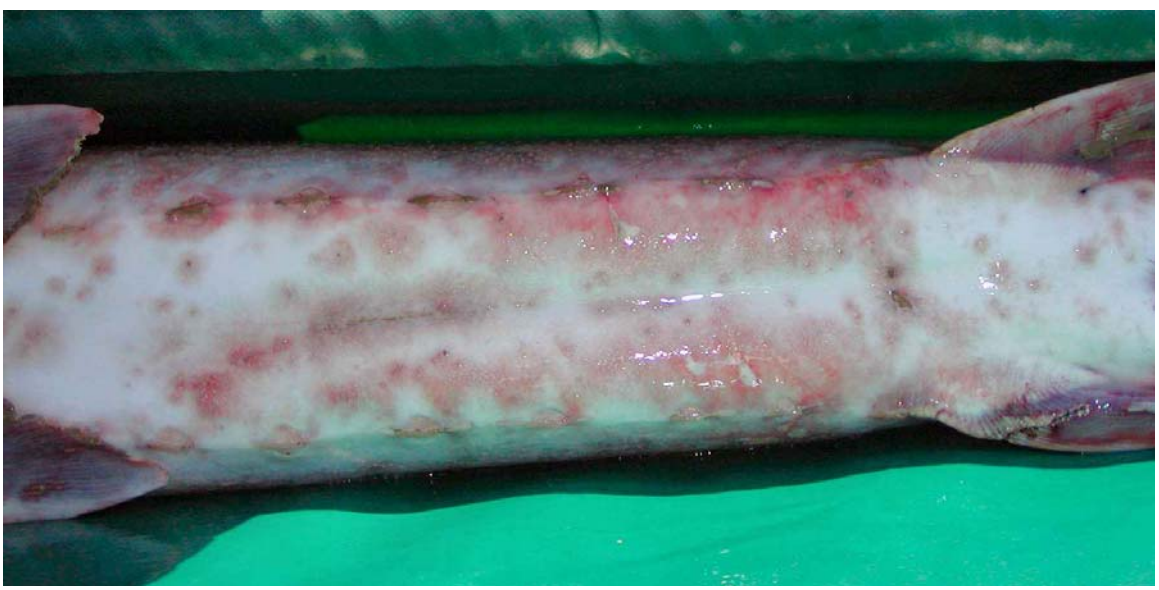


Photo 3. **Example of set gillnet sturgeon bodily markings after a three-day holding period.**

APPENDIX A – HOLDING PEN WATER QUALITY

Appendix Table A1. **Correlations among dissolved oxygen values measured in Hatzic holding pens and mid-channel surface water. Correlation coefficients are shown above the diagonal, and *P* values below the diagonal. *P* values in bold font were statistically significant.**

	Pen A	Pen B	Pen C	Pen D	mid-channel
Pen A		0.69	0.80	0.34	0.63
Pen B	**0.01**		0.95	0.67	0.67
Pen C	**0.005**	< **0.0001**		0.57	0.51
Pen D	0.28	**0.009**	0.08		0.60
mid-channel	**0.03**	**0.009**	0.052	**0.01**	

Appendix Table A2. **Correlations among dissolved oxygen values measured in Westham holding pens, immediately outside of the pens, and at locations 4m away from the pens. Correlation coefficients are shown above the diagonal, and *P* values below the diagonal. *P* values in bold font were statistically significant.**

	Pen E/F in	Pen E/F out	4 m away
Pen E/F in		0.99	0.94
Pen E/F out	< **0.0001**		0.91
4 m away	**0.0006**	**0.0046**	

Appendix Table A3. **Correlations among temperature values measured in Hatzic holding pens and mid-channel surface water. Correlation coefficients are shown above the diagonal, and *P* values below the diagonal. *P* values in bold font were statistically significant.**

	Pen A	Pen B	Pen C	Pen D	mid-channel
Pen A		0.98	0.99	0.74	0.52
Pen B	< **0.0001**		0.98	0.85	0.61
Pen C	< **0.0001**	< **0.0001**		0.89	0.48
Pen D	**0.006**	**0.0001**	**0.0006**		0.77
mid-channel	0.08	**0.02**	0.07	**0.0004**	

Appendix Table A4. **Correlations among temperature values measured in Westham holding pens, immediately outside of the pens, and at locations 4m away from the pens. Correlation coefficients are shown above the diagonal, and *P* values below the diagonal. *P* values in bold font were statistically significant.**

	Pen E/F in	Pen E/F out	4 m away
Pen E/F in		0.95	0.93
Pen E/F out	**0.0012**		0.92
4 m away	**0.0010**	**0.0034**	

Appendix Table A5. **Comparisons among dissolved oxygen values measured in Hatzic holding pens and mid-channel surface water. Mean differences are shown above the diagonal, and *P* values below the diagonal. ns = not statistically significant.**

	A	B	C	D	mid-channel
A		-0.69	-0.89	-1.98	-2.33
B	ns		0.02	-1.52	-1.56
C	ns	ns		-0.69	-2.67
D	ns	ns	ns		-0.53
mid-channel	**0.038**	ns	**0.048**	ns	

Appendix Table A6. **Comparisons among temperature values measured in Hatzic holding pens and mid-channel surface water. Mean differences are shown above the diagonal, and *P* values below the diagonal. ns = not statistically significant.**

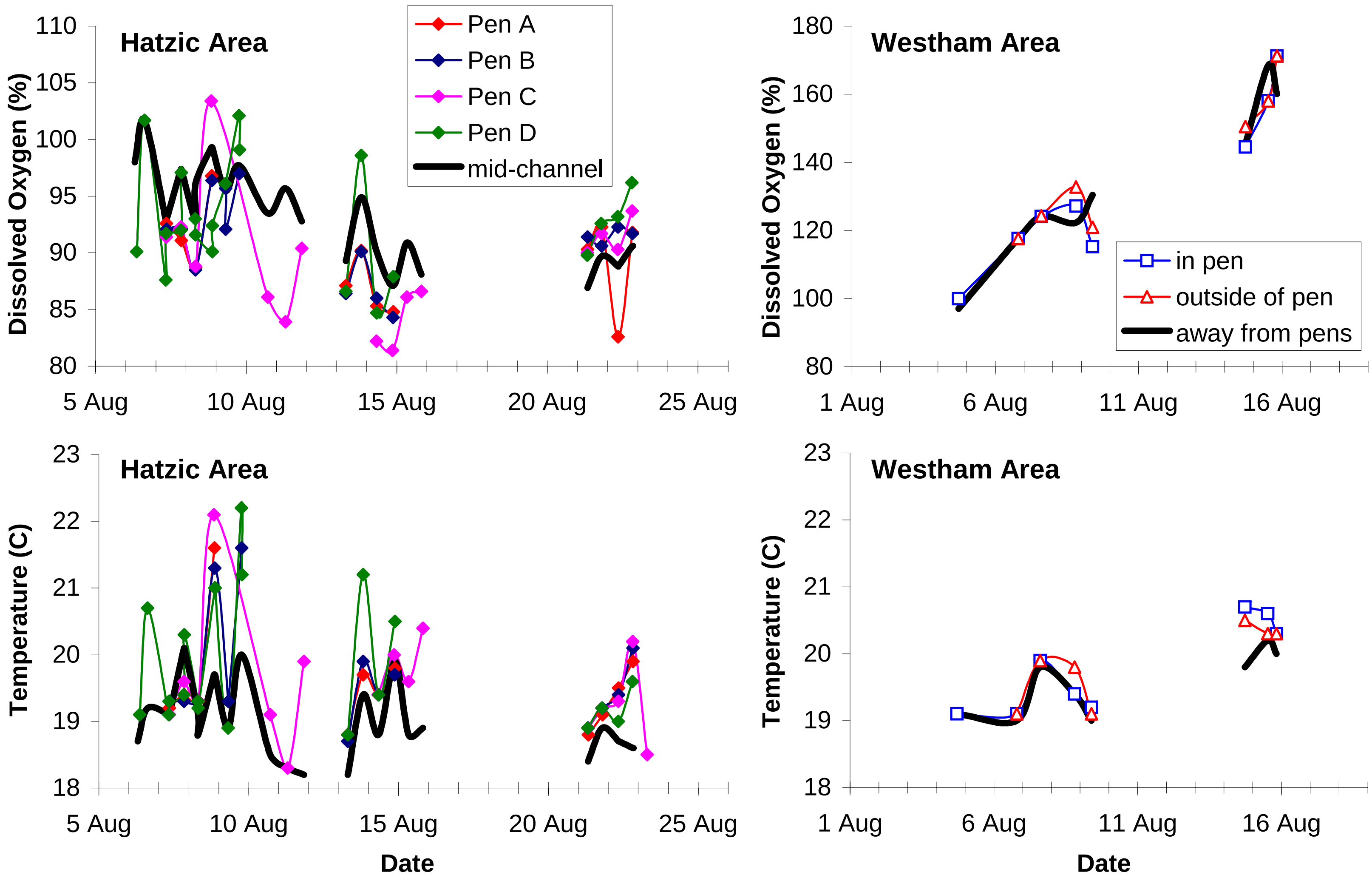
	A	B	C	D	mid-channel
A		0.00	-0.11	-0.12	0.48
B	ns		-0.12	-0.08	0.55
C	ns	ns		0.12	0.70
D	ns	ns	ns		0.67
mid-channel	**0.029**	**0.008**	**0.004**	**0.001**	

Appendix Table A7. **Comparisons among dissolved oxygen values measured in Westham holding pens, immediately outside of the pens, and at locations 4m away from the pens. Mean differences are shown above the diagonal, and *P* values below the diagonal. ns = not statistically significant.**

	Pen E/F in	Pen E/F out	4 m away
Pen E/F in		-2.49	-0.93
Pen E/F out	ns		1.00
4 m away	ns	ns	

Appendix Table A8. **Comparisons among temperature values measured in Westham holding pens, immediately outside of the pens, and at locations 4m away from the pens. Mean differences are shown above the diagonal, and *P* values below the diagonal. ns = not statistically significant.**

	Pen E/F in	Pen E/F out	4 m away
Pen E/F in		0.03	0.25
Pen E/F out	ns		0.26
4 m away	**0.049**	**0.025**	



Appendix Figure A1. **Dissolved oxygen and temperature of holding pens and of mid-channel surface water in the Hatzic Slough and Westham Island areas, 2005.**