EXECUTIVE SUMMARIES OF 2001 STUDIES ON POTENTIAL CAUSES OF EARLY UPSTREAM MIGRATION OF LATE-RUN FRASER RIVER SOCKEYE SALMON

In June, 2001, the Pacific Salmon Commission's Standing Committee on Scientific Co-operation approved funding for seven studies on the potential causes of the early upstream migration behaviour observed in recent years in Late-run Fraser River sockeye salmon. Funding for these studies was from the Commission's budget and from the United States Government. Below are the Executive Summaries from the reports prepared by the research scientists or extracts from the Rapporteur's report of the Third Late-run Sockeye Workshop held at the Pacific Salmon Commission on January 30-31, 2002. The material presented below documents the scope and findings of the studies undertaken to identify the cause(s) of this early migration behaviour.

A. Water Quality/Contaminants

1. Trends in discharges of effluent from the Annacis Island STP., R. Addison Ph. D. (Consultant)

Monitoring data from the Annacis Is. wastewater treatment plant (WWTP) between 1991 and 2000 have been examined for a possible association with abnormal late-run sockeye migration which was first observed in the mid-1990's.

Analysis of monthly mean data showed that total amounts of effluent discharged increased between 1991 and 2000. An appreciable "step" occurred in effluent flow at the beginning of 1995 which may have been due to changes in flow measurement methods. Concentrations of total suspended solids (TSS), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) all increased until 1997 when secondary treatment began to be implemented. Loads of TSS, BOD and COD discharged to the Fraser River also increased until secondary treatment was introduced. Dissolved oxygen (DO) in effluent declined until the introduction of secondary treatment, but ammonia-N concentrations and discharges increased in the late 1990's. Acute toxicity of effluent declined after 1996. In general, effluent quality *improved* following the introduction of secondary treatment. Furthermore, the major changes in effluent quality which occurred between spring 1997 and fall 1998 during the phasing in of secondary treatment took place *after* the apparent change in sockeye migration. It is therefore difficult to associate any of the major changes in Annacis Is. WWTP effluent discharges with changes in sockeye migration.

Three variables in effluent showed some increase during the early to mid-1990's: these were dissolved iron (which increased sharply in 1995, apparently as a result of groundwater releases during construction at the site) and methylene blue active substances (MBAS) which is generally taken to indicate anionic detergents, and whose increase may indicate a change in detergent use pattern in the service area of the Annacis Is. WWTP. Residual chlorine (used in summer months to disinfect effluent) also increased in the early to mid 1990's but excess chlorine should be destroyed by SO_2 treatment before the final discharge of effluent.

Effluent volume, effluent DO and Fraser River discharge volumes were compared on a daily basis for the interval June to September from 1994 to 1999. Effluent DO was lowest in 1996, but total effluent volume in 1996 were not unusual, nor were Fraser River discharge volumes unusually low. The lowest Fraser River discharge volumes occurred in 1998 by which time effluent DO had increased due to the introduction of secondary treatment. Salmon are sensitive to reduced oxygen tension, but the patterns of effluent volume and DO and of Fraser River discharges do not suggest an unusually low oxygen environment which might trigger unusual behaviour in the mid-1990's. However, no data for DO concentrations in Fraser River "receiving waters" were examined.

Some "candidate" chemicals which are expected to affect salmon migration were considered. Urinary steroid hormones were not measured successfully in Annacis Is. WWTP effluents, but calculations based on expected estrogen production by the approx. 1m population served by the plant suggest that estrogen concentrations in effluent could approach those known to have adverse effects on fish. Nonylphenol and its ethoxylates (NP and NPEO) have also been recorded in Annacis Is. WWTP effluent, but the physiological significance of the concentrations measured is difficult to assess.

On the basis of the analyses summarised here it seems unlikely that changes in the operations of, and discharges from, the Annacis Is. WWTP over the last decade have directly affected sockeye migration. However, no monitoring data are available for some chemicals which could be "candidates" to cause subtle adverse effects on fish; these include some therapeutic drugs. Furthermore, some chemicals known to cause adverse effects (including urinary steroids and NPEOs) have not been analysed reliably or often enough to allow a reliable assessment of their significance in effluent. Finally, chemical trends in the lower Fraser River "receiving waters" (perhaps arising from changing agricultural or forestry practices) have not been assessed. Future consideration of the role of chemical contaminants in affecting sockeye migration should consider these factors.

2. Impact of endocrine disrupting chemicals on migration, reproduction and survival of returning Pacific salmon, M. Ikonomou, Ph. D. (DFO/IOS)

The report discusses the hypothesis investigated in this study: whether or not contaminants play a role in the abnormal behaviour of salmon or their ability to handle disease challenges. The focus of this research is endocrine disrupting chemicals and exposure at different life stages and bio-markers that are linked to contaminants. The research is aimed at determining the contaminant burdens during various life stages and off-loading of contaminants from the mother to eggs that could have toxic effects.

The research is designed to distinguish between two types of effects: (1) the toxicity effect, i.e., controlling mortality; and (2) the endocrine disrupting effect, which controls hormones affecting the ability to reproduce and survive. Having looked at the early life stage, the research team is now beginning to look at the exposure during the migration stage. The hypotheses are:

- that the returning adults are bioaccumulating contaminants and are mobilising these internally into the liver, bloodstream and eggs; and that the contaminants are responsible for the mortalities;
- that there is an uptake of mostly water-soluble contaminants through the gills that are causing the behavioural problem.

3. Contaminant risk factors in sockeye habitats: Are any chemicals (old or new) disrupting migratory timing? D. Johannessen (DFO/IOS), P. Ross, Ph.D., (DFO/IOS)

A search of the literature for data on the use of chemicals in British Columbia over a period of time covering the change in behaviour of Late-run Fraser River sockeye salmon was undertaken to determine if contaminants in their environment may be correlated to this change in behaviour.

Contaminants which are likely to be increasing in the BC environment: endocrine disrupting chemicals – phenols, phthalates, etc. and personal care products, some heavy metals, and a new generation of POPs (persistent organic pollutants) such as polychlorinated napthalenes, polychlorinated paraffins, etc.

The research team proposes a life-history stage-based study of the different types of contaminants to which Late-run sockeye are exposed.

B. Oceanography

1. Biophysical studies in support of research examining why Late-runs sockeye salmon leave the Strait of Georgia earlier than in the past. R. Beamish, Ph.D. (DFO/PBS), R. Sweeting, Ph.D. (DFO/PBS)

This study focuses on the biophysical aspects of the Strait of Georgia. The team has been unable to find any indicators in the available data that correlate with the 1995-97 fish behaviour change. Regime shifts in the North Pacific Ocean occurred in 1976-77, 1989-90 and again in 1998-99, possibly because of ENSO events (El Nino) or Southern Oscillation index or another proxy – such as the length of day.

The biological productivity in the Strait of Georgia changed in 2000. The biomass of euphasids nearly tripled between 1999 and 2000. This was not only an increase in abundance but also in the size of euphasids. The regime shift of 1998/99 has likely had an impact on the behaviour of Late-run sockeye salmon, but the examination of available data did not indicate the mechanism causing early river entry.

2. Exploratory data analysis of ocean (and other) parameters related to Late-run sockeye upstream timing. D. Blackbourn, Ph.D. (Consultant)

This study examined a large number of ocean and other physical parameters for correlation with the early river entry behaviour of Late-run Fraser River sockeye salmon observed in recent years.

The variables that showed large values (+/-) of change in 2000 and 2001 was Gulf of Alaska currents in July, and some sea level stations in B.C. and Washington State (although these values were also high in some earlier years).

Future explorations of the data were suggested:

- Use estimates of daily discharge and channel cross-section at Fraser mouth in July, Aug., Sept. (from UBC Dept. of Geography) to supplement Hope discharge and Mission estimates of sockeye escapement;
- Check Gulf of Alaska currents and SST during earlier years of Weaver sockeye marine phase (lagged one or two years) where initial work shows that there are extreme values in the 1990s although none that were unprecedented;
- Incorporate both into some simple models.

3. Late-run Early Migration: A response to an abrupt climate-scale shift in estuarine exchange between the Strait of Georgia and adjoining coastal waterways. R. Thomson, Ph.D. (DFO/IOS)

A preliminary analysis of oceanographic conditions in summer and fall along the migration path of Fraser River Late-run sockeye salmon from the open North Pacific open to the continental shelf, the Strait of Georgia, Juan de Fuca Strait, and the Fraser River, has revealed the following:

- The pronounced anomalous timing behaviour of the 1998-2001 fish returns are *not* reflected consistently in anomalies of scalar properties – such as sea surface temperature and salinity – in the inner and outer coastal waters of southwestern British Columbia.
- The pronounced anomalous timing behaviour of the 1998-2001 fish returns *are* reflected consistently in the Pacific Decadal Oscillation (PDO) and North Pacific (NPI) indices which indicate a weaker than normal Aleutian Low Pressure system in the Gulf of Alaska, colder than normal SST anomalies along the coast of North America accompanies by warmer than normal SST anomalies in the central North Pacific, and intensified northwesterly wind stress (enhanced upwelling-favourable conditions or, what amounts to the same effect, weaker downwelling-favourable conditions).
- The effect of open ocean SST and surface current patterns during salmon return cannot be ruled out, and the link with salmon migration timing may well be manifested locally with inner coastal waters through links with the large-scale oceanic processes.

A preliminary interpretation of our findings is that the observed variability in Late-run sockeye salmon migration timing is linked to variability in the degree of mixing (upper ocean variance structure) in the Strait of Georgia – Juan de Fuca system. Mixing is a function of river runoff, tidal current intensity, and basin-scale winds, with the latter apparently linked to fish migration timing indirectly through the PDO and NPI*. Variability in mixing affects variance in the upper ocean scalar properties – such as temperature and salinity – as well as the mixed layer depth. Ongoing efforts suggest evidence for a link between migration timing and summertime variability of sea surface temperature and salinity in Juan de Fuca Strait, presumably related to the degree of mixing in the strait and the region upstream (i.e. the Strait of Georgia). Although statistically significant correlations between migration timing and the magnitudes of inner and outer coastal winds were not found, we intend to continue our examination of changes in wind stress variability. Given the encouraging link with the PDO and NPI, we expect to find a relationship – direct or indirect – between changes in local wind forcing and salmon migration into and out of the Strait of Georgia.

C. Migration/Physiology

1. Weaver Creek sockeye as a physiological model in the investigation of pre-spawning mortality in early entry Late-run Fraser River sockeye salmon. A. Farrell, Ph.D. (SFU) and E. Donaldson, Ph.D. (Consultant)

Salmon use a variety of environmental cues to successfully migrate into their home rivers. The change in behavior of Late-run Fraser River sockeye salmon and their early entry into the Fraser River may be related to misreading of cues in relation to the "biological clocks" that control maturation and migration events. For example, the juveniles may be mis-imprinting information on their seaward journey, which later results in the behavioural change as adults. Conversely, adult fish could be entering the Fraser River early because their clocks are triggering migration owing to misreading of environmental cues such as light, salinity, and temperature. Another possible mechanism is that it is not intrinsic but is extrinsic – either an attractant in the river or repellent in the ocean is driving the fish into the river early.

A separate, yet possibly related issue, is the early mortality and failure to spawn. Again biological clocks would be implicated in three possible ways: a) reproductive hormones follow a distinctive pattern during salmonids maturation, one that is triggered at least six months earlier in the open ocean; Therefore environmental factors in the open ocean cannot be excluded as the precipitating event in these events. Conversely, stress can disrupt and delay reproductive hormone cycles in fish; b) senescence and death follow spawning in Pacific salmon. Therefore, the biological clock for senescence could have become out of phase and advanced relative to the maturation cycle. It is known that surgical removal of the gonads or other means of sterilisation in salmon can delay senescence and death; c) osmoregulation processes undergo a major reorganization when salmon move from saltwater to freshwater. Therefore, if fish enter freshwater prematurely, they may be physiologically unprepared for this drastic environmental change, and their body fluids may become osmotically diluted over time. Similarly, they may remain too long in this freshwater environment for their senescence clocks.

Their study was a pilot project aimed at providing clues to the possible consequences and causes of early river entry using recognized physiological indicators in sequential samples of Weaver Creek sockeye. Blood and tissue samples were collected from sockeye captured over an eight-week period as the fish were entering the Harrison River and/or delaying there and in Weaver Creek/Channel. The tissues were analyzed for a number of stress, reproductive and metabolic indicators and gill enzyme levels. The working hypotheses were that:

- the fish may be abnormally stressed (as revealed by unusually high values for plasma lactate, cortisol and interrenal nuclear diameter).
- the reproductive hormone cycle was abnormal (hormone levels in the blood were not changing as expected), or
- the fish were not properly osmoregulating (as revealed by disturbances to plasma sodium, potassium and chloride levels, plasma osmolality and gill Na^+ K^+-ATPase).

The team found the following important patterns:

- Gill Na^+ K^+-ATPase (a critical enzyme involved in ionic balance) – levels were generally not as high as those expected for freshwater fish; suggests fish may not be able to maintain osmotic status in freshwater over long periods of time;
- Plasma sodium, chloride and osmolality (indicators of osmotic balance) – levels were lower than expected during the later sampling dates; suggests osmotic problems developed over time.
- Plasma potassium and lactate (good indicators of stress) – levels were higher than expected for rested fish for fish sampled early and probably reflect swimming activity prior to capture;
- Plasma cortisol (levels in quiet fish are = 10 ng/ml) - levels were more than an order of magnitude higher than expected for resting fish; even higher values have been seen in Early Stuart sockeye salmon after passage through Hell's Gate;
- Plasma sex hormones (important in reproductive capability) - peak levels of ketotestosterone in females, testosterone in both males and females, and dihydroprogesterone in males did not reach the expected values; suggests the reproductive cycles may have been impaired.

The evidence is of an osmoregulatory collapse and also changes from the expected cycle for certain hormones affecting reproductive timing. The reasons for these findings are unknown. There is also insufficient data from "normally" migrating Weaver sockeye to make definitive conclusions.