# Evaluation of the Potential Freshwater Factors Linked to the Decline of Early and Late Stuart Sockeye Salmon: SEF Final Report[†]

Principal Investigators:

David A. Patterson[1], Erland A. MacIsaac[1], Timber R. Whitehouse[2], and Ken S. Shortreed[1]

Report Prepared by:

David A. Patterson[1] and Merran J. Hague[1]

[1]Fisheries and Oceans Canada, Science Branch
[2]Fisheries and Oceans Canada, Stock Assessment Branch

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Fisheries and Oceans Canada | Pêches et Océans Canada

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## EXECUTIVE SUMMARY

Previous Fisheries and Oceans Canada (DFO) reviews identified declines in spawning abundances of Early and Late Stuart sockeye salmon (*Oncorhynchus nerka*) over the previous three generations, classifying these stocks in the “red zone” of the Wild Salmon Policy (WSP). Given their current red-listing, it is unlikely the status of either stock would meet the goals of the Pacific Salmon Treaty, “to obtain spawning escapement goals by stock or stock groups”, or the WSP, “to restore and maintain healthy and diverse salmon populations and their habitats”. Furthermore, the WSP promotes a pro-active management approach to prevent listed populations from dropping below critical threatened or endangered thresholds identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). These concerns prioritised the need for research on Stuart sockeye populations and the reasons contributing to their declines.

Contrasting the observed declines in Stuart sockeye is the stability of proximate Stellako River populations over the same time period. A significant proportion of total mortality for Pacific salmon stocks occurs in the freshwater environment, leading to the speculation that the differences in abundance trends between Stuart and Stellako populations could be due to differences in stock-specific freshwater habitats and/or innate biological vulnerabilities to shared marine and freshwater migration environments. This hypothesis, in addition to the WSP goal for pro-active fisheries management, stimulated the development of our SEF Proposal: “*Evaluation of the potential freshwater factors linked to the decline of Early and Late Stuart sockeye salmon”.*

We identified three major objectives during the development of this project, as outlined in the original proposal:

1) Establish the magnitude and spatial scale of the decline for each Early Stuart and Late Stuart sockeye salmon spawning populations.

2) Systematically evaluate and rank the likelihood of a list of possible freshwater factors relating to the decline. The list includes but is not limited to the following: adult migration conditions, spawning and incubation habitat, lake rearing environment, and biological differences.

3) Provide advice on potential management strategies for mitigation of those freshwater factors that can be implicated in the decline.

In order to address these objectives, we first compiled a comprehensive database of historic data relating to physical, chemical and biological conditions in Stuart sockeye freshwater habitats, as well as Stuart sockeye physiology and stock status (see attached Data Sources Table). Where possible, time series were updated with information collected during strategic physical and biological sampling completed during

2007 and 2008. Ultimately, our goal was to determine if trends in any of the freshwater life history stages of Stuart sockeye were consistent with the overall population declines and to use this information to provide advice with respect to the development of future research projects and potential mitigation and/or recovery strategies.

The framework of this report consists of four chapters, each representing an independent paper addressing one of the three objectives outlined above:

1. Quantification of the magnitude and spatial scale of declines in Early and Late Stuart sockeye salmon in the Fraser River, British Columbia
   *M.J. Hague*

2. Evaluation of spawning migration conditions in relation to the decline of Stuart sockeye salmon
   *M.J. Hague, D.A. Patterson and J.A. Hills*

3. Evaluation of spawning and incubation environment for Stuart sockeye salmon
   *D.A. Patterson, H.E. Herunter, P. Vimos, L.A. Thompson, M.J. Hague, J.A. Hills, and D. C. McKay*

4. Rearing environments and body condition of juvenile Stuart sockeye salmon
   *D.A. Patterson, L.A. Thompson, D.C. McKay, H.E. Herunter, J.A. Hills, and M.J. Hague*

Executive summaries for each of these chapters have been summarized below with specific reference to the objectives outlined above. A summary of the databases analysed with respect to each objective is also provided. Finally, we include an extensive bibliography of publications related to Stuart sockeye.

## MAIN CONCLUSIONS

The completion of this study provided valuable insight into the scale of the Stuart sockeye declines and the relative contribution of conditions in freshwater migratory, spawning, incubation and rearing habitats. The initial stock assessment (Ch. 1) revealed that abundance declines were consistent across the majority of natal spawning creeks and were not the result of changes in a single, predominant population. This result suggested that the driving force for changes in these stocks was occurring on a regional scale. Stock-recruit analyses indicated that a shift from relatively high to low productivity levels from the 1980’s to present day was common to both Stuart and Stellako stocks. However, in populations of Early and Late Stuart sockeye, additional pressures from harvest (primarily Late Stuart) and increased severity in en route migration conditions (primarily Early Stuart) contributed to recruitment returns to the lower Fraser River below levels of brood year abundance in the majority of recent years. In addition, there was some evidence to suggest that trends in stock-specific productivity (reflecting changes occurring because of innate biological vulnerabilities and/or differences in stock-specific freshwater habitats) were also consistent with the spatial and temporal scale of Stuart stock declines. The conclusions drawn from the stock assessment

confirmed the need to more closely investigate physical and biological trends in Stuart sockeye freshwater habitats and associated life history stages.

The correlation between increased severity of en route loss (as parameterised using differences between upper and lower escapement estimates for a given year, i.e. “Management Adjustments” or MAs), and decreases in Early Stuart productivity and abundance stimulated the research on freshwater migration conditions summarised in Chapter 2. Increases in both average and maximum river temperature exposure for Stuart and Stellako stocks has occurred concurrent to both Early and Late Stuart spawner declines. Stuart and Stellako spawners also experience the highest accumulation of thermal units of any Fraser sockeye stocks, due in part to warm temperatures encountered in the watershed (in the lower Fraser for Late Stuart and Stellako fish; in Nechako and Stuart Rivers for Early Stuart fish) and the extended freshwater residency resulting from the long migration (>1000km). Trends in extreme river environmental conditions are consistent with the theory that en route migratory losses are a contributing factor to the decline in Early Stuart sockeye. Thermal profile models also provided evidence that Late Stuart sockeye may be experiencing more extreme levels of en route loss than the Summer run-timing aggregate; suggesting that Summer-run MAs may underestimate recent en route losses for Late Stuarts. However, there was no evidence of inter-generational consequences of spawners experiencing extreme in-river temperatures or flows.

From the analysis of migratory environments and biology, we concluded that mortality suffered during the spawning migration is a likely contributor to Early Stuart declines. However, more evidence from the development of stock-specific and/or biological MA models is required to elucidate our suspicions that in-river mortality is also contributing to declines of Late Stuart spawners. Strategies to mitigate in-river loss are already occurring in some parts of the watershed, such as the Nechako River cold-water release facility (Macdonald et al. 2008). Several additional “hard infrastructure” strategies for off-setting salmon losses in the freshwater environment are summarised in Nelitz et al. 2007. If summer warming trends in the Fraser River persist as forecasted, sockeye managers will continue to be faced with the probability of high en route loss. Therefore, we also suggest that current work into the development of stock-specific and biologically-based MA models should continue, to improve both the accuracy of pre-season and in-season MAs forecasts used for management as well as post-season estimates of en route loss.

The stock assessment also provided some evidence of declines in stock-specific productivity, which could result, in part, from differences in incubation and rearing environments. Therefore, we chose to investigate physical and biological trends in creek and lake habitats under more scrutiny. Closer examination of physical and biological trends in key Early Stuart index streams (i.e. Forfar, Gluske and Kynock Creeks) did not provide any indication that trends in egg-fry survival or incubation habitat variables were consistent with the patterns in spawner declines (Chapter 3). In addition, although land development has increased throughout the watershed over the timeframe of the decline, road densities remain at very low levels and spawner abundances have changed

regardless of the extent of land development. Although productivity trends were correlated across the majority of creeks; there was still some variability with respect to the rates of decline observed among other non-index spawning grounds; therefore, we recommend continuing with existing physical and biological monitoring programs with additional expansion to key non-index creeks which have experienced high rates of decline. We also recommend a pro-active approach for the assessment and planning of future land-use activities (e.g. forestry, mining) and their potential impacts on stream environments at the Stuart-Takla watershed scale.

Finally, we investigated whether changes in rearing lake habitats would be indicative of declines in fry-smolt survival (Chapter 4). Strategic sampling was completed in 2007 and 2008 to extend historic timeseries of historic lake chemistry and productivity, and to collect smolt samples for comparison with Stellako and Chilko populations. Survival in the rearing environment could not be directly estimated due to the lack of smolt abundance data. However, the limited data available suggests that Middle River smolts are larger, and have higher energy levels, than smolts from other Fraser River stocks located downstream (e.g. Stellako, Chilko, Cultus). Examination of summer zooplankton abundances and scale-circuli distances also provide no evidence of a decline in freshwater growth in recent years. However, correlations were noted between spawner abundance and freshwater growth for Takla Lake suggesting resources may become limited at high fry densities (e.g. 1993 brood year). Again, there is no reason to speculate that lake rearing conditions are the limiting factor in Stuart sockeye productivity, and given the relative stability of the current conditions, a thorough evaluation of associated risks should be conducted prior to the initiation of any enhancement activity.

In conclusion, the regional-scale declines in Early and Late Stuart sockeye salmon spawning abundances are likely primarily a function of: (1) changes in underlying marine productivity, (2) harvest and (3) en route mortality during the freshwater component of the spawning migration. In some years, declines may have been exacerbated by isolated occurrences of higher-than-average pre-spawn mortality, egg-to-fry mortality and/or fry-smolt mortality. However, trends in spawning, incubation and rearing environments are not consistent with the observed spatio-temporal trends in spawner abundance suggesting it is unlikely that survival in these freshwater habitats are the primary causes of the overall decline. In addition to the continuation of current physical and biological monitoring programs, we also propose future research into the completion of a more thorough stock-assessment analysis and improved estimates of stock-specific en route mortality.

Key objectives and results, as well as major findings and recommendations relating to each chapter are further summarised in the point-form executive summaries provided below.

## CHAPTER 1 EXECUTIVE SUMMARY

- **Purpose:** to determine whether the spatial and temporal patterns of abundance and productivity trends for Stuart and Stellako sockeye salmon are consistent with changes in survival in freshwater habitats
- **Report objectives:**
    - examine spawner abundance trends at the stock, lake, watershed area and creek level
    - use different recruit and spawner scenarios to evaluate the relative contribution of harvest, spawning migration mortality, and pre-spawn mortality to declines in productivity
    - calculated temporal and spatial trends in a stock-specific survival index
    - determine whether trends in the stock-specific index are consistent with trends in population declines
- **Result summary:**
    - declines in Stuart sockeye were persistent across the majority of spawning creeks
    - productivity declines have paralleled more recent declines in abundance
    - both harvest and increased en route mortality contributed to levels of recruitment below replacement over the past 25-years
    - the role of en route mortality is sensitive to the definition of the management adjustment (MA) used as a proxy for en route loss (e.g. post-season MA; predicted MA; stock specific MA)
    - temporal trends in the declining freshwater survival index were consistent with the trends in total survival
    - freshwater survivals were spatially correlated across watersheds
- **Key conclusions:**
    - processes contributing to observed declines in Stuart spawner abundances are occurring at a regional scale
    - harvest, declines in marine productivity, and increased freshwater en route loss explain the majority of the abundance trends
    - evidence suggests changes in incubation and rearing habitats may also affect spawner abundance; further research is required to confirm this
- **Recommendations:**
    - thoroughly investigate biological and physical processes occurring in freshwater habitats (migration corridors, spawning and incubation streams, rearing lakes) to determine whether there is additional evidence to suggest changes in these habitats may contribute to the declines in spawner abundance

## CHAPTER 2 EXECUTIVE SUMMARY

- **Purpose:** to determine whether environmental conditions in the Fraser River during the adult spawning migration are likely contributors to the recent observed declines in the spawning abundance of Stuart sockeye
- **Report objectives:**
    - examine patterns in Fraser River temperature and discharge exposures experienced by Stuart and Stellako migrants
    - examine patterns in fish energy density upon river arrival as an indicator of susceptibility to en route stressors
    - relate environmental conditions to trends in Early Stuart and Summer-run management adjustments
    - determine whether there are trends in spawning ground physiology (e.g. ovary mass, fecundity, egg size, gamete viability) which are related to en route environmental variables and/or are consistent with declines in Stuart sockeye
- **Result summary:**
    - Stuart and Stellako migrants experience warmer and more extreme water temperatures post-decline period (e.g. 1990's onwards) than prior to the observed abundance declines (1980's)
    - Early Stuart migrants have experienced several extreme discharge events since 1990
    - Stuart and Stellako fish accumulate more thermal units en route to the spawning grounds than any other Fraser sockeye stock
    - there has been no trend in energy density at river arrival after adjusting for maturity status
    - gamete viability of Early Stuart is comparable to other Fraser stocks
- **Key conclusions:**
    - recent increases in the number of Early Stuart en route mortalities, as estimated from management adjustments, are consistent with the trends in river temperature and flow exposure
    - the mortality estimates are consistent with available information on the impact of extreme conditions on migratory success
    - river environmental exposures for Late Stuart and Stellako fish suggest that a Summer-run MA may not provide an accurate estimate of en route mortality for these individual stocks
    - trends in river environmental conditions are not correlated to detectable patterns in estimates of spawning ground fecundity and/or egg size
- **Recommendations:**
    - continue with refinement of DNA analyses required for the development of post-season stock-specific MA estimates
    - continue ongoing research into the development of model selection procedures for the selection of robust pre-season and in-season MA forecasting models

- partition MAs into separate en route mortality, escapement observation error, and catch estimation error components in an effort to develop a biologically-based en route mortality model

## CHAPTER 3 EXECUTIVE SUMMARY

- **Purpose:** to evaluate the condition of the spawning and incubation environments in our assessment of the potential freshwater factors influencing declines in Stuart sockeye abundance
- **Report objectives:**
  - characterize the land-use patterns in the Stuart Takla watershed over the decline period
  - link the spatial-temporal information on land-use changes with watershed, lake, and stream specific escapement estimates
  - document the range of key physical parameters known to limit spawning and incubation success
  - evaluate the temporal trend in the key physical parameters that would be indicative of deterioration in the physical environment
  - evaluate the temporal trend in the key biological assessments of sockeye productivity during the spawning and incubation period
- **Result summary:**
  - land use changes, associated with forest harvesting, have occurred in all of the major watersheds
  - road length and stream-crossings have increased 10% and 4% from 1993-2001
  - no clear pattern emerged between the level of land-use change, road densities, or stream-crossings and the abundance trends at the sub-watershed level
  - physical spawning and incubation conditions in Early Stuart streams are considered good for salmon incubation
  - most spawning conditions for Late Stuarts are within species thermal optimal ranges, but pockets of low intragravel dissolved oxygen were observed in 2007
- **Key conclusions:**
  - we would rank the enhancement of spawning and incubation as a very low priority in any mitigation strategy for the recovery of these populations
  - although increases in land use changes can be correlated with population declines at the Stuart-Takla watershed level, closer examination of the spatial-temporal trends within the watershed do not point to a clear connection between these two indices
  - the present level of road densities is lower than other studies connecting land-use activities to declines in freshwater abundance, but stream conditions could change rapidly with increasing land-use activities
  - based on the range and temporal trends in physical and biological variables, we found no evidence that the spawning and incubation environment is responsible for the declines in Early Stuart populations
  - the information on Late Stuarts is too limited to reject the hypothesis that spawning and incubation environments are sub-optimal

- **Recommendations:**
  - recommend a pro-active approach for the assessment and planning of future land-use activities (e.g. forestry, mining) and their potential impacts on stream environments at the Stuart-Takla watershed scale
  - further scrutiny of those watersheds that had both higher rates of population decline and increases in changes in land-use (e.g. Driftwood)
  - compile an updated land-use database, especially indexing changes to the road and road-stream crossing networks to reflect 2008 conditions
  - continue to monitor water temperatures in Stuart index streams (Forfar, Gluske, Kynock, Middle River) to assess potential changes in habitat status; implement a short term synoptic survey to assess how representative the index streams are to the watershed as a whole
  - assess the vulnerability of streams to different low flow and scouring flow conditions (i.e. forecast sensitivity of streams to hydrologic change – e.g. Mountain Pine Beetle)
  - establish a formal water quality monitoring program to better represent both Early and Late Stuarts freshwater habitats
  - conduct more extensive intragravel D.O. assessments on Late Stuart systems to further investigate the 'low' D.O. measurements in 2007
  - continue with the egg-fry survival monitoring program; a single assessment can provide an integrative measure of the relative quality of the spawning and incubation quality
  - extend egg incubation studies to other stream systems with different rates of population decline (i.e. Driftwood)
  - determine the temperature dependent embryo development rates for Late Stuarts and Kokanee to determine the level of synchrony in emergence between Kokanee and Stuart fry
  - further investigate the possible reasons behind the 2 week delay in fry emergence timing

## CHAPTER 4 EXECUTIVE SUMMARY

- **Purpose:** to assess whether the conditions in the rearing habitats utilized by Stuart sockeye could be limiting freshwater survival during the recent decline period
- **Objectives:**
    - document juvenile fry growth and invertebrate community structure within these environments
    - evaluate current information on predators and competitors
    - examine trends in biological information
    - compare results from 2007 lake sampling with historic data on lake chemistry and zooplankton abundance
    - assess temporal changes in smolt size via an analysis of scale growth patterns
    - compare time series of Stuart smolt energy status to Chilko and Stellako smolts
- **Results summary:**
    - invertebrate abundance and distribution with stream/off-channel, lake littoral and limnetic environments appear to provide a stable foraging base for sockeye salmon fry
    - lake chemistry values obtained in 2007 were within the range of those reported in the 1990's
    - fish survey results suggest that a number of potential predators and competitors exist within the system; but there is no quantitative data on predator abundance or distribution
    - there was no detectable change in smolt size over the past 18 years; however, sample sizes were limited
    - energy density of Middle River smolts was significantly higher than Chilko and Stellako smolts sampled in 2007 and 2008
    - there was no observed temporal trend in freshwater growth, based on scale circuli distances, from 1988 to 2006
- **Key conclusions:**
    - available data on patterns in rearing environmental and biological conditions are not consistent with observed declines in spawner abundance
    - there has been no notable change in either lake nutrient levels or in the abundance of food supply, including the most preferred prey item, Daphnia
    - there is no evidence that food availability is limiting the use of stream/off-channel and littoral zone rearing habitats by Stuart sockeye
    - limnology surveys suggesting that Stuart, Takla and Trembleur lakes can support healthy populations of fry are supported by the analysis of body size and body condition (e.g. energy status)
    - there was no trend in the freshwater growth phase over time, but there was a negative relationship between effective female spawner abundance and freshwater growth

- **Recommendations:**
  - given the relative stability of the current conditions, a thorough evaluation of associated risks should be conducted prior to the initiation of any enhancement activity
  - recognition and protection of all juvenile sockeye salmon habitats being utilized
  - more research is required to estimate the abundance and impact of competitor (kokanee) and predator populations
  - monitor the abundance and condition of sockeye smolts leaving the different lake environments; compare smolt condition to non-Stuart Fraser stocks

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