Fraser River Pink Salmon (*Oncorhynchus gorbuscha*) Data Review: Inputs for Biological Status and Escapement Goals

Final Project Report to Southern Boundary Restoration and Enhancement Fund

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ABSTRACT

The Fraser River Pink Salmon Run is one of the largest runs of this species on the Pacific Coast. Harvest of this run is shared by Canada and the United States (U.S.) under terms stipulated in the Pacific Salmon Treaty (PST). It has been over twenty years since the escapement goal for Fraser River Pink Salmon has been reviewed. During this period, the Fraser River Pink Salmon run size has increased from an average of approximately 10,000,000 fish (1957-1989) to almost 15,000,000 fish (1991-2013), with a number of recent years as high as 20,000,000 fish. Fishery managers require updated biological data that will allow examination of the existing escapement policy, which includes the evaluation of biological status and the development of associated abundance-based biological benchmarks and, concurrently, the development of an escapement goals for the Fraser River Pink Salmon aggregate. This report summarizes historic biological data required for these assessments and includes the following: estimates of adult Fraser River Pink Salmon escapements, catches, total run sizes, and adult biological data. The time series of escapement data, in particular, has changed over the period assessed (1957 to present) and include four distinct method: stream-specific escapements estimates generated from a variety of methods (1957-1991), system-wide mark-recapture escapement estimates (1993-2001), system-wide indirectly-derived test fishery escapement estimates (2003-2007) and in the current period system-wide hydroacoustic estimates (2009-present). As a result, the escapement (and consequently return) time series are not completely comparable as no inter-method calibration work was conducted. Similarly, catch assessment methods also vary over time, largely due to the approach used to assign Fraser Pink catch to total Pink catch estimates (different run reconstruction methods were used for two broad periods: 1959-1977 and 1979-1985 and different genetic stock identification methods were also used over two periods: 1987-2005 and 2007-2013). There has also been substantial variation across the time series in the proportion of the total return associated with catch (1957-2013 range: 4.5% to 86%) and conversely escapement, which affect the degree to which each of these component contribute to the variation in total return. Therefore, total return estimates are subject to variation resulting from both methodological and component (catch and escapement) changes over time, which complicate the interpretation productivity changes between years (e.g. returns-per-spawner). In addition to adult data, estimates of Fraser Pink Salmon fry abundances (used as indices of abundance only) and sizes are also compiled in the current report. Although data for the fry abundance time series exist from the 1961 brood year to present, it is largely comparable from the 1967 to present brood years given early shifts in methodologies. Fry abundances may be useful in quantify differences in productivity between freshwater and marine life stages and thus help to identify potential causal

mechanisms for variation to total life cycle productivity. Therefore, considerations of data and data quality presented in this report are required for any subsequent analyses.

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INTRODUCTION

The Fraser River has the fourth largest watershed in the Pacific Rim, draining 223,000 km^2 (Northcote and Larkin 1989). This watershed supports all species of Pacific Salmon, including Pink Salmon (Roos 1991). Prior to the Hells Gate landslide in 1913, the greatest proportion of Fraser River Pink Salmon spawners occurred upstream of Hope (Pess et al. 2012). Following the landslide, however, the concentration of Pink Salmon spawners shifted to the Lower Fraser watershed, downstream of the Fraser Canyon, and the largest aggregates include spawners in the Lower Fraser mainstem, Harrison, and Chilliwack-Vedder systems. In addition, a few larger spawning aggregates in the Upper Fraser include the Thompson and Seton systems. Fraser Pink Salmon have a two year life cycle with the adults spawning in the fall of odd-years and the juvenile fry emerging in the spring of the following even year. The fry migrate directly to the ocean where they rear for approximately the next year and a half before returning to spawn.

Fraser River Pink Salmon have been harvested in Canada and the United States (U.S.) for over a century (Roos 1991). In the early 1900's, Pink Salmon were only harvested in large quantities in odd years that coincided with the off-cycle years for Sockeye Salmon; canneries were fully utilized by Sockeye Salmon catches on the dominant Fraser River Sockeye Salmon cycle (1901, 1905, etc.) that occurred once every four years (Ricker 1989). The demand for Pink Salmon increased during World War I (1914-1918), and an intensive fishery developed, just as the Fraser River Pink Salmon population was experiencing a major population crash caused by the Hells Gate landslide (Vernon 1958; Ricker 1989). The fishery subsided during the recession of the early 1920's, then increased again into the late-1920's as new markets developed (Ricker 1989). Fishing effort and catches declined once more leading up to World War II, primarily because of the restrictions imposed on Japanese fishermen, and then subsequently increased (Ricker 1989).

Although the International Pacific Salmon Fisheries Commission (IPSFC), a joint Canada-U.S. body, was formed in 1937 specifically to manage Sockeye Salmon, no single regulatory body was responsible for Pink Salmon fisheries management until the 1950's. Up until the 1940's, the majority of Pink Salmon (66%) were harvested by the U.S. (Ricker 1989). Despite dwindling stocks, competition over Pink Salmon catches increased between Canada and the U.S. during this time, and Canadian fishermen were encouraged by the Canadian Minister of Fisheries, James Sinclair, to increase their share of catches so that U.S. fishermen would agree to a catch-sharing treaty (Ricker 1989; Roos 1991). During the late-1940's to early-1950's, Canadian fishermen began purse seining at the entrance of the Juan de Fuca Strait, intercepting the Fraser River and Puget Sound Pink Salmon stocks before they entered U.S. waters (Vernon 1958; Roos 1991). By 1955 Canada was harvesting 50% of the Pink Salmon catch, and both countries agreed to a 50:50 catch sharing agreement, known as the Pink Protocol (Roos 1991). At this time, the IPSFC took on responsibility for Pink Salmon management recommendations. However, despite the Pink Protocol and IPSFC recommendations for more severe restrictions, effort and harvest rates in Pink Salmon fisheries continued to increase (Roos 1991). From 1959-1981, exploitation rates on Fraser River Pink Salmon averaged 70% (DFO 1995), and the spawning stock abundance increased towards the latter end of this period (1973-85) (Ricker 1989). Pink Salmon have traditionally been harvested as by-catch in the Fraser River Sockeye Salmon fishery, as their arrival timing coincides with that of the late-run-timed Fraser Sockeye Salmon. Beginning in 1999, concerns over the status of several late-run-timed Fraser Sockeye stocks led to harvest restrictions across all Salmon species during these Fraser Sockeye migrations. In addition, the low price of Pink Salmon, combined with the high price of gas over this period meant that fishers were unlikely to make late-season expeditions solely targeting Pink Salmon, resulting in a dramatic decrease in their harvest from 1999-2007 (Figure 3).

The Fraser River Panel of the Pacific Salmon Commission is currently responsible for managing Fraser River Pink Salmon so that spawning escapement and international and domestic catch allocation goals are achieved. Estimates of Fraser River Pink Salmon run size are available from 1959 to 2013 with changing methodology over this period, therefore, comparisons are not necessarily direct between years. Returns range from approximately 2,000,000 to 24,000,000 fish with an average of about 12,000,000 fish (1961-2013) (Figure 3). Since 2001, the average run size of Fraser River Pink Salmon has increased considerably (average: 17 million). The current escapement policy for Fraser River Pink Salmon was developed over twenty years ago and sets a goal of 6,000,000 spawners when the run size of Fraser River Pink Salmon is between 7,000,000 and 20,000,000 fish. When the run size is below 7,000,000 fish, the escapement goal decreases below 6,000,000 fish and when it is above 20,000,000 it increases above 6,000,000 fish. Because of the growing demand for Fraser River Pink Salmon and the long period since the escapement goal was examined, fishery managers consider it necessary to re-examine the escapement policy for these fish.

Key components of escapement policy development include evaluation of both biological stock status, which includes the production of abundance-based biological benchmarks for these evaluations (Holt et al. 2009; Grant et al. 2011; Grant & Pestal 2012), and the development of management escapement goals (i.e. reference points) that may combine biological benchmarks with additional information on socioeconomic factors (Holt and Irvine 2013). A foundation of both these elements of escapement policy development include stock-recruitment models that rely on data with well-described characteristics, which include information on assessment methods and the quality of the results in terms of bias and precision. To this end, the report is focused specifically on compiling historic biological data on Fraser River Pink Salmon that is relevant to re-examining the escapement policy that includes escapement, catch, return, juvenile fry abundance, and adult and juvenile biological data. In addition to providing data sets, this report will also describe methodological changes through time, quality of data sets, and comparability of time series over the historic period given changes in methods over time. Although another aspect of stock-recruitment modeling includes an understanding of the productive capacity of the limiting habitat used by the stock of interest (i.e. Fraser Pink Salmon), this was beyond the scope of the current report and will be addressed directly in a subsequent paper that addresses Fraser River Pink escapement policy. Further, other aspects of escapement policy development that include understanding fishing policy on interactions of co-migrating species, or additionally (non-science) socio-economic factors, are beyond the scope of the current paper.

FRASER RIVER PINK SALMON ESCAPEMENT

Stock status evaluations and the development of biological escapement goals for fisheries management require stock-recruitment data to quantify population dynamics. For Fraser River Pink Salmon, escapement data are available from 1947 to present (qualitative from 1947 to 1955 and quantitative from 1957 to present) (Tables 1 - 3). Escapement data for this stock are not available for years prior to 1947, although packing records from fish canneries provide a very rough indication of the abundance (which includes escapement) in those earlier years (see Argue and Shepard 2005). Since 1947, several different methods have be used to estimate Fraser River Pink Salmon escapements. The accuracy and precision of escapement estimates generated from these different methodologies has varied substantially from 1947 to 2013.

From 1947 to 1979 qualitative escapement indices were generated from fishery officer observations and these indices partially overlap with quantitative estimates that begin in 1957 (Table 3). Fishery officer escapement indices for the years they were generated are not inter-annually comparable and are also not comparable to quantitative estimates. Quantitative escapement estimates of Fraser River Pink Salmon have been generated by the International Pacific Salmon Fisheries Commission (IPSFC) (1957-1985), Fisheries and Oceans Canada (DFO) (1987-2001), and the Pacific Salmon Commission (PSC) (2009-2013) (Tables 1 & 2; Figure 3). Although from 2003 to 2007 no direct estimates of escapement are available, indirect estimates have been generated using PSC test fisheries' estimates of total return minus DFO catch estimates. The estimates for the 1957-2013 period should be used selectively in stock-recruitment analyses, given no calibration work was conducted between methods (Tables 1 & 2; Figure 3). Of particular note are the escapement estimates for the years 2003 to 2007 (test fishery minus catch estimates), which are particularly unique relative to other years in the escapement time series. A brief summary of the qualitative and quantitative Pink Salmon escapement enumeration methods is provided below with additional information provided in the Appendices A to E.

Qualitative Estimates

<u>Visual Estimates by Fishery Officers: 1947-1979</u>

Fraser River Pink Salmon escapement indices for the period 1947-1979 are available from fishery officer observations of Salmon populations in their respective districts and were recorded annually in BC16 stream survey forms (DFO unpublished data, undigitized) and published in DFO stream catalogues (Table 3; Brown et al. 1979a, 1979b, Manzon and Marshall 1980, Marshall et al. 1980, Hancock and Marshall 1985a, 1985b). These indices are consistently smaller (average: < 50%) than estimates generated by more rigorous quantitative methods used by the IPSFC (Table 3).

These visual assessments were not implemented with scientifically rigorous study designs (e.g. surveys did not cover the entire temporal or spatial distribution of spawning activity, surveys typically only included one or two surveys-per-season, and estimates were not expanded for observer efficiency or residence time of adult Pink Salmon on their spawning grounds), did not consistently apply survey methods between years and populations (e.g. survey timing and survey location could vary across years and systems), and were conducted on typically turbid systems subject to frequent fall floods. In addition, published summaries of these escapement estimates generally include only the mid-point (e.g. 7,500 fish) of the range of estimates that fishery officers recorded on their data sheets (e.g. 5,000 to 10,000 fish observed), thus omitting the uncertainty in the observations. As a result, these subjective escapement indices should not be used for stock-recruitment modeling purposes.

Quantitative Estimates

Stream-Specific Estimates (Various Methods): 1957-1991

Beginning in 1957, resources became available to develop more appropriate escapement enumeration programs after the IPSFC assumed responsibility for the management and assessment of Pink Salmon (Tables 1 & 2; Figure 3). From 1957 to 1991, stream-specific estimates of Fraser River Pink Salmon escapement were generated by the IPSFC (1957-1985) and DFO (1987-1991). Since these estimates were conducted on the spawning grounds and, therefore, only included fish that 'escaped' the fisheries, the total escapement estimate is the same as the net escapement estimate (see Tables 1 & 2). Since the program was similar between these years (1957 – 1991), escapement estimates during this period are comparable.

From 1957 to 1985, the IPSFC conducted a comprehensive, stream-specific Pink Salmon escapement monitoring program in the Fraser River watershed (Roos 1991). Escapement estimates were generated for virtually all spawning areas including those where less than 1,000 Pink Salmon typically spawned (Figure 2; see Appendix A). The 1957 study design was described in Ward (1959) and includes a description of the spawning populations surveyed and the methods used to estimate individual stream escapements. Starting in 1957, thorough surveys were conducted of streams in the Fraser River watershed where Pink Salmon spawned and the results were used to define and plan survey methods in subsequent years (IPSFC historical data; T. Cone, DFO, pers. comm.).

The IPSFC developed a two-tiered program whereby the methods implemented to estimate escapement for each stream and year were selected based on the number of spawners expected to return to each system (based on the average escapements in recent prior years). For stocks with larger expected escapements (over 25,000 spawners), high precision methods (i.e. mark-recapture or enumeration fences; see Appendix A) were used to assess escapements. In practice, the escapements of five stocks were routinely estimated using mark recapture methods (Seton, Thompson, Harrison, and Vedder-Chilliwack tributary stocks and the Fraser mainstem stock) (Appendix A, Table A1). For populations with lower expected escapements (fewer than 25,000 spawners), low-precision methods (e.g. visual surveys, tower counts, dead count expansions, and observer estimates; see Appendix A, Table A1) were applied. During this period of the two- tiered Fraser Pink Salmon escapement assessment program (1957-1991), a high percentage (92%) of the total Fraser Pink Salmon escapement was estimated on average using high precision methods.

In 1987, after the establishment of the Pacific Salmon Treaty (PST) between Canada and the United States (U.S.), DFO assumed responsibility for estimation of Fraser River Pink Salmon escapement. From 1987 to 1991, DFO applied IPSFC methods to estimate stream-specific escapements (Tables 1 & 2; Figure 3). Thus estimates from the period 1957 to 1991, are comparable, given the general consistency in methods over this period.

In 1987, DFO commissioned a review of all the IPSFC's past enumeration programs, including high and low precision methods (Andrew and Webb 1987a). The first component of the review involved entering the complete Pink Salmon enumeration summaries from 1957 to 1985 into a computer database, to facilitate data verification and regeneration of the escapement estimates. This exercise generally validated the historic IPSFC estimates. However, Andrew and Webb (1987a) found that their summaries of the revised estimates differed slightly from the original escapement estimates because (1) they only included estimates for which precision could be estimated and (2) there was some double counting of estimates in their summaries resulting from streams that were estimated both independently and as part of a group.

Andrew and Webb (1987a) also developed and applied methods to assign precision to the IPSFC estimates and commented on accuracy and future experimental design. They found the information was insufficient to quantify accuracy, but they noted that the largest single source of bias was related to the potential for fish to lose tags between the tagging and recovery sites and they recommended that a double tagging study be conducted to quantify its impact. Further details on the Andrew and Webb (1987a) study and the specifics of particular high and low precision methodologies used during the period of stream-specific estimates are provided in Appendix A.

System-Wide Estimates (Mark Recapture): 1993-2001

From 1993-2001 system-wide mark recaptures were conducted by DFO to estimate Fraser Pink Salmon escapement for these years (Tables 1 & 2; Figure 3). Since these estimates were conducted on the system downstream of most Fraser Pink Salmon spawning grounds (Figures 1 & 2), these escapement estimates would have included fish caught in upstream fisheries. Therefore, the total escapement estimate is different from the net escapement estimate (see Tables 1, 2 & 4), since the net escapement estimates removes catch in upstream fisheries from the escapement estimate (Table 4) generated from the mark-recapture program. Since the program was similar between these years (1993-2001), escapement estimates during this period are comparable.

The switch to a more cost-effective system-wide Fraser River Pink Salmon escapement program in 1993 was the result of reductions in DFO’s assessment budgets and the realignment of most funds to higher priority stocks (such as Sockeye and Chinook). Due to fewer assessment dollars available to assess Fraser River Pink Salmon and high anticipated escapements, the budget review resulted in the consolidation of individual stream estimates in the Fraser watershed into a single system-wide mark-recapture escapement estimate. Given the considerable overlap in run timing amongst the individual Fraser Pink populations, which can be broadly grouped into earlier (Fraser River mainstem, Seton and Thompson Rivers) and later timing (Harrison and Vedder-Chilliwack Rivers) components, it is not possible to manage these fisheries based on their run timing. As a result, from a fisheries management perspective the loss of population-specific escapement information was not considered problematic, given the Fraser Pink Salmon fishery is managed as a single aggregate (Cass et al. 1995). However, the absence of population-specific escapement information post-1991 does preclude the ability to assess distribution changes through time, which are important for stock status evaluations and, separately, for the understanding of a system’s carrying capacity required for population dynamics modeling. At the time, the Fraser River Panel was very concerned over the loss of the more intensive tributary programs and noted that “…the loss of tributary escapement data will be to seriously compromise the future ability of scientists and management biologists to understand specific stock dynamics and to relate them to environmental conditions (Pacific Salmon Commission 1993).

For the first two years of DFO’s system-wide assessment program (1993 and 1995), escapement estimates generated from the previously conducted standard mark-recapture carcass recovery program were compared to a new mark-recapture live recovery program (Cass & Whitehouse 1993; Cass et al. 1995; Schubert et al. 1997). Both methods involved applying tags to Pink Salmon at Duncan Bar near Mission, B.C. Tagging commenced when Pink Salmon first entered the river (usually in August), and continued daily (eight hours/day) for the duration of the run (typically ending in early October) (Figure 2). Sampling effort was standardized over an eight hour period with eight to nine beach-seine sets per day. All Pink Salmon caught were sexed, assessed for external marks, and measured (nose-fork length). A sample of females was retained to assess fecundity. The standard mark-recapture program involved recovery of carcasses in the Lower Fraser

River mainstem (Chilliwack-Vedder River confluence to Ruby Creek in the Fraser Canyon) where most of the Fraser Pink spawning occurred. The live recovery program involved recapturing migrating Pink Salmon with beach seines at Strawberry Island, which is located 22 km upstream from Duncan Bar and downstream of virtually all Pink Salmon spawning areas (Figure 2). Seining at Strawberry Island was conducted over a 24 hour period with 33 sets per day; commencing on the first day of tagging and continuing until several days after the last day of tagging at Duncan Bar. Each fish was assessed for marks (tags) then released alive. Both tag and recapture sites were located upstream of the major commercial net fisheries in the lower Fraser River.

Given carcass recovery in the traditional mark-recapture carcass recovery program is not representative of the later timed populations that spawn upstream of the Fraser Canyon, unbiased total Fraser River Pink escapement estimates for this program required meeting the following two assumptions: 1) tagged fish are proportional to abundance so that the tagging rate is the same in all populations and; 2) the number of Pink Salmon sampled in each recovery stratum is proportional to abundance. In contrast, since all Fraser Pink Salmon are vulnerable to recovery at Strawberry Island in the mark-recapture live recovery program, unbiased total Fraser River Pink escapement estimates are required to meet only one of the two above assumptions (Appendix B). Based on the 1993 program, although the optimal recovery component (carcass recovery or live recovery) could not be ascertained, the mark-recapture live recovery program was recommended over the carcass recovery program, given a number of advantages associated with the live recovery program that included the requirement to satisfy only one of the two assumptions outlined above (Appendix B). In addition, live recovery requires a shorter period of time and fewer personnel than carcass recovery and poor environmental conditions are more problematic for carcass versus live recovery (Cass et al. 1995). In a similar comparison between approaches in the subsequent year (1995), Schubert et al. (1995) concluded the carcass recovery component (and therefore, the traditional mark-recapture carcass recovery program) has little utility in the estimation of the total Fraser Pink Salmon escapement. Specifically, their conclusion was based on of non-representative application (capture and tagging and limited during the arrival peak of the large returns) and recovery (mainstem Pink Salmon are an earlier-timed run which is not present later in the total Fraser Pink migration) and also because the mainstem bars are highly susceptible to relatively small increases in river levels limiting access to carcasses. As a result, DFO's Pacific Science Advice Review Committee (PSARC) concluded that the Fraser mainstem spawning ground survey is not a representative sample of the system-wide escapement and therefore, recommended the cancellation of this survey starting in the subsequent (1997) year (Schubert et al. 1997).

Beginning in 1997, the mark-capture live recovery program was retained as the sole method for generating escapement estimates through 2001 (Tables 1 & 2; Figure 3; Appendix B). Escapement was estimated from the mark-recapture live recovery program for each sex separately, and was adjusted for tag loss and handling stress. Three population estimates were calculated using the pooled Petersen estimator, the Darroch maximum likelihood estimator, and the Schaefer estimator. The pooled Petersen estimator was consistently applied to estimate escapement from Fraser River Pink Salmon mark-recapture live recovery escapement programs conducted between 1995 and 2001 (i.e. the analytic practice was to accept the pooled-Peterson estimator if the 95% confidence limits overlapped with a stratified estimator). Precision around the annual escapement estimates was consistently below the 95% confidence limits of ± 25%. Assumptions underlying mark-recapture live-recovery methods were evaluated throughout the program and are summarized in Appendix B.

The system-wide survey was discontinued following the 2001 season due to further reductions to DFO's Salmon assessment budgets where the remaining Fraser River Pink Salmon escapement budget was redirected to higher priority Fraser River Salmon species (Tables 1 & 2; Figure 3). This decision was made given the large budget associated with the Fraser River Pink Salmon live mark-recapture program, relative to other Salmonid assessment programs, and the limited fisheries on this stock that were restricted by co-migrating stocks of concern and the low commercial value of this species. The Fraser River Panel expressed concern over the loss of this escapement enumeration program post-2001 for reasons similar to those that were noted following the elimination of the stream-specific escapement enumeration program after the 1991 season.

Indirect System-Wide Estimates (Test Fishery): 2003-2007

Following DFO's termination of the spawning ground assessment post-2001, the Fraser River Panel of the PSC sought other options for deriving an escapement estimate. The PST approved method applied by PSC secretariat staff from 2003-2007, generated an estimate of system-wide escapement by subtracting the total catch from the total return (Table 1, 2 & 5; Figure 3; Appendix C; Pacific Salmon Commission 2007a, 2009, 2012). The total return estimates were derived from purse seine test fisheries operating marine locations that were seaward of all locations where catches of Fraser River Pink Salmon occurred in these years (Figure 4). Thus, the subtraction of all catches from the total run size resulted in an estimate of net escapement to the Fraser River that is analogous to the net escapement estimates derived from other methods in prior and subsequent years (see last column of Table 2). The method was similar between these years (2003-2007), therefore, escapement estimates during this period are comparable. However, because the method involved no direct assessment of the abundance of Pink Salmon in the Fraser River, estimates in these years (2003-2007) are qualitatively different from previous years' (1957 to 2001) and subsequent years' (2009 to present) escapement estimates that were directly assessed by either mark-recapture or hydroacoustic programs conducted in the Fraser River.

The Fraser Pink total return estimates for 2003 to 2007, are derived from daily catch-per-set (CPUE based on 6 sets) data collected from two to three purse vessels operating in Johnstone (Area 12) and Juan de Fuca Straits (Area 20) for in-season assessment purposes (Figure 4). The average daily CPUE divided by an estimate of the average historical catchability for each test fishery was used to estimate the daily abundances for the duration of the Pink Salmon migration. These daily abundances were then summed to estimate the total return for each year (see Appendix C for more details). Catchability is the proportion of a stock caught by one unit of fishing effort (i.e. one purse seine set) and interannual variation in catchability is the largest source of uncertainty in the Fraser Pink run size estimate for these years. Because the escapements are estimated from total return minus catch, and the catch estimates were small relative to the total return (Table 5), virtually all of the absolute variation in the total return estimates is transferred to the escapement estimates. Thus, the coefficient of variation (CV) in the escapement estimates of approximately 40% results from the large interannual variation in historic catchability of the test fisheries. Analysts using the escapement and total return estimates for 2003 to 2007 should take the lower precision and qualitatively different characteristics for these estimates into account in their assessments. The variation in the run sizes and escapement estimates derived from these methods is described in more detail in Appendix C.

System-Wide Estimates (Hydroacoustic Methods): 2009 to 2013

From 2009-2013, a system-wide hydroacoustic escapement estimate program was conducted by the PSC at Mission, B.C. to estimate Fraser Pink Salmon escapement (Tables 1 & 2; Figures 3 & 4). The Mission site (Figures 1 & 4), is located approximately 10 km upstream from Duncan Bar and downstream of all Fraser Pink Salmon spawning grounds (spawning of Fraser Pink Salmon downstream of Mission is negligible). The hydroacoustic escapement estimates include fish caught in fisheries located upstream of the Mission site. These catches must be subtracted to obtain net escapement estimates comparable to other years (last two columns Tables 2; Tables 1 & 6). .

The hydroacoustic program in the Fraser River at Mission, B.C. was initiated in 1977 to provide data on daily Salmon abundance during their upstream spawning migration for in-season management of Fraser River Sockeye and Pink Salmon (see Figure 4 for Mission location in the Fraser River). Attempts to provide reliable Mission abundance estimates of specifically Pink Salmon, however, were complicated by equipment limitations that provided incomplete assessments of the near-shore oriented migration of Fraser River Pink Salmon. It was not until 2009, when refinements were made to the hydroacoustic methods, that this program could be used to generate reliable estimates of the total escapement of Fraser River Pink Salmon. Specific refinements to the hydroacoustic program in 2009 included a combination of left-bank split-beam sonar and two Dual Frequency Identification Sonar (DIDSON) units (one on each bank) along with a mobile split-beam sounder (Figure 5). In comparison to previous years' hydroacoustic methods, this system resulted in more accurate total daily Salmon counts with high precision when near-shore oriented Pink Salmon dominated the migration (Xie et al. 2013) because the newly implemented shore-based DIDSON and split-beam sonar units sampled the majority of the fish passage that had been undersampled by the vessel based sampling in previous years. This enhanced hydroacoustic sampling design was also implemented in 2011 and 2013 and is anticipated to continue in future Pink migration years.

Net escapement estimates generated by subtracting the total catch estimates upstream of Mission from the Mission hydroacoustically-derived abundance estimate (last column Table 2) are considered superior to the net escapement estimates derived from test fishing and catch data. Therefore, the hydroacoustically-derived escapement estimates are included in the Fraser Pink Salmon time series from 2009 to present (Tables 1 & 2; Figure 3; Appendices D & E). Escapement estimates for this period are comparable because a similar hydroacoustic program was conducted in each year. However, any hydroacoustic estimates derived from the Mission program prior to 2009 are considered to be substantial underestimates of the Total Pink Salmon escapement and they should not be used in escapement policy analysis.

There are two primary sources of observation error in the hydroacoustic estimates of Pink Salmon passage since 2009. The first source comes from the uncertainty in the fraction of total Salmon passage that is observed by the hourly subsampling of the migration. Subsampling leads to random errors in the estimates of the total passage. However, Xie and Martens (2014) have demonstrated that despite this error, the daily estimates of Mission total Salmon abundance remain relatively precise (coefficient of variation: CV of 5.7%). The uncertainty in the annual estimate of total Salmon abundance is further reduced to approximately 1%, assuming that errors in daily estimates of Salmon passage are independent (i.e. uncorrelated). Further details on development of the sampling designs currently used for hydroacoustic estimates are provided in Appendix E.

Allocation of hydroacoustic estimates of total Salmon to species

In order to generate Pink Salmon abundance estimates, hydroacoustics estimates of total Salmon migrating past the Mission hydroacoustic site must be partitioned to various Salmon species. Beginning in 2009, new methods were used to partition daily estimate of total Salmon to Pink Salmon and other species. In some cases, to estimate Pink Salmon abundance involved estimating the proportions of Pink Salmon and multiplying this proportion by the total Salmon abundance estimate. In other cases, Pink Salmon abundance was estimated either directly or indirectly by subtracting the abundance of other species. These methods are detailed below and the resulting estimates associated with each method are presented in Table 7, column E.

Specifically, in 2009 and 2011, daily Pink Salmon proportions were estimated from a combination of three methods that were applied during various periods (Table 7, columns B & C). The daily abundances of Pink Salmon during their earliest migration period were estimated either by applying the species proportions obtained from the relative abundance of Pink Salmon caught in the Whonnock test fishery (see Figure 4 for Whonnock location) or by assuming a small daily abundance of Pink Salmon based on expert judgement. These early-period estimates represent a very small fraction of the total Pink Salmon migration (0-1%; first row for 2009 and 2011 in Table 7, column G).

Following this early period, Pink Salmon abundance increased from being a minor to a major component of the total Salmon migration. During this middle period, Pink Salmon species proportions were estimated using the ratio of the total abundances of Sockeye and Pink Salmon estimated from marine purse seine test fishery catch-per-unit-effort (CPUE) data and historical estimates of catchability (middle row for 2009 and 2011, Table 7; and see Appendix C for example of how test fishery CPUE is used to generate abundance estimates). The marine abundances were adjusted to account for different travel times of Sockeye and Pink Salmon from marine areas to Mission. The abundances of Chinook Salmon and other minor species (e.g. Coho and Chum Salmon) were estimated by expert judgement (assuming small daily abundances), that were informed by the species proportions in the Whonnock test fishery. These minor species abundances were subtracted from the total Salmon resulting in total Sockeye and Pink Salmon abundance. The daily proportion Pink Salmon from the marine abundance ratios was then multiplied by the daily total Sockeye and Pink Salmon abundance (from the hydroacoustic methods) to estimate the daily Pink Salmon abundance. Though this method relies on multiple steps and assumptions it is important to note that it is applied during a period when the total Salmon migration is small relative to the season total (compare middle rows to bottom rows for 2009 and 2011, column D Table 7), and that resulting Pink Salmon estimates represent a very small fraction of the total Pink Salmon estimates for the season (1-5%; middle rows for 2009 and 2011 Table 7, column G).

During the last period Pink Salmon dominated the total Salmon migration, Pink Salmon abundance was estimated indirectly by subtracting the relatively minor abundances of other species from the total Salmon estimate (third rows for 2009 and 2011, column E, Table 7). Under this method Sockeye Salmon abundance was estimated from the Whonnock test fishery CPUE divided by average catchability derived in the same year during the period prior to Pink Salmon upstream migration. The abundances of Chinook Salmon and other minor species (e.g. Coho and Chum Salmon) were estimated by expert judgement as described above. Pink Salmon passage at Mission was then estimated from total Salmon abundance minus Sockeye (from CPUE methods) and Chinook Salmon abundances (from expert judgement; third rows for 2009 and 2011, Table 7, column E). The potential error associated with the non-Pink Salmon species estimates is small because most of the total Salmon are attributed to Pink Salmon (97% and 87%; third rows for 2009 and 2011 respectively, column F; i.e. only 3% and 13% attributed to non-Pink Salmon species).

The methods used to estimate Fraser River Pink Salmon abundance at Mission in 2013 were the same described above with two exceptions: (1) During the middle period, the marine, relative abundance method based on test-fishery data (middle rows for 2009 and 2011, Table 7) was largely replaced with a method that apportioned species in the near-shore area using a mixture model applied to fish lengths taken from DIDSON images (third row for 2013 Table 7; Fleischman & Burwen 2003; Michielsens et al. 2010) and (2) Chinook Salmon passage used as part of the methods for the first and last periods was estimated from the average historical daily passage in recent years rather than expert judgement. These average historical Chinook estimates were cross checked with daily estimates derived from the Albion Chinook gillnet test fishery that operates just downstream of the Whonnock test fishery. During the middle period, when the mixture model was used, a stratified approach was followed whereby species proportion estimates from different methods were applied to abundance estimates associated with different parts of the cross river distribution. The total Salmon abundance estimates in the near-shore area (i.e. with 20 meters of the left bank and within 50 meters of the right bank) were multiplied by the mixture model's estimate of species proportions obtained from DIDSON lengths. The total Salmon abundance in the offshore area (between 60 and 350 meters from the left bank) were multiplied by the species proportions obtained from the relative catches of each species in the Whonnock test fishery. Lastly for the area between near- and off-shore (between 20 and 60 m off the left bank) areas, the average of the mixture model and Whonnock species proportions was multiple by the total Salmon.

Estimates of species proportions are subject to both bias and random sampling error. To understand the potential biases resulting from species proportion methods used by the PSC to generate the Pink Salmon estimates in Table 7, column E, these estimates were compared to estimates derived from a stratified method (Table 7, column H), which used the relative abundances in catches of two fish wheels to estimate near shore species proportions (Robichaud et al. 2010). The estimates of total Pink Salmon obtained from both methods were very similar in each of the years (differences in total Pink Salmon estimates ranged from 1% to 9%; compare bottom rows of columns E and H for each year in Table 7). The temporal distribution of Pink Salmon estimates across the periods was also very similar for each of the methods in each year (compare columns G and I in Table 7). If the estimates of total Salmon were accurate (see previous section), this comparison provides some confidence that the potential biases in the Pink Salmon Mission abundance estimates that result from errors in species assignments are likely small (see Appendix E for further details).

Sampling error in species proportions occurs because only a small portion of the total Salmon population is sampled by the daily test-fishing effort. The error causes the estimate of Pink Salmon proportion derived from the relative catches in test fishing sample to deviate from the true underlying proportion of Pink Salmon by some random amount. Because 90-98% of the total Pink Salmon estimate (Table 7, last periods for each year in column G) occurs during a period when the total Salmon migration is dominated by Pink Salmon (87-97%; Table 7, last periods for each year, column F), the variation associated with daily Pink Salmon estimates is only slightly larger than the variation in the daily total Salmon estimates (i.e. CV: 7%; Xie and Martens 2014). Summing the daily estimates results in an even lower variation in the total Pink Salmon estimate because of the independence of the errors in the daily estimates (over estimates on some days are offset by underestimates on other days). Thus, the effect of species composition errors on the precision of the Pink Salmon escapement estimate is small relative to the variation associated with the sampling effort used to generate the total Salmon escapement estimate.

FRASER RIVER PINK SALMON CATCH

Overview

Total catch estimates are the second essential component for stock-recruit analyses, as they are combined with escapement data to generate data on total returns. Prior to 1951, B.C. catch data was largely comprised of information collected from processing plants on product volume (canned, fresh, frozen, salted, etc.). These data were based on aggregated and incomplete information with variable reliability. Argue and Shepard (2005) re-analysed historical records (1828-1950) from ten Areas of the B.C. coast to convert the available catch data (processed volumes of Pacific Salmon) to annual area-specific catches by species, in both weight (tonnes) and number of fish. To perform the analysis they used 'product-to-landed weight conversion factors, species composition information, and adjustments for transfers between areas'. While these data provide insight into historical Pink Salmon fisheries in B.C., they do not identify the stock composition of these catches, therefore the contribution of Fraser River Pink Salmon to total catch during this period is unknown. Therefore, data pre-1951 are not included in this current report. Although the sales slip program resulted in more reliable catch data in 1951, run reconstruction processes that partitioned catch into different stock groups (such as Fraser and non-Fraser stocks) started several years later in 1959. Therefore, Fraser River Pink Salmon catch and return data (catch plus escapement) are only available starting in 1959, and these data (from 1959 to 2013) are specifically presented in the current report.

For stock-recruitment modeling, return data (recruitment) are comprised of escapement (see preceding sections) and catch data, and both these data contribute to the reliability of return estimates through the time series. Reliable catch data for Fraser Pink Salmon are available starting in 1959 and comprise, on average, half the total run size (Table 1), with escapement comprising the remaining half. Due to increasing restrictions placed on Pink Salmon fisheries due to co-migrating stocks of concern and decreasing interest in harvest of this species by fishers, exploitation rates (percentage of catch relative to total returns) has decreased over time. Specifically, in the first half of the time series (1959-1997), exploitation rate was 64%, versus the second half of the time series (1999-2013) where exploitation rate was only 18% (Table 1).

Given the contribution of catch to the total return, accurate estimates of Pink Salmon catches are necessary so that estimates of total return are also reliable. There are two main components to the estimates of Fraser Pink Salmon catch: (1) estimates of total Pink Salmon catch (Fraser and non-Fraser stocks) for which the methodology has varied over time and by fishery, and (2) estimates of the contribution of Fraser Pink Salmon to those total catches. For the second component to the estimation of Fraser Pink Salmon catch, two methods have been used to partition total catch into Fraser and non-Fraser components: (a) from 1959 – 1985 the Pink Salmon catch estimates were partitioned based on run reconstruction methodologies; and (b) from 1987 to 2013, GSI techniques have been used.

Total Pink Catch

Pink Salmon are caught in commercial, recreational and aboriginal fisheries in both the United States and Canada. The fraction of Fraser Pink Salmon allocated to the United States and Canada are stipulated in the Pacific Salmon Treaty. These regulations coupled with interannual fluctuations in Pink Salmon total returns, varied demand for Pink Salmon and other factors have contributed to large variation in both the magnitude of total catches (Table 1, 'Total Catch' column), and the fraction of the total catch caught by various sectors. As documented below, the methods used to estimate catches vary between commercial and non-commercial sectors and for the same sectors in different countries. But lacking detailed records that quantify the accuracy of methods used in specific periods, it is difficult to draw more that qualitative inferences associated with different methods applied to different sectors and periods. Canadian commercial fisheries include conventional commercial Salmon licenses (Salmon troll, gillnet and seine) in authorized and protest fishing, Salmon directed scientific fisheries by commercial gears, Salmon-directed test fisheries, and First Nations fishing under economic opportunity licences. To quantify Canadian commercial catch, DFO started a sales-slip program in 1951 that documented all commercial catches (by species, numbers, and weight) at the point of landing (Wong 1983). During much of the period of operation of this system, a relatively high fraction of the number of fish (pieces) landed at various locations (packers, processors, etc.) were counted and sales slips were the official source of commercial catch estimates in Canada. Annual summaries were published in Blue Books to1995. Data from sales slips to 1995 are generally considered to be quite accurate (R. Houtman, DFO, pers. comm.).

Although sales slips historically are considered accurate, in recent years (1996 – present), the quality of sales slips declined due to the large increases in commercial buyers and increases in fishers selling directly to consumers. Given the cooperation required between sellers and buyers required for effective sales slip reporting, the dramatic increase in the numbers of buyers resulted in a deterioration of sales slip data quality. This deterioration is further confounded by the tax and other benefit (employment insurance) disincentives to reporting catch. This resulted in increased non-reporting and mis-reporting (incomplete or biased reporting) of fish sales to the sales slip program, which results in the underestimation of catch that in some years that could be quite large (DFO 2009; Bijsterveld et al. 2002). Further, although sales slips are required for all fish caught, they are typically recorded as landed weights versus numbers, therefore, the conversion of weights to numbers using an average landed weight-per-fish, introduces error into these estimates (DFO 2009). Recognizing the issues with sales slip catch estimates, DFO recently reviewed and finalized catch estimates for 1996 to 2004, using data from various sources (sales slips, fishers logbooks, mandatory catch hails made in-season, observer estimates and creel programs that combine surveys of catch rates and effort) (DFO 2009) (Table 1). Differences, however, for Pink Salmon between the sales slip estimates versus final estimates produced from the recent review for these years was relatively small (2.4%) (DFO 2009). For subsequent years (post-2009), DFO has not yet developed a process to rigorously evaluate catch estimates similar to the methods described in DFO (2009).

For U.S. commercial fisheries, harvest of Fraser River Pink Salmon in U.S. primarily occur in the Washington State waters of Juan de Fuca Strait and northern Puget Sound. Catch in U.S. waters represents a variable proportion of total catch, but most of the catch is associated with commercial fisheries. The Washington Department of Fish and Wildlife (WDFW) also implements a sales slip program which forms the basis for catch estimates. All fishers are required to sell fish to designated buyers and report fish taken that are not sold. To facility management decisions by the Fraser River Panel , a "quick" reporting system requires buyers to report landing to WDFW by 10 a.m. of the day following the purchase date (Contact WDFW for more details, e.g. http://wdfw.wa.gov/publications/01537/wdfw01537.pdf). Compliance is strictly enforced. The relatively low catches of Pink Salmon that occur in Oregon waters are available from the Oregon Department of Fish and Wildlife (ODFW).

Major recreational fisheries in marine areas and the Fraser River and its tributaries are generally assessed by DFO using creel surveys. A small recreational catch also occurs in

US marine waters, that is also assessed by creel census methods. These recreational fisheries usually represent a small percent (e.g. <5%) of the total Pink Salmon catch in most years. Recreational fisheries are assessed using creel program methods. The creel method involves conducting representative samples of angler interviews over the course of the fishing period and over the spatial distribution of anglers in the fishery being assessed, to quantify angler catch-per-unit-effort (CPUE). In addition, instantaneous counts of actively fishing rods-per-angler are conducted hourly at locations representing a high proportion of a fishery's angling effort. Instantaneous counts are then combined with bi-weekly overflight angler rod counts (randomized weekly to cover one weekend day and one weekday) to estimate total effort within a system. Catch is then estimated by essentially multiplying CPUE estimated from angler interviews by the total effort estimated from the hourly rod counts and bi-weekly overflights. See Bratty et al. (1998) for more detailed methods. In addition a small portion of the recreational anglers may participate in voluntary surveys that can contribute to catch and CPUE estimation.

Generally, Pink Salmon catch in First Nations food, social, and ceremonial fisheries (FSC) is negligible, and are caught largely as by-catch in other Salmon-species directed FSC fisheries (M. Parslow, DFO, pers. comm.). First Nations FSC catch represents, therefore, represents a very small percentage of the total Pink Salmon catch (M.Parslow, DFO, pers. comm.). Catch in FSC fisheries is estimated using a variety of methods and include use of fishery observers to record catch and release on a set-by-set basis and use of creel programs that include boat and vehicle patrols for catch and effort data and fisher interviews and overflights to assess instantaneous total set net fishing effort during an opening.

In more recent years, First Nations have engaged in pilot commercial harvest of Fraser Pink Salmon either include sales of carcasses and roe. Catch in these fisheries are estimated using similar techniques to those described above and using fish sales slips where applicable.

Partitioning Catch into the Fraser Pink Salmon Component

Run Reconstruction

Run Reconstruction and Tagging Based Methods: 1959-1977

Canada and the United States agreed to coordinate the management of Fraser River Pink Salmon stocks when they signed the Pink Salmon Protocol in 1957. The Parties recognized that there was considerable uncertainty about the stock composition of Pink

Salmon catches in the coastal waters around Vancouver Island and Puget Sound (IPSFC 1959). Consequently, a coordinated and large-scale mark-recapture study of Pink Salmon was undertaken in 1959 in the waters between Vancouver Island and the mainland of British Columbia and the State of Washington (Vernon et al. 1964). This study was used to estimate the Fraser Pink Salmon catches in these areas. Coupled with mark-recapture estimates of populations in spawning and other local areas, it provided the first comprehensive estimates of the total return of Fraser River Pink Salmon stocks as well as those from the Puget Sound and other non-Fraser Canadian stocks spawning south of Cape Caution.

In 1961, a more limited mark-recapture program was undertaken in Juan de Fuca Strait to assess the abundance by stock (Hourston et al. 1965). It was determined that the marine timing of Pink Salmon by stock group (including Fraser Pink Salmon) was similar to 1959. The estimates of catch by stock group from the northern approach (through Johnstone Strait) in 1961 were based on estimated rates of harvest in 1959, after adjusting for differences in the week-ending date between 1961 and 1959 (Hourston et al. 1965). The limited catches by stock group in Juan de Fuca Strait and northern Puget Sound Convention Waters in 1961 were determined based on the 1959 tagging study and adjusted by timing information of Georgia Strait and Puget Sound stocks from the 1961 tagging study in Juan de Fuca Strait. Information from the 1959 tagging study largely formed the basis for future (until 1987) estimates of exploitation patterns, the proportion of the terminal-area stock timing and abundance from the northern and southern approaches and the relative migration profiles entering each fishing area. The 1959 and 1961 mark-recapture programs formed the basis for estimating Fraser River Pink Salmon catches and returns in those years.

Chapman (1973) summarized the methods that were used to estimate Fraser Pink Salmon catches and total returns from 1963-1971 and described specific interrannual differences in methodology that were applied to the specific fishing areas, some of which were due to changes in the management of individual fisheries. These analyses were based on the available information on the terminal (near river mouths or in spawning areas) population sizes and while the escapement of Pink Salmon to the Fraser River was based on relatively precise mark-recapture methods, the spawning estimates of many of the other populations were not as rigorously estimated. Variability and bias in escapement estimation methods affected estimates of catch contribution by stock. However, in most years, the later timing of Fraser River Pink Salmon (relative to non-Fraser stocks) resulted in much of this uncertainty being associated with earlier-timed (non-Fraser) stocks. The run reconstruction approach and 1959 and 1961 tagging programs formed the basis for estimates of Fraser River Pink Salmon catch and total return (when coupled with escapement estimates describe above) for 1959-1977. These historic estimates indicated that interannual variability in the migration behavior of Fraser River Pink Salmon stocks, in terms of both marine timing and the fraction of the run migrating through Johnstone Strait (i.e. northern diversion rate) can be high.

Run Reconstruction Methods: 1979-1985

By the early 1980s, personal computer technology was readily available and enabled numerically intensive methods to be used in the reconstruction of catches and total returns of Fraser River Pink Salmon. In 1985, IPSFC and DFO staff (Paul Starr, Al Gould, Jim Woodey and Jim Cave) agreed to replace the methods previously used for estimating the 1963-1977 Fraser River Pink Salmon returns with a standardized, backwards run-reconstruction approach (Starr and Hilborn 1988). Contributions by stock group of Pink Salmon to catches were estimated in northern approach (Canadian statistical Areas 11-16) and southern approach fisheries (Washington State statistical Areas 4B 5, 6, 7 and 7A and Canadian statistical Areas 18-20) for the return years 1979-1985. These methods were used to explore alternative assumptions about timing and migration pattern of the stocks. However, information from the 1959 return was used to establish the timing of the escapement profiles of the stocks, as more direct information on the migration and catches were still unavailable. The reliance on the 1959 tagging and reconstruction results was considered to be a major limitation throughout the analyses.

The procedure that was used followed a backwards reconstruction in time and space:

$N_{ijkl} = P_{ijkl} + C_{jk} \cdot \left[\frac{P_{ijkl}}{\sum_{i=1}^{ns}\sum_{l=1}^{np} P_{ijkl}}\right]$ (Starr and Hilborn 1988*, Equation 5)*

where N_{ijkl} is the abundance of stock *i* entering fishery *j, k^{th}* period, and lump *l*, P_{iklj} is the number of stock *i* escaping fishery *j*, for k^{th} period, and lump *l*, and C_{jk} is the catch in fishery j, for the k^{th} period.

More simply, the catch-by-stock by fishery period was estimated based on the proportion of that stock in the total number of fish surviving from all stocks from that period and fishery.

The methodology assumed that all stocks follow an order of movement through the migratory areas and also that all stocks within an area or at the very least sub-area were equally vulnerable. Another important assumption was that escapements were measured without bias. Biases in escapement estimation were transferred directly into a proportional bias in catch estimation; for example, if the escapement of a stock was overestimated by 50%, the reconstructed catches and therefore total return would also be overestimated by 50%. Bias in escapement estimation applies not only to the total estimate of escapement but also to how that escapement is apportioned in a migration curve at the exit of each migration approach (i.e. from the north and south) (Pacific Salmon Commission 1995).

A “half-weekly” time step was used for the temporal resolution of the reconstructions. Catch data were provided by the IPSFC for Convention Waters (IPSFC 1986; currently Fraser Panel area, Figure 5) and by DFO for Canadian Non-Convention Waters. Catches for troll and sport fisheries in United States Non-Convention waters were provided by Washington Department of Fisheries (WDF) and Oregon Department of Fisheries (ODF). The tag recoveries by approach and by stock from the 1959 tagging study (Vernon et al. 1964) were used to assign the terminal catch and escapement data for all stocks (except Fraser River Pink Salmon) into terminal timing curves by stock group for the northern and southern approaches. The timing-abundance curve for Fraser River Pink Salmon was derived by partitioning the terminal catch and escapement into temporal strata using catch-per-effort data from the Cottonwood gillnet test fishery. These curves were moved backwards in time and space according to migration speed estimates from the 1959 tagging study. Catches were assigned and accrued to the individual stock migration curves in each fishery area according to the methodology described above by Starr and Hilborn (1988).

Sensitivity analyses were conducted on run-reconstruction methods applied to estimate Fraser Pink Salmon catches in 1985. These analysis focused on varying the fraction of Washington Pink Salmon populations that migrated via Johnstone vs. Juan de Fuca Strait because the migration routes of these populations were poorly understood. Sensitivity analyses indicated that the early timing of the Washington stocks likely resulted in an overestimate of catch assigned to these populations. However, for Fraser River Pink Salmon, the mean-percent-variation was very low for estimates of total return (2%), exploitation rate (1%) and proportion of run through the north (2.5%), across the sensitivity analyses that were explored. This small impact on the Fraser Pink Salmon estimates likely resulted from their later timing through the migratory areas relative to the earlier timed Washington populations.

Genetic Stock Identification

Genetic Stock Identification Methods: 1987- 2005

From 1987 to 2005 genetic stock identification (GSI) involving protein electrophoretic analysis of allozymes in Pink Salmon tissues (White 1996) was used to estimate the contribution of Fraser River Pink Salmon in mixed-stock fisheries; primarily in areas south of Cape Caution (B.C. mainland coast near the northern tip of Vancouver Island). Most of these electrophoretic analyses were conducted by the Genetics Unit at the Washington Department of Fish and Wildlife. The GSI program relies on genetic differences among stocks of Pink Salmon to estimate their individual contributions in mixed stock fisheries. The GSI program required: (1) the development of a genetic baseline comprised of Fraser River and other Pink Salmon stocks (i.e. southern Canadian non-Fraser and Washington stocks) that could be present in fisheries where Fraser River Pink Salmon could be harvested; (2) in-season electrophoretic analyses of muscle tissue samples from fisheries where Fraser River Pink Salmon could be harvested; and (3) estimation of the proportion of Fraser, Canadian non-Fraser and Washington Pink Salmon stocks present in the samples using maximum likelihood estimation methods that compare data in the genetic baseline to the sample data.

During this period, the largest marine catches of Fraser River Pink Salmon typically occurred in Canadian Statistical Areas 12, 13, 20 and 121-127, while in the U.S most of the catch was taken in Washington Statistical Areas 7 and 7A. Approximately 150 Pink Salmon tissue samples per week were collected and analyzed from the each of these areas during periods when substantial catches occurred in odd years. Sampling was also conducted in other, smaller fisheries when substantial contributions of Fraser River Pink Salmon were expected. In most of the major Pink Salmon fisheries noted above, Fraser River Pink Salmon proportions were low prior to early August and then increased fairly rapidly through mid-August and then typically peaked from late August to early September. During their peak migration through these major fisheries, Fraser River Pink Salmon often comprised over 80% of the Pink Salmon contributing to the catches.

From 1987 to 2005 development of the genetic baseline continued so that the accuracy of the stock composition estimates would be as high as possible. The baseline development included adding additional genetic traits (loci) to the baseline and expanding the number of stocks in the baseline as well as the sample sizes representing each of the stocks. Although the primary application of the GSI estimates was for estimating the catch of Fraser River Pink Salmon by country, and user group as required by the FRP, the information was also used for other fisheries management applications including run size estimation and assessments of the migratory behavior of Fraser Pink Salmon such as their diversion rate and marine timing.

Estimation of Fraser River Pink Salmon catches required multiplying the total Pink Salmon catch in fisheries by the estimated stock composition in the fisheries to provide an estimate of the Fraser River Pink Salmon catch in the fishery. Accounting of the catch and stock composition estimates was performed with computer spreadsheets. Due to budget constraints it was not possible to sample every fishery that could potentially harvest Fraser River Pink Salmon. . In cases where catches of Fraser River Pink Salmon may have occurred in fisheries but in-season GSI samples were not collected, the missing GSI estimates were estimated by interpolating between GSI estimates (e.g., from adjacent weeks or areas) or extrapolating as required. Since 1987, in-season Pink Salmon GSI samples have been collected from a high proportion of the major fisheries where Fraser River Pink Salmon could likely be harvested. Therefore, the proportion of the total Fraser River Pink Salmon catch that has been estimated by interpolation and extrapolation methods is relatively low. Pink Salmon catches occurring in the Fraser River are assumed to be 100% Fraser origin, which eliminates the need to conduct in-season GSI analyses from samples collected in the Fraser River.

Genetic Stock Identification Methods: 2007- 2013

By 2003, the number of laboratories still conducting electrophoretic analysis of Salmon tissue samples was declining rapidly. Consequently, research was accelerated to develop a new method of Salmon GSI for Fraser River Pink Salmon that would also potentially increase the accuracy of the stock composition estimates and ensure that GSI methods could continue to be used for in-season management.

In 2006, the Molecular Genetics Unit (MGU) at the Pacific Biological Station in Nanaimo, B.C. was contracted by the PSC to analyze Pink Salmon tissue samples collected from numerous spawning grounds in B.C. and Washington. The MGU had conducted microsatellite DNA analyses for the PSC's Fraser River Sockeye Salmon stock identification program since 2000 and consequently the DNA methodologies were well developed. A preliminary Pink Salmon microsatellite DNA baseline was assembled in 2007 with 14 microsatellite DNA loci. Simulation analyses based on microsatellite DNA indicated that estimates of Fraser River Pink Salmon contributions to mixed-stock fisheries were reasonably accurate for in-season application (Beacham et al. 2012).

From 2007 to 2013, the PSC relied on in-season GSI programs based on microsatellite DNA to estimate Fraser River Pink Salmon catches and provide data used in other fisheries management applications that was previously available from the electrophoretic allozyme analyses. The microsatellite DNA baseline was expanded between 2007 and 2013 in terms of the number of microsatellite DNA markers analyzed and the number of Pink Salmon stocks (and their sample sizes) in the baseline.

Through the period of analysis the baseline samples comprised Pink Salmon stocks from the three regions: (1) Fraser River, (2) Canada South Coast and (3) Washington. The 2013 baseline contains samples from most of the Pink Salmon stocks that could contribute to marine fishery catches where Fraser River Pink Salmon are typically harvested including 15 populations from the Fraser River, 19 populations from Canada South Coast and 12 populations from Washington. In 2013, in-season tissue samples from up to 100 Pink Salmon were collected at approximately weekly intervals from fisheries where Fraser River Pink Salmon are typically caught. Adipose fin tissue was sampled for DNA analyses at 16 microsatellite loci. The genotypes of the fish in the mixture sample were compared to the 46 baseline stocks noted using the program ONCOR [1]. Stock composition estimates derived from these analyses were used to estimate the catch of Pink Salmon from the three regions by country, area and user group.

FRASER RIVER PINK SALMON TOTAL RETURN

Stock-recruit analyses require estimates of the total return (escapement plus catch) of Pink Salmon that has been produced from the brood year spawning escapement. Estimates of total annual Fraser River Pink Salmon return are simply the sum of annual estimates of Fraser River Pink Salmon catch and escapement described in preceding sections. This method applies to all but three years (2003, 2005 and 2007) in the return time series (1959-2013), when no direct estimates of escapement exist. In those years, the total returns were estimated by the cumulative CPUE in marine purse test fisheries divided by the median historical catchability (see preceding section “Indirect System-Wide Estimates (Test Fishery): 2003-2007“, and Appendix C for further details). The estimates of total return from 1959 to 2013 are presented in Table 1 and vary from a low of slightly under two million fish to a high of slightly over 24 million fish with an average return of approximately 12 million fish (Figure 3). Methods of total return estimates have varied both due to large changes in escapement methods over the time series (system-specific

[1] Kalinowski, S.T., K.R. Manlove, and M.L. Taper. 2008. ONCOR: a computer program for genetic stock identification, v2.0. Montana State University, Bozeman. Available: http://www.montana.edu/kalinowski/Software/ONCOR.htm (January 2012).

estimates from 1957-1991; system-wide mark recaptures from 1993-2001; and hydroacoustic estimates from 2009-2013) and also due to changes in largely total Pink Salmon catch assignment to Fraser Pink (versus non-Fraser Pink) stocks (run reconstruction methods varied between 1959-1977 and 1979-1985 periods and more broadly between GSI methods that changed from 1987-2005 and 2007-2013 periods). As a result, the return time series is not entirely comparable due to all these differences in methodology and the lack of calibration between these approaches.

FRASER RIVER PINK SALMON FRY ABUNDANCE

Total Fry Abundance

Following adult spawning that occurs in the fall of odd years, Fraser River Pink Salmon fry emerge from the gravel in early spring of the following even year, as early as February, and migrate immediately to the Fraser estuary in the Strait of Georgia. Peak downstream migration generally occurs between mid-April and early May. The primary goal of the Fraser River Pink Salmon fry enumeration program is to obtain a quantitative index of the total number of Pink Salmon fry migrating downstream at Mission in the Fraser River (see Figures 4 & 6). Since sampling error is largely unquantified, estimates of Pink Salmon fry abundances represent indices of abundance only. Data from the Pink Salmon fry enumeration program are also used to generate daily estimates of abundance to provide an indication of the migration timing of Fraser River Pink Salmon fry. In addition, subsamples of Pink Salmon fry are collected to assess fry lengths and weights (these data are reviewed in subsequent sections).

Data Availability

Pink Salmon fry migration has been monitored continuously by DFO since 1962 (although estimates are only largely comparable from 1968 to present) (Table 1). The methods for fry enumeration were developed by Vernon (1966) and Todd (1966), and were compiled into a field guide by Moir (1978). This section was compiled from the above references, with input from J. Tadey (DFO, pers. comm.), who is currently responsible for estimating the Pink Salmon fry migration at Mission.

A comparable time series of outmigrating Fraser River Pink Salmon fry exists for the years 1968 to present, using largely consistently applied sampling methods and analyses (Table 1). All electronic Pink Salmon fry data from the sampling program and analyses from 1968 to present are available through DFO (J. Tadey, DFO). Since DFO does not have the electronic data sheets used to record and analyse escapement estimates prior to 1968, DFO cannot confirm whether or not this earlier time period is comparable to the post-1968 period. Detailed raw data are missing for the years 1962 to 1964, and a portion of 1966, though summary data (estimated abundance) are available for these years. Data from 1962 and 1964 are thoroughly described in Vernon (1966), although the methodology is different from subsequent years; these years are therefore not comparable to the subsequent years in the time series. Specifically, different weighting methods were used to sum lateral, vertical and diurnal periods for 1962-1966 versus 1968-2012 (see final section of Appendix F, Table F2). In addition, from 1968-1974 slightly different field methods were employed, where trap speed was variable during this period, as opposed to be standardized following this period. Although it is thought that this would not result in large differences in estimates between methods (T.Cone, DFO, pers. comm.). Fry data and analyses from 1976-present have been verified by DFO.

Juvenile data for 1966 to 2010 have recently been compiled into a single excel file by a separate DFO group (DFO Science: L. de Mestral Bezanson). However, this DFO file has not been verified for the years 1966 to 1974, and, given that errors were found upon a quick spot check of the file, it is recommended that data verification be completed prior to its use (approximate time to complete: 1 month of technical support at the DFO EG01 level).

Data are also compiled for the fry assessment program start and end dates and the associated fry abundances with these dates, and also include the 50% migration date, when half the fry run has moved downstream past the Mission sampling program (see Appendix F, Table F1).

Field sampling operations have occasionally been suspended due to logistical (crew or equipment maintenance) constraints. Standard sampling protocol includes one to two day gaps between sampling. Periods greater than four days were reviewed for their possible impact on abundance indices. In analyses, extended gaps between samples are treated the same way as the normal one to two day period between samples. Specifically, gaps are filled by first averaging the fry density estimates for the previous and subsequent sampling dates, and the averages are then multiplied by their respective daily discharge estimate (see Appendix F) to generate the estimate of total fry per day past Mission. Over the time series for which juvenile abundance estimates were generated (brood years: 1961-2011), there were only three years during which more than three days passed between sampling events. The details regarding these data gaps and their potential impacts on the estimates for each of these years are described below.

- **1990:** There were two periods of more than three days between sampling events: March 27-30 (4 days) and May 16-21 (6 days). As these two periods occurred at the beginning and end of the migration (Figure 7), the interpolated estimates for these days only account for 9.3% of the total 1990 fry abundance estimate.
- **2006:** There was one period of more than three days between sampling, May 12-20 (9 days). This period was near the end of the migration (Figure 7) and the interpolated estimates only accounted for 1.3% of the total 2006 fry abundance estimate.
- **2010:** There was one period of greater than three days between sampling, April 22-May 1 (10 days). This gap resulted from an engine breakdown on the vessel that occurred just after the peak of migration (Figure 7) and the interpolated values accounted for 28.9% of the total 2010 fry abundance estimate. If the fry abundance further increased during the gap in sampling, the 2010 estimate of 1.06 billion fry (the highest on record) could be biased low.

Methods

The IPSFC developed a Fraser River Pink Salmon fry enumeration program in the lower Fraser River near Mission (Figure 4 & 6) for estimating the total fry abundance outmigrating from virtually the entire Fraser River watershed. The early development and design of the fry enumeration program is described in Vernon (1966). The sampling program uses two traps that are attached to each side of a vessel. An inclined plane trap is used to samples from the surface to a depth of about 1 m (Figure 8). The second trap consists of a net mounted on a rectangular support that is used to adjust the sampling depth down to 3.7 m (Figure 9). The sampling schedule and estimation procedures are stratified by day, time, and sample trap type with systematic sampling of twelve stations spawning the cross river width upstream of the highway bridge at Mission. Average catches are calculated and scaled by the discharge to calculate daily (24 hour) abundance estimates. Estimates are interpolated on non-sampling days. Analytical methods and assumptions are detailed in Appendix F.

Stream Specific Fry Estimates

While records indicate that fry production estimates were generated for several individual streams, the actual estimates could not be located for this report. It is possible that hatchery or spawning channel operators may possess paper copies of these data, although most of these programs targeted Sockeye Salmon smolt enumeration, and Pink Salmon fry were recorded as by-catch. The Seton spawning channels are an exception, as they were constructed for enhancing Pink Salmon populations and a short time series exists for the Pink Salmon fry produced from those channels (Roos 1991).

BIOLOGICAL DATA

Adult Data

Male and Female Weights and Lengths

Although it would be preferable for escapement policy analysts to use average Pink Salmon weight data collected from the Fraser River spawning grounds (i.e. the sample fish are from known origin), estimates of the average weight of adult male and female Fraser River Pink Salmon recorded in the marine environment, shortly before they enter the Fraser River are the only source of weight data for this stock. The IPSFC (1959-1985) and the PSC (1987-2013) have made estimates of the average marine-area weight of Fraser River Pink Salmon. The IPSFC estimated the average weight of Pink Salmon caught in Area 20 purse seine fisheries during the peak of the Fraser Pink Salmon migration (Table 9). Although these estimates of average weights contain a component of non-Fraser River Pink Salmon stocks, it is likely that the majority of the Pink Salmon in the samples are Fraser origin fish. Additionally, Fraser and non-Fraser Pink Salmon in these catches generally have similar average body sizes in the same return year.

With the development of the PSC's Pink Salmon GSI program in 1987, the likelihood that adult Pink Salmon sampled in marine areas were of Fraser origin was consequently increased (1987-present). Since 1989 the average weights of adult Pink Salmon returning to spawn that were caught and sampled from Canada's Area 20 purse seine fisheries and in Washington Areas 7 and 7A fisheries were recorded (see Figure 4 for location; Table 9). The average Pink Salmon weight from the GSI samples (in Areas 7, 7A, and 20) where Fraser River Pink Salmon were estimated to comprise at least 70% of the mixtures were summed and the average weight was calculated. The average Fraser River Pink Salmon weight-per-year was based on approximately six to ten samples of approximately 100 fish each (total of about 600 to 1,000 fish) from the areas assessed (see example calculation in Table 10 from the 2013 season; this example illustrates the calculation as well as being indicative of the variability in average weights across samples within a year that was observed from 1989 to 2011). For comparison, non-Fraser stocks in these samples (primarily Washington Pink Salmon, with lower proportions of Canada's South Coast/non-Fraser stocks) have similar average post-orbital hypeural (POH) lengths as Fraser River Pink Salmon average POH lengths, as measured on the spawning grounds (Table 11), are typically within approximately 1 cm of those from the non-Fraser stocks in the same return year. The estimated annual weights of adult Fraser River Pink Salmon in Table 9 are considered to be reasonably accurate.

Fraser River Pink Salmon post-orbital hypeural (POH) length data were collected for males and females starting in 1987 (1987-2013), by the PSC for genetic stock identification purposes (Table 11).

Female Length and Fecundity

Estimates of total escapement do not account for variation in fecundity which can impact estimates of productivity and stock-recruit relationships. During the period when stream-specific escapement estimates were conducted (1957-1991), female POH length and fecundity samples were taken from moribund females collected from the major spawning populations. Samples from female Pink Salmon (typically 100 fish from the Mission tagging site, with others taken from the Chilliwack-Vedder, Harrison, Seton, and Thompson tagging sites) were collected using beach-seine nets during tagging operations. These samples were typically taken by DFO staff as they rotated through the different systems over typically a one week period. The fish were euthanized and their egg sacs were removed and weighed. The number of eggs-per-egg sac were counted in 20% of the samples. The egg sac weights and egg-counts were used to calculate eggs-per-gram, which was then multiplied by the egg sac weights to estimate fecundity for the rest of the sample. In addition their standard lengths and POH lengths were measured. Since data from 1957-1985 have not been digitized, results for these years are not included in our existing female length and fecundity data set (Table 12). Data collected from stream-specific escapement programs on female length and fecundity are available only from 1987-1991 (Table 12).

Subsequently, in the years of DFO's system-wide mark recapture program (1991-2001), female length and fecundity samples were taken in recovery areas (either near spawning areas) or at Strawberry Island and were weighted by abundance indices derived from tag incidence and CPUEs at the recovery site. Following the termination of DFO's system-wide mark recapture program post-2001, female fecundity was not assessed. So the complete fecundity time series presented in the current report include the years 1987-2001 only (Table 12).

Sex Ratios

In addition to estimates of female fecundity, estimates of total escapement do not account for variation in sex ratios which can also impact estimates of productivity and stock-recruit relationships.

The programs used to estimate escapements in preceding sections also collected data on sex ratios. For all years with mark-recapture programs (1957-2001) separate estimates of escapement were made for each sex (Table 13). Although the PSC has recovered Pink Salmon carcasses during GSI baseline development, the sampling goal was generally to sample a similar number of fish from each sex and, therefore, the sampling was not conducted in a random manner for possible use in estimating the sex ratio.

Spawning Distribution

Historically, prior to the 1913 Hells Gate landslide, the greatest proportions of Fraser River Pink Salmon spawning occurred in the Upper Fraser watershed (Rounsefell & Kelez 1938; Pess et al. 2012). Despite the establishment of a fishway in 1947, Fraser Pink, spawning distribution remains concentrated in the Lower Fraser watershed after the landslide (Pess et al. 2012). Adult spawner distribution is available in detail for the years when stream-specific escapements were estimated (1957-1991)(Table 2; Figure 10). Tributary specific estimates are presented in Table 2 and higher resolution stream-specific estimates for this period are also available through DFO's NuSEDs escapement database. Adult spawner distribution is also available during the more recent period when two estimates of Fraser Pink abundance were generated at Mission, B.C. and Qualark, B.C., which could be used to partition escapement broadly into downstream and upstream of Qualark components (Figure 4 for map; Figure 11). From 1993 to 2007, no data are available assess Fraser River Pink Salmon spawning distribution since only a single system-wide escapement estimate was generated during these years.

For the period when stream-specific escapements were generated (1957-1991), Pink Salmon spawners in the Lower Fraser watershed (including the Lower Fraser, Harrison, and Vedder-Chilliwack systems) contributed, on average, 70% of the total spawners (Table 2; Figure 10). Upstream spawners (including the Upper Fraser, Fraser Canyon, Seton-Anderson, and Thompson systems) contributed, on average, 30% of the total spawners during this period. Combining the system-specific distribution data with the two separate hydroacoustic estimates produced at Mission (official escapement program) and Qualark (experimental program) from 2009 to 2013, total escapement can be partitioned into downstream and upstream of Qualark (see Figure 4 for locations of these programs)(Figure 11). For these years (1957-1991 and 2009-2013), the greatest proportion of total Fraser Pink Salmon escapement occurred downstream of Qualark (average: 71%), versus upstream of this site (average: 29%).

Adult Migration Timing and Diversion Rate

Historic data on Fraser River Pink Salmon migration timing and diversion rate would not necessarily be used directly in the development of escapement policies for Fraser River Pink Salmon. However, these data are used in the development of pre-season fishing plans for Fraser River Pink Salmon, which as noted previously in this report, can affect the achievement of fisheries management goals of the Fraser River Panel, including escapement goals. Therefore, a brief summary of these data are provided below.

Area 20 Migration Date

The most consistent measure of adult marine migration timing is the Area 20 migration date. The Area 20 migration date is an index of marine migration timing indicating when 50% of the total run of Fraser River Pink Salmon would have migrated through Canadian Area 20 in Juan de Fuca Strait, assuming that the entire run migrated through this area. These estimates are calculated using daily abundance estimates based on CPUE data from test fisheries, and catchability estimates, and have been calculated in a similar manner across the time series (C. Michielsens, PSC, pers. comm.). Details on methodology can be found in annual reports from the IPSFC and PSC. The Area 20 migration date for Fraser River Pink Salmon typically falls within a two week period between late August and early September (Table 14), with the earliest estimated date being August 19 (1961) and the latest September 7 (1999).

Diversion Rate

Diversion rate (also referred to as northern diversion rate or Johnstone Strait diversion rate) refers to the proportion of the Fraser River Pink Salmon run returning through the northern approach (Johnstone Strait) as opposed to the southern approach (Juan de Fuca Strait: Figure 4). This proportion is calculated by expanding CPUE rates from test fisheries in Area 20 (Juan de Fuca Strait) and Areas 12 and 13 (Johnstone Strait) to estimate fish passage, then using GSI to estimate the Fraser River Pink Salmon component in the passage estimates (detailed in Pacific Salmon Commission 2013, Appendix D). The diversion rate has historically ranged from 22% to 85%, and has increased over time (Table 14).

In-River Migration Timing

Historically, observers have classified Pink Salmon entering the Fraser River into an “early” and “late” run separated by 7-10 days. This phenomenon was described by Ward (1959), who found two separate peaks in the migration through the lower Fraser River past

Mission in 1957. The first peak occurred from September 14 to 17 and primarily included fish bound for the Seton, Thompson, and lower Fraser River mainstem areas. The second peak was less defined and included fish bound for the Harrison River (peaking from September 26 to October 6) and the Chilliwack-Vedder system (peaking during the first week of October. DFO tagging studies (1987-2001) offer another source of information on in-river migration timing in the form of CPUE from beach seines below Mission. (DFO unpublished data). More recently, hydroacoustic enumerations by the PSC in 2009 and 2011 have shown two clear peaks in migration past Mission, and the 2013 migration showed a similar pattern (data not available at time of report, Y. Xie, PSC, pers. comm.). In addition, information on the timing of Pink Salmon spawning activity exists in the form of notes recorded by IPSFC and DFO field crews on spawning summary cards. These records are for the period from 1959-1991, and note both the time of arrival on the spawning grounds and the time of peak spawning. This information has not been digitized, and is archived with Tracy Cone (DFO Data Manager).

Juvenile Data

Fry Size

Coupled with the annual estimates of fry abundance described above, estimates of fry size can improve our understanding of freshwater production dynamics and adult productivity. Currently, however, limited data are available (brood years: 1987-2009, excluding 2003) for Pink fry size data (Table 1) since data have not been digitized or summarized throughout the times series.

CONCLUSIONS AND DISCUSSION

This report summarizes historic biological data required for the evaluation of biological status assessment and the development of abundance-based biological benchmarks and, concurrently, the development of an escapement goal for the Fraser River Pink Salmon aggregate. The data that supports these assessments summarized in the current report include the following: estimates of adult Fraser River Pink Salmon escapements, catches, total run sizes, and adult biological data. These data are characterized by several changes in methodology over time, where no calibration occurred between methods, that must be carefully considered when conducting analyses and interpreting analytical results.

The time series of escapement data has changed over the period assessed (1957 to present) and include four distinct method: stream-specific escapements estimates generated from a variety of methods (1957-1991), system-wide mark-recapture escapement estimates (1993-2001), system-wide indirectly-derived test fishery escapement estimates (2003-2007) and in the current period system-wide hydroacoustic estimates (2009-present). Data particularly from the test-fishery estimates represent the weakest estimates in the time series given these escapements are indirectly derived. During this period, projections of the escapements in each of those years were made by subtracting the estimated catches from the estimated total run sizes, which have high uncertainty associated with them. Given all the changes in the escapement time series over time, and the fact that no inter-calibration work was done between methods, the escapement (and consequently return) time series are not completely comparable.

Similarly, catch assessment methods also vary over time, largely due to the approach used to assign Fraser Pink catch to total Pink catch estimates (different run reconstruction methods were used for two broad periods: 1959-1977 and 1979-1985 and different genetic stock identification methods were also used over two periods: 1987-2005 and 2007-2013). There has also been substantial variation across the time series in the proportion of the total return associated with catch (1957-2013 range: 4.5% to 86%) and conversely escapement, which affect the degree to which each of these component contribute to the variation in total return. Therefore, total return estimates are subject to variation resulting from both methodological and component (catch and escapement) changes over time, which complicate the interpretation productivity changes between years (e.g. returns-per-spawner).

Estimates of total return of Fraser River Pink Salmon are considered to be of similar accuracy over the period of record (1959-2013). This is because for slightly more than half of this period (i.e. until 1991) escapement estimates were the most accurate and then from 1987 to 2013 the catch estimates are considered to be the most accurate. It is possible that the most accurate estimates of total run size occurred in 1987, 1989, and 1991, which was the overlap period when both the most accurate escapement and catch estimates were generated.

In addition to adult data, estimates of Fraser Pink Salmon fry abundances (used as indices of abundance) and sizes are also compiled in the current report. Although data for the fry abundance time series exist from the 1961 brood year to present, it is largely comparable from the 1967 to present brood years given early shifts in methodologies. Fry abundances may be useful in quantify differences in productivity between freshwater and marine life stages and thus help to identify potential causal mechanisms for variation to total life cycle productivity. Therefore, considerations of data and data quality presented in this report are required for any subsequent analyses.

The time-series of estimates of the average body size of Fraser River Pink Salmon is good (1959-2013) however, the level of accuracy over this period is variable. The average weight of adult Fraser River Pink Salmon for the period 1959 to 1987 was estimated from the average weight of Pink Salmon caught in Area 20 purse seine fisheries and for the period from 1989 to 2013 it was estimated based on the average weight of Pink Salmon caught in near-terminal marine fisheries in Canada and Washington where GSI confirmed that a high proportion of the Pink Salmon in the samples were destined for the Fraser River. Estimates of the average length of Fraser River Pink Salmon collected from various tributaries is also available. The estimates are considered accurate since they are from confirmed Fraser River origin fish. Most of the average length data is available for the period from 1989 to 2013.

Data on the average sex ratios of spawners in the Fraser River watershed as well as estimates of female fecundities (and resulting total egg deposition) require more work to verify and expand the data sets for inclusion in the time series. Although longer-time series have been reported in PSC annual reports, DFO and PSC have not been able to verify this entire time series. So further work is required before inclusion of these data sets into the stock-recruitment time series. This work would be important to conduct since both female numbers and fecundity can be used to calculate egg deposition, for a more accurate estimate of freshwater survival in this system.

Estimates of fry size are presented for the 1987 to 2009. More work is required to extract historical data and update the data to current years.

Other biological data that may indirectly factor into the development and/or application of Fraser River escapement policies include estimates of the diversion rate of Fraser River Pink Salmon through Johnstone Strait and estimates of the 50% migration timing of Fraser River Pink Salmon through Area 20 and past Mission. These estimates are considered to be reasonably accurate and supported by a long-time series (1959-2013). Estimates of the exploitation rate, and freshwater and marine survival rates for Fraser River Pink Salmon are supported by a long-time series of estimates (1959-2013). All of these estimates are subject to the variability in the data used for calculating them. For example, estimates of

Fraser River Pink Salmon exploitation rates are simply the estimated catch divided by estimated total run sizes (catch plus escapement) for each year. As noted above, the accuracy of estimates of catch and escapement are quite variable over the period of record and hence estimates of the exploitation rate are also subject to similar uncertainty.

In summary, the data that are available for re-examining the Fraser River Pink Salmon escapement goal are not directly comparable over the time series and analysts must consider the differences in methods for escapements, returns, and fry abundances in any subsequent stock-recruitment modeling work and calculations of freshwater and marine survival.

The next steps in regards to Fraser Pink data sets include the following:

(1) Date on adult sex ratios have been reported in annual PSC reports from 1961 to 2001, however, this data could not be cross-referenced to DFO or PSC detailed data sets. Specifically, DFO could only identify data for the period of 1977 to 2001 (Table 13) in their records. Therefore, further work is required to source the more complete time series, including methods used to generate these estimates.

(2) Data on female fecundity have also been report in annual PSC reports from 1961 to 2001, however, this data could not be cross-referenced to DFO or PSC detailed data sets. Specifically, DFO only has electronic records for the period from 1987 to 2001 (Table 12) in their record. DFO also has paper copies of data from 1957 to 1985 that have not been digitized is recommended for future work. Therefore, further work is required to source the more complete time series, including methods used to generate these estimates.

(3) Juvenile length and weight data were only available electronically through DFO from 1987 to 2009 (brood years). Further work is required to obtain data for the years prior to 1987 and to generate estimates for recent years.

(4) Error checking of a juvenile data file from 1966 to 2010 compiled by DFO Science (L. de Mestral Bezanson) is required for the years from 1966 to 1974, given this period has not yet been verified and several errors were found on spot checks.

(5) Assessments of the past and present spawning habitat in the Fraser River watershed for Pink Salmon should be conducted to determine if the spawning habitat has been relatively stable over the period of record (e.g. a reduction in spawning habitat and/or quality would tend to support lower numbers of spawners than if the quality and quantity of spawning habitat has increased).

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Table 1. Net escapement (upstream catch was removed from escapement program estimate from 1993-2003 and 2007-2013), fry production (numbers), average annual fry length (mm) and wet weight (g), total catch, total adult returns, exploitation rate, and freshwater and marine survival. Escapement methods changed over the time series from stream-specific methods (1961-1991) (grey cells), system-wide mark recaptures (1993-2001) (green cells), indirect system-wide test-fishery estimates (2003-2007) (red cells), and system-wide hydroacoustic estimates (2009-2013)(blue cells). Since no calibration work between methods was conducted, estimates may not be directly comparable and this is most notable for the test fishery estimates (red cells). Grey shaded cells for fry production estimates (1961 to 1965) used slightly different methodology and, therefore, are not directly comparable to subsequent years.

Brood Year	Net Escapement Total	Fry Production	Fry Size Length (mm)	Fry Size Wet Weight (g)	Total Catch	Adult Returns (Catch + Escapement) [1]	Exploitation Rate	Survival Freshwater	Survival Marine
1957	2,242,867	NA	NA	NA	NA	NA	NA	NA	NA
1959	1,078,000	NA	NA	NA	5,382,055	6,460,055	83.31%	NA	NA
1961	1,092,561	284,231,670	NA	NA	796,685	1,889,246	42.17%	26015%	0.7%
1963	1,954,038	143,612,379	NA	NA	3,528,312	5,482,350	64.36%	7350%	3.8%
1965	1,194,099	274,038,242	NA	NA	1,125,788	2,319,887	48.53%	22949%	0.8%
1967	1,831,219	307,992,793	NA	NA	11,131,572	12,962,791	85.87%	16819%	4.2%
1969	1,530,913	287,672,663	NA	NA	2,400,548	3,931,461	61.06%	18791%	1.4%
1971	1,804,952	273,648,793	NA	NA	7,958,376	9,763,328	81.51%	15161%	3.6%
1973	1,754,261	212,282,112	NA	NA	5,049,723	6,803,984	74.22%	12101%	3.2%
1975	1,367,089	319,661,462	NA	NA	3,526,866	4,893,955	72.07%	23383%	1.5%
1977	2,387,811	483,705,232	NA	NA	5,821,674	8,209,485	70.91%	20257%	1.7%
1979	3,560,654	341,349,198	NA	NA	10,843,466	14,404,120	75.28%	9587%	4.2%
1981	4,488,336	606,956,510	NA	NA	14,196,353	18,684,689	75.98%	13523%	3.1%
1983	4,631,721	557,372,656	NA	NA	10,714,376	15,346,097	69.82%	12034%	2.8%
1985	6,460,950	264,501,452	NA	NA	12,577,074	19,038,024	66.06%	4094%	7.2%
1987	3,223,521	435,961,784	33	0.26	3,948,252	7,171,773	55.05%	13524%	1.6%
1989	7,189,201	400,400,254	37	0.25	9,295,074	16,484,275	56.39%	5569%	4.1%
1991	12,942,835	685,494,109	33	0.25	9,230,804	22,173,639	41.63%	5296%	3.2%
1993	10,768,335	437,726,552	32	0.24	6,215,163	16,983,498	36.60%	4065%	3.9%
1995	7,174,584	279,138,265	33	0.25	5,729,124	12,903,708	44.40%	3891%	4.6%
1997	2,842,108	257,454,524	32	0.21	5,333,856	8,175,964	65.24%	9059%	3.2%
1999	3,444,982	218,993,888	32	0.23	163,283	3,608,265	4.53%	6357%	1.6%
2001	19,813,620	714,393,790	33	0.24	1,448,154	21,261,774	6.81%	3606%	3.0%
2003	22,181,030	418,963,073	NA	NA	2,068,970	24,250,000	8.53%	NA	5.8%
2005	8,809,624	614,491,334	33	0.22	1,060,376	9,870,000	10.74%	NA	1.6%
2007	7,650,052	496,977,147	32	0.22	839,948	8,490,000	9.89%	NA	1.7%
2009	15,428,836	1,062,364,862	32	0.23	4,507,317	19,936,153	22.61%	NA	1.9%
2011	12,788,355	519,268,309	NA	NA	7,860,612	20,648,967	38.07%	NA	4.0%
2013	9,344,490	NA	NA	NA	6,553,329	15,897,819	41.22%	NA	NA
Average	6,580,007	419,178,963	33	0.23	5,700,929	12,280,935	49%	12068%	3%

1. the adult return in 2003, 2005, and 2007, was derived marine purse seine test fisheries (see text and Appendix C),

Table 2. System-specific Fraser Pink Salmon escapement estimates conducted by the IPFSC (1957-1985) and DFO (1987-1991), and system-wide escapement estimates conducted by DFO (1993-2001) and the PSC (2003-present). The escapements are organized into an earlier timed (Early Run) and later run timed (Late Run) component, based on the return timing of adults to the Fraser watershed. From 1957 to 1991 total escapements are the same as net escapements (minus upstream catch) and from 1993 to 2013 total escapements include upstream catch and net escapement removes upstream catch (see Tables 3 to 5 for details during the 1993 to 2013 period). Colours refer to escapement enumeration method as described in previous table.

	EARLY RUN						LATE RUN				
Year	**Lower Fraser**	**Fraser Canyon**	**Upper Fraser**	**Seton - Anderson**	**Thompson**	**Total: Early Run**	**Harrison**	**Vedder - Chilliwack**	**Total: Late Run**	**Total Escapement (from enumeration programs)**	**Net Escapement (minus upstream catch for applicable years: 1993-**
1957 [a]	1,081,957	12,660	263	60,820	269,340	1,425,040	595,480	222,347	817,827	2,242,867	2,242,867
1959 [a]	735,987	28,334	62	16,153	87,224	867,760	117,127	93,113	210,240	1,078,000	1,078,000
1961 [a]	552,681	14,842	83	62,175	69,411	699,192	198,597	194,772	393,369	1,092,561	1,092,561
1963 [a]	518,764	21,218	723	136,562	285,243	962,510	658,563	332,965	991,528	1,954,038	1,954,038
1965 [a]	544,246	7,577	3,180	125,248	233,100	913,351	77,396	203,352	280,748	1,194,099	1,194,099
1967 [a]	786,297	7,726	3,015	239,720	450,487	1,487,245	70,831	273,143	343,974	1,831,219	1,831,219
1969 [a]	848,532	4,894	NA	212,980	248,900	1,315,306	104,462	111,145	215,607	1,530,913	1,530,913
1971 [a]	929,185	21,410	5,346	308,241	258,203	1,522,385	107,494	175,073	282,567	1,804,952	1,804,952
1973 [a]	767,114	17,176	NA	249,058	283,504	1,316,852	211,345	226,064	437,409	1,754,261	1,754,261
1975 [a]	315,049	9,516	36	280,860	480,350	1,085,811	184,020	97,258	281,278	1,367,089	1,367,089
1977 [a]	775,016	9,276	3,444	435,341	978,325	2,201,402	132,755	53,654	186,409	2,387,811	2,387,811
1979 [a]	1,523,458	25,610	1,846	712,840	891,191	3,154,945	272,779	132,930	405,709	3,560,654	3,560,654
1981 [a]	2,255,753	43,234	5,532	626,402	1,166,348	4,097,269	316,998	74,069	391,067	4,488,336	4,488,336
1983 [a]	3,311,099	46,456	1,721	501,475	512,398	4,373,149	149,792	108,780	258,572	4,631,721	4,631,721
1985 [a]	5,270,436	164,437	530	274,120	193,448	5,902,971	447,377	110,602	557,979	6,460,950	6,460,950
1987 [b]	1,067,391	11,736	496	743,286	253,109	2,076,018	1,035,626	111,877	1,147,503	3,223,521	3,223,521
1989 [b]	4,782,107	40,697	6,535	1,059,491	281,640	6,170,470	687,421	331,310	1,018,731	7,189,201	7,189,201
1991 [b]	9,295,013	121,763	2,309	1,618,828	769,800	11,807,713	964,158	170,964	1,135,122	12,942,835	12,942,835
1993 [b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	10,774,681	10,768,335
1995 [b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	7,291,100	7,174,584
1997 [b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	2,889,600	2,842,108
1999 [b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	3,453,200	3,444,982
2001 [b]	NA	NA	NA	NA	NA	NA	NA	NA	NA	19,930,366	19,813,620
2003 [c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	22,181,030
2005 [c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8,809,624
2007 [c]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7,650,052
2009 [d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	16,151,501	15,428,836
2011 [d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	13,701,635	12,788,355
2013 [d]	NA	NA	NA	NA	NA	NA	NA	NA	NA	10,535,493	9,344,490
Average:	1,964,449	33,809	2,195	425,756	428,446	2,854,411	351,790	167,968	519,758	3,374,168	3,374,168

a. International Pacific Salmon Fisheries Commission (IPSFC) escapement estimates; b. Fisheries and Oceans Canada (DFO) escapement estimates
c. Pacific Salmon Commission (PSC) test-fishery escapement estimates; d. Pacific Salmon Commission (PSC) hydroacoutic escapement estimates

Table 3. Fisheries Officers qualitative (subjective) adult Fraser Pink Salmon escapement indices from 1947 to 1979 for six Fisheries Officer districts, and the annual totals across districts. These indices are the mid-point of the range of fish counted, as recorded by Fisheries Officers in BC16 data sheets and published in stream catalogues. Methods involved visual observations conducted once or twice per season, and were not based on a scientifically rigorous study design. These indices are compared with the International Pacific Salmon Fisheries Commission (IPSFC) Fraser Pink Salmon quantitative escapement estimates produced using scientific study designs that started in 1957. The Fisheries Officer estimates consistently underestimate (comprise less than 100% of the) total escapement as presented in the final column (percent).

	Stream Catalogue Data: Based on Fisheries Officer Observations							IPSFC Estimates	
Year	**Kamloops**	**Cariboo (Quesnel)**	**Chilliwack /Hope**	**Lillooet District (Seton)**	**Mission-Harrison**	**Fraser tributaries below Mission**	**Total Fraser (excluding tribs below Mission)**	**Total Escapement Estimate**	**Percent[1]**
1947			194,900	1,525	125,200	27,775	349,400	NA	NA
1949	400		124,200	825	53,100	9,975	188,500	NA	NA
1951	3,500		197,825	15,500	95,200	8,500	320,525	NA	NA
1953	4,650		125,662	57,500	114,275	34,550	336,637	NA	NA
1955	78,525		124,900	50,475	163,150	14,400	431,450	NA	NA
1957	301,900		221,025	76,025	270,275	500	869,725	2,242,867	39%
1959	75,200		152,225	7,975	118,295		353,695	1,078,000	33%
1961	75,200		261,075	36,650	203,616	3	576,544	1,092,561	53%
1963	284,447		252,850	135,150	660,693		1,333,140	1,954,038	68%
1965	234,159		228,825	135,950	77,871	5	676,810	1,194,099	57%
1967	452,700		281,628	240,175	84,675		1,059,178	1,831,219	58%
1969	241,575		80,729	204,025	14,950		541,279	1,530,913	35%
1971	251,950	3,500	183,975	276,425	117,400		833,250	1,804,952	46%
1973	281,175		218,650	250,225	20,200		770,250	1,754,261	44%
1975	355,050	600	96,845	55,150	92,075		599,720	1,367,089	44%
1977	974,632	1,500	37,720	430,500	169,575		1,613,927	2,387,811	68%
1979		500	61,199		36,800		98,499	3,560,654	NA[2]
average:	241,004	1,525	165,583	131,503	143,259	9,705	662,696	1,816,539	49%

1.Percent of the qualitative Fisheries Officer Fraser Pink Salmon escapement indices relative to the quantiative estimates generated by the International Pacific Salmon Fisheries Commission (IPSFC)

2. Given the incomplete time series for Fisheries Officer Fraser Pink Salmon observations, the ratio between these and total escapement estimates from stock assessment program could not be compared

Table 4. From 1993 to 2001, a Fraser Pink Salmon mainstem mark-recapture program was conducted with tagging and live recovery occurring downstream of most spawning location. Therefore, catch estimates above the tagging area were subtracted from the escapement estimate to provide a net escapement estimate that would include spawners only.

Year	Mainstem Tagging Program Escapement	Catch Above Tagging	Net Escapement
1993	10,774,681	6,346	10,768,335
1995	7,291,100	116,516	7,174,584
1997	2,889,600	47,492	2,842,108
1999	3,453,200	8,218	3,444,982
2001	19,930,366	116,746	19,813,620

Table 5. From 2003 to 2007 no Fraser Pink Salmon spawning ground enumerations occurred and instead escapements were estimated indirectly from total return obtained from test fishing data minus the estimated total catch .

Year	Total Return Estimate From Test Fisheries	Total Catch	Net Escapement to spawning
2003	24,250,000	2,068,970	22,181,030
2005	9,870,000	1,060,376	8,809,624
2007	8,490,000	839,948	7,650,052

Table 6. From 2009 to 2013, hydroacoustic estimates of Fraser Pink Salmon abundance at Mission, B.C. were generated. The estimated catch above Mission was subtracted from this estimate to provide a net escapement estimate.

Year	Hydroacoustic Escapement Estimate at Mission	Total Catch Upstream of Mission	Net Escapement
2009	16,151,501	722,665	15,428,836
2011	13,701,635	913,280	12,788,355
2013	10,535,493	1,191,003	9,344,490

Table 7. Summary of the PSC hydroacoustic estimates of Pink Salmon total escapement at Mission, B.C. in 2009, 2011, and 2013. For each year (column A) and period (column B), the methods (column C), total salmon escapement estimates (column D), Pink Salmon escapement estimates (column E), percentage of the total Salmon in each period attributed to Pink Salmon (column F; column E/column D) and percentage of the annual Pink Salmon escapement estimate attributed to the Pink Salmon escapement estimates in each sampling period (column G; each row of column E/[bottom row totals in column E for each year]) are presented. Comparable estimates to columns E and G of the PSC estimates are presented for the Stratified estimates in columns H and I respectively. Row totals for each year in column E correspond to the total escapement estimates presented in the second to last column of Table 2.

				PSC Official Estimate [1]			Stratified [2]	
A	B	C	D	**E**	F	G	H	I
Year	**Period**	**Method**	**Total Salmon Escapement**	**Pink Salmon Escapement**	**Pink Salmon Percent of Total Salmon**	**Pink Salmon Percent of Total Pink Salmon**	**Pink Salmon Escapement**	**Percent of Total Pink Salmon**
2009	Aug 7-19	Expert Judgement	713,461	**137,000**	19%	1%	105,256	1%
	Aug 20-25	Marine relative abundance	322,985	**183,808**	57%	1%	126,610	1%
	Aug 26-Sept	CPUE for sockeye, pinks by subtraction	16,372,398	**15,830,693**	97%	98%	15,368,017	99%
		Totals	**17,408,844**	**16,151,501**			**15,599,882**	
2011	Aug 8-16	Whonnock relative abundance	1,012,545	**30,400**	3%	0%	NA	
	Aug 17-28	Marine relative abundance	1,549,115	**616,844**	40%	5%	762,007	5%
	Aug-29-Sept 29	CPUE for sockeye, pinks by subtraction	14,937,391	**13,054,391**	87%	95%	14,216,740	95%
		Totals	**17,499,052**	**13,701,635**			**14,978,747**	
2013	Aug 3-18	Expert judgement	1,140,571	**36,681**	3%	0%	144,810	1%
	Aug 19-20	Marine relative abudance	219,629	**56,000**	25%	1%	50,282	0%
	Aug 21-31	Mixture model and Whonnock	1,765,234	**960,812**	54%	9%	1,212,897	11%
	Sept 1 -26	CPUE for sockeye, pinks by subtraction	9,975,318	**9,466,000**	95%	90%	9,214,412	87%
		Totals	**13,100,751**	**10,519,493**			**10,622,402**	

1 PSC methods varied by period as described in column C, see text for further details.

2 The Stratified method applied the proportion of Pink salmon obtained from fish wheel catches to total salmon abundances within 50 meters of each shore and estimates of proportions from the Whonnock test fishery to the abundances in the remainder of the river.

Operation periods for fish wheels

2009 Continuous Aug. 7-Sep. 17, Sep. 17 estimate applied to Sep. 17-27.

2011 Continous Sep. 5-20; interpolation, Aug. 19-21, Aug. 26-29, Sep. 4; Sep. 20 estimate applied Sep. 21-27.

2013 Continuous Aug. 3 - Sep. 6; Sept 6 estimate was applied to Sep. 7-26.

Table 8. Estimates of Fraser Pink Salmon net escapement and total return obtained from the combination of the Mission hydroacoustic program abundance estimates (blue text) and catch estimates for 2009, 2011, and 2013. Net escapement is estimated from the Mission Fraser Pink Salmon abundance estimate minus catch above Mission. Total return is estimated from Mission abundance estimate plus total catch. The proportion of the Fraser Pink population that occurs upstream of Qualark and downstream of Qualark are also presented.

	2009	**2011**	**2013**
Mission Abundance Estimate	16,151,501	13,701,635	10,535,493
Upstream of Mission Catch	722,665	913,280	1,191,003
Net Escapement (Mission abundance minus above Mission catch)	**15,428,836**	**12,788,355**	**9,344,490**
Total Catch	4,507,317	7,860,612	6,553,329
Total Return (Mission abundance plus total catch)	**19,936,153**	**20,648,967**	**15,897,819**
Upstream of Qualark Pink Escapement Estimate (CPUE for non pink species); Upriver populations (incl. Thompson, Seton and Bridge River)	6,757,153	4,351,605	5,334,831
Proportion above Qualark	0.4	0.3	0.6
Downstream of Qualark Pink Escapement (incl. Main Stem, Coquihalla, Harrison and Chilliwack Rivers)	8,860,281	8,588,360	4,026,732
Proportion below Qualark	0.6	0.7	0.4

Table 9. Average weight of Fraser Pink Salmon from 1959 to 1987 caught in Canada Area 20 and U.S. Area 7 and 7A purse seine fisheries. Fraser Ricer Pink Salmon comprise on average 70% of these samples based on genetic stock identification analyses. Data are presented in pounds (lbs.) and kilograms (kg). An example of how these values are calculated is available in the subsequent table (Table 10).

Return Year	Average Weight Per Fish (lbs.)	Average Weight Per Fish (kg)
1959	5.28	2.39
1961	6.60	2.99
1963	5.17	2.35
1965	6.23	2.82
1967	5.39	2.44
1969	6.01	2.72
1971	5.19	2.36
1973	5.41	2.45
1975	6.05	2.74
1977	5.90	2.67
1979	5.04	2.29
1981	4.84	2.20
1983	4.29	1.95
1985	5.32	2.41
1987	4.51	2.05
1989	4.51	2.05
1991	4.00	1.82
1993	3.81	1.73
1995	3.81	1.73
1997	4.05	1.84
1999	3.87	1.76
2001	4.29	1.95
2003	4.29	1.95
2005	4.22	1.91
2007	4.19	1.90
2009	3.64	1.65
2011	4.26	1.93
2013	4.11	1.86
Average:	4.80	2.18

Table 10. Example of the calculation used to estimate the average weight of adult Fraser River Pink Salmon using 2013 data. DNA analysis of the samples indicated contributions of Fraser River Pink Salmon in the 70% to 85% range. The methodology was similar from 1989 to 2013.

Sample Collection Area	Sample Date	Sample Size	Average Weight (lbs.) of Pink Salmon	Average Weight (kg) of Pink Salmon
Canadian Area 20	01-Sep	100	4.05	1.84
Canadian Area 20	08-Sep	100	4.27	1.94
U.S. Area 7	25-Aug	100	4.07	1.85
U.S. Area 7	27-Aug	100	4.07	1.85
U.S. Area 7	02-Sep	100	4.17	1.89
U.S. Area 7	09-Sep	100	4.11	1.86
U.S. Area 7A	25-Aug	100	4.01	1.82
U.S. Area 7A	02-Sep	100	4.24	1.92
U.S. Area 7A	06-Sep	100	4.00	1.81
Average	01-Sep	09-Apr	4.11	1.86
Standard deviation	5.7 days	0	0.10	0.04

Table 11. Fraser River Pink Salmon post-orbital hypeural (POH) lengths for males and females for various populations. These data were collected starting in 1987 by the PSC for genetic stock identification purposes to establish genetic baselines for key Fraser Pink tributary spawning aggregates (*n*=sample size).

		Males + Female POH Lengths			Male POH Lengths			Female POH Lengths		
Year	**Population**	***n***	**Average**	**Standard Deviation**	***n***	**Average**	**Standard Deviation**	***n***	**Average**	**Standard Deviation**
1987	Fraser Mainstem	100	44.32	3.09	37	46.38	3.04	63	43.12	2.42
	Chilliwack-Vedder	150	44.94	2.10	3	44.83	2.56	147	44.94	2.10
	Harrison River	149	45.86	2.72	79	46.55	2.85	70	45.08	2.37
	Seton Creek	149	44.65	2.29	87	45.17	2.40	62	43.92	1.91
	Thompson River	119	43.48	2.73	41	44.85	2.55	78	42.75	2.55
	Bridge River	24	42.47	3.30	5	45.88	1.18	19	41.57	3.08
1989	Fraser Mainstem	150	42.83	1.91	44	43.82	1.96	106	42.42	1.74
	Chilliwack-Vedder	150	44.34	2.32	104	44.64	2.47	46	43.68	1.77
	Harrison River	150	43.94	2.32	80	44.37	2.63	70	43.44	1.80
	Coquihalla River	150	43.03	2.29	98	43.34	2.44	52	42.46	1.84
1991	Fraser Mainstem	76	40.93	1.79	20	40.90	2.30	56	40.94	1.59
	Seton Creek	100	41.47	1.82	50	41.79	2.12	50	41.15	1.41
	Thompson River	100	42.07	1.80	50	42.57	1.85	50	41.57	1.62
1993	Fraser Mainstem	100	41.34	2.23	50	41.83	2.45	50	40.85	1.88
	Chilliwack-Vedder	100	42.27	2.27	50	42.47	2.52	50	42.06	2.00
	Harrison River	100	42.11	2.78	50	42.41	3.23	50	41.81	2.25
1995	Fraser Mainstem	100	42.87	2.43	35	43.74	3.03	65	42.41	1.90
	Seton	100	42.25	2.65	48	42.73	2.80	52	41.81	2.45
1997	Fraser Mainstem	51	43.12	1.84	9	44.43	1.50	42	42.84	1.79
	Thompson River	100	43.19	2.40	50	43.75	2.59	50	42.63	2.08
1999	Fraser Mainstem	55	41.07	1.95	6	41.28	1.85	49	41.04	1.97
	Harrison River	100	41.44	2.24	50	41.96	2.60	50	40.92	1.70
	Seton Creek	100	40.69	2.04	50	40.61	2.22	50	40.78	1.86
	Thompson River	100	42.02	2.47	50	42.59	2.73	50	41.45	2.06
	Bridge River	90	40.06	1.64	45	39.87	1.77	45	40.25	1.48
2003	Fraser Mainstem	100	44.33	2.22	50	44.92	2.11	50	43.74	2.20
	Harrison River	100	44.74	2.17	50	45.59	2.41	50	43.89	1.49
2005	Fraser Mainstem	100	43.70	2.35	50	44.33	2.21	50	43.07	2.34
	Chilliwack-Vedder	100	43.49	2.10	50	43.92	2.24	50	43.07	1.89
	Seton Creek	100	42.91	1.97	50	43.33	1.82	50	42.49	2.04
	Thompson River	100	43.36	2.29	50	43.74	2.15	50	42.98	2.38
	Coquihalla River	100	43.29	2.10	50	43.75	2.16	50	42.83	1.95
2007	Bridge River	100	41.79	1.84	39	41.68	2.17	61	41.86	1.60
2009	Thompson River	100	40.24	2.18	50	40.15	2.42	50	40.33	1.94
	Seton Creek	100	40.25	2.39	50	40.50	2.42	50	40.01	2.37
	Bridge River	100	39.68	1.81	50	40.07	1.77	50	39.29	1.78
	Cayoosh Creek	100	39.95	2.02	50	40.41	2.34	50	39.49	1.52
	Chehalis River	100	40.67	1.96	50	41.03	2.22	50	40.31	1.59
	Chilcotin River	11	40.00	2.04	9	40.02	1.53	2	39.90	4.81
	Churn Creek	0			0			0		
	Coquihalla River	100	40.85	2.54	54	41.46	2.83	46	40.13	1.95
	Gates Creek	100	39.88	1.84	46	40.06	2.04	54	39.73	1.64
	Nahatlatch River	100	40.21	1.95	58	40.51	2.04	42	39.79	1.74
	Portage River	100	41.12	2.13	56	41.64	2.37	44	40.44	1.54
2013	Nahatlatch River	87	43.15	2.34	44	43.45	2.88	43	42.84	1.57

Table 12. Fraser River Pink Salmon post-orbital hypural (POH) lengths for adult females (*n*=sample size) for various populations collected during their Fraser upstream migration. Broader system-specific estimates are available from 1987 to 1991, when DFO conducted system-specific escapement programs. From 1993 to 2001, only Fraser system-wide length data are available since only this level of enumeration was conducted during this period. Only hard copy data are available from 1957 to 1985 (available through T. Cone, DFO) as these data have not been digitized, and therefore, are not presented in the below table. No data are available post-2001 after the termination of DFO's escapement programs.

			Female POH Length		**Fecundity**	
Year	**System**	***n***	**Average**	**SD**	**Average**	**SD**
1987	Chilliwack-Vedder	49	NA	NA	1774	245
	Harrison	50	NA	NA	1853	283
	Seton	47	NA	NA	1850	238
	Thompson	7	NA	NA	2025	182
1989	Chilliwack-Vedder	50	44.8	1.8	1615	195
	Harrison	50	45.5	1.6	1773	236
	Seton	51	43.5	2.0	1643	205
	Thompson	50	44.1	1.6	1615	194
1991	Chilliwack-Vedder	50	44.8	1.8	1615	8
	Harrison	50	45.5	1.6	1552	266
	Seton	51	43.5	2.0	1564	241
	Thompson	50	44.1	1.6	1521	227
1993	Fraser	100	NA	NA	1426	315
	Harrison	50	45.5	1.6	NA	NA
1995	Fraser	94	43.0	1.7	1576	324
	Harrison	50	45.5	1.6	NA	NA
1997	Fraser	99	43.2	1.8	1647	316
	Harrison	50	45.5	1.6	NA	NA
1999	Fraser	99	43.0	1.8	1435	225
	Harrison	50	45.5	1.6	NA	NA
2001	Fraser	100	44.6	2.0	1707	242
	Harrison	50	45.5	1.6	NA	NA

Table 13. Female and male Fraser Pink Salmon tagged at Duncan Bar as part of the DFO escapement enumeration program, including ratios of females to males.

Year	Females	Males	Ratio Females: Males
1977	4,757	4,506	1.1
1979	7,303	7,182	1.0
1981	9,495	8,071	1.2
1987	11,832	12,435	1.0
1989	11,794	10,492	1.1
1991	21,827	19,153	1.1
1993	17,360	12,325	1.4
1995	13,273	11,643	1.1
1997	11,331	9,099	1.2
1999	19,936	16,652	1.2
2001	20,307	23,018	0.9

Table 14. Fraser Pink Salmon run size estimates, Area 20 50% migration date (the date when 50% of the run has passed this area; see Figure 4 map), and the diversion rate of Fraser Pink Salmon through the Johnstone Strait relative to the Juan de Fuca Strait.

Return Year	Run Size	Area 20 50% Migration Date	Johnstone Strait Diversion Rate
1959	6,460,055	24-Aug	26%
1961	1,889,246	19-Aug	33%
1963	5,482,350	6-Sep	27%
1965	2,319,887	25-Aug	30%
1967	12,962,791	29-Aug	28%
1969	3,931,461	24-Aug	23%
1971	9,763,328	30-Aug	42%
1973	6,803,984	1-Sep	22%
1975	4,893,955	28-Aug	29%
1977	8,209,485	24-Aug	26%
1979	14,404,120	28-Aug	22%
1981	18,684,689	30-Aug	33%
1983	15,346,097		66%
1985	19,038,024	31-Aug	36%
1987	7,171,773	25-Aug	45%
1989	16,484,275	5-Sep	48%
1991	22,173,639	4-Sep	45%
1993	16,983,498	2-Sep	73%
1995	12,903,708	29-Aug	32%
1997	8,175,964	1-Sep	56%
1999	3,608,265	7-Sep	85%
2001	21,261,774	2-Sep	57%
2003	24,250,000	25-Aug	54%
2005	9,870,000	25-Aug	73%
2007	8,490,000	22-Aug	53%
2009	19,936,153	28-Aug	39%
2011	20,648,967	28-Aug	55%
2013	15,897,819	28-Aug	65%
59-69 AVG	5,507,632	26-Aug	28%
71-79 AVG	8,814,974	28-Aug	28%
81-89 AVG	15,344,972	30-Aug	46%
91-99 AVG	12,769,015	2-Sep	58%
01-09 AVG	16,761,585	26-Aug	55%
All YRS AVG	12,073,047	28-Aug	44%

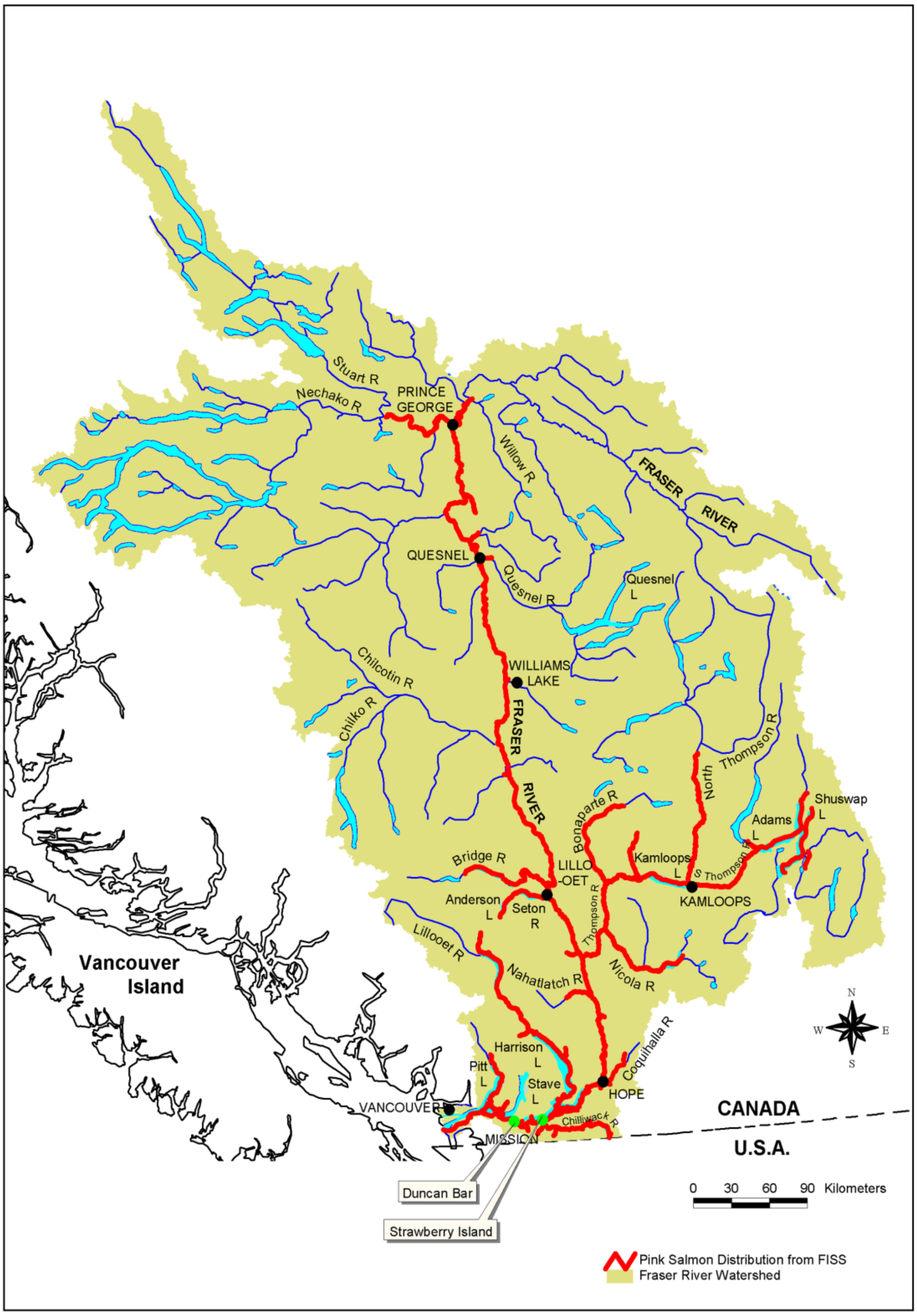

Figure 1. Fraser River drainage (located in South-Western British Columbia) with current Fraser River Pink Salmon (*Oncorhynchus gorbuscha*) distribution indicated in red.

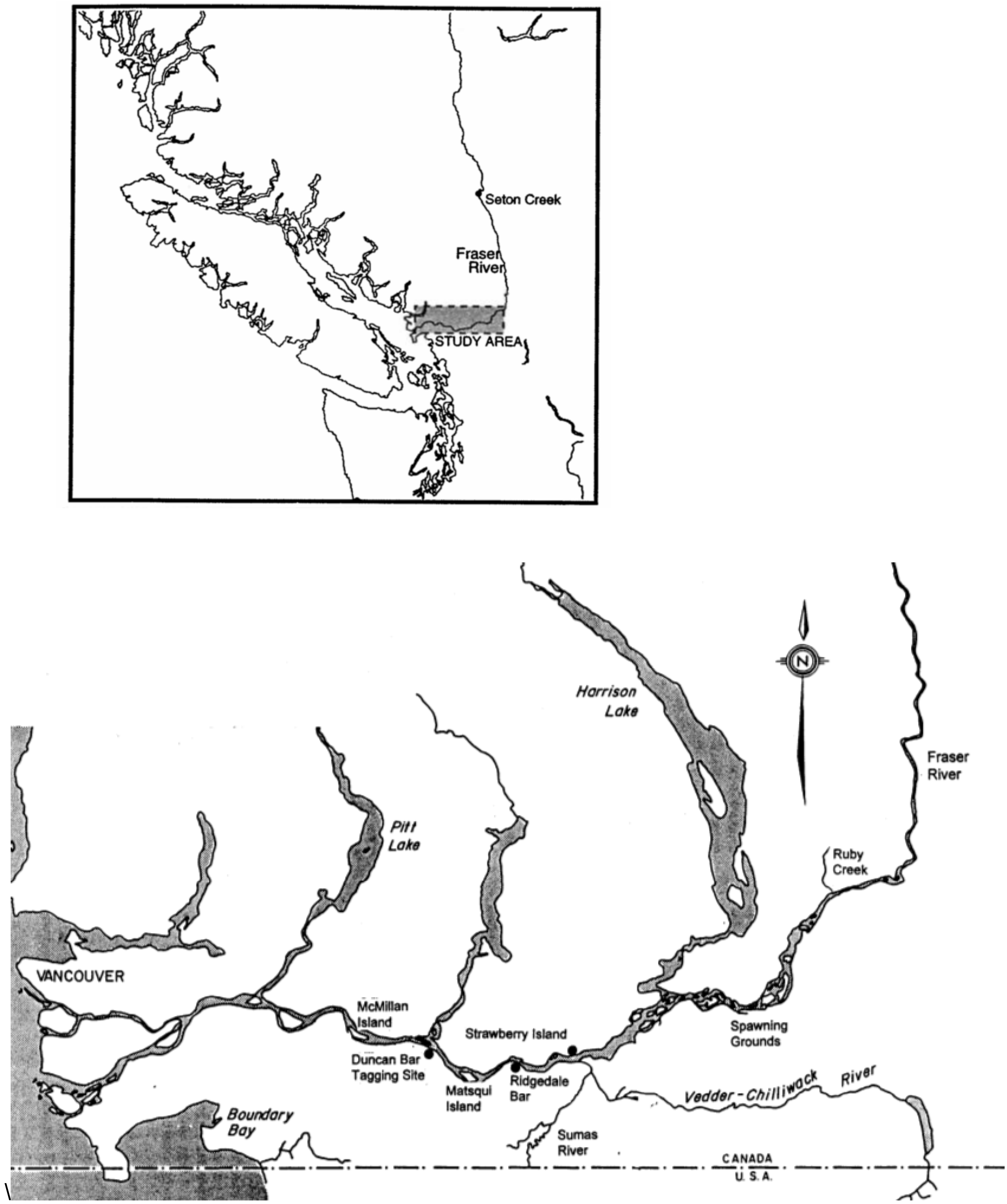

Figure 2: Map of the lower Fraser River showing the Duncan Bar tagging site and Strawberry Island live-recovery sites, and the lower Fraser River spawning grounds which were part of the 1993-2001 DFO Pink Salmon escapement studies. Reprinted from Cass et al. 1995 & Schubert et al. 1997.

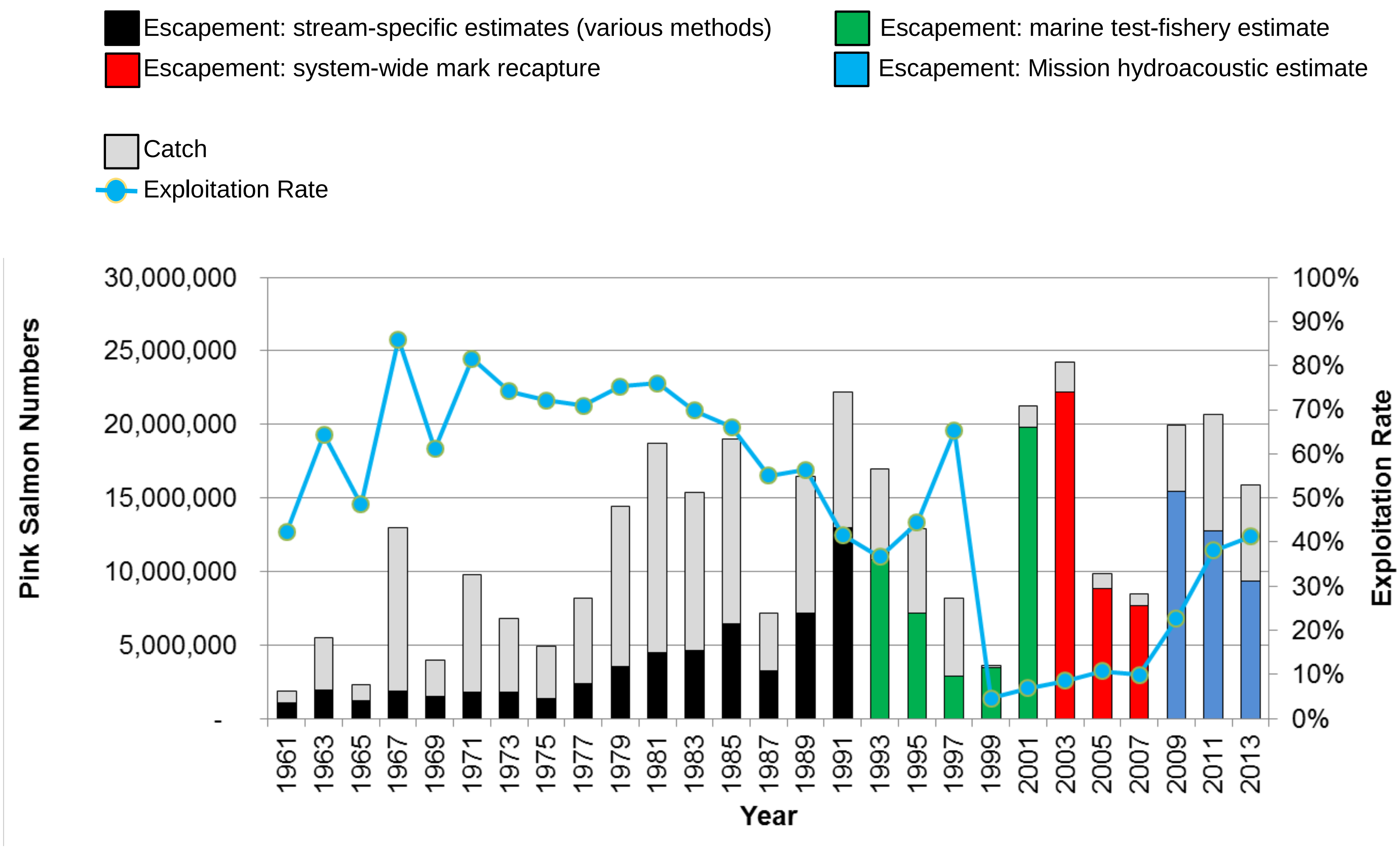

Figure 3: Fraser River Pink Salmon escapement, catch, and return estimates. Escapement estimates were generated from system-specific programs from 1957 to 1991 (black bars), system-wide single mark recaptures from 1993-2001 (green bars), indirect system-wide marine test fisheries estimates from 2003 to 2007 (red bars), and system-wide hydroacoustic estimate from 2009 to present (blue bars). Given the lack of calibration work between methods, escapement estimates between years (and particularly test fishery estimates) are not completely comparable. No quantitative escapement monitoring programs occurred prior to1957 (only qualitative Fisheries Officer visual surveys were conducted as presented in Table 2).

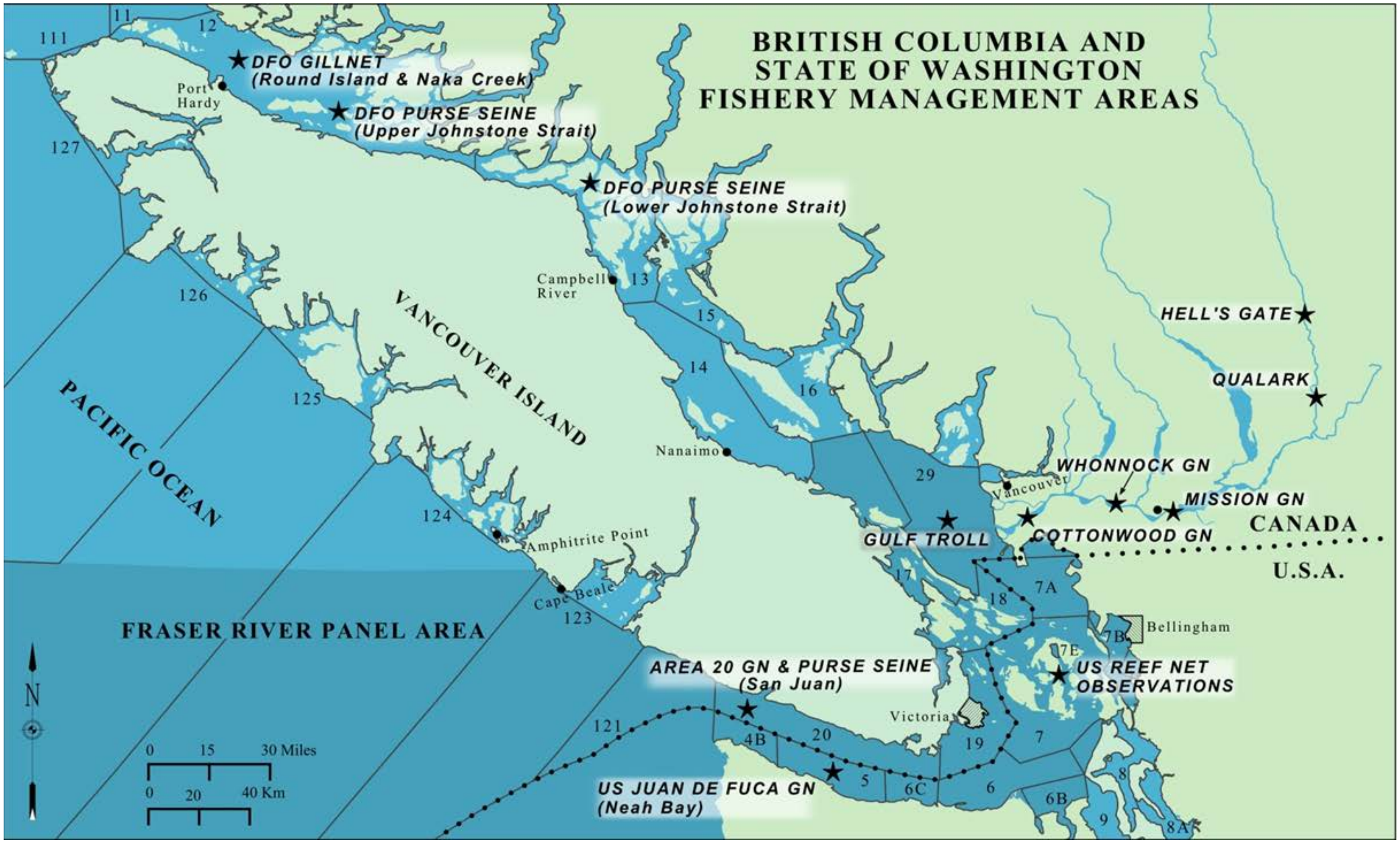

Figure 4: Test fishery locations for Fraser Panel fisheries including Sockeye and Pink Salmon.

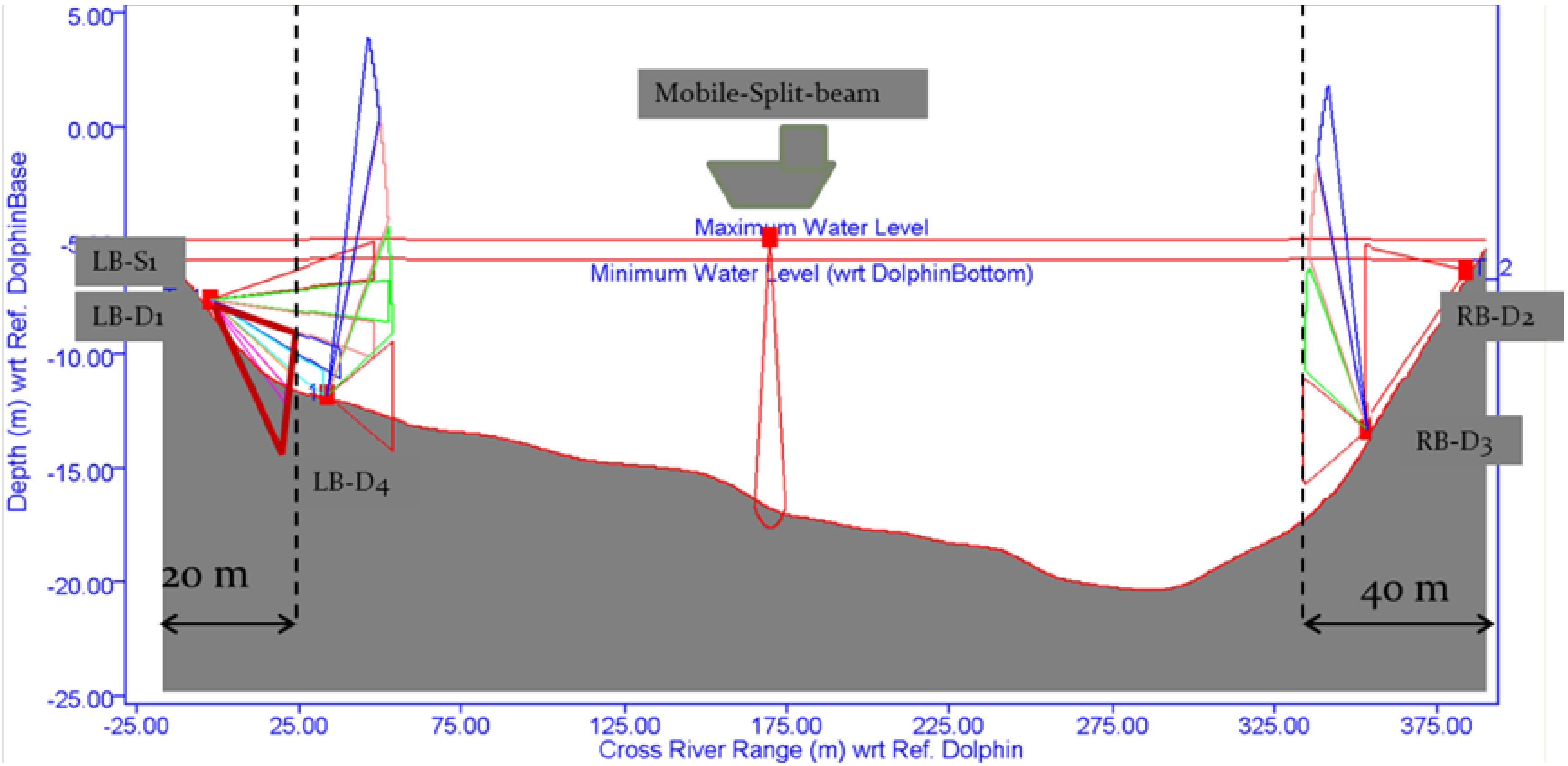

Figure 5: Configuration of the PSC Mission hydroacoustic station (from Xie et al. 2013).

A.

B.

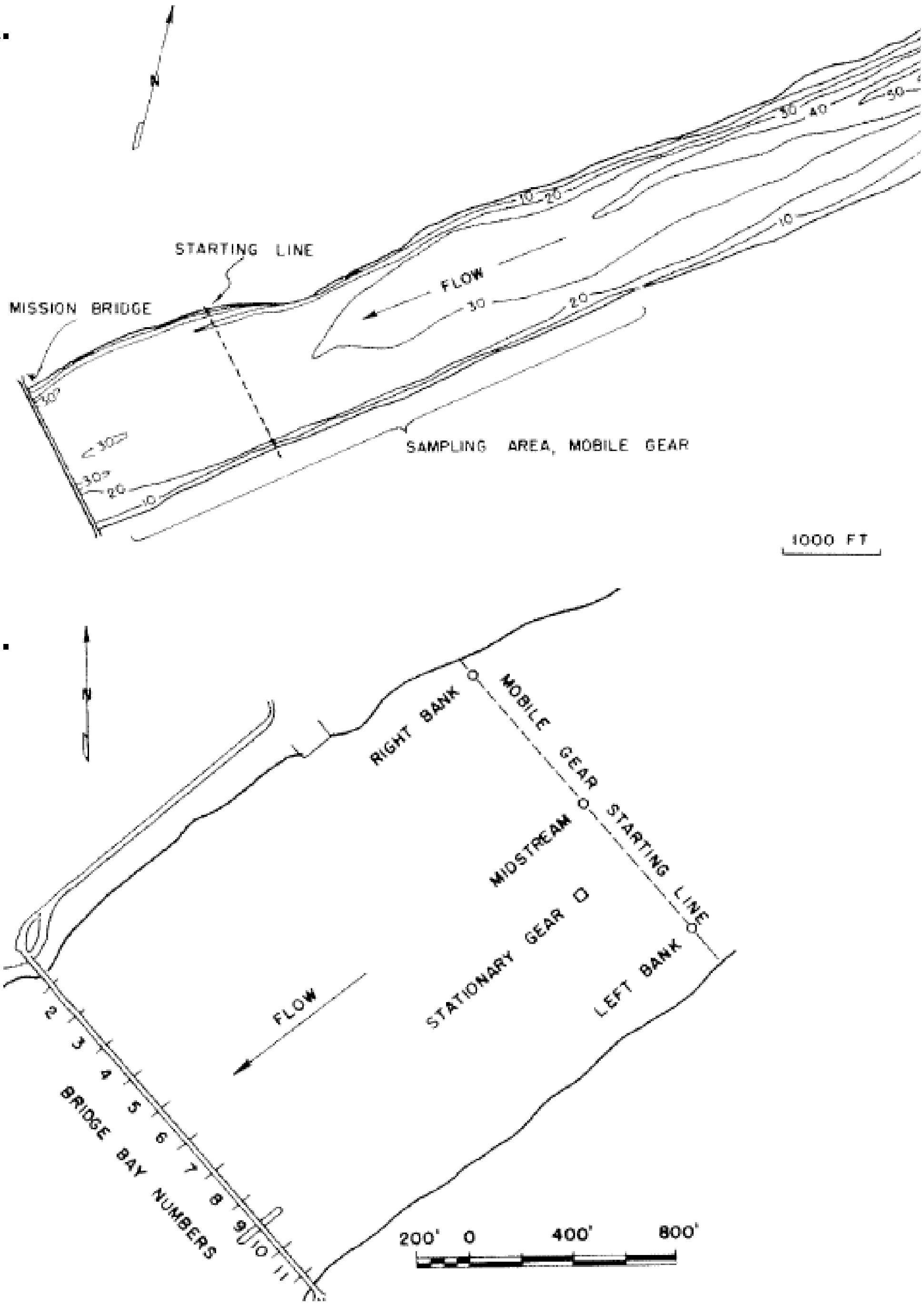

Figure 6. Fraser River Pink Salmon fry assessments conducted at Mission: **A)** channel topography of the fry sampling area (dotted line) and **B)** sampling locations of fry traps.

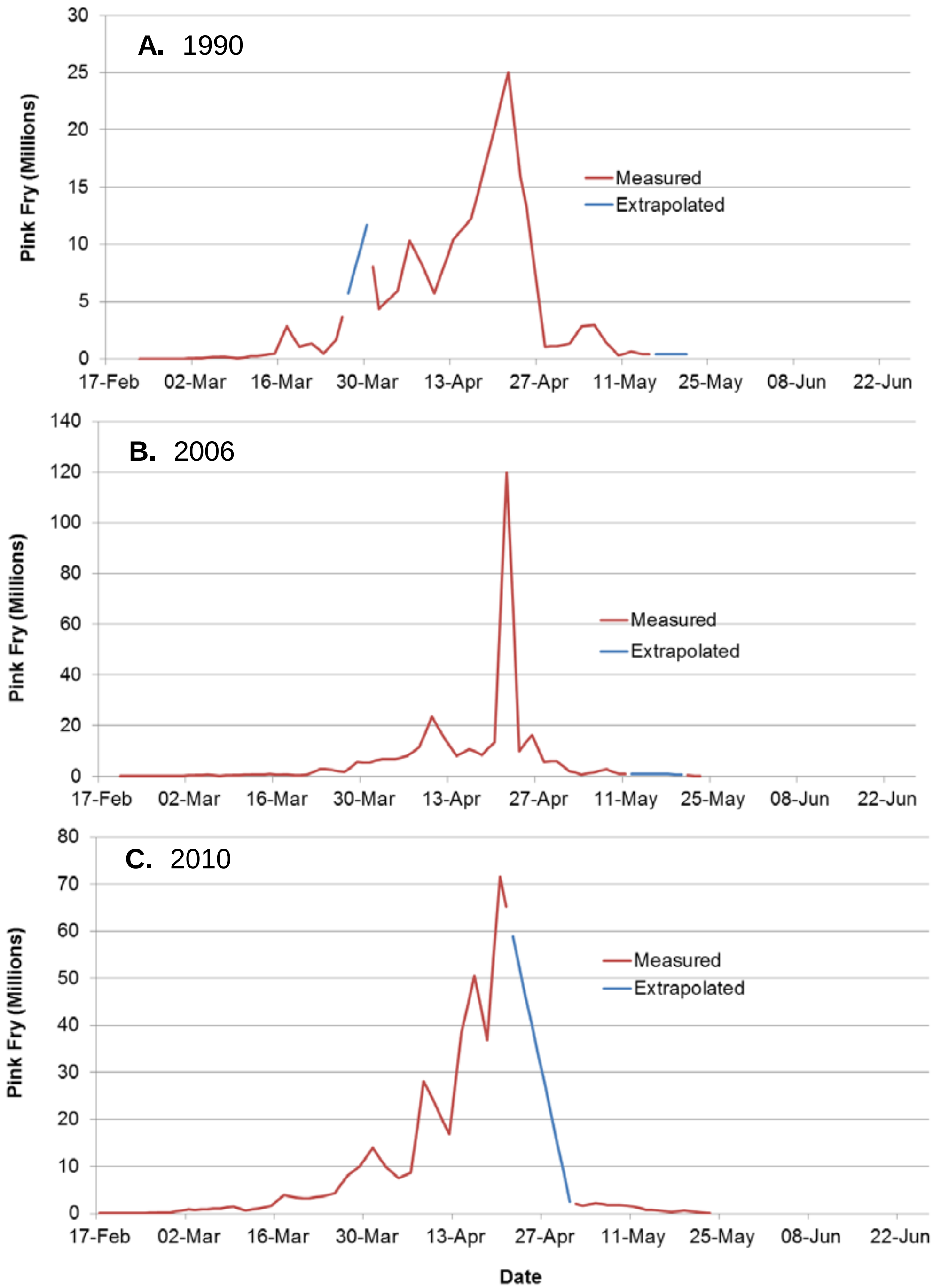

Figure 7: Years when gaps between sampling days in the Fraser River Pink fry enumeration program at Mission, B.C. were greater than four days (these include A. 1990; B. 2007; and C. 2010). Gaps larger than four days are attributed to field logistical constraints such as crew or equipment (including vessel) maintenance. The red line represents time periods during which boat sampling was conducted and the blue line represents time periods when sampling had to be suspended for various reasons.

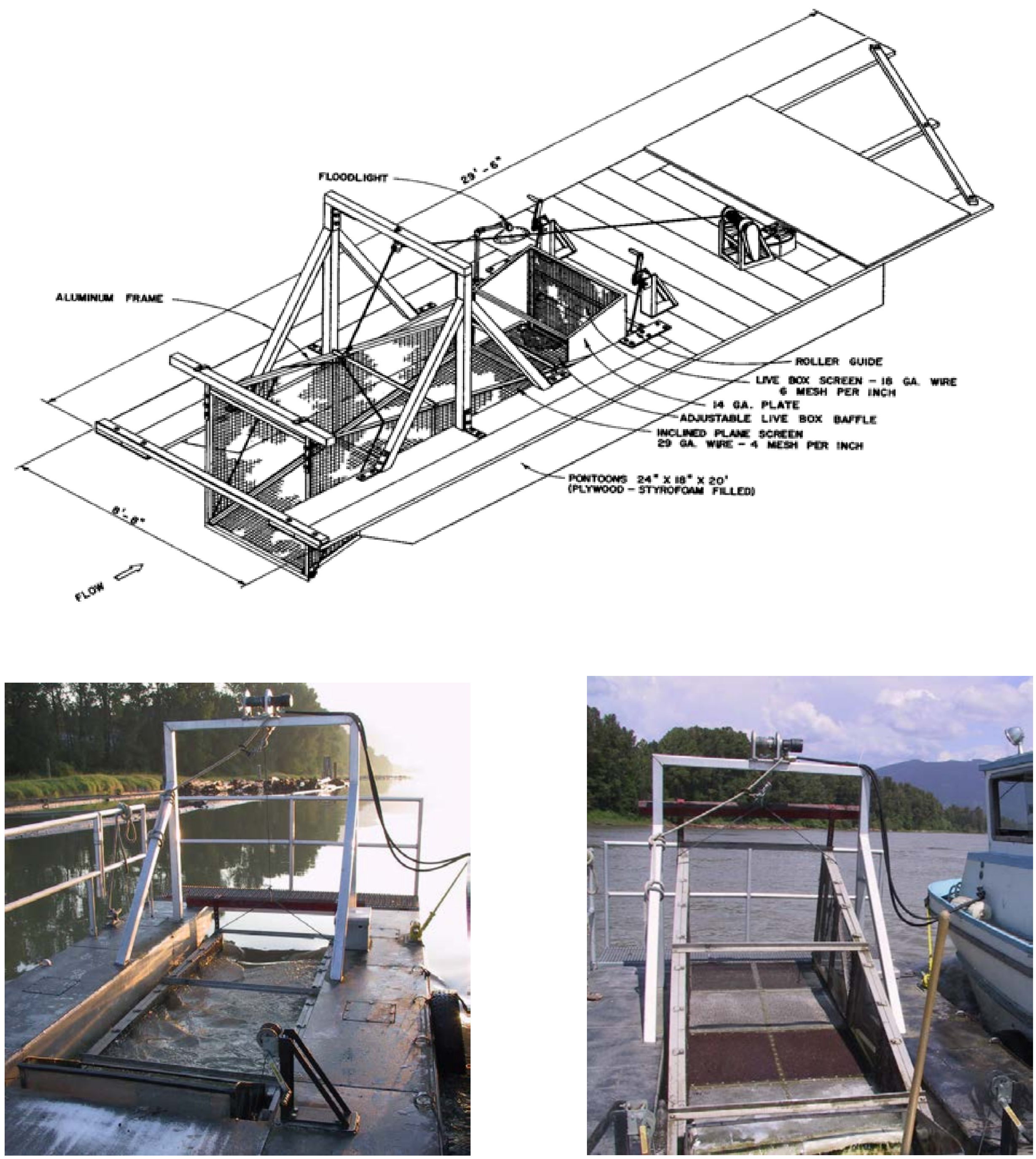

Figure 8: Mission Fraser River Pink Salmon fry sampling program. Schematic diagram of the inclined plane trap (top) (reprinted from Vernon 1966) and photos of the trap in the fishing (bottom left) and raised (bottom right) positions. Fry are entrained through the front of the trap, over a sloped screen, and into a holding pen at the downstream end.

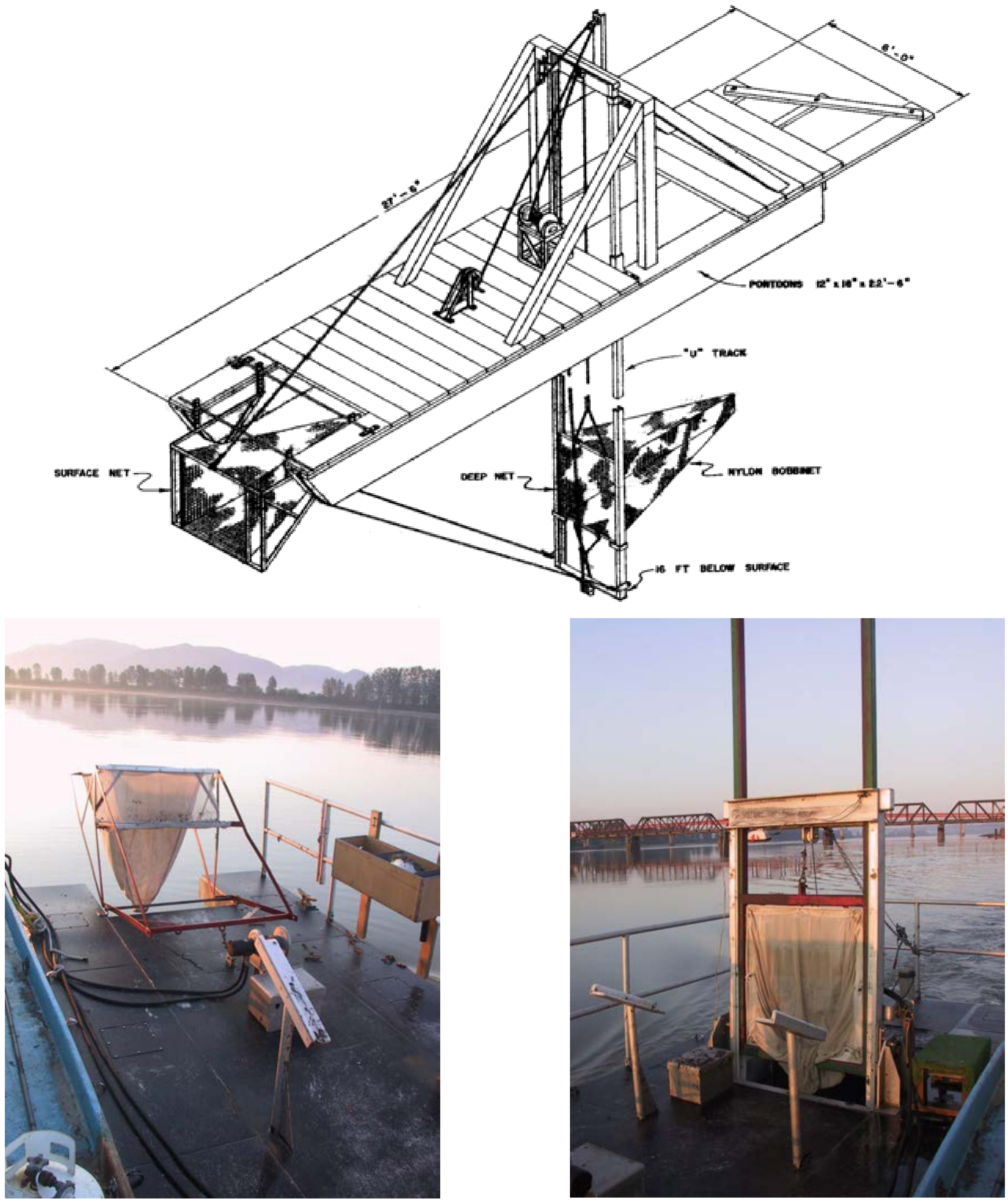

Figure 9: Schematic diagram of the vertical-sampling trap (top) (reprinted from Vernon 1966). The surface net (bottom left, located on the upstream end of the trap), is fished simultaneously with the depth-sampling net (bottom right, shown in the raised position), in order to measure the proportion of surface migrants to migrants at depth. The Mission railroad bridge can be seen in the background (downstream) of the photo at right.

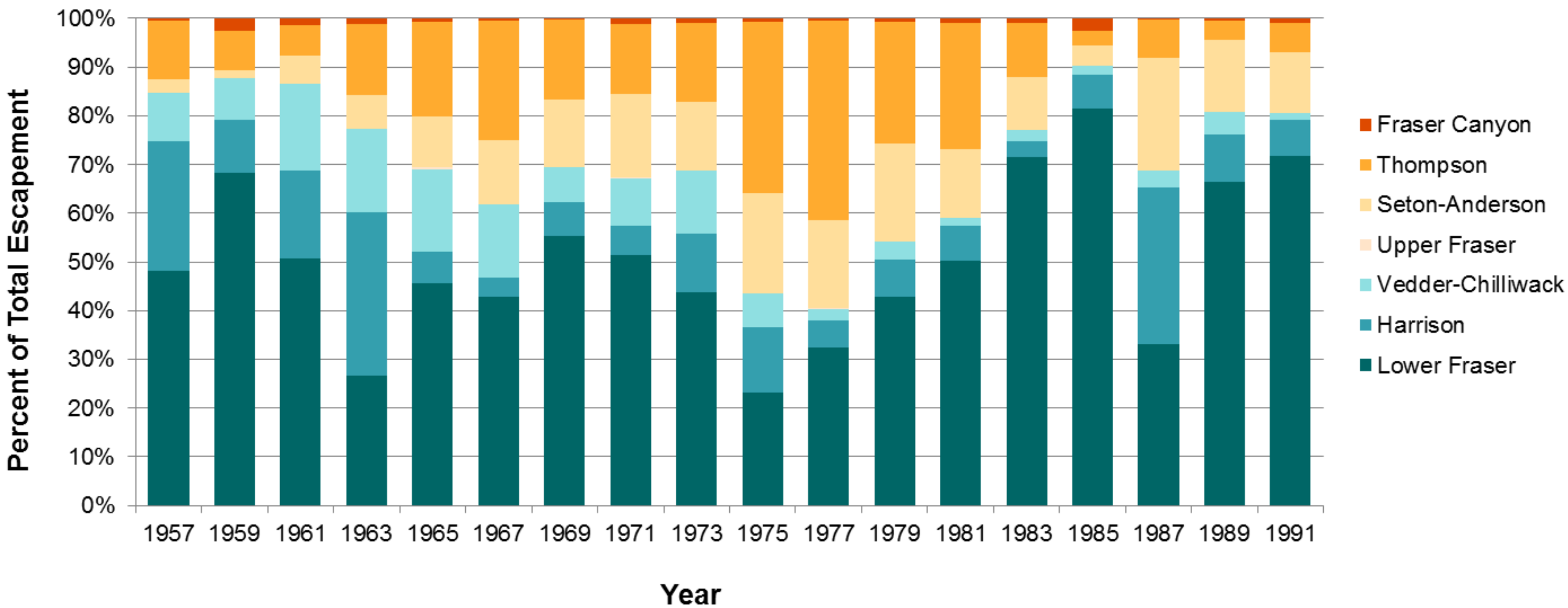

Figure 10. Distribution of Fraser Pink Salmon based on proportions each major system (Lower Fraser, Harrison, Vedder-Chilliwack, Upper Fraser, Seton-Anderson, Thompson, Fraser Canyon) comprise relative to the total escapement for years when stream-specific escapements were assessed (1957 to 1991). Blue coloured systems (Lower Fraser, Harrison, Vedder-Chilliwack) represent spawning in the Lower Fraser watershed below Hells Gate, and orange coloured systems (Upper Fraser, Seton-Anderson, Thompson, Fraser Canyon) represent spawning upstream of Hells Gate.

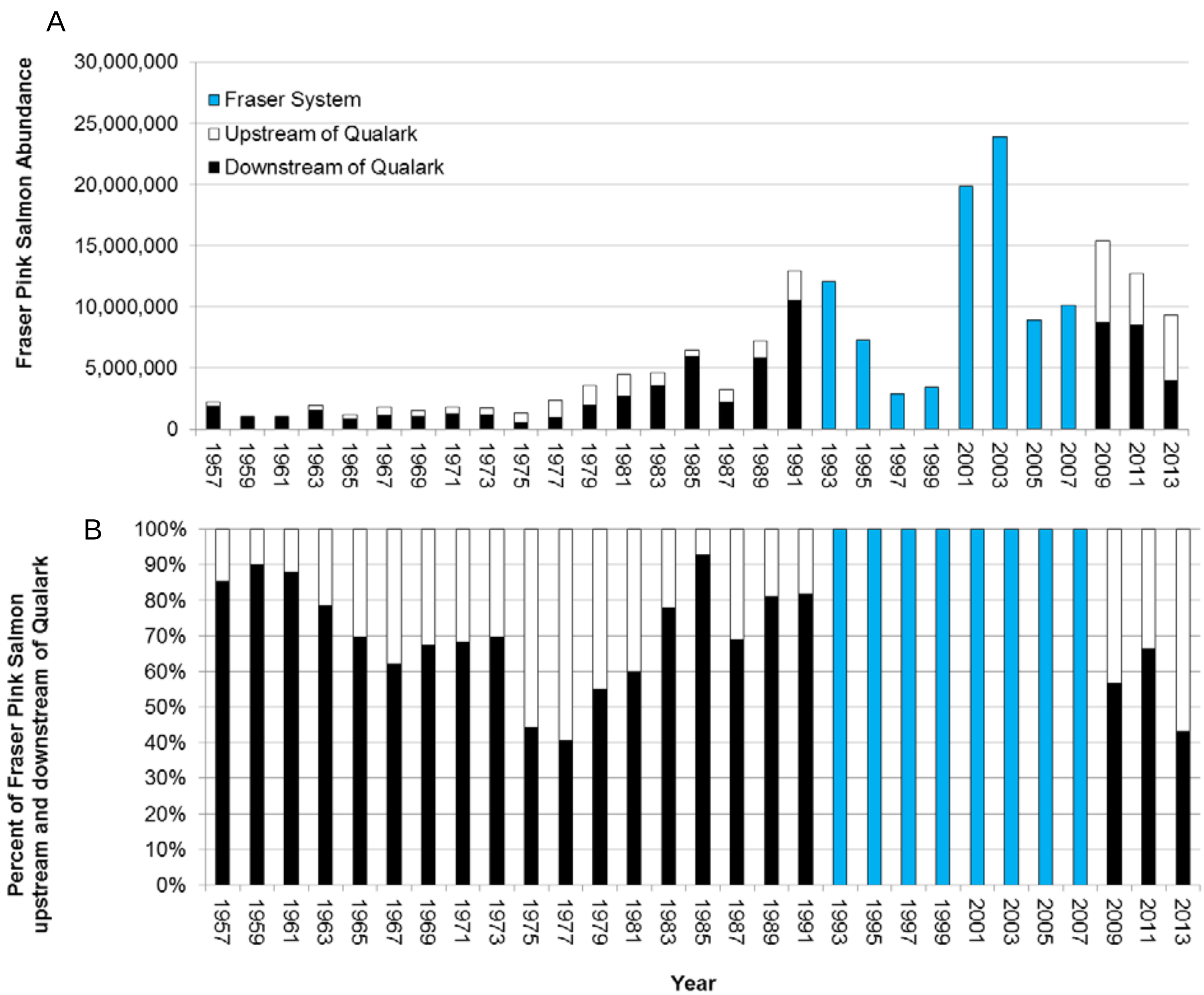

Figure 11. Fraser Pink Salmon upstream (white bars) and downstream (black bars) of Qualark for the years from 1957 to 1991 when stream-specific escapements were estimated, and from 2009 and 2011 when both Mission and Qualark hydroacoustic programs operated presented by A) escapement; and B) percentage of the total escapement. The years from 1993 to 2007 (blue bars) were not assessed using methods that could distinguish between the downstream and upstream abundances/percentages so only total abundances are presented in Figure A or 100% in Figure B.

APPENDIX A

Stream-Specific Estimates: 1957-1991

Precision

In addition to the digitization of the escapement data and the production of new escapement estimates, Andrew and Webb (1987a) generated the variances associated with their verification of the IPSFC escapement estimates (this was not conducted prior to Andrew and Webb (1987a). Specifically, for tagging estimates, the same approach was used to estimate variances as for a normal Petersen estimate (Ricker 1975), with the exception of systems where tag loss to tributary populations was estimated (i.e. the lower Fraser River mainstem spawning area). For these systems, an additional term was added to the equation to estimate variance, taking into account error in the estimate of tags lost to tributaries (Andrew & Webb 1987a). For escapement estimates based on complete counts of live or dead fish (fence count), a CV of 5% was assumed. For estimates based on the peak live count + cumulative dead visual survey method, the CV was related to the number of surveys conducted. If there was only a single survey, the CV was assumed to be 39%. If there were multiple surveys, the inverse of the square root of the number of surveys was subtracted from 39% (or 0.39). For other estimates (dead count expansions, observer estimates), precision was not calculated. These estimates account for a very small percentage of the overall Fraser River Pink Salmon escapement estimate, averaging 3,046 Pink Salmon per odd year (Andrew & Webb 1987a). Andrew and Webb (1987a) did not note how they assigned a CV to Thompson River tower counts in 1965-69.

Mark-Recapture Methods: High Precision Estimates

Peterson mark-recapture methods generate high precision estimates of escapement (Ricker 1975). The Petersen mark recapture method was chosen by the IPSFC as a statistically defensible method for estimating escapements in streams with relatively large populations. This method was consistently applied in tributaries with Pink Salmon populations that had annual average escapements exceeding 25,000 fish. Tributary streams that were consistently assessed using this mark-recapture method include the Chilliwack-Vedder, Harrison, Seton, and Thompson Rivers, as well as of additional tributaries that were included periodically (Table A1). The Lower Fraser River mainstem (Mission to Hope) spawning grounds were separately assessed using Petersen mark-recapture methods, by applying tags at Duncan Bar in Mission and recovering carcasses throughout the watershed (Figure A1). In the early years of the Fraser River Pink Salmon mark-recapture program, escapement to the Lower Fraser area was estimated by subtracting tributary (i.e. Chilliwack-Vedder, Harrison, Seton, and Thompson) escapement estimates (obtained from mark-recapture, visual surveys, and other methods) from the whole-river estimate (based on the system-wide mark recapture). Different Petersen disk tags were applied in the individual tributary mark recapture programs and the Fraser River system-wide program, so they could be distinguished from each other on the spawning grounds (Hourston et al. 1965).

In the early years of the mainstem Fraser River Pink Salmon mark recapture program (1957-1961), tagging and recovery efforts were considered insufficient to meet the assumptions of the Petersen mark-recapture method (i.e. minimal spatial and temporal application bias, handling stress mortality, tags removal in gillnets, and no assessments of tag loss) (Vernon et al. 1964; Hourston et al. 1965). Therefore, beginning in 1963, tagging and recovery efforts were increased and, in the lower Fraser River mainstem program, the number of tags applied was adjusted in the Peterson mark-recapture escapement calculation by subtracting tags lost: this included 1) an assumed 5% tag loss; 2) tagged adults caught by in-river fisheries upstream of Duncan Bar; 3) an estimate of tags lost to migration of tagged adults into tributaries (Hourston et al. 1965). The third tag loss factor described above was calculated separately for each tributary population by multiplying the tributary population estimate (obtained using various escapement programs: mark recapture, visual surveys, fence etc.) by the proportion of mainstem mark-recapture tags recovered in each tributary (proportion equals number of mainstem mark-recapture tags recovered in each tributary divided by the total number of carcasses recovered in each tributary).

Several reviews of the historical mark-recapture Fraser River Pink Salmon data have been conducted. Andrew and Webb (1987a) recommended that a study be conducted to assess the 5% tag loss assumption in the Petersen mark-recapture methods (describe above as the first tag loss factor). They considered the 5% tag loss factor of Mission-applied tags to be the single largest source of consistent bias in the escapement estimate. Their recommendation was addressed in two separate studies by Cass & Whitehouse (1993) and Cass et al. (1995), each of which generated different results. The study conducted by Cass and Whitehouse (1993) used data from 1989 and 1991, and identified a wide array of tag loss rates in different streams, ranging from 1% to 26% (cited in Schubert et al. 1997). A subsequent study by Cass et al. (1995) used data from 1993 (double tagging fish with Petersen disk tags and cinch up tags), and identified a tag loss rate of 4.2% (Cass et al. 1995). Therefore, the assumption of 5% tag loss, used throughout the Fraser River Pink

Salmon mark recapture programs, could introduce a positive bias to the escapement estimates during this period. However, the mark-recapture results have not been revisited.. In a separate review conducted in 1991, Schwarz and Taylor (1998) compared escapement estimates generated with a stratified-Petersen model and the traditionally used pooled-Petersen model. The stratified-Petersen model found no effect of temporal application or recovery bias, but it did find a possible spatial bias from tagging-induced stress in some systems.

Enumeration Fence Methods: High Precision Estimates

Enumeration fences were used to estimate Fraser River Pink Salmon escapements in suitable streams and artificial spawning channels. Enumeration fences produce high-precision escapement estimates by either permitting live-counting of all fish that migrate past the fence, or counting of the total carcasses upstream of the fence (assuming that carcasses cannot drift downstream of the fence). Permanent fences have been used on the Weaver (1965-present), Seton (1961-present), and Wahleach (1957-1991) artificial spawning channels, as well as at the Cultus Lake outlet at Sweltzer Creek (1959-present), while temporary fences have been used on several smaller streams (Table A1). Fences used to enumerate Pink Salmon are usually operated in conjunction with other Salmon species, given the cost of installing and operating a permanent counting fence. The exceptions to this are the Seton and Wahleach spawning channel fences, as both the spawning channel and counting fences at these sites were built for the express purpose of enhancing Pink Salmon production following the installation of hydroelectric facilities (Fraser and Fedorenko 1983; Cooper 1977). Of the streams where fences were employed from 1957-1991, none had escapements greater than 25,000 spawners, with the exception of the Seton artificial spawning channel. For these systems a CV of 5% was assumed.

Visual Surveys: Low Precision Estimates

The most widely used low-precision Fraser River Pink Salmon escapement enumeration method was the ‘peak-live plus cumulative dead’ visual survey method (Table A1). This method involved regular visual surveys, conducted primarily on foot; during which numbers of observed live and dead Pink Salmon were recorded. Large streams with relatively large Pink Salmon populations were surveyed multiple (4 to 7) times, while smaller streams with smaller populations were surveyed opportunistically, sometimes only once-per-season (Andrew & Webb 1987a). The largest number of live spawners observed during a single survey (the peak live-count) was added to the cumulative number of carcasses observed on all surveys up to and including the peak live-count survey. This sum was then multiplied by an expansion factor of 2.6 to generate the escapement estimate (Ward 1959).

Despite the widespread and consistent use of the ‘peak-live plus cumulative dead’ visual survey method (Table A1), the expansion factor of 2.6 was based on a single 1957 study, where a mark-recapture program was conducted simultaneously with visual surveys on the Chehalis River (Ward 1959). The Chehalis River, however, does not represent all Fraser River Pink Salmon systems from an observer efficiency/stream life perspective, based on the physical characteristics of the system (size, clarity, distance from ocean etc.) and abundance of Pink Salmon in the system. For example, the estimated escapement to Chehalis River in 1959 was 3,540 Pink Salmon. However, out of 515 streams enumerated using visual survey methods from 1957-1991, 15% (75 streams) had escapements greater than 3,500 fish, and 7% (34 streams) had escapements greater than 10,000 (DFO database). In addition, Andrew and Webb (1987a) state that a similar study (unpublished) to Ward (1959), conducted on the Coquihalla River in 1959, produced an expansion index of 5.2, which suggests a potential negative bias in escapement estimates that are based on the 2.6 expansion factor. For comparison, data used to calibrate Fraser River Sockeye Salmon expansion factors was derived from 11 separate studies, with estimated escapements for the calibrated systems ranging from 780 to 18,000 fish, and the resulting expansion indices ranging from 1.4 to 1.9 (averaging 1.8) (K. Benner, DFO, pers. comm.). Recent calibration work on Fraser River Sockeye Salmon systems with escapements of less than 125,000 has produced calibration factors ranging from 1.0 to 6.0. For Fraser River Pink Salmon specifically, although Ward (1959) recommended that further calibration studies be conducted to refine the 2.6 expansion index and to determine factors that may affect the expansion index, this work has not been conducted.

The level of precision of the peak live + cumulative dead index method was calculated for Fraser River Sockeye Salmon by Andrew and Webb (1987b), and was adopted by them in their corresponding paper on Fraser River Pink Salmon (Andrew & Webb 1987a). Since the distribution of escapement estimates was normal, the uncertainty surrounding these estimates was modeled using a lognormal distribution. It was assumed that with a single stream survey, timed close to the peak live count, there was 95% certainty that the actual escapement fell within the range of 0.5 – 2.0 times the estimate (based on a 1.8 expansion factor for Sockeye Salmon), with a coefficient of variation (CV) of 39%. If there were multiple surveys, the CV was decreased by the square root of the inverse of the number of surveys ($1/\sqrt{n}$). For Pink Salmon surveys this method of assigning precision likely underestimates the CV, as Pink Salmon surveys are expanded by a factor of 2.6 (as opposed to 1.8 for Sockeye).

Survey life (i.e. number of days on the spawning grounds) was estimated in a separate study for Thompson River Pink Salmon (Williams et al. 1986), at 11.5 days, 12.9 days, and 11.5 days for the 1957, 1979, and 1983 Thompson River Pink Salmon runs (respectively). These estimates are comparable to the recent 11.2 day estimate generated by Decker et al. (2012). If regular visual surveys are carried out for Pink Salmon spawners in the future, it would be advisable to generate Area-Under-the-Curve estimates for comparison to past peak live + cumulative dead estimates.

Tower Counts: Low Precision Estimates

Another low precision escapement enumeration method used for Fraser River Pink Salmon was tower counts (Table A1; Andrew and Webb 1987a). Tower counts have been used only three times since 1957; all on the Thompson River (1965, 1967, and 1969). A 15 foot tower was erected on either side of the Thompson River at Big Horn, upstream of the Thompson Canyon. The Thompson River Pink Salmon stock is a significant component of the overall Fraser River Pink Salmon population, and use of this method from 1965-1969 substantially increased the percentage of the Fraser River Pink Salmon escapement that was estimated using low-precision methods (Table A1). Although for some species and sites, tower counts are considered high precision estimates, for Fraser River Pink Salmon in the Thompson River this is considered a low precision method. This was attributed to the challenge of counting fish at night, which was thought to be when most Pink Salmon migration occurred. Observations indicated that they avoided the light used to help enumerate them. However, more recent acoustic observations by DFO's applied technology group in the Thompson River near Spences Bridge suggest that the migration of Pink Salmon slows down as darkness approaches and then virtually stops before resuming near daybreak the following morning (Hermann Enzenhofer, pers. comm.). Thus, it is possible that the lights used to assist with counting actually stimulated night time migration that wouldn't normally occur. Nonetheless, the reduced ability to observe the fish in the evening, likely resulted in underestimates of escapement from the tower counts consistent with the direction of bias implied by Andrew & Webb (1987a).

Dead Count Expansions: Low Precision Estimates

Dead count expansions were used infrequently (for 25 individual stream estimates from 1957-1991), and were only used when inadequate live-counts were carried out (i.e. surveyors arrived after peak die-off; Table A1). For these estimates, the total number of carcasses observed was expanded by an index, usually the ratio of total population to dead recovered from a nearby Sockeye Salmon population (Andrew & Webb 1987a)

Observer Estimates: Low Precision Estimates

The final low precision method used to estimate escapement was observer estimates, which were used when IPSFC or DFO personnel were not present (Table A1). A total of 54 observer estimates were recorded from1957 to1991, with the majority of these (39) estimates being < 1,000 fish (DFO database). Observer estimates of population size in a system are considered subjective and are not based on rigorous study designs (T.Cone, DFO, pers. com.).

Table A1. Sites in the Fraser River system for which Pink Salmon escapement estimates were generated by the IPSFC, 1957-1985 (from information from Andrew and Webb 1987) and by DFO, 1987-1991 (from DFO database).

Area	Site	Enumeration Methods
Lower Fraser	Fraser River	Petersen Mark-Recapture (1957-1991)
	Johnson Slough	Peak Live + Cumulative Dead x2.6 (1981-1991)
	Stave River	Peak Live + Cumulative Dead x2.6 (1957, 1961-1967, 1985-1991) Peak Live+ Cumulative Dead x 5.3 (1959) Observer Estimate (1981)
	Coquitlam River	Peak Live + Cumulative Dead x2.6 (1957 only) Not Present (1961-1963, 1981)
	Kanaka Creek	Peak Live + Cumulative Dead x2.6 (1957-1965) Not Present (1967) Observer Estimate (1985)
	Whonnock Creek	Peak Live + Cumulative Dead x2.6 (1957-1967)
	Silverdale Creek	Peak Live + Cumulative Dead x2.6 (1957-1965) Not Present (1967)
	Norrish Creek	Peak Live + Cumulative Dead x2.6 (1957 only) Not Present (1961-1967)
	Salmon River	Not Present (1961 only)
	Beaver (Nathan) Creek	Not Present (1957, 1961)
	West Creek	Not Present (1961 only)
	Silver Creek (Pitt Lake)	Not Present (1961 only)
	Alouette River	Peak Live + Cumulative Dead x2.6 (1957, 1985-1989) Observer Estimate (1991) Not Present (1961-1963)
	Squakum Creek	Not Present (1963 only)
	Lagace Creek (Hatzic Lake)	Not Present (1957 only)
	Upper Sumas Creek	Not Present (1957 only)
	Maria Slough	Fence (1985 only)
	Hoy Creek	Observer Estimate (1985 only)
	Upper Pitt River	Observer Estimate (1985 only)
	Deboville Slough	Observer Estimate (1985 only)
Chilliwack-Vedder	Chilliwack-Vedder River	Petersen Mark-Recapture (1957-1991)
	Liumchen Creek	Peak Live + Cumulative Dead x2.6 (1973 only) Not Present (1959-1961, 1975, 1979-1991)
	Sweltzer Creek	Fence Count with Peak Live + Cumulative Dead Below Fence *2.6 (1959-1991)
	Paleface Creek	Peak Live + Cumulative Dead x2.6 (1963-1967, 1979, 1985-87) Observer Estimate (1989-1991) Not Present (1969-1973, 1981-1983)
	Depot Creek	Peak Live + Cumulative Dead x2.6 (1963-1967, 1979-1981, 1987-1991) Not Present (1869-1973, 1983-1985)
	Upper Chilliwack River (Dolly Varden Creek)	Peak Live + Cumulative Dead x2.6 (1963-1971, 1983, 1987, 1991) Observer Estimate (1973, 1979-1981)

Area	Site	Enumeration Methods
		Not Present (1975, 1985, 1989)
	Slesse Creek	Peak Live + Cumulative Dead x2.6 (1959-1983)
		Not Present (1985-1991)
	Tamihi Creek	Peak Live + Cumulative Dead x 2.6 (1963-1973)
		Not Present (1961, 1975-1989)
		Observer Estimate (1991)
	Foley Creek	Peak Live + Cumulative Dead x2.6 (1975-1977, 1983-1985)
		Present (1981 only), Not Present (1987-1991)
	Borden Creek	Peak Live + Cumulative Dead x2.6 (1985 only)
		Not Present (1975, 1983, 1987-1991)
	Middle Creek	Peak Live + Cumulative Dead x2.6 (1959-1981, 1985, 1991)
		Not Present (1987)
	Centre Creek	Peak Live + Cumulative Dead x2.6 (1979 only)
		Not Present (1975 only)
	Chipmunk Creek	Peak Live + Cumulative Dead x2.6 (1971 only)
		Not Present (1975 only)
	Ryder Creek	Peak Live + Cumulative Dead x2.6 (1967-1969, 1985)
		Not Present (1987-1991)
	Little Chilliwack River	Peak Live + Cumulative Dead x2.6 (1957 only)
	Brown Creek	Peak Live + Cumulative Dead x2.6 (1957 only)
Harrison	Harrison River	Petersen Mark-Recapture (1957-1991)
	Chehalis River	Petersen Mark-Recapture (1957, 1961)
		Peak Live + Cumulative Dead x2.6 (1959, 1963-1985)
		Not Present (1987-1991)
	Weaver Creek	Petersen Mark-Recapture (1957-1967, 1977-1983)
		Peak Live + Cumulative Dead x1.8 (1969-1975, 1985)
		Dead Count * Sockeye Tag Recovery Ratio (1987)
		Fence Count with Peak Live + Cumulative Dead Below Fence *2.6 (1989-1991)
	Weaver Creek Spawning Channel	Total Dead Recovery (1965-1989) Fence Count (1991)
	Steelhead Creek	Peak Live + Cumulative Dead x2.6 (1985)
		Observer Estimate (1991)
		Not Present (1987-1989)
	Birkenhead River	Petersen Mark-Recapture (1981 only)
	Big Silver Creek	Peak Live + Cumulative Dead x2.6 (1965, 1969, 1987-1991)
Fraser Canyon	Coquihalla River	Petersen Mark-Recapture (1959, 1971-1973, 1987)
		Peak Live + Cumulative Dead x2.6 (1957, 1965-1969, 1975-1985, 1989)
		Peak Live + Cumulative Dead x 5.2 (1961-1963)
		Total Dead Recovery *2.6 (1991)
	Ruby Creek	Peak Live + Cumulative Dead x2.6 (1959-1991)
	Wahleach (Jones)	Peak Live + Cumulative Dead x2.6 (1957, 1977-

Area	Site	Enumeration Methods
	Creek	1991) Observer Estimate (1961-1965, 1969-1975)
	Wahleach (Jones) Creek Spawning Channel	Weir Count (1957, 1961) Total Dead Recovery (1979-1981, 1985-1991) Observer Estimate (1959, 1963, 1967-1973, 1977, 1983)
	Lorenzetti Creek	Peak Live + Cumulative Dead x2.6 (1959-1967, 1981-1991)
	Silverhope Creek	Peak Live + Cumulative Dead x2.6 (1957-1991)
	Hunter Creek	Peak Live + Cumulative Dead x2.6 (1959-1967, 1971-1985, 1989-1991) Not Present (1957, 1987)
	American Creek	Peak Live + Cumulative Dead x2.6 (1957-1967, 1973, 1981-1991)
	Spuzzum Creek	Peak Live + Cumulative Dead x2.6 (1957-1973, 1977, 1983-1991)
	Nahatlatch River	Peak Live + Cumulative Dead x2.6 (1957-1967, 1971, 1975-1991)
	Anderson Creek	Peak Live + Cumulative Dead x2.6 (1957-1991)
	Emory Creek	Peak Live + Cumulative Dead x2.6 (1959-1967, 1971, 1983-1991) Not Present (1957, 1973, 1977)
	Stoyama Creek	Peak Live + Cumulative Dead x2.6 (1959) Not Present (1963, 1983)
	Kawkawa Creek	Peak Live + Cumulative Dead x2.6 (1957-1973, 1981-1991)
	Texas (Choate) Creek	Peak Live + Cumulative Dead x2.6 (1959) Present (1981), Not Present (1961-1963)
	Nine-Mile Creek	Peak Live + Cumulative Dead x2.6 (1977) Not Present (1971-1973, 1979)
	Yale Creek	Peak Live + Cumulative Dead x2.6 (1959-1963, 1967, 1971, 1985-1991) Not Present (1965)
	Hawkes Creek	Observer Estimate (1965) Not Present (1967)
	Popkum Creek	Peak Live + Cumulative Dead x2.6 (1959) Not Present (1957, 1961-1963)
	Flood Creek	Peak Live + Cumulative Dead x2.6 (1959, 1963) Not Present (1961)
	Sawmill Creek	Peak Live + Cumulative Dead x2.6 (1985-1989)
Seton-Anderson	Seton Creek	Petersen Mark-Recapture (1957-1971, 1975-1991) Dam count (1973)
	Seton Creek Spawning Channel	Fence count (1965) Total Dead Recovery (1961-1963, 1967-1991)
	Cayoosh Creek	Peak Live + Cumulative Dead x2.6 (1971-1973, 1977-1979, 1983-1987) Dead Count Expansion (1963-1965, 1975) Fence Count (1991)
	Portage Creek	Petersen Mark-Recapture (1977-1979) Peak Live + Cumulative Dead x2.6 (1957-1975, 1981-1991)
	Gates Creek	Peak Live + Cumulative Dead x2.6 (1977-1981,

Area	Site	Enumeration Methods
		1987-1991)
	Bridge River	Peak Live + Cumulative Dead x2.6 (1959-1991) Not Present (1957)
	Yalakom River	Peak Live + Cumulative Dead x2.6 (1959) Not Present (1957, 1961-1965)
Thompson	Thompson River mainstem	Petersen Mark-Recapture (1957-1963, 1971-1991) Live Count at Bighorn Less Population Estimates for Tributaries (1965-1969)
	Nicola River	Peak Live + Cumulative Dead x2.6 (1957, 1961-1967, 1971-1989) Peak Live + Cumulative Dead x 5.3 (1959)
	Bonaparte River	Peak Live + Cumulative Dead x2.6 (1957-1979, 1983-1991)
	Deadman Creek	Peak Live + Cumulative Dead x2.6 (1957, 1961-1965, 1969-1971, 1975-1983) Fence Count (1985-1991) Not Present (1959, 1967, 1973)
	Adams River	Dead Count * Sockeye Tag Recovery Ratio (1965, 1971, 1979-1985) Dead Count Expansion (1973-1975) Peak Live + Cumulative Dead x2.6 (1977, 1989-1991)
	Little River	Petersen Mark-Recapture (1979-1983) **Peak Live + Cumulative Dead x2.6 (1975**, 1989-1991) Observer Estimate (1985) Dead Count Expansion (1977) Dead Count * Sockeye Tag Recovery Ratio (1987)
	South Thompson River	Petersen Mark-Recapture (1983) Peak Live + Cumulative Dead x2.6 (1977-1981, 1985, 1989-1991) Dead Count * Sockeye Tag Recovery Ratio (1987)
	North Thompson River	Peak Live + Cumulative Dead x2.6 (1979-1981, 1985-1991) Observer Estimate (1977, 1983)
	Lower Shuswap River	Peak Live + Cumulative Dead x2.6 (1977-1989) Dead Count Expansion (1975)
	Nicomen River	Peak Live + Cumulative Dead x2.6 (1959, 1969) Not Present (1961, 1965)
Upper Fraser	Stein River	Peak Live + Cumulative Dead x2.6 (1957-1967, 1971, 1975-1991)
	Churn River	Peak Live + Cumulative Dead x2.6 (1957, 1963-1967, 1971, 1977, 1981-1991) Observer Estimate (1979)
	Quesnel River	Petersen Mark-Recapture (1967) Peak Live + Cumulative Dead x2.6 (1981) Observer Estimate (1965, 1971, 1977-1979, 1983, 1991)

Area	Site	Enumeration Methods
		Present (1969), Not Present (1973, 1985-1987, 1991)
	Williams Lake Creek	Peak Live + Cumulative Dead x2.6 (1971, 1979) Not Present (1967, 1973)
	Chilcotin River	Observer Estimate (1967)
	Fraser River (Bridge River rapids to Quesnel)	Not Present (1967)
	Watson Bar Creek	Peak Live + Cumulative Dead x2.6 (1963) Observer Estimate (1967)
	Gaspard Creek	Not Present (1957, 1967)
	Canoe Creek	Not Present (1967)
	Big Bar Creek	Not Present (1967)

APPENDIX B

Assumptions underlying live-recapture methods.

The following five assumptions were evaluated throughout the mark recapture program.

1) Mark-recapture methods typically assume that the population being estimated is "closed". The closure assumption was compromised at the tagging site, as sampling effort was restricted to an eight-hour period during daylight hours and a large diel component of the daily migration was not vulnerable to tagging. However, the closure assumption was satisfied at the live-recapture site, since sampling was conducted 24-hours per day through the entire migration period. Since all stock components of the Fraser River Pink Salmon run were vulnerable in one of the two samples (live-recapture) violations of the closure assumption did not have significant impacts on the estimates.

2) In the 1993 study, Pink Salmon were tagged with Petersen disk tags (the same type of tags used since 1957), and a portion of the fish were double tagged with both Petersen disk tags and cinch-up spaghetti tags to estimate the tag loss-rate (Cass et al. 1995). At the Strawberry Island live recovery site (Figure 2), no tag loss (0%) was observed for either tag type. However, for carcasses recovered on the spawning grounds, a tag loss rate of 4.2% was observed for disk tags which compared to a tag loss rate of 8.6% for cinch-up tags. The 1995 study used , cinch-up tags instead of disk tags, despite their higher loss-rate. This was due to concerns about disproportionate loss of disk tagged fish to in-river gillnet fisheries conducted by First Nations to harvest Sockeye Salmon for food social and ceremonial purposes (disk-tagged fish were more likely to be caught than untagged fish; Schubert et al. 1997). The 1995 study also included a "double mark" (adipose fin clip) component to estimate tag loss, and, similar to the 1993 study, they found a very low rate of tag loss-rate (0% for males, 1.2% for females) for cinch-up tags between the tag site and the live recovery site. As a result of the findings of the 1993 and 1995 studies, the mark-recapture programs from 1997 to 2001 used only cinch-up tags (T. Cone, DFO, pers. comm.). During this period loss was assessed by applying a permanent secondary mark (opercular hole punch) to all marked fish. Mark loss was assessed for each program, and results from 1995 to 2001 showed very low loss rates (average was less than 0.6%).

3) Mark recognition at the live recapture site was considered to be accurate because virtually no mark misidentification error occurred.

4) The effects of handling and tagging stress on the behaviour of fish subsequent to their release were assessed at both the tag and recapture sites. The programs at each site were designed to minimize handling stress during the capture and tagging processes. Acute handling stress was assessed by conducting regular carcass recovery surveys below the tag site to calculate the proportion of marked fish in the recovered carcass sample. Recovery rates for recaptured tagged fish were compared to migration rates to assess the potential effects of handling stress.

5) The assumption of simple random sampling and equal probability of capture and recapture is violated in most mark-recapture studies. The live recapture study attempted to minimize these concerns by designing capture and recapture sampling to be as representative as possible. Both tag application and live recaptured samples were assessed for sampling bias to evaluate impacts on the population estimate. Sampling bias (temporal) has been observed in all studies analyzed to date, however, the observed bias is inconsistent between the two samples, suggesting that the sources of selectivity are independent.

APPENDIX C

Test-Fishery Indirect estimates 2009 to 2013

For the period 2009-2013, no direct estimates of escapement are available. Therefore, estimates of catch were subtracted from the total return to generate indirect estimates of escapement. The total return estimates used to calculate Pink Salmon escapements for 2003 to 2007 are based on test fishery data collected in Johnstone Strait (Area 12) and Juan de Fuca Strait (Area 20). The average daily catch per set (CPUE based on 6 sets) was used in combination with an estimate of the catchability (q) by the test fishery to estimate the total return (N) following equation 1 below.

(1) $N = N_{20} + N_{12} = \Sigma CPUE_{20,d} * (1/q_{20}) + \Sigma CPUE_{12,d} * (1/q_{12})$

For purse seine test vessels there is a difference in the efficiency of vessels catching Pink Salmon in Area 12 versus Area 20. Given the natural variability in the CPUE data, variation in the proportion of Pink Salmon migrating though Area 12 vs. Area 20 (i.e. the diversion rate) and the error associated with estimates of the total Salmon abundance, it is difficult to generate independent estimates of catchability for each area using equation 1. Therefore, the relative catchability of Salmon in each area (Johnstone and Juan de Fuca straits) was derived from the ratio of areas swept by the fishing nets. Juan de Fuca Strait is much wider than Johnstone Strait. Based on the migration areas for Pink Salmon, and the size of the nets used in each area, a net fishing in Johnstone Strait accesses three times the available migration area relative to a net fishing in Juan de Fuca Strait. Thus we assumed that the catchability in Johnstone Strait was three times that of Juan de Fuca Strait, given the same fishing effort (number of sets) is applied in both areas (equation 2 below).

(2) For purse seine vessels catching Fraser River Pink Salmon: $q_{12} = 3 * q_{20}$

Pink Salmon caught in the test fisheries are comprised of Fraser River Pink Salmon, other Canadian Pink Salmon stocks as well as Washington stocks. The non-Fraser stocks tend to migrate through the test fishing areas earlier than Fraser River Pink Salmon and therefore often dominate test fishery catches early in the season. Later in the season, the proportion of Fraser River Pink Salmon gradually increases. Daily Fraser River Pink Salmon stock proportion estimates (p_d), based on genetic stock identification methods, were used to estimate the CPUE of Fraser bound Pink Salmon separately from non-Fraser Pink Salmon stocks following equation 3 below.

$$(3)\quad N = \Sigma(p_{20,d} * CPUE_{20,d}) (3/q_{12}) + \Sigma(p_{12,d} * CPUE_{12,d}) (1/q_{12})$$

Equation 3 was used to produce yearly estimates of catchability for the period 1987 to 2001 and 2009 to 2013. The total returns (N) in each year were based on the sum of catch and escapement and thus were independent of the test fishery CPUE. The median of these yearly catch ability estimates was then used to calculate total return and escapements for 2003, 2005 and 2007. The original total return estimates for Fraser River Pink Salmon for the period 2003 to 2007 were revised based on improved catchability estimates. The revised run size estimates for Fraser River Pink Salmon in 2003, 2005 and 2007 are 24,250,000, 9,870,000 and 8,490,000 fish, respectively and the associated uncertainty in these estimates is +/- 37% (Table C1). The original estimates of run size (2003, 26,000,000;2005, 10,000,000; and 2007, 11,000,000) were based catchability estimates derived from varying sets of historic years, depending on the year for which run size was estimates. The revised catchability estimates used to generate the estimates for 2003, 2005 and 2007 come from a consistent set of historical data which includes years prior to 2003 and subsequent to 2007 as described above. Overall, the revised run size estimates are lower than the original estimates because the revised catchability estimates are larger.

Because the escapements are estimated from total return minus catch and the catch estimates were small relative to the total return (Table C1), virtually all of the absolute variation in the total return estimates is transferred to the escapement estimates. Thus, the coefficient of variation in in the escapement estimates of approximately 40% results from the large interannual variation in historic catchability of the test fisheries. Consequently the 80% probability intervals for the escapement are quite broad. (There is a one in ten chance that the underlying escapement values could be less than minimums or larger than maximums shown in these intervals).

Table C1. Estimates of total return and net escapement of Fraser River Pink salmon and their 80% probability intervals for 2003, 2005, and 2007 based on Marine area test fishery and catch estimates.

	2003	2005	2007
Total return	24,250,000	9,870,000	8,490,000
80% Probability Interval (Return)	15-38 million	6-16 million	5-13 million
Total Catch (All Areas)	2,068,970	1,060,376	839,948
Implied escapement estimate	22,181,030	8,809,624	7,650,052
80% Probabillity interval (Escapement)[1]	13-36 million	5-15 million	4-12 million

Notes: 1 Assumes catches are estimated without error

Appendix D

Hydroacoustic Estimates: (2009 to 2013)

The history of the hydroacoustic program at Mission and its modifications in recent years have been reviewed by the PSC (PSC 2007b; Xie et al. 2005). The program was operated by the IPSFC from 1977-1984 and the PSC from 1985 onwards. For most of the program (1977 to 2003), Salmon densities were sampled using a single vessel, with a downstream-directed single-beam transducer (echosounder) that laterally transected the Fraser River at Mission, B.C. 160–180 times daily. This system operated during the upstream migration period of both Sockeye and Pink Salmon. The single beam technology detected adult Salmon sized fish targets, but it could not determine the direction of fish movement or directly measure fish swimming speed. More importantly, the mobile vessel system was ineffective for sampling fish in the near-shore waters (where most Fraser River Pink Salmon migrate) because fish reacted to the presence of the vessel and avoided detection by the sonar (Xie et al. 2008).

In 1995, a stationary split-beam transducer (echosounder) was installed on the left[2] bank of the Fraser River at the same sampling site to examine Salmon behaviour, which included taking measurements of fish swimming speed and direction of travel (Xie et al. 1997). The shore-based system was tested in 2004 by comparing the split-beam sonar counts to separate dual-frequency identification sonar (DIDSON) counts also taken on the left bank. The study found a high correlation and statistical agreement between the two separate counts, and concluded that the split-beam sonar provided accurate abundance estimates at Salmon passage rates of up to 2,500 fish-per-day through a commonly sampled cross-section located in the region 0- 40 m from shore (Xie et al. 2005). However, at densities greater than 2,500 fish-per-day, which is the case when most Fraser River Pink Salmon migration is occurring , split-beam sonar results in biased abundance estimates. Most potential sources of bias in split-beam sonar estimates are negative (Cheng and Levy 1991; PSC 2007b). Biases can result from high Salmon densities that saturate the sonar, detection problems resulting from Salmon swimming too close to the transducer, violations in assumptions regarding uniform migration behaviour for fish in near- and off-shore waters, and fish avoiding detection by the vessel sampling areas of the river beyond the range of the shore-based systems (Xie et al. 1997, 2002, 2008).

[2] Left and right are relative to facing downstream and are the standard references used in riverine work.

Comparisons between the split-beam and DIDSON methods in the 2004 study found that DIDSON sonar provided three significant advantages over the traditional split-beam sonar: (1) improved target identification (e.g. fish vs. debris), (2) reduced sizes of acoustical blind zones near the river bottom (Xie et al. 2005), and (3) improved estimation at higher fish passage rates. This latter advantage is especially important during the Pink Salmon migration. For example, the Qualark acoustic program conducted by DFO (Enzenhofer et al. 2010) reported a maximum right-bank hourly count by the DIDSON of 25,600 fish within a 5-m range bin at 1100 hours on September 26, 2013 (J.Krivanek, DFO, pers. comm.), and a maximum left-bank hourly count of nearly 30,000 fish at 1100 hours on September 16, 2010 (H. Enzenhofer, DFO, pers. comm.). Conversely, split beam sonar tracking was less effective when passage reached an hourly count of 21,000 fish at 1000 hours on September 12, 2010 at Mission (Y. Xie, PSC, pers. comm.).

Appendix E

Comparison of estimates from alternative species composition methods

To understand the potential implications of the different methods used to estimate species proportions at Mission, the PSC estimates were compared to estimates derived from a stratified method, which used the relative abundances in catches of two fish wheels to estimate near shore species proportions (Table 7; Robichaud et al. 2010). Two fish wheels (one large and one small) were operated at Crescent Island (left side of Fraser River) approximately 10 km downstream of the Mission site each summer from 2009 to 2013. Data were provided by K. English (LGL Limited, Sidney B.C., pers. comm.) and the combined catches from the large and small fish wheels were used to estimates species proportions. Data included catches of Sockeye, Pink, Chinook, Coho, Chum, and Steelhead, but the primary species caught by the fish wheels during the Pink Salmon migration period were Pink and Sockeye Salmon. The periods of operation were continuous in 2009 and 2013, but due to program constraints there were a few three or four day gaps in 2011 and the programs terminated in each year prior to the end of the Pink Salmon migration (see footnote 2 in Table 7 for details). Linear interpolation from adjacent days was used to estimate species proportions for days without data. The species proportions from the last observed day(s) with reasonable total catches were used to fill in missing data at the end of the season. The potential impact of errors in the species proportions used at the end of the season on the estimates is small because in all cases the proportion of Pink Salmon in the fish wheels on the last observed day was very high (i.e. 98%) and the proportion of the total Salmon in the near-shore areas during this late period was also high (avg. 79-95%). The method used to generate Pink Salmon estimates follows that described by Robichaud et al. (2010) for Sockeye Salmon. The proportion of Pink Salmon from fish wheel data was applied to the total Salmon estimates within 50 meters of each shore. The proportion of Pink Salmon in the Whonnock test fishery was applied to abundance estimates for the remainder of the river cross section. This method is completely independent of the methods used by the PSC described in the text in section "Allocation of hydroacoustic estimates of total Salmon to species".

The estimates of total Pink Salmon obtained from both methods were very similar in each of the years (differences in total Pink estimates ranged from 1% to 9%; compare bottom rows of columns E and H for each year in Table 7). The temporal distribution of Pink Salmon estimates across the periods was also very similar for each of the methods in each year (compare columns G and I; Table 7). Lastly, the pattern of daily estimates derived from the two methods is very similar (Figure E1). If the estimates of total Salmon were accurate (see text "System-Wide Estimates (Hydroacoustic Methods): 2009 to 2013"), these comparisons provide some confidence that the potential biases in the Pink Salmon Mission abundance estimates that result from errors in species assignments are likely small.

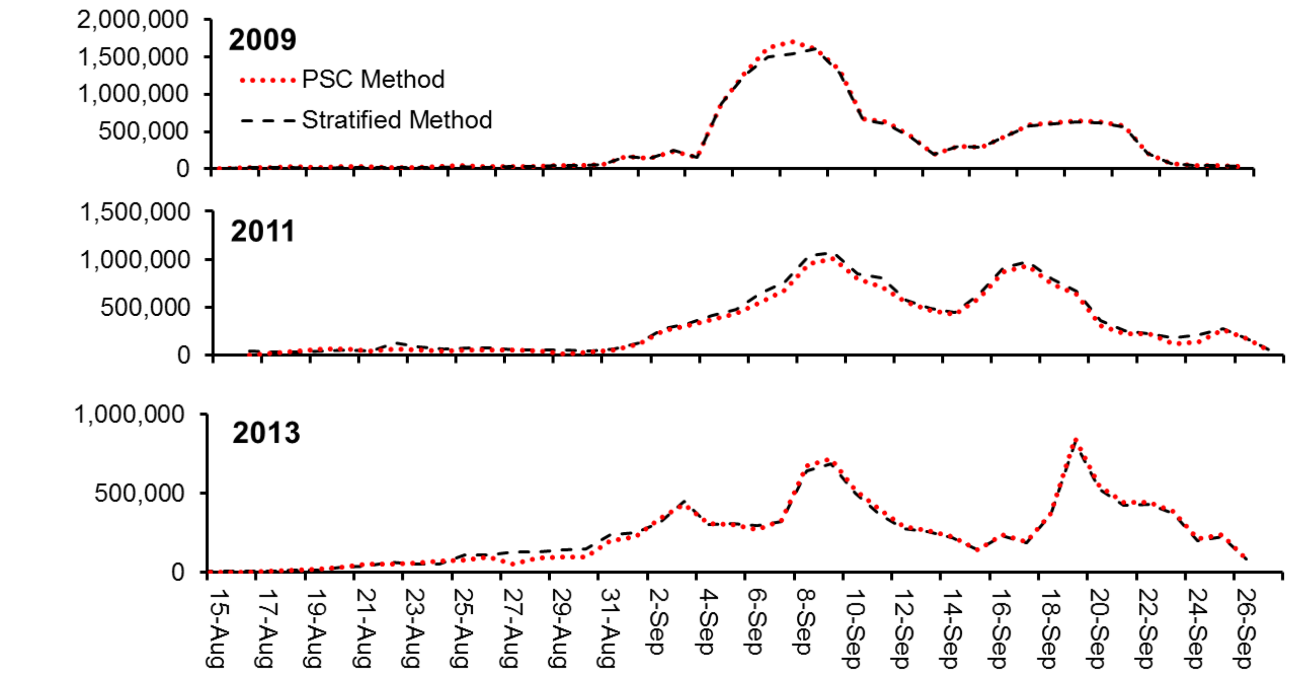

Figure E1. Comparison of daily estimates of Pink Salmon abundances from the Mission hydroacoustic program. The Pink Salmon estimates derived from applying the PSC methodology are compared to estimates derived from the Stratified approach using data from the fishwheel. Red dotted lines correspond to the daily estimates associated with the totals shown in Column E of Table 7. The black dashed lines correspond to the daily estimates associated with the totals shown in Column H of Table 7.

APPENDIX F

Fry Abundance Estimates: Analytical *A*ssumptions

Estimation of Pink Salmon fry abundances at Mission relies on the assumption that fry are randomly distributed laterally and vertically in the Fraser River during sampling. Vernon (1966) tested this assumption using identical surface nets to simultaneously fish different sections of the Fraser River at Mission, to examine the schooling behaviour of Pink Salmon fry and its possible effects on sampling bias. The study found that fry exhibited schooling behaviour very early in the season when Secchi disk readings were greater than 1 m. However, as the season proceeded and flow and turbidity increased, the fry schooling behaviour dissipated and they became randomly distributed. Given that fry were randomly distributed during most of the sampling period, Vernon (1966) concluded that non-random distribution of fry was not a source of sampling bias. The assumption of random fry distribution, however, has not been re-examined, although anecdotal information from more recent sampling observations indicates that the assumption is likely still valid (J. Tadey, DFO, pers. comm.).

The start and end dates, and associated abundances, for the Fraser River Pink Salmon Mission fry Program are presented in Figure F1 below.

<u>Analyses</u>

Daily Pink Salmon fry catches are expanded to generate an index of the total number of fry that have migrated past the Mission sampling site, using a stepwise procedure (described in Vernon 1966).

1. **Averaging for each sampling station**: The catch-per-run is averaged separately for each sampling station (right bank, mid-stream, and left bank) for the day's 8-hour incline plane trap (IPT) sampling shift.

2. **Weighting for trap efficiency**
   As the IPT is the primary trap from which index estimates are generated, an estimate of trap efficiency is required. Simultaneous sampling with the IPT and the fine-meshed surface net from the vertical trap in 1962 found that, on average, the fine-meshed net caught 16% more fry than the IPT (Vernon 1966). This difference is primarily due to the passage of Pink Salmon fry through the larger mesh of the IPT. Therefore to adjust for trap efficiency in analyses, Pink Salmon fry captured

from the IPT are multiplied by a factor of 1.16 to account for loss of fry through the IPT screen (Vernon 1966). In the Mission Pink Salmon excel analysis files, it is assumed that trap efficiency is included in weighting factors; however, it is not currently clear where this occurs.

3. **Weighting for lateral distribution:** The daily averages for each sampling station (right bank, mid-stream, and left bank: see Figure 11) are weighted to account for differences in the lateral distribution of fry and flows, then summed together for a weighted average surface concentration.

As river flow differs across the width of the Fraser River, surface catch estimates must be weighted to account for lateral differences in velocity in each section. Vernon (1966) measured the percentage of river flow through each section of the river daily during the 1964 Pink Salmon fry enumeration and found that the percentage of total flow through each section changed with the river discharge (i.e. a higher percentage of the flow passed through the right-bank section during high flows than during low flows). As a result, weighting factors were applied to the fry catches to account for the variable river discharge.

For each sampling day, the catch-per-run (i.e. fry density), weighted for trap efficiency, was averaged for each section of the lateral sampling area (Figure 6). The average fry density for each section was then multiplied by the weighting factor appropriate for the discharge on that day. The weighted fry densities for the three sections were then added together for a daily surface fry density estimate which was weighted to account for differences in flow across the channel.

4. **Weighting for vertical distribution**: The average surface concentration was weighted to account for differences in the vertical distribution of fry.

IPT sampling was conducted every second day on the surface of the river. Daily estimates of fry concentration on the surface, calculated from the IPT samples, were weighted to represent the concentration throughout the water column. This was done by using the vertical net catches in conjunction with the surface net catches, to calculate a ratio of the surface fry concentrations to total fry concentrations as measured vertically throughout the water column.

For each day, the daily surface fry concentration estimate (weighted for trap efficiency and lateral flow distribution) was divided by the ratio of surface fry concentration to total fry concentration to generate an estimate of fry concentration that was weighted for trap efficiency, lateral flow distribution, and vertical fry distribution.

5. **Weighting for diurnal distribution**: The differential distribution of fry was weighted over 24 hours.

The standard daily sampling period was 8 hours, and therefore it was necessary to weight the daily estimates of fry concentration to represent the concentration during full 24 hour period. The weighting factor was calculated as the ratio of the mean catch-per-run for a daily 8-hour sampling period (unweighted) to the mean catch-per-run for the corresponding 24-hour sampling period.

The daily estimate of fry concentration (weighted for trap efficiency, lateral flow distribution and vertical fry distribution) was divided by the corresponding ratio of 8-hour to 24-hour catch for an estimate of fry concentration that was weighted for trap efficiency, lateral flow distribution, and vertical, and diurnal fry distribution.

6. **Multiplying the average fry density (weighted by the above factors) by the average daily flow for the day to estimate the total number of fry per day**.

Due to the confounding effects of tidal influence, discharge records are not available for the Fraser River near Mission. However, gauging stations are maintained by the Water Survey of Canada on the Fraser River at Hope (70 km upstream of Mission) and on the Harrison and Chilliwack-Vedder Rivers (which are the two principal tributaries of the Fraser River between Hope and Mission).

These gauging stations represent discharge from over 99% of the Fraser River watershed above Mission. However, approximately 1,850 km^2 of drainage area in the mild coastal region is unaccounted for by these gauging stations. The unaccounted for area may contribute a significant amount to the discharge of the lower Fraser River, especially in the early spring when runoff from snowmelt is low but runoff from coastal precipitation may be high.

For the purpose of estimating discharge at Mission, the sum of discharges from the three stations listed above (Fraser River at Hope, Chilliwack-Vedder River, and Harrison River) has been used consistently since 1962 (J. Tadey, DFO, pers.com.).

The daily estimate of fry concentration (fry-per-unit-volume, weighted for trap efficiency, lateral flow distribution, and vertical, and diurnal fry distribution) was multiplied by the daily discharge estimate for the Fraser River at Mission to calculate a daily estimate of total number of fry past Mission.

7. **Summing daily estimates to generate an estimate of total fry migrating past Mission.**

Changes in methodology

Originally, from 1962 to 1978, Pink Salmon fry estimates, lateral, vertical, and diurnal weightings of fry concentration were subjectively grouped into different temporal strata, as described in Vernon (1966). For example, fry appeared to be more concentrated at the surface up until April 8 (during the 2100-0500 hour period versus 0500-2100 period), after which they appeared to be evenly distributed, Therefore, different weighting factors were applied to all catches before and after April 8 (Table 10, 'arbitrary group weightings column).

Where data are electronically available for this time series, estimates were revised using surface IPT trap catches (the base measurement for all fry abundance data), which were weighted according to the most recent vertical or 24-hour sampling data, rather than being subjectively grouped into a category with assigned weighting factors (Table 10, 'official fry estimate' column). This was the approach adopted throughout most of the time series as the official fry abundance estimate, with the exception of 1962-1966 years when no electronic data were available to adjust the arbitrary weighted estimates to the new ungrouped weighting estimate. In the period of overlap between the two approaches (1968-1978), the difference between the ungrouped weighting and subjective arbitrary group weightings was 13% higher, on average (Table F2).

F2. Fraser River Pink fry abundance estimates at Mission by year. The column on the left represents the official fry estimates generated using methods developed by R. Kent (DFO Biologist) which weighted temporal and depth distributions according to the most recent 24-hour and depth sampling runs. Although analytical methods were similar, sampling methodologies for 1968-1974 were inconsistent with those from subsequent years (i.e. variable trap speed). The column on the right represents estimates generated using methodology described in Vernon (1966), for which weightings for temporal and depth distribution are arbitrarily grouped and averaged and are only included in the official time series for years when ungrouped weightings could not be generated (no electronic data for these years).

Total Pink Fry Past Mission Estimates

	Official Fry Estimates Using "ungrouped weightings" methodology [a]	Comparison "arbitrarily grouped weightings" methodology from Vernon (1966)	Percent Difference Between Methods
1962	NA [b]	284,231,670 [d]	NA
1964	NA [b]	143,612,379 [d]	NA
1966	NA [b]	274,038,242 [e]	NA
1968	307992793 [c]	237,576,364 [e]	30%
1970	287672663 [c]	195,550,040 [e]	47%
1972	273648793 [c]	245,155,876 [e]	12%
1974	212282112 [c]	292,362,641 [e]	-27%
1976	319,661,462	279,193,227 [e]	14%
1978	483,705,232	473,348,358 [e]	2%
1980	341,349,198		
1982	606,956,510		
1984	557,372,656		
1986	264,501,452		
1988	435,961,784		
1990	400,400,254		
1992	685,494,109		
1994	437,726,552		
1996	279,138,265		
1998	257,454,524		
2000	218,993,888		
2002	714,393,790		
2004	418,963,073		
2006	614,491,334		
2008	496,977,147		
2010	1,062,364,862		
2012	519,268,309		

a. Calculated using spreadsheet with formulas and factors by R. Kent
(T. Cone, DFO data manager, pers. comm.)

b. Raw data not available for calculation

c. Field methods were slightly different from subsequent years for these years (variable trap speed)

d. Methodology documented in Vernon (1966)

e. Estimate calculated by A.B. Chapman using Vernon (1966) methodology

Appendix G

Pink Salmon spawning distribution from Mission and Qualark acoustic programs

The relative distribution of Pink Salmon spawning below and above the Fraser Canyon can be estimated by comparing the Fraser Pink Salmon abundance estimates at Mission to estimates obtained from the Qualark hydroacoustic site (approximately 95 km upstream of Mission and 30km downstream of Hell's Gate: Figure 4).The methods used to estimate Fraser River Pink Salmon were describe in the section "Hydroacoustic Estimates 2009-2013" with future details provided on the hydroacoustic program and species proportion methods in Appendices E and F above.
Two DIDSON units system has been operated by DFO at Qualark since 2008 (Enzenhofer et al. 2010) where the Fraser River is approximately 150 m wide. These units cover approximately 30 m of the river on each side and they have operated continuously during the duration of the Sockeye and Pink Salmon migrations. Though there is a gap of approximately 90 m in the center of the channel, this has not been a source of error in the estimate, as virtually all fish migrating past Qualark are shore-oriented and migrate within 30 m of the bank (Whitehouse et al. 2012).

The total Salmon passage is apportioned to species using data from a drift gillnet test fishery operated at the site. The test fishery makes six sets (three at dawn and three at dusk) daily. As fish are shore-oriented at this site, the Qualark test fishery is not susceptible to the same sources of bias that are associated with the Whonnock gillnet test fishery that samples the fish migrating in the main river channel downstream of the Mission site (Whitehouse et al. 2012). However, during periods when the abundance of Pink Salmon predominates the migration, the estimates for other species (e.g. Sockeye Salmon) obtained by applying species proportions in the Qualark test fishery to the total Salmon abundance appear to be too large relative to upstream estimates. Thus, it appears that the Qualark test fishery may catch fewer Pink Salmon than is indicative of their actual abundance. The mechanisms that cause this bias have not been thoroughly examined. Potential sources of bias include differential saturation of the gillnet by species related to their relative abundance, and/or migratory behavior differences.

Because of this potential source of bias which could lead to underestimates of Pink Salmon passage, an alternative method was used to generate Pink Salmon escapement estimates similar to that used at Mission during the periods of high relative abundance of Pink Salmon. This alternate method involved estimating the catchability of each of other Salmon species (i.e. Sockeye, Chinook, Coho Salmon; the CPUE in the Qualark test fishery divided by their abundance estimates at Qualark) during the period prior to Pink Salmon upstream migration. The abundances for these species in subsequent periods were estimated by dividing the species-specific CPUEs by the respective catchability estimates derived from the earlier periods. The estimates of Pink Salmon escapement are then estimated by subtracting the abundances of these other species from the total Salmon estimate. The alternate method assumes that the catchability of the other species is the same before and after the increase in the Pink Salmon migration. In contrast applying the species proportion to the total Salmon assumes that the other species have the same vulnerability to the drift gillnet test fishery as Pink Salmon. Irrespective of differences in the location of the Qualark and Whonnock test fisheries relative to the shore oriented migration of Pink Salmon at both sites, the assumption that Pink Salmon and other species are equally vulnerable to drift gillnet sampling results in Pink Salmon estimates that are lower than estimates generated by alternate methods at both sites (Table 7).

Therefore, the alternate method of estimating species abundance at Qualark was used to generate the estimates of Pink Salmon abundance bound for spawning areas upstream of Qualark (fourth from bottom row Table 8 “Upstream of Qualark Pink escapement estimates (CPUE for non Pink species). Because these methods are most consistent with those used for species proportions at Mission, the Qualark estimates based on this alternate methodology were also used to estimate the relative fraction of Fraser River Pink Salmon spawning upstream of Qualark (Table 8).

Comparisons of Mission and Qualark daily estimates can also be used to estimate daily Fraser Pink Salmon migration speeds. Most (e.g. 79% in 2011) Fraser River Pink Salmon migrate upstream along the left side of the river at Mission (Xie et al. 2012). Based on a time series analysis comparing the hourly fish count made by the left-bank DIDSON at Mission the DIDSON counts from both banks at Qualark (95 km apart), Xie et al. (2012) estimated a daily migration speed of 28 km or a travel time of 3.4 days for Fraser River Pink Salmon between Mission and Qualark in 2011. However, this estimate may overestimate the average migration speed for the entire Fraser population, because the Qualark estimate represents a higher proportion of the early-timed run and those fish may migrate faster than and the later-timed Pink Salmon runs that spawn in the lower Fraser mainstem and its tributaries (J. Cave, PSC, pers. comm.).