

Environmental Watch Program Overview: *with specific reference to Fraser River sockeye salmon*

PROGRAM INTRODUCTION

The focus of the DFO Environmental Watch (EWatch) Program is to provide scientific advice on the impact of different environmental factors on the migration success of Pacific salmon in fresh water. This advice is based on our understanding of migration biology of Pacific salmon and the interaction with environmental conditions. More specifically, we address our research objectives using a three-fold approach:

1. Monitoring, analysis, and forecasting of Fraser River environmental conditions
2. Research on migration biology of Pacific salmon
3. Quantitative modelling of salmon migration behaviour and success

We combine information from our environmental and biological monitoring programs to develop quantitative models that can be used to evaluate and forecast the influence of fresh water conditions on salmon migratory success. The environmental monitoring program consists of a comprehensive network of temperature logger stations along key sockeye salmon migration routes in operation since the 1990's. The biological research component of our program seeks to better understand the relationships between fresh water migration conditions and salmon reproductive development, stress response, disease, energy utilisation, migration behaviour, thermal ecology, and homeostasis. Ultimately, the research conducted through the EWatch program is used to provide scientific advice to both fisheries and habitat managers based on a combination of environmental forecasts, ecological modeling and salmon migration research. A conspicuous example is the provision of pre-season and in-season scientific advice to fisheries managers to assist in the prediction of en route loss (salmon that die in fresh water during their migration from river entry to the spawning grounds) and pre-spawning mortality (salmon that survive to the spawning grounds but die before they successfully deposit all of their eggs) associated with adverse river conditions.

The majority of work conducted by EWatch is enhanced by facilitating additional research on Pacific salmon and environmental monitoring through productive collaborations with other research groups within DFO and external government and academic institutions, including: University of British Columbia, Simon Fraser University, Carleton University, Pacific Salmon Commission, University of Northern British Columbia, BC Ministry of Environment, University of Guelph, McGill University, and Rutgers University.

A complete description of the EWatch program, staff, collaborators and publications can be found on the program website at: <http://www.pac.dfo-mpo.gc.ca/science/habitat/frw-rfo/index-eng.htm>

OBJECTIVE 1: MONITORING, ANALYSIS, AND FORECASTING OF FRASER RIVER ENVIRONMENTAL CONDITIONS

Environmental Monitoring Programs

The EWatch program has been responsible for near-continuous monitoring of fresh water temperatures along key sockeye salmon migration routes since the early 1990's. This temperature network consists of a combination of real-time and non real-time logger stations distributed from the lower Fraser River as far north as Stuart River. Since 2006 the program has partnered with Environment Canada Water Survey Canada (WSC) to provide real-time access to an expanded network of water temperature, and flow, stations throughout the basin. We currently collect water temperature from approximately 15 DFO stations and 10 WSC stations (see Fig. 1) on an annual basis with additional stations added as required for specific projects. Thermistor chains have also been installed in some of the major lake systems to provide temperature-depth profiling. Some of this temperature data is currently publically available and published in DFO technical and data report series (Lauzier et al. 1995; Barnes and Walther 1997; Brown et al. 1998; Barnes and Magnusson 2000; Patterson et al. 2007; Hague et al. 2008; Macdonald et al. 2007).

In addition to stationary data loggers, the EWatch program has also collected data on fresh water thermal profiles for individual migrating adult salmon. Temperature loggers

are attached to radio transmitters and then collected from fish recovered in river fisheries or on the spawning grounds. These data provide accurate information on actual temperature experiences and can be used to construct biologically realistic migration models (Donaldson et al. 2009). Furthermore, comparison of observed temperature profiles and those reconstructed from the stationary loggers validates the use of historic logger data to model thermal fresh water experiences.

We have also engaged in significant data recovery efforts over the previous two years in order to convert historic temperature records collected by the International Pacific Salmon Fisheries Commission (IPSFC; now the Pacific Salmon Commission, PSC) to electronic files. We are currently vetting both the historic and current temperature time series into through a standardised quality assurance procedure and working with multi-regional DFO partners to develop a permanent, nationally accessible repository for fresh water temperature data (Thompson et al. 2010).

The monitoring of fresh water temperature data is essential to understand the impact of river environment, both current and future, on salmon survival. As such, water temperature data collected by the EWatch program is in high demand from academics, environmental consultants and other government agencies. This information has been used in the development of DFO environmental (Foreman et al. 2001; Morrison et al. 2002; Morrison 2005; Morrison and Foreman 2005; Patterson and Hague 2007) and management (Hague and Patterson 2007; Hague and Patterson 2008; Cummings 2009; Macdonald et al. *in press*) forecasting models [see Objective 3]. These data have also been used as predictor variables in multiple studies of migratory success [see references below].

Environmental Forecasting

The EWatch program currently generates forecasts of Fraser River environmental conditions on three different time-scales:

- (1) short-term (~days)
- (2) medium-term (~months)
- (3) long-term (~years)

Both short-term (Morrison 2005; Morrison and Foreman 2005; Ch. 2 in Hague and Patterson 2008) and medium-term (Patterson 2005; Patterson and Hague 2007) environmental models are used to forecast average lower-river temperature and flow conditions experienced by major Fraser River sockeye salmon management groups. This information is then incorporated into in-season and pre-season management adjustment (MA) models, respectively, which are run by the Pacific Salmon Commission [see Objective 3]. These forecasts can be used to guide pre-season fishery planning given the expected environmental conditions in the river and their potential impact on returning adult salmon. Short-term (10-day) environmental forecasts are typically generated in-season using physical models (Morrison 2005; Morrison and Foreman 2005); although statistical models have also been considered in some years (Ch. 2 in Hague and Patterson 2008). Medium-term forecasts are based on regression relationships between meteorological, hydrological and river environmental variables and are usually generated 2-3 months prior to the first sockeye salmon returning to the Fraser River (Patterson 2005; Patterson and Hague 2007).

The EWatch program has also been involved with, indirectly, generation of long-term forecasts of Fraser Basin temperature and flow conditions (Morrison et al. 2002; Ferrari et al. 2007; Hague and Patterson 2009). Global-scale meteorological forecasts generated from global climate models are downscaled and used to simulate possible changes to fresh water migration conditions and impacts on salmon migratory success under future warming scenarios (Hague and Patterson 2009).

OBJECTIVE 2: RESEARCH ON MIGRATION BIOLOGY OF PACIFIC SALMON

Publication Overview

The research on migration biology of Pacific salmon is broad in nature but EWatch program research has been centred on examining the biological impact of different freshwater environmental conditions on migratory and reproductive success. Major advancements in the knowledge of migration biology of sockeye salmon have occurred in recent years. The level of detail involved in these studies is beyond the scope of the current overview, but the following publications highlight the involvement of the EWatch program in several areas relating to migration biology:

- Quantifying in-river mortality: Cooke et al. 2005; Cooke et al. 2006a; Patterson et al. 2007a; Hague and Patterson 2008; Macdonald et al. *in press*
- Migration behaviour: Cooke et al. 2004; Cooke et al. 2006b; Magnoni et al. 2006; Wagner et al. 2006; Crossin et al. 2007; Cooke et al. 2008a,b; Hanson et al. 2008; Pon et al. 2009b, Donaldson et al. *in press*
- Migration physiology: Patterson et al. 2004b; Shrimpton et al. 2005; Miller et al. 2007; Cooke et al. 2008b; Crossin et al. 2009a; Miller et al. 2009; Clarke et al. *in press*
- Flow impacts: Macdonald et al. 2007; Hasler et al. 2009; Pon et al. 2009a
- Thermal ecology: Young et al. 2006; Patterson et al. 2007b; Farrell et al. 2008; Donaldson et al. 2009; Mathes et al. 2010
- Temperature and disease progression: Wagner et al. 2005; Crossin et al. 2008; Bradford et al. *in press*
- Sub-lethal fishing impacts: Cooke et al. 2009
- Climate impacts on migration success: Morrison et al. 2002; Rand et al. 2006; Hague and Patterson 2009
- Reproductive development and success: Patterson et al. 2004a; Patterson 2005; Crossin et al. 2009a,b
- Intergenerational effects; parental condition and offspring fitness: Patterson et al. 2004a; Patterson and Hague 2008; Nadeau et al. 2009; Tierney et al. 2009

For a more complete list of program publications, please visit the EWatch website ([EWatch Publications](#)).

In partial response to previous sockeye salmon reviews, two main areas of research for the EWatch program have included: (1) temperature impacts on salmon migration success, and (2) Late-run migration behaviour. More specific information on each of these topics is provided below.

Temperature impacts on salmon during spawning migration

It has been well recognised that sockeye salmon in the Fraser River are vulnerable to high river temperatures during their once-in-a-lifetime upstream adult migration (Macdonald et al. 2000; Crossin et al. 2008; Farrell et al. 2008). The impact of high temperatures on salmon is a combination of the absolute temperature to which the fish are exposed and the duration of exposure itself. Extreme high temperatures for short periods can lead to thermal shock and mortality (e.g. Servizi and Jensen 1977) while continued exposure to high temperatures over extended periods can elicit a variety of stress responses leading to chronic sub-lethal impacts such as disease progression, changes in migration behaviour, decreased swim performance and altered reproductive success (see Macdonald et al. *in press*). The singular and/or cumulative effects of these temperature mediated impacts have been related to migration mortality for Fraser sockeye salmon. Moreover, thermal sensitivity appears to be a population specific trait and is likely a function of adaptation to ambient temperatures (Farrell et al. 2008). For more detailed examples please see the references in the list below flagged as “temperature impacts” (T).

Research into Late-run migration behaviour

Since 1995, the aggregate of sockeye salmon spawning populations known collectively as Late-run management group, has been entering the Fraser River approximately 2-6 weeks earlier by shortening their traditional holding phase in the Strait of Georgia. However, there has been no change in timing of arrival at the Strait of Georgia or in the time of peak spawn. As a result, Late-run sockeye salmon now exhibit holding behaviour in warm freshwater environments near their spawning grounds instead of holding in the cooler waters of the Strait. This shift has resulted in Late-run fish being exposed to higher river temperatures for a longer duration in fresh water than prior to 1995. Associated with this shift towards early river entry has been a dramatic increase in both en route and pre-spawn mortality (See Cooke et al. 2004).

The causes for the change in river entry behaviour and its consequences have been extensively studied over the past nine years through a combination of radio tagging, acoustic tagging, field biological sampling, and controlled laboratory experiments (see

reference list below). However, while there has been general agreement on some of the key mechanisms underlying the high mortality prior to spawning, there has not been consensus on the fundamental causes behind the shift in the behaviour (see Hinch and Gardner 2009 review). The mechanisms linking Late-run in-river mortality to their change in migratory behaviour are consistent with known impacts of continued exposure to high temperatures and the interaction with disease progression in fresh water. For more detailed examples please see selected publication list below flagged as Late run research (LR).

OBJECTIVE 3: QUANTITATIVE MODELING OF SALMON MIGRATION BEHAVIOUR AND SUCCESS

Management Adjustment Models

In years of extreme temperature and flow, large discrepancies between sockeye salmon spawning escapements estimated in the lower Fraser River (at Mission) and spawning escapements measured on the spawning grounds have been associated with increased in-river mortality. Forecasts of escapement discrepancies are used to adjust the total allowable catch of Fraser River sockeye salmon to account for the anticipated mortality during spawning migration. These harvest, or management, adjustments (MAs) are applied to the total allowable catch to increase the probability of achieving escapement targets on the spawning grounds. Since 2002, the EWatch program has used observed and forecasted in-river environmental conditions to produce pre-season and in-season forecasts of management adjustments. Extensive research has been conducted by the EWatch program, in collaboration with graduate students and faculty at Simon Fraser University, and scientists at the Pacific Salmon Commission, to develop the most accurate MA models possible (Hague and Patterson 2007; Hague and Patterson 2008; Cummings 2009; Macdonald et al. *in press*). Iterative model selection protocols have been created that easily allow scientists to re-assess a wide variety of model structures, performance measures and predictor variables. Some examples of analyses conducted to date include:

- (a) statistical validation of environmental variables in MA models
- (b) incorporation of uncertainties in environmental forecasts
- (c) impact of variability in run-timing on MA forecasts

- (d) daily vs. monthly resolution environmental predictor variables
- (e) model fitting exercises (e.g. comparing predicted vs. observed values from multiple MA models)
- (f) model validation (i.e. forecasting power)

Through these analyses we have confirmed the value of using environmental variables to forecast MAs and have highlighted the need for different model structures pre-, in-, and post-season and for different sockeye salmon management groups. We continue to collaborate with the Pacific Salmon Commission on an annual basis to identify the most appropriate suite of forecasting models and to investigate new approaches for including known uncertainties in the data and model predictions.

Climate Change and Migratory Success

Warming temperature conditions have already been documented in the Fraser River (Patterson et al. 2007a), and have been associated with increased frequency of high in-river losses of sockeye salmon (Macdonald et al. *in press*). Increasing temperature trends, in combination with shifting hydrological regimes, are expected to continue under climate change scenarios for the Fraser Basin (Morrison et al. 2002; Ferrari et al. 2007). As such, a recent focus of the EWatch program has been to combine downscaled climate scenarios for the Fraser River with models that predict absolute or relative indices of migratory success (Hague and Patterson 2009). Modelling approaches have included the development of physiological constraint relationships (i.e. defining critical thermal thresholds related to the physiological limits of the fish) and temperature-survival curves derived from radio tagging data (Hague and Patterson 2009). Both studies suggest that responses to climate change will likely vary on a population level as a function of fish behaviour (e.g. river entry timing), physiology, and historic levels of exposure (Farrell et al. 2008).

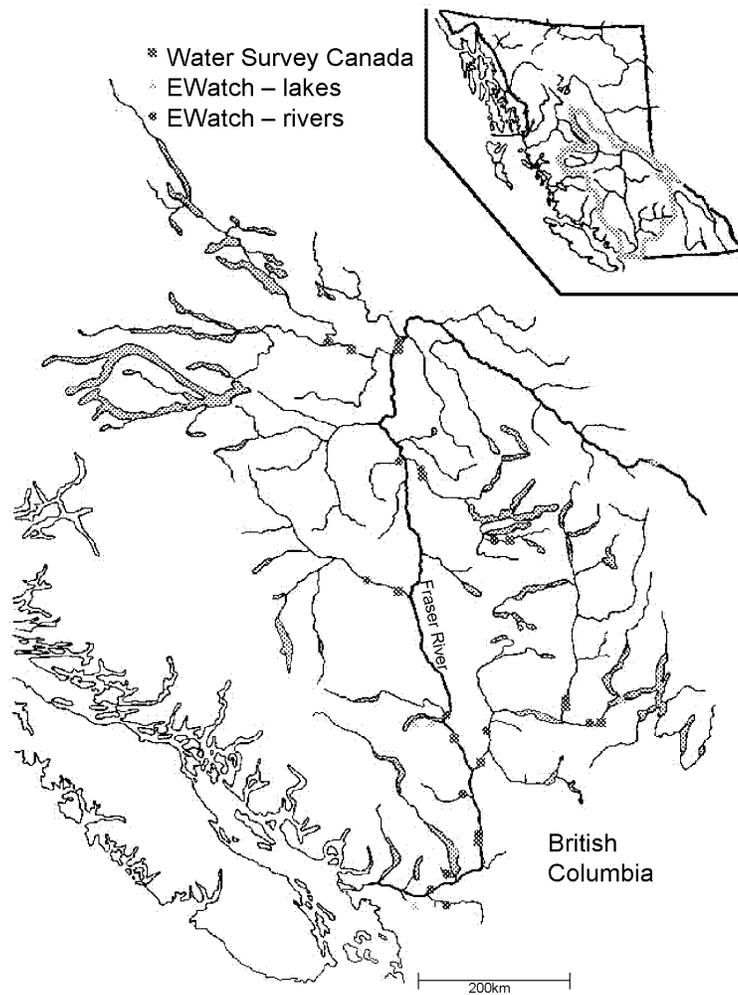


Fig. 1 Map of fresh water temperature logger stations currently monitored by the EWatch program.

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