Final Report and Financial Statement of Expenditures

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Summary

Research conducted during the 2006-07 funding cycle reveals strong correlative links between the migration timing of Late-run Fraser River sockeye at Mission and observed environmental factors. A manuscript is being prepared on understanding (and predicting) the migration timing (peak and 50%) of the Adams River and Weaver Creek stocks past Mission in the lower Fraser River based on oceanic and meteorological variables for the periods 1978 to 2007 for the west coast of Vancouver Island, Strait of Georgia, Juan de Fuca Strait and Johnstone Strait. We have found consistent and significant relations between migration timing and the alongshore component of wind stress on the outer coast and, by extension, the alongshore component of the wind-driven surface current. When the wind stress (and hence, surface currents) anomalies are northward – and therefore act like a “headwind” for the southward migrating fish prior to their arrival in the Strait of Georgia – migration timing at Mission is relatively late. In contrast, when the wind anomalies are southward – and therefore act like a “tailwind” to the migrating fish – migration timing at Mission is relatively early. Interannual variations in sea surface salinity in Juan de Fuca and Johnstone straits continue to show strong links with timing of Adams River stocks at Mission.,

Introduction

This report provides a summary of the ongoing SEF-funded research at the Institute of Ocean Sciences (Sidney, BC) into the causes for the earlier than normal initiation of in-river spawning migration by late-run Fraser River Sockeye salmon. The research is a component of a larger program led by Dr. Scott Hinch of the University of British Columbia entitled "Investigations to determine the cause of early migration behaviour and magnitude of in-river survival and losses above Mission for adult Late-run Fraser River sockeye".

As outlined in Appendix A of the signed collaborative agreement between the Pacific Salmon Commission and the Department of Fisheries and Oceans, three general factors involving migration behaviour and mortality have been identified:

The first factor – which mainly involves the university scientists – is that fish which display their historically typical “Strait of Georgia holding behaviour” for more than two weeks have high rates of river migration success (> 80%), while those that do not hold have low migration success (< 20%). Those that do not hold have statistically higher levels of reproductive hormones and lower gross somatic energy (GSE). The primary hypothesis is that Late-run fish depart the Strait of Georgia (SOG) early because they are more mature and their reproductive clocks are advanced. However, additional maturation is still required which occurs by holding in freshwater lakes near spawning areas, instead of holding in the SOG. Unfortunately, these early-timed fish are exposed to freshwater diseases and parasites (i.e. *Parvicapsula minibicornis*) for longer periods of time with disease development being accelerated by higher river temperatures and higher degree days due to earlier summer migrations. The early evidence suggests that a combination of factors including low energy levels, premature senescence, elevated stress, haemophilia and disease kills these fish in freshwater before spawning. What remains completely unknown is why some Late-run fish are advanced reproductively in the ocean and whether this trait alone (the “maturation hypothesis”) causes immediate departure from the ocean into freshwater (see factor 2). The maturation hypothesis is being tested by scientists at the University of BC with support from the water property data collected as part of the IOS contribution to the overall program.

The second factor – which involves research and data collecting by the Institute of Ocean Sciences – is that since the start of the early migration phenomenon in the mid 1990s, a negative correlation has been found between levels of early in-river migration and salinity in the upper layer of the SOG system (based on the “Brackish Layer Model” developed by Richard Thomson of DFO/IOS). The role of coastal salinity patterns on fish behaviour is unknown, however it is possible that fish which are more developed reproductively could be more susceptible to the abundant freshwater ‘cues’ that are now available in the SOG during the time of in-migration. Exposure to these cues may accelerate upregulation of the osmoregulatory system (which may begin in offshore waters directly affected by coastal runoff or other environmental factors) and lead to more immediate entry into the Fraser River. There have been no studies to examine the salinity-exposure history of individual migrating sockeye nor any way to test this ‘osmoregulatory hypothesis’. Funds provided to this study were used to support contractors to collect and interpret oceanographic data as part of the Brackish Layer model study. In conjunction with PSC troll test-fishing, DFO and UBC towed the IOS CTD-oxygen probe throughout the SOG (as in past years) to further the development of the DFO Brackish Layer Model and to characterize the spatial patterns in water quality. This information, in conjunction with depth/temperature data from transmitters, will help in the interpretation of holding behaviour-environment linkages in the SOG.

The third factor, which involves data analysis and interpretation by DFO, is that the underlying physiological differences between Late-run fish that hold or don’t hold are already evident at Johnstone Strait. Therefore, the osmoregulatory systems clearly upregulate prior to JS, consistent with the fact that coastal runoff can “dilute” open ocean waters far offshore. We still need to identify general locales north of JS where these changes begin to occur, we may be able to identify what if any migratory environmental factors have changed and may be causing the physiological differences we see in maturation and GSE levels among Late-run sockeye.

The overall goal of this project is to better understand the physiological system(s) and/or environmental cue(s) that have been altered since 1995 and which are causing the abnormally early in-river migration of Late-run sockeye. As part of the DFO mandate, findings will help managers predict in-season whether large segments of Late-run fish will or will not hold, and hence adjust coastal and in-river fishing effort (if fish do not hold, their chances of freshwater survival are low) and/or adjust fishing gear (if fish do not hold, they are difficult to capture by purse seine in SOG). For instance, if maturation level is the physiological system most responsible for holding behaviour, and SOG salinity plays little role, then simple physiological assays of Late-run sockeye captured between QCI and JS may provide immediate information on potential SOG holding behaviour. If SOG salinity plays a contributing or dominant role in holding behaviour through accelerated upregulation of the osmoregulatory system, then water quality measures from SOG, potentially made pre-season, may be a useful predictive tool.

Mission Migration Timing versus Monthly Mean Winds and Surface Currents

Alongshore wind stress and Bakun Upwelling Index

Migration timing predictions for Mission for Adams River late-run sockeye for 2006 based on oceanic and meteorological observations for 1990-2003 and 1977-2003 indicated strongest correlations for 50% and peak timing with monthly mean Bakun upwelling index and alongshore wind stress off the southwest coast of Vancouver Island obtained from the Pacific Fisheries Environmental Laboratory, NOAA (Figure 1). The alongshore winds are, in turn, a direct measure of the alongshore surface currents on the outer coast. [Note that the Bakun Index and alongshore wind stress are not independent variables since the index is derived directly from the alongshore component of wind stress along the west coast. Because of the Coriolis effect, the alongshore wind stress causes a surface Ekman transport normal to the coastline and is therefore a measure of the degree of upwelling or downwelling occurring along the outer coast. Hence the use of the term “index”.] This relation was explored further by examining additional timing measures such as 10%, 25%, 75% and 90% fish counts at Mission. All timing measures were more strongly correlated to the upwelling index than 50% timing that fisheries managers tend to employ.

The comparison with Mission sockeye return migration timing was expanded further to include winds and Bakun Index measured further north and south of southern Vancouver Island along the coast of North America. Relations north and south of 48°N were statistically significant but not as strong as for the winds off the south coast.

We also conducted regressional analyses for monthly means of upwelling index and alongshore winds versus Mission timing for different year classes and time periods. The results showed consistency across year classes.

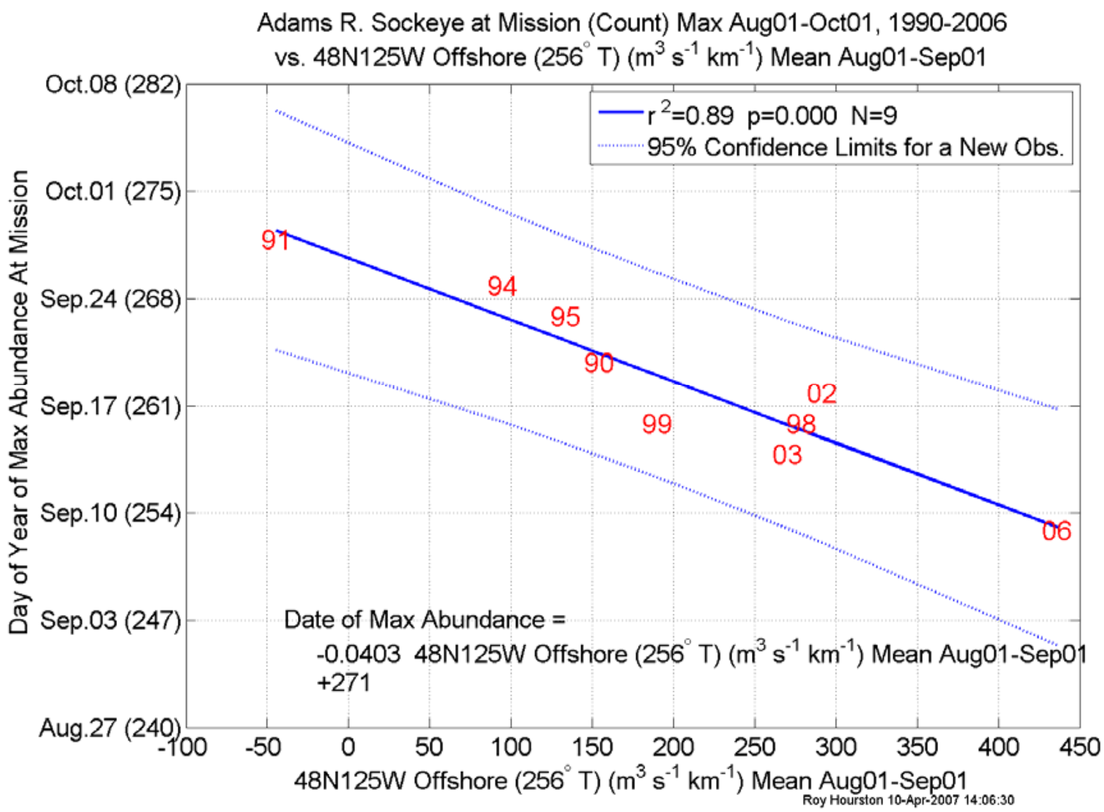

Figure 1. Day of year of peak abundance of Adams River late-run sockeye at Mission versus monthly mean Bakun Index (a direct measure of the alongshore component of wind stress and offshore Ekman transport) at 48°N 125°W for the period 1990-2006.

Six-hourly wind stress data beginning in 1948 are available at a 3° x 3° spatial grid resolution for the northeast Pacific. These data were averaged to generate daily average wind fields for the study region. Alongshore wind stress and Bakun Index for various grid locations off the west coast were then averaged relative to fish timing through Juan de Fuca (the 50% "Marine Timing" date for fish passing the entrance to Juan de Fuca Strait) and compared with timing at Mission at sub-monthly time-scales of a few days. We find significant negative correlation with daily mean alongshore winds and associated Ekman transport that peaks at a maximum for averaging periods of about 5 days, about 22 days before the Marine Timing date, and for different timing metrics at Mission (maximum, 10%, 25%, 50%, 75%, and 90%). This suggests that the decision for Late-run stocks to enter the river or hold in the Strait of Georgia is determined by ocean conditions along the outer coast approximately one month before the fish enter the river.

Near-Surface Currents

Late-run sockeye return timing at Mission was compared with current velocities, temperatures, and salinities collected by DFO at long-term current moorings sites A1 and E01 off the southwest coast of Vancouver Island. Relations between near-surface current velocities at mooring site E01 (off Estevan Point) and migration timing were consistent with those for the alongshore winds stress (and hence, Ekman Transport). Significant correlations were evident for alongshore velocities at E01 at 25 m, 22 days before JdFS timing but over longer data averaging periods of 10-15 days. Overall, salinity was most consistently related to timing, with near-surface salinity at 25 m depth at E01 negatively correlated with timing at Mission. This is consistent with both coastal upwelling (stronger southward winds cause greater upwelling of high salinity water onto the shelf) and alongshore wind-induced surface currents (stronger southward winds reduce the strength of the northward flowing Vancouver Island Coastal Current and hence reduce the northward transport of low salinity from the south). Relations for significant ($p \leq 0.05$) summertime monthly data are summarized in the table below.

Table 1. Adams River Sockeye Migration Timing at Mission versus current meter data at moorings A1 and E01 (averaged over July, August, and September). Here, U is the cross-shore component of current velocity, V is the alongshore component of current velocity, and S is the salinity. Instrument depths are 25 and 75 m.

Timing Metric	Variable	Sign of Relation	Comment
Peak, 10%, 25%, 75%, 90%	S 25 m E01	–	Dominated by low outlier in 1991
Peak, 25%, 50%, 75%, 90%	S 75 m E01	+	Observations evenly distributed
50%	S 100m A1	+	Dominated by low outlier in 2003
50%	S 175m A1	+	Dominated by low outlier in 2003
Peak	V 25 m E01	+	Dominated by high outlier in 1991
10%	V 75 m E01	–	Observations evenly distributed
10%	V 100 m A1	+	Dominated by high outlier in 1991
50%	U 100 m A1	–	Dominated by low outlier in 2003

Surface Wind Stress Extended

Reanalysis time series of 6-hourly surface wind stresses available from the U.S. National Centers for Environmental Prediction and the National Center for Atmospheric Research

(NCEP/NCAR) for the entire northeast Pacific, 1948-2007, were obtained to use as surrogates for surface wind driven currents for comparison with migration timing at Mission relative to migration timing through Juan de Fuca Strait.

Initially, only the wind stress at 49°N 126°W over periods relative to timing through Juan de Fuca was compared with timing at Mission. There is a consistent significant positive correlation with wind stress averaged over periods of ~7 days, about 24 days before the 50% (Marine) timing date for Juan de Fuca Strait, for peak and 50% timing at Mission (Figure 2). This result was found for each year class and both year classes combined. This means stronger than average southward (equatorward) upwelling favourable winds are associated with earlier migration times at Mission, and vice versa. There is also a secondary weaker peak for an averaging period of 31 days about 22 days after 50% migration timing at Juan de Fuca which may be due to a long-term serial autocorrelation in the wind field. Our investigation of the relationship between timing and wind stress over the whole northeast Pacific is ongoing.

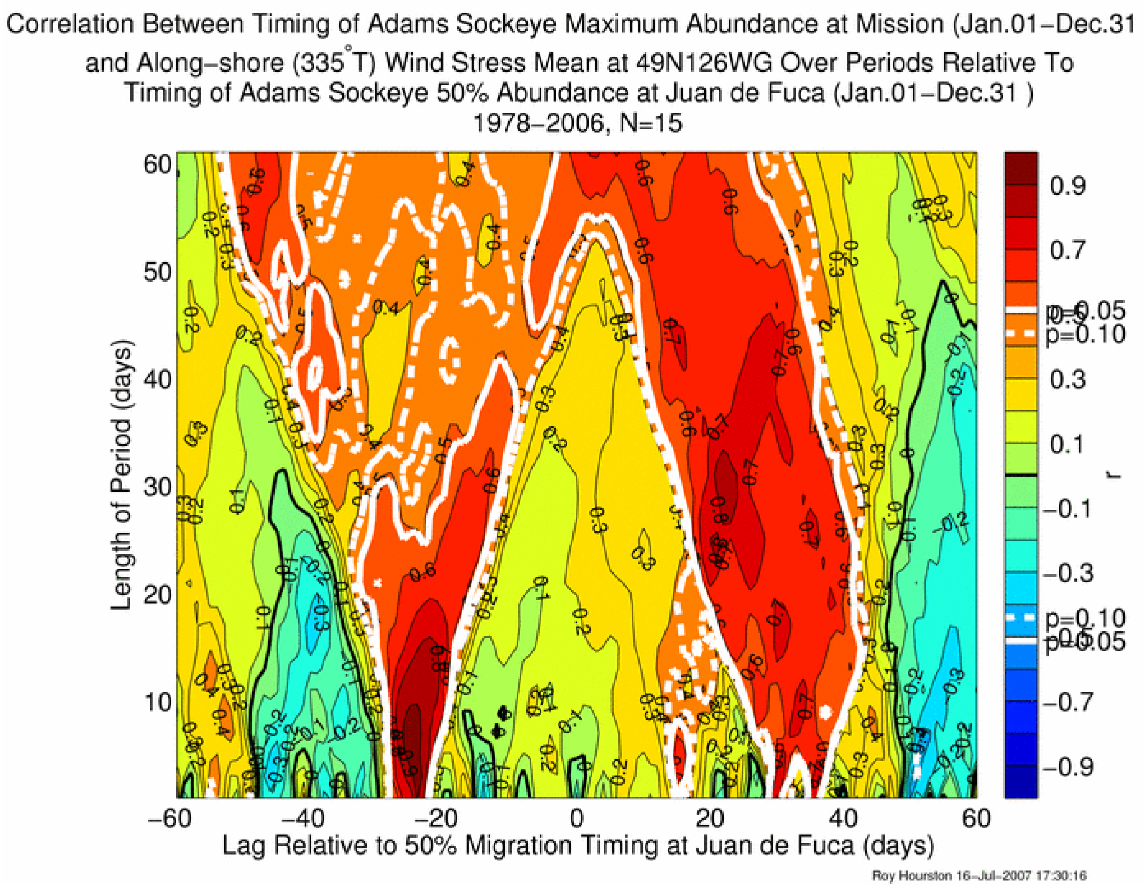

Figure 2. Lagged correlations between day of year of peak abundance of Adams River late-run sockeye at Mission and daily mean along-shore (335° True) Reanalysis surface wind stress at 49°N 126°W, 1978-2006. r-values are shown for wind stress averaged over different odd-numbered lengths of days (1, 3, 5, … 61) along the y-axis, and for various

lags relative to 50% migration timing at Juan de Fuca (Marine Area 20) along the x-axis. Zero lag indicates the averaging period is centered on the day of 50% migration timing at Juan de Fuca.

2006 Test Fishing

The attached Appendix 1 summarizes data from the 2006 Strait of Georgia/Juan de Fuca Strait/Johnstone Strait test fishery and water properties (temperature, salinity, and oxygen with depth) observations. Analyses of fish-depth-water property relations were performed for the Strait of Georgia data and comparisons made between 2003, 2004, and the two vessels used in 2006. The 2006 vessel that used the same instrumentation as previous years recorded similar temperature and salinity properties as previously, but the vessel using different instrumentation recorded significantly different temperature and salinity properties on the order of 2 C and 4 psu, respectively. The DFO Branker CTD that has been used since 2003 was lost overboard during the 2006 Test Fishery during one of the CTD casts on the Ocean Bounty. Although this loss is considered part of the "in-kind" contribution from DFO (the Federal Government does not carry insurance for this type of loss), the instrument will need to be replaced if there are to be future water property measurements as part of this program.

Juan de Fuca and Johnstone Strait Salinity and Temperature Differences: 2005 versus 2006

In 2005 and 2006, sockeye were sampled in Juan de Fuca Strait and Johnstone Strait during their in-migration towards the Fraser River. According to DNA analyses by Dr. Miller-Saunders (PBS), Juan de Fuca fish in 2005 were more advanced in their freshwater adaptation compared to Johnstone Strait fish; in 2006 the reverse was true. Following a request by Dr. Miller-Saunders, we examined sea surface salinity and temperature anomalies from lighthouse stations in the two regions. We found that salinity and temperature were lower and higher, respectively, near Juan de Fuca Strait (Amphitrite Point) in 2005 compared to 2006 (Figures 3a and 3b). For the northern (Johnstone Strait) region, sea-surface salinity and temperature anomalies at Chrome and Pine islands were higher and lower, respectively, in 2005 compared to 2006; i.e., they were out of phase with those for outer Juan de Fuca Strait. Thus, site specific lower relative salinities and higher relative temperatures coincided with more advanced freshwater adaptation of the river-bound migrating sockeye in Juan de Fuca Strait in 2005 and in Johnstone Strait in 2006.

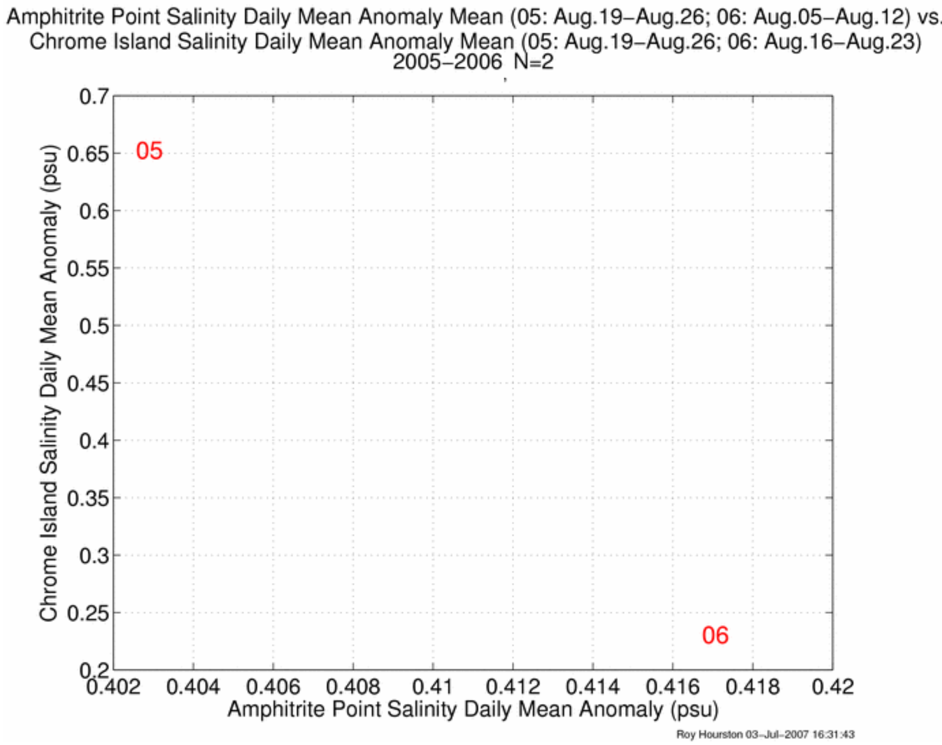

Figure 3a. Daily salinity anomalies averaged over the weeks nearest fish sampling times at Amphitrite Point (near Juan de Fuca) and Chrome Island (near Johnstone Strait), 2005 and 2006.

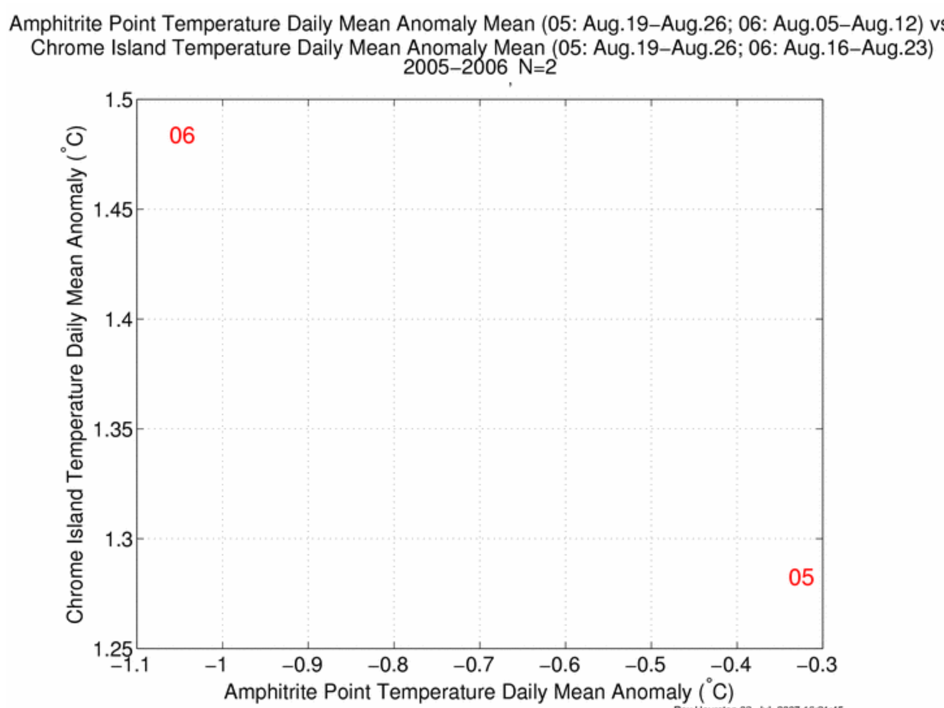

Figure 3b. As for Figure 3a but for temperature.

Historical Summary of Mission Hydroacoustic Salmon Abundance Assessments

A report including bibliography was prepared summarizing historical hydroacoustic counting of salmon at Mission by the Pacific Salmon Commission. Text from this report is being used as background material for the journal manuscript being prepared on this research.

Expenditures

All funds available to this program have been spent on contract support to Mr. Roy Hourston for the assembly, processing and interpretation of oceanic and meteorological data and 2006 test fishery data from the Strait of Georgia, Juan de Fuca Strait and Johnstone Strait. Mr. Hourston also wrote MatLab regression software to compare environmental time series with fish count timing past Mission. This software forms the basis of our investigation relating changes in environmental conditions with the observed changes in Late-run return timing behaviour. Funds were also used to support the considerable contribution by Dr. Steve Mihaly to the collection and processing of oceanographic test fishery data. In addition to his time, the funds were used to pay for Dr. Mihaly’s travel and operating expenses.

Appendix 1: 2006 Test-fishery Water Property-Fish Relations

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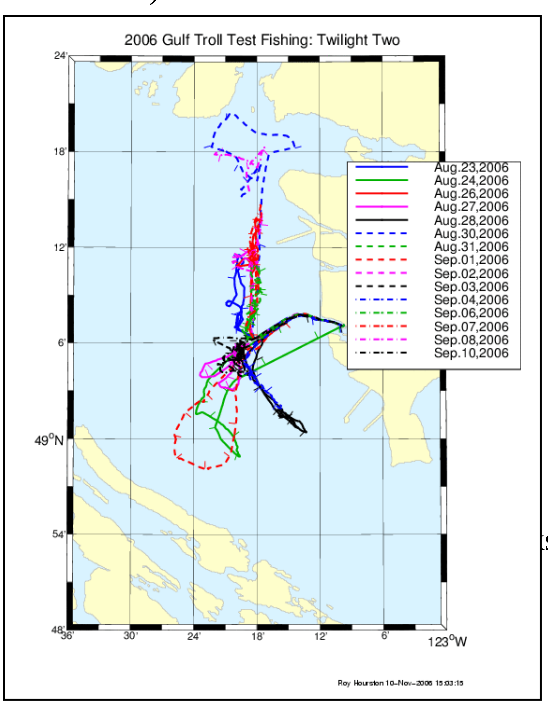
Summary
This component of the FY2006-07 SEF Project is investigating relations between water properties and fish abundance and physiology in the Strait of Georgia, Juan de Fuca Strait and Johnstone Strait for the summer of 2006. Research is in support of the program led by Dr. Scott Hinch of the University of British Columbia and his CTS Postdoctoral student Dr. Ivan Olsson. Findings are also supporting the DNA research of Dr. Kristi Miller-Saunders of the Pacific Biological Station in Nanaimo.

Data Collected
Strait of Georgia: For the Strait of Georgia Gulf Troll, we collected vertical profiles of temperature, salinity, and oxygen, as wells as individual fish capture depth (hook) information for the period August 21 to September 18, 2006 (see figures below for the Twilight-Two and Ocean-Bounty Test Fishery vessels). These data are analyzed in conjunction with scientists at the University of BC and the Pacific Biological Station to determine water property – fish location relations for individual fish.

Figure 1. Twilight-Two vessel tracks and water property structure (Oxygen sensor failed).



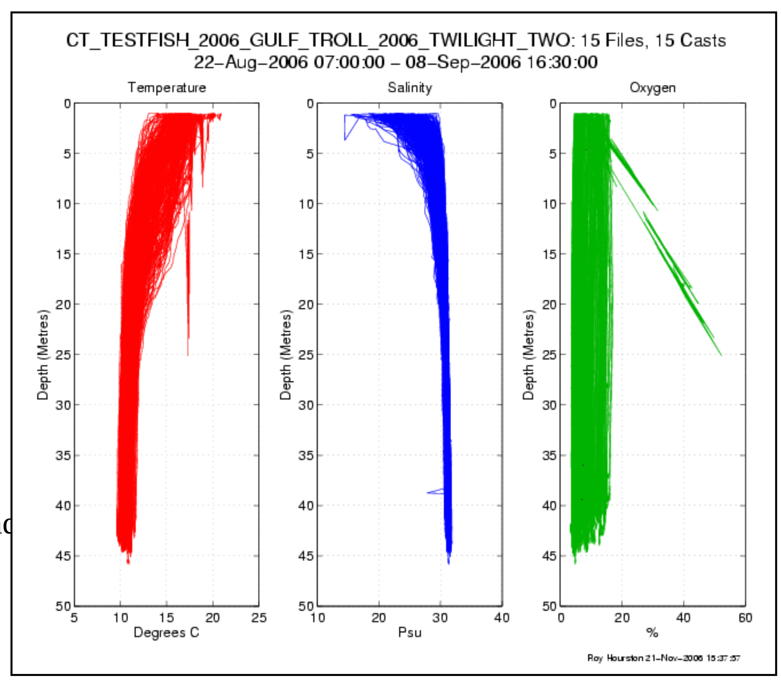


Figure 2. Ocean Bounty vessel tracks and water property structure.

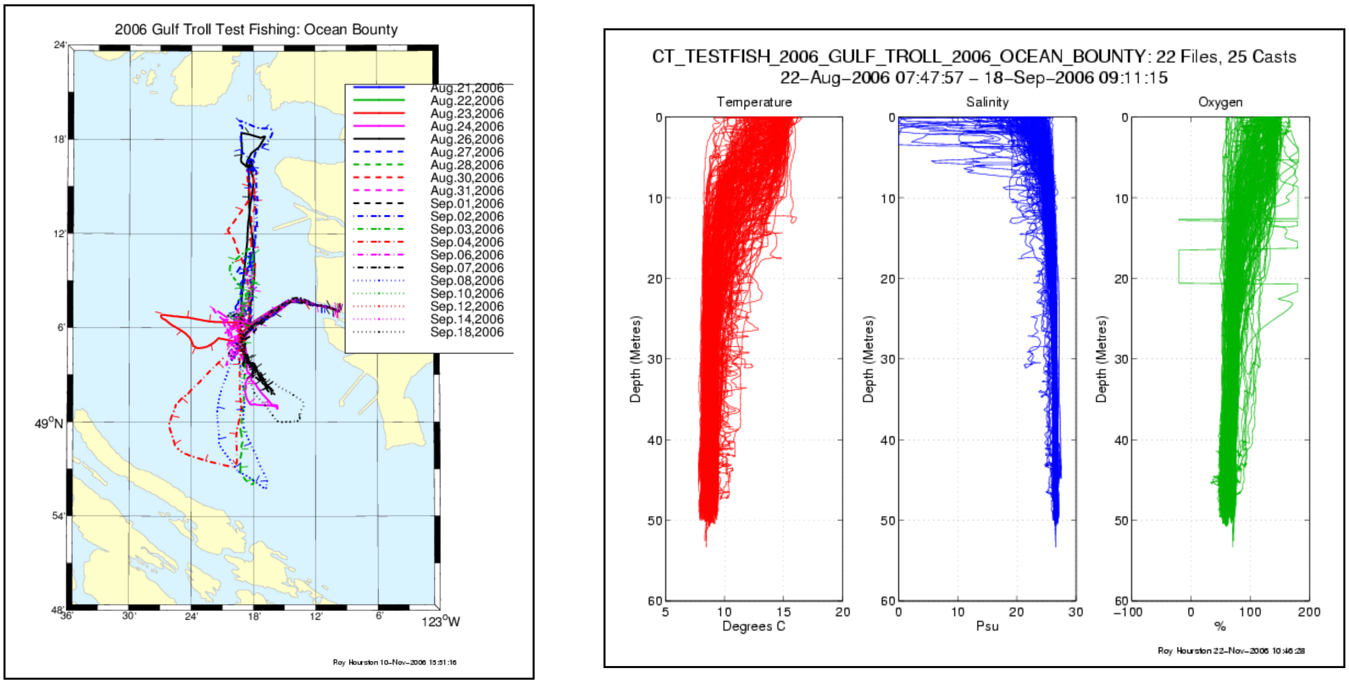
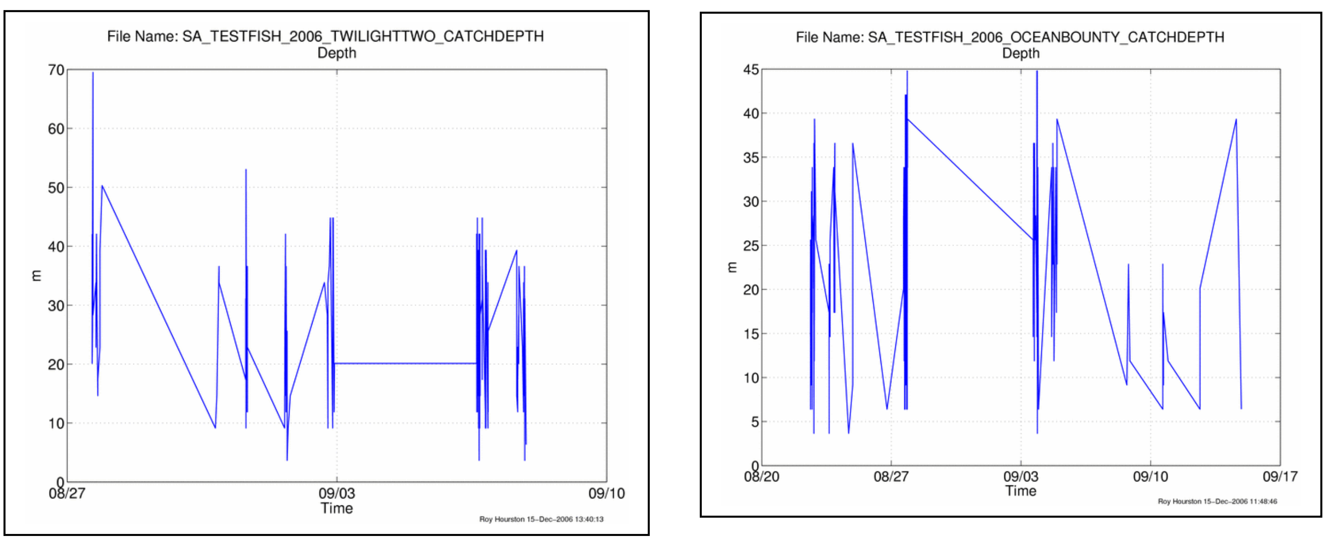
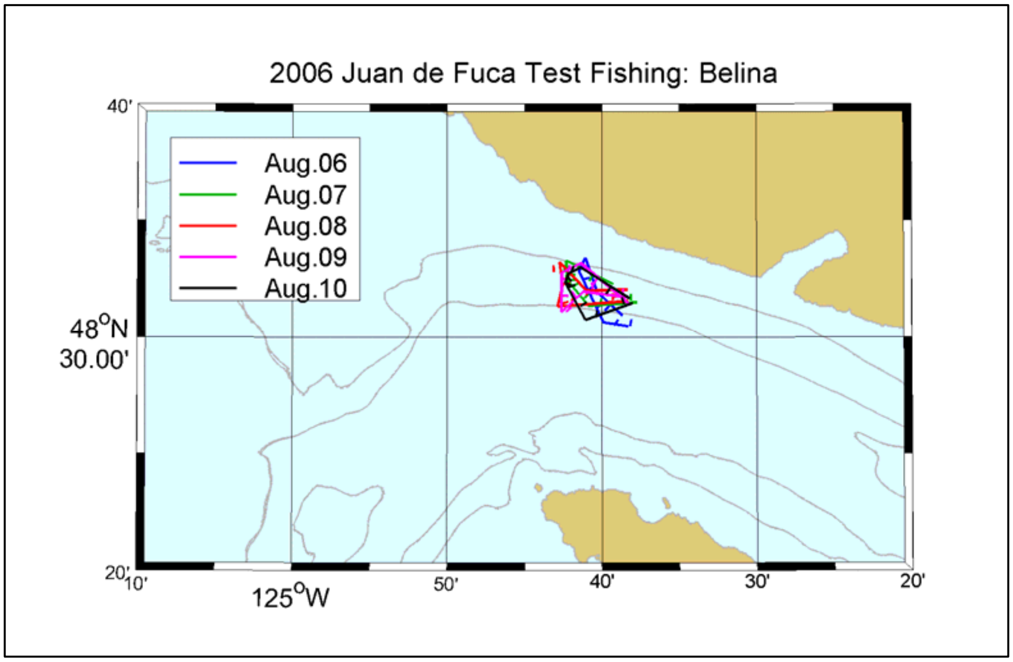
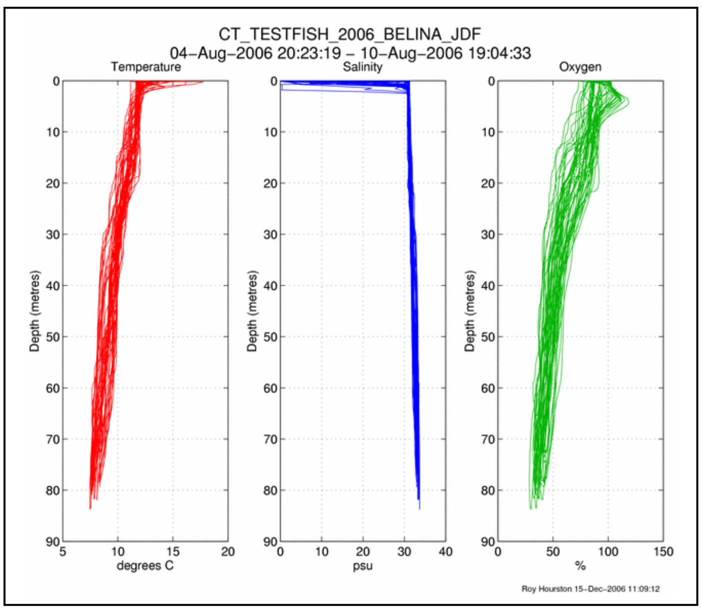


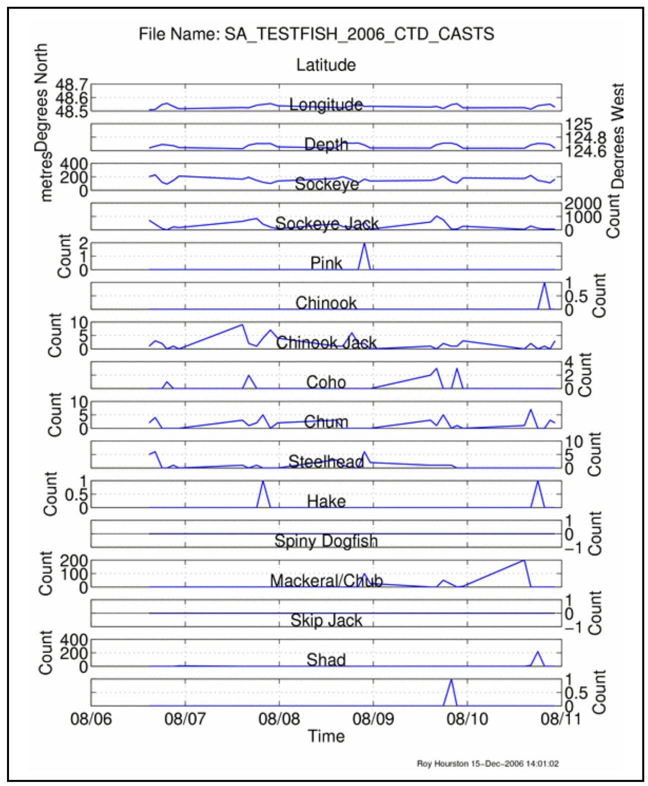
Figure 3. Depth at which fish were caught for the two test fishery vessels



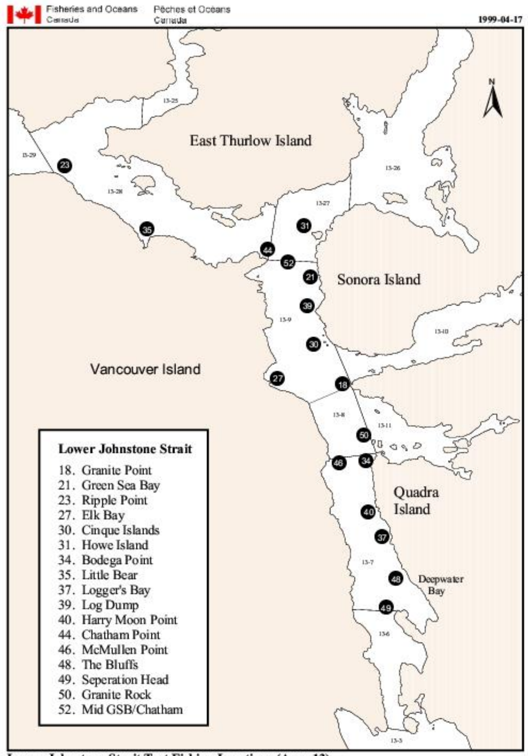
Juan de Fuca Strait: For Juan de Fuca Strait, vertical profiles of temperature, salinity, and oxygen, and seine fish catch and depth information were collected from the Belina for the period August 6 to 10, 2006. For each set, water temperature, salinity, and oxygen are compared to fish catch totals.



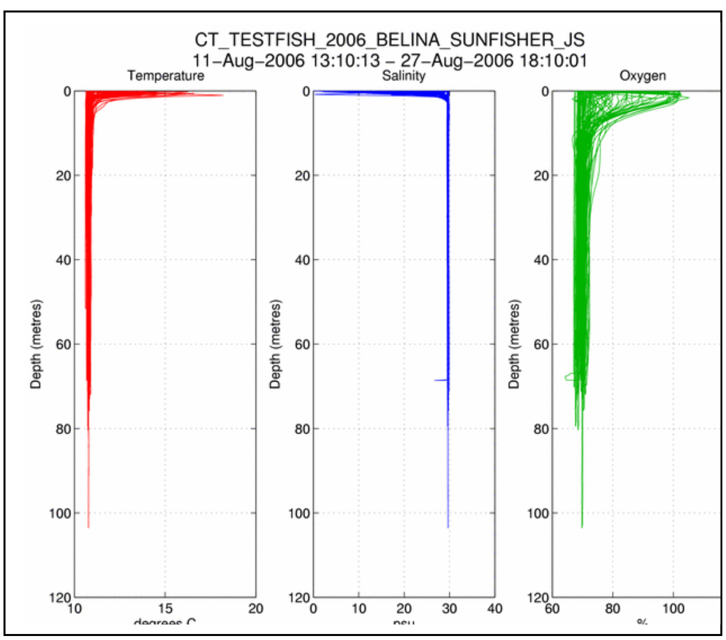


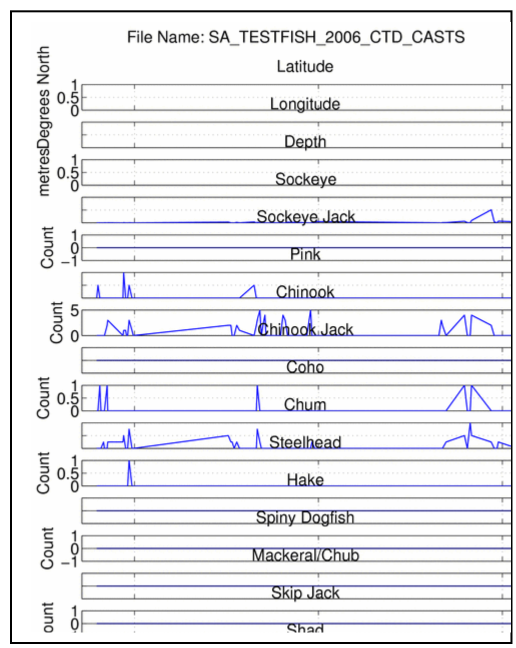


Johnstone Strait: For Johnstone Strait vertical profiles of temperature, salinity, and oxygen were collected from the Belina and Sunfisher for the period August 11 to 27, 2006.



Lower Johnstone Strait Test Fishing Locations (Area 13)





All water property data have been analyzed and compared with fish abundance and fish species. These data have been transferred to Dr. Hinch's research group in Vancouver for comparison with fish physiology.