LATE-RUN FRASER RIVER SOCKEYE MIGRATION BEHAVIOR, EN ROUTE MORTALITY, RESEARCH, AND FISHERIES MANAGEMENT PLANS

(Updated July, 2003)

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Introduction

Background

Late-run sockeye have historically delayed in the lower Strait of Georgia for four to six weeks prior to entering the Fraser River en route to their spawning grounds. Since 1996, Late-run sockeye (excluding Birkenhead sockeye) have often entered the Fraser River with little or no delay, which has resulted in mortality rates of some Late-run sockeye stocks exceeding 90% in some years. The cause(s) of this early entry behavior have not yet been identified, despite intensive and on-going research studies. Some of the most serious implications of this early entry behavior of Late-run sockeye are that: (1) the future viability of some Late-run stocks may be jeopardized; and (2) substantially lower harvest rates on Late-run and Summer-run sockeye (a portion of which overlap in their migration timing with Late-run fish) have been necessary in recent years to help ensure that Late-run sockeye stocks are conserved. The greatly reduced harvest rate on Fraser River sockeye is having significant adverse impacts on the multitude of commercial and non-commercial users of this resource. The severe curtailment of harvest has been necessary to protect the sustainability of Late-run stocks, including the famous Adams River sockeye run.

Migration Behavior of Late-run Fraser River Sockeye in 2002

In 2002, as in recent past years, early entry of Late-run Fraser River sockeye stocks into the Fraser River occurred. The Late-run return was predominantly comprised of Late Shuswap sockeye, since 2002 is the dominant cycle line return for the famed Adams River sockeye population. Late-run sockeye were first identified in DNA analyses of sockeye tissue samples

collected from the Whonnock gillnet test fishery (Fraser River, Area 29-16) on July 27 and 28, which confirmed the continuation of the early upstream migration behavior. However, as the migration progressed, marine assessments indicated that a substantial portion of the run was delaying in the Strait of Georgia. This was different from their behavior in 2000 and 2001, when virtually all Late-run fish entered the Fraser River without delay, and approximately 90% of these fish died prior to spawning.

As the Late-run sockeye migration progressed through August, an increasing component of the run showed a normal behavior pattern, and delayed in the Strait of Georgia. The delaying fish began migrating in large numbers into the Fraser River in early September, when an estimated 1,200,000 Late-run sockeye migrated past Mission between August 30 and September 5. The migration tapered off for a few days, and then a larger second group of Late-run fish began migrating past Mission where the Pacific Salmon Commission maintains a hydroacoustic monitoring station. Between September 11 and September 20, an additional 3,600,000 Late-run fish were estimated migrating past Mission. The run had virtually completed its upstream migration by September 24. The date when 50% of Late-run sockeye were estimated to have migrated past Mission was September 12, which is approximately two weeks earlier than the long-term average date.

The entry pattern of Late-run sockeye into the Fraser River in 2002 was similar to the 1998 brood year when significant early upstream migration occurred in August, followed by a strong surge of escapement between September 12 and 17, and very low escapement after September 20. The 50% upstream migration date of Late-run sockeye passing Mission in 1998 was September 14, and approximately 36% of Late Shuswap sockeye were estimated to have died en route between Mission and their natal spawning areas. In 2002, with a 50% migration date past Mission that was two days earlier (September 12), a much smaller fraction of the run died en route (less than 10% based on comparison of hydroacoustic estimates of Late-run sockeye passing Mission and upstream accounting estimates from spawning grounds).

The Pacific Salmon Commission (PSC) funded several studies in 2002 directed at improving understanding of the dynamics of the early upstream migration behavior of Late-run sockeye, and at testing hypotheses to determine mechanisms causing the abnormal behavior of Late-run sockeye observed in recent years. The research plan was coordinated by the Committee on Scientific Cooperation (CSC) of the PSC, with total funding of approximately $1,000,000 (Cdn.) contributed by the Canadian and United States governments. A summary of the research conducted in 2002 is presented below:

Summary of Studies Conducted on Late-run Fraser River Sockeye in 2002

Telemetry/Disk Tagging

Tagging objectives:

1. Determine if Late-run sockeye enter the river in the same chronological order as they arrive in ocean approach areas.
2. Estimate the amount of delay of Late-run sockeye in the Strait of Georgia by timing group.
3. Estimate in-river survival and spawning success of Late-run sockeye by timing group.

Nearly 900 radio-tagged Fraser River sockeye were released in ocean approach areas. Late-run sockeye accounted for 50% of the releases. Tagged Late-run sockeye were released in early, mid and late timing groups in both Johnstone and Juan de Fuca straits. An additional 170 radio-tagged fish were released in the Thompson River near Ashcroft (approximately 35 km downstream from Kamloops Lake) along with about 20,000 disk-tagged fish in early, mid and late-timed groups.

Results:

- The survival rates of radio-tagged fish released in the marine areas varied among the six time-area release groups. Estimates of survival from the telemetry data in four of the six groups ranged from 73-75%. These survival estimates are consistent with other marine tagging studies. For the remaining two groups, only 36% of the radio-tagged fish survived and were accounted for in the Fraser River.
- The reason for the low survival rates in two of the time-area marine release groups is unknown. Both releases occurred at times when the abundance of sockeye in the release areas was low based on DFO and PSC test fishing data. It is unclear if tagging effects reduced the survival of tagged fish. All radio-tagged fish were also tagged with an external orange "spaghetti" tag possibly making them more vulnerable to predation in areas of low sockeye abundance. Alternatively, the hypothesis that low survival of both tagged and untagged fish occurred in these areas and times cannot be rejected.
- Marine-tagged Summer-run sockeye (as identified through DNA analysis) generally entered the Fraser River in the same chronological order as they were tagged. For combined releases in Johnstone Strait and Juan de Fuca Strait, the travel times between release location and Mission for the 1st, 2nd and 3rd release timing groups were similar.
- River entry timing of marine-tagged Late-run fish was more variable and protracted compared to Summer-run fish. On average, Late-run fish had travel times from release locations to the lower Fraser River of about 3 weeks compared to 1 week for Summer-run fish.
- Some Late-run sockeye from each release group entered the Fraser River with little or no delay in the Strait of Georgia and at the same time as the Summer-run. Of the three release groups, higher proportions (51%) of Late-run sockeye in the 1st group entered the river early. The proportion that entered early declined in the 2nd (11%) and 3rd (10%) release groups. The amount of delay declined successively between the 1st, 2nd and 3rd release groups.
- In-river survival in 2002, which excludes pre-spawn losses in terminal spawning areas, was similar in each of the three Summer-run release groups. In contrast, the in-river survival of Late-run fish varied from 59% in the 1st release group to 88% for the 3rd release group. These survival estimates in 2002 were higher than estimates based on Mission acoustic abundance estimates of Weaver Creek sockeye in 2000 and 2001 when survival was estimated at about 10%.
- In-river survival was very poor for Late-run fish that entered the river earliest. Late-run sockeye that passed Mission before August 18, 2002 had an in-river survival rate of 11%, whereas after September 11 the survival rate was 92%.
- The overall survival rate from Mission to the spawning areas, excluding likely in-river fishery removals, was 80% for Late-run sockeye and 92% for Summer-run fish.
- The radio telemetry data for Late-run sockeye suggests a relationship between river entry timing and survival from Mission to the spawning grounds for Adams and Lower Shuswap river sockeye.
- A curve describing the in-river survival, excluding pre-spawn losses at terminal spawning sites, by time of river entry based on telemetry data reveals an increase in

survival with date of passage. Late-run sockeye that passed Mission before August 18, 2002 had an in-river survival rate of 13%. Survival rates increased rapidly for Late-run sockeye that passed Mission from late-August to early September. Late-run sockeye that passed Mission after September 11 had a survival rate of 92%.

- It is important to note that the sample size of Late-run sockeye that passed Mission before August 18 was low (15 fish). Consequently, the in-river survival estimate for the early entry group has low precision and is potentially inaccurate.
- The trend in survival over time of radio-tagged fish and disk-tagged fish was similar with lower survival in the early-timed portion of the Late-run return.
- The low numbers of radio-tagged carcasses recovered from spawning sites precluded rigorous evaluation of spawning success by timing group based on radio-tag recoveries.
- The large number of disk-tagged carcasses recovered from spawning sites provided sufficient data to estimate spawning success by tag-release timing group.
- The disk tagging results indicate that the Late-run fish tagged at Ashcroft early in the run (before August 26) had the highest pre-spawn mortality rate (70%). In contrast, the pre-spawn mortality rate was less than 3% for fish that were tagged at Ashcroft after September 30.
- Combining estimates of en route mortality and pre-spawn mortality by timing group is required to estimate the overall survival from river entry to spawning by timing group. The overall survival estimates for the Adams/Shuswap Late-run sockeye ranged from 4% for fish that passed Mission before August 18 to 90% for those that passed Mission after September 11.

Physiology

Osmoregulation

Salmon must undergo a number of physiological adjustments prior to initiating their migration into freshwater from the ocean, including a change in kidney function to expel surplus water from the blood. These physiological adjustments are necessary to maintain osmoregulatory function in the fish. Plasma and gill samples were used to assess osmoregulatory function. Samples were collected off southwest Vancouver Island near Port Renfrew, in the Strait of Georgia and in the lower Fraser River in 2002.

Hypothesis 1: Osmoregulatory adaptation to freshwater has been triggered earlier than normal, forcing Late-run sockeye to enter the Fraser River early.

Hypothesis 2: In-river mortality of early entrants is higher than normal because fish that enter early are not fully prepared physiologically for freshwater, leading to osmoregulatory dysfunction and premature death, especially if fish are stressed.

Hypothesis 3: The early entry of Late-run sockeye, combined with prolonged freshwater residence and the full development of kidney parasitic infection leads to pre-spawning mortality, particularly if fish enter the river unprepared for osmoregulation in freshwater.

Results:

- The 2002 results indicated that based on the physiological traits assessed, both Summer and Late-run fish were already in the process of preparation for freshwater at both marine locations. This implied that adaptation for freshwater started seaward of Port Renfrew.

- Samples taken in the Georgia Strait showed a bimodal distribution in the traits measured, which suggested two groups of freshwater preparation levels. Both groups of fish holding in the Strait of Georgia would be seawater tolerant under low stress conditions.
- Experimental evidence from the Late-run Adams River fish held at the Shuswap hatchery showed that sockeye holding at higher temperatures had an accelerated decline in osmoregulatory function compared to fish holding in cooler water.
- The initial hypotheses that early entry into the Fraser River is related to osmoregulatory dysfunction cannot be rejected, but could be properly tested if blood samples were collected from radio-tagged fish that were subsequently released into the ocean.

Reproduction:

Reproductive hormones play a key role in gonad maturation rates and may be important for determining the timing of migration into freshwater.

Hypothesis 1: Late-run fish enter the Fraser River early due to an advanced state of maturity and early entry fish have lower reproductive success.
Hypothesis 2: Early entry fish wait on the spawning ground because the hormones related to final sexual maturation are no longer synchronized to arrival at the spawning ground.

Results:

- Ovary mass for both Summer-run and Late-run sockeye increased with date of river entry and proximity to the spawning grounds. There was a fixed rate of egg development with distance traveled upstream. This is consistent with studies of other sockeye populations.
- The hypothesis that early entry Late-run sockeye are more mature based on ovary mass alone is rejected.
- Further analyses of factors affecting gonad development should consider issues such as body energy reserves and reproductive hormone levels.
- There was no temporal difference in final ovary mass or egg size among the different timing groups for both Summer-run and Late-run sockeye. In general, Adams sockeye had high fertilization success (>90%) throughout the spawning period, regardless of spawning date.
- The surviving sockeye that were sampled in 2002 were healthy and had high reproductive success, regardless of entry timing. The hypothesis that early entry fish have a lower reproductive success is not supported by the 2002 results. However, the very early entrants to the spawning grounds were not assessed for fertilization success.

Energetics:

As adult sockeye approach the Fraser River, they stop feeding in marine areas. They also do not feed during in-river migration. Salmon therefore have limited energy to complete development of gonads and their spawning migration. In recent years, body energy reserves in Fraser sockeye have been low compared to earlier years.

Hypotheses: Late-run stocks are ascending the river earlier than normal due to low initial somatic energy reserves (i.e., they may have low stores of fatty tissue, and since they do not feed during their up-river migration they may be more susceptible to dying prior to spawning).

Results:

- Fraser sockeye energy states were assessed in 2002 by researchers from the University of British Columbia.
- The results to date indicate that early-timed fish have greater energy reserves than later-timed fish. However, there is some evidence that early-timed fish use energy less efficiently than later-timed fish during their migration.
- The trade-off between metabolic energy required to sustain life and gonad development required for reproduction was identified as a confounding effect in the preliminary analysis. The recommendation from their work is to integrate the energy work with other physiological and parasite measures.
- At present it is not possible to refute or support the hypotheses that early entry into the Fraser River is due to low initial energy reserves or that they are dying in large numbers before spawning because of energy depletion. Experiments planned for 2003 should provide additional information to examine these hypotheses.

Parasitology

Hypothesis: Mortality from *Parvicapsula minbicornis* infection is highest in early entry Late-run fish compared to late-entry fish. Early-entry fish remain in the Fraser watershed longer that late-entry fish and are therefore more prone to severe *Parvicapsula* infection.

Results:

- *Parvicapsula* incidence rates in 2002 were similar to 2001 and approached 100% in sockeye samples from both Summer and Late-runs at the end of the spawning migration. The high incidence of infection but lower mortality rates in 2002 compared to earlier years indicated that infected fish do not necessarily die when infected.
- The severity of *Parvicapsula* infection and mortality rate is dependent on environmental conditions. Holding studies indicate higher severity and higher mortality with increased temperature. At the highest exposure temperatures in the holding studies, the severity of infection increased to near-lethal levels.
- A bimodal pattern of *Parvicapsula* infection severity was observed in which samples collected from the Adams River showed early and late peaks of severity. This suggested two patterns of salmon migratory behavior: (1) late river entry, leading to reduced in-river residence and low infection severity, and (2) early river entry, leading to greater in-river residence and greater infection severity. It is predicted that en-route and/or pre-spawn mortality was higher in the latter group. Tagging data supported this.

Oceanography

Hypotheses: Early entry is dependent on upper ocean conditions in ocean migratory areas as adults enter the Strait of Georgia. In-river mortality is related to the productivity regime experienced in the ocean-entry-year of juvenile sockeye.

Environmental variables were used to assess processes affecting migration timing based on the concept that the upper layer of the Strait of Georgia system is, to varying degrees, an extension of the Fraser River estuary. This has been called the “Brackish Layer Depth Model” and focuses on environmental conditions in near-surface depths where salmon migrate. A second approach is investigating the influence of ocean productivity regimes and first-year marine growth of sockeye to explain variations in in-river mortality.

Results:

- For specific time periods, there are significant statistical correlations between the sockeye return time series and *individual* physical variables (specifically, the variability of surface temperature and salinity) in the Georgia Basin.
- For specific time periods, there are significant statistical correlations between the sockeye return time series and physical variables after accounting for the proportion of sockeye that migrate either through Johnstone Strait or Juan de Fuca Strait.
- High variability in temperature and salinity implies that river water is retained as a layer. Low variability implies vertical mixing, and low retention of freshwater.
- The individual environmental variables were combined in a statistical analysis that assessed the overall effect of environmental variables. The analysis revealed that the return timing was correlated with overall temporal variability derived from sea-surface temperature, sea-surface salinity, river discharge, wind stress, water levels, and other variables for the Georgia Basin.
- The combined effect of the individual environmental variables was consistent with results based only on the individual variables. The dominant variables retain their importance regardless of where they are measured in the basin.
- The analysis also reveals that long-term effects of the combined environmental variables are correlated with the *Pacific Decadal Oscillation* (PDO) Index. This indicates a strong link between return timing and decadal-scale ENSO-type warming/cooling in the North Pacific.
- There appears to be distinct climate regimes or low-frequency climate cycles that are related to variations in the survivability of Late-run Fraser River sockeye. For example, Fraser sockeye were characterized by low survival in the 1990s. Late-run in-river mortality was also high for fish from brood years 1991-1997.
- Decadal-scale climate regimes identified from large-scale environmental indices result in different relationships between the abundance of spawners and future recruitment.
- Climate regimes affect 1st year marine growth of sockeye. The hypothesis proposes that if 1st year marine growth conditions are good then sockeye will be able to withstand environmental factors affecting early river entry and in-river survival.

Other Hypotheses

Two additional hypotheses were considered. The potential effect of chemical contaminants on early entry and subsequent mortality are being assessed. Samples were collected in 2002 but they have not been fully analyzed. Another hypothesis considered in 2002 was that marine mammal (killer whales, seals and sea lions) activity near the Fraser River estuary has forced sockeye into the river earlier than normal. Marine mammal effects were considered a lower priority for research and therefore marine mammal studies were not undertaken in 2002.

An important conclusion from the 2002 studies was that environmental conditions in the river potentially affect survival rates of early-entry fish. Premature death of highly stressed fish could be from several factors including predation, physiological dysfunction, energy depletion or disease (i.e. *Parvicapsula* infection). Conditions in 2002 were favorable during the migratory period of Late-run sockeye compared to other years. The average in-river survival of Late-run sockeye was higher in 2002 than in 2000 and 2001. Nevertheless, the early entry phenomenon persisted in 2002 and the early entrants of Late-run sockeye still had low survivals (13%) compared to later entry groups of Late-run sockeye (92%). Combining the estimates of in-river

survival with terminal area pre-spawn losses reduced the overall survival of early entry Late-run sockeye to 4%.

The tagging studies were designed to estimate timing and survival rates rather that to test specific hypotheses on the causes of early migration. A new hypothesis to explain the early entry of Late-run sockeye, however, has been proposed based on results of the telemetry study. The hypothesis proposes that selective pressure to school ("stay with the school hypothesis") would result in a substantial portion of the Late-run fish entering the Fraser early with the Summer-run fish when the latter are numerically dominant. During time periods or years when Late-run sockeye were numerically dominant, the migratory behavior of Summer-run sockeye would not have a significant influence on the genetically programmed delay behavior of Late-run sockeye. If early entry of Late-run fish is controlled to some extent by the relative abundance and timing overlap with Summer-run stocks, then the potential for early entry and lower in-river survival would be highest in years like 2000 and 2001. The Late-run stocks were relatively small compared to Summer-run in those years and there was almost complete overlap in the marine migration timing of Summer-run and Late-run stocks. This theory can be tested to some degree using historical data. Recent advances in DNA analyses may be able to provide the in-season data required to assess the potential for early entry and make the appropriate adjustments to the pre-season expectations regarding in-river survival rates. The evidence in support of this hypothesis must eventually be considered along with the evidence supporting competing hypotheses.

Research Plans for Fraser River Late-run Sockeye in 2003

The individual studies have been useful for developing and testing hypotheses to explain: (1) why Late-run sockeye have entered the Fraser River earlier than normal; and (2) why, and to what extent, Late-run sockeye die in-river or on the spawning sites before spawning. The telemetry and disk tagging studies have proven to be extremely valuable methods for investigating this problem. The tagging studies were successful at meeting their three primary objectives in 2002. The non-tagging research focused on hypotheses that potentially explain the causes of early-entry and subsequent mortality.

All principal investigators involved with the research in 2002 agree that future studies need to be multi-disciplinary and integrated because of the potential linkages among individual study disciplines. Therefore, future studies should utilize a team approach to developing study designs.

Tagging

A telemetry study is planned for 2003, which would be similar to the study conducted in 2002. This will be the last year in the four-year cycle of Adams River sockeye when abundance levels are projected to be sufficiently high enough to tag suitable numbers of Late-run fish in marine areas and detect them at later stages in their migration.

Physiology

Research in 2003 will repeat the spatial and temporal sampling of Summer and Late-run sockeye and the sample sizes will be increased over those sampled in 2002. They will focus on body energy data, ocean growth patterns, and reproductive status in the Georgia Strait and the early entrants into the Fraser River.

Hypothesis testing in 2003 will focus on the assumption that prolonged freshwater residence, high river temperatures, disease and stress will contribute to osmoregulatory dysfunction and death.

The proposed approach in 2003 will integrate sampling with other studies and involve researchers from UBC, SFU, and DFO. Sampling during the ocean tagging period is planned to maximize information on differential survival rates in relation to freshwater residency times, osmoregulatory state, disease, and body energy reserves. It may be possible to use osmoregulatory condition to predict premature mortality.

The hypotheses on the effect of the reproductive state to be tested in 2003 are: (1) Late-run sockeye that enter the river early are in an advanced state of maturation relative to their body energy reserves forcing them to enter early, (2) early entry fish have lower reproductive success in years with difficult in-river migrations or low initial energy states, and (3) hormonal control of final maturation state is suppressed in early entry fish.

Efforts will be directed at maintaining a flexible strategy to respond to changes in environmental conditions and fish behavior in 2003 and assess the reproductive success of the very early migrants to the spawning grounds.

Disease/Parasitology

The hypothesized relationship between severe infection with *Parvicapsula* and en route/pre-spawn mortality will be tested in 2003 by maintaining captive adult sockeye under various environmental conditions.

Oceanography

The "Brackish Layer Depth" model will continue to be examined with the Adams River population and the model will be applied to all Late-Run stocks, including the Cultus Lake stock.

Research will be undertaken to determine the lag time that provides the "best" correlation between fish return timing and physical variables. The research will examine whether the bio-physical impact is most important for returning adults or for outgoing juveniles and which combinations of months are "biologically appropriate".

The comprehensive Nanoose Bay time-series data set will be used to determine how well surface measurements are representative of the Brackish Layer Depth and upper layer conditions in the Georgia Basin.

The two oceanographic approaches will be integrated that predict migration timing (Brackish Layer Depth Model) and in-river survival (Climate Regime Model).

Fishery Management Considerations of the Fraser River Panel in 2003

The 2003 cycle is the sub-dominant cycle for Adams River sockeye. Management objectives/actions implemented in 2003 will be designed to preserve this stock's future productive capacity, as well as address the status of co-migrating Fraser River Late-run stocks, including the Cultus Lake sockeye stock, which has been listed as endangered by COSEWIC, and is expected to be formally listed as endangered under the new SARA legislation. It is assumed

that Late-run sockeye (excluding Birkenhead) will continue their early upstream migration behaviour and the associated en route mortality that has occurred in recent years will also continue. The Fraser Panel adopted an initial planning assumption that the 50% upstream migration date into the Fraser River will be September 12 based on recent Late-run behaviour observed in Late Shuswap dominant and sub-dominant cycle lines. The associated en route mortality rate of 47 %, was estimated from an Environmental Management Adjustment model, which has been approved by the Panel.

Policy decisions about Late-run harvest during the in-season management period in 2003 will depend on assessments of Late-run abundance, in-river migration timing and associated en route mortality projections. Late-run sockeye stocks will be managed with the intent that fisheries directed at Summer-run sockeye will not compromise the achievement of Late-run management objectives. Weekly fisheries management information updates will be included in the Fraser River Panel news releases that will be posted on the PSC website (www.psc.org) during the season.

Spokespersons

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