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Research Document 2008/013 / **Document de recherche 2008/013**

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State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems

État des ressources physiques et biologiques et de certaines ressources halieutiques des écosystèmes des eaux canadiennes du Pacifique

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ISSN 1499-3848 (Printed / Imprimé)

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ABSTRACT

This report is the ninth in an annual series describing the state of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. This region has seen dramatic changes in atmospheric and oceanic conditions over these years, all of which affect resident and migratory marine populations in B.C., many of which are of significant commercial importance. Monitoring and reporting on these conditions annually provides a brief synopsis of their present state and how they are changing, and how these changes might affect commercial and non-commercial living resources in this region. Cool winter conditions in 2007 benefited some species that thrive in cooler waters, but there will be time lags before we see these benefits for others, particularly longer-lived species.

The information in this report is based on the contributions of more than 40 experts from several scientific disciplines (Appendix 2). The workshop was held at the Pacific Biological Station in Nanaimo on February 25 2008. Participants are members of the Fisheries and Oceans Working Group, supported by the Centre for Science Advice – Pacific Region, Fisheries and Oceans Canada.

RÉSUMÉ

Le présent rapport est le neuvième d'une série annuelle qui décrit l'état des ressources physiques et biologiques et de certaines ressources halieutiques des écosystèmes des eaux canadiennes du Pacifique. Cette région a subi des changements considérables quant à ses conditions atmosphériques et océaniques au cours des ans. Or, ces changements ont tous eu une incidence sur les populations marines tant résidentes que migratrices de la Colombie-Britannique, dont bon nombre sont très importantes sur le plan commercial. La surveillance de ces conditions et la production de rapports annuels à leur sujet nous donnent un bref survol de leur état actuel, de leur évolution et de la mesure dans laquelle ces changements pourraient avoir des répercussions sur les ressources biologiques commerciales et non commerciales dans la région. Les conditions fraîches de l'hiver 2007 ont profité à certaines espèces qui privilégient les eaux plus fraîches, mais il faudra un certain temps avant que nous les voyions profiter à d'autres espèces, en particulier celles qui sont plus longévives.

L'information contenue dans le présent ce rapport repose sur les contributions de plus de 40 experts de plusieurs disciplines scientifiques (annexe 2). L'atelier a eu lieu le 25 février 2008 à la Station biologique du Pacifique, à Nanaimo. Les participants sont membres du Groupe de travail de Pêches et Océans, soutenu par le Centre des avis scientifique de la Région du Pacifique de Pêches et Océans Canada.

INTRODUCTION

Pacific Canadian waters lie in a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions, and experience strong seasonality and considerable freshwater influence. Variability is closely coupled with events and conditions throughout the tropical and North Pacific Ocean, experiencing frequent El Niño and La Niña events particularly over the past decade. The region supports important resident and migratory populations of invertebrates, groundfish and pelagic fishes, marine mammals and seabirds. Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by a number of government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. Support for these programs is provided by Fisheries and Oceans Canada, and Environment Canada.

About 40 scientists as part of the Fisheries Oceanography Working Group (FOWG) met at the Pacific Biological Station (PBS) in Nanaimo on 25 February 2008 for presentations on the state of the ocean in 2007 and early 2008. Ian Perry completed a 2-year term as co-chair of FOWG and Jim Irvine of PBS is taking his place. Bill Crawford will remain for at least another year as co-chair. The meeting was chaired by Ian, Jim, and Bill – Jim and Bill subsequently produced this report with input from all participants. Included this year are invited reports from American scientists, describing conditions along the west coast of Oregon and southern Washington State.

This report provides the proceedings of the workshop on the physical and biological state of the marine ecosystems of Canada's Pacific Region in 2007 and early 2008. The products of the FOWG workshop have changed this year. In previous years (1999 to 2006), the outcome of the Fisheries Oceanography Working Group workshops were reported in Ocean Status Reports, for example:

DFO, 2007. State of the Pacific Ocean 2006. Ocean Status Report 2007/001.

That report and others dating back to 1999 can be found at:

English: www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm.
French: www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_f.htm

The outcome of the 2008 FOWG meeting will be summarized in the Science Advisory Report series of the Canadian Science Advisory Secretariat (CSAS). The agenda for this meeting is in Appendix 1. The list of participants is in Appendix 2. Additional sources of information are listed in Appendix 3. The format of the workshop allowed each participant 10 minutes to present their assessments. This was followed by a brief question period. The detailed presentation of each participant is found in Appendix 4. The overall assessment and conclusions of the workshop were developed by the meeting chairs and were circulated to meeting participants for comments prior to finalizing the Science Advisory Report.

Top Stories of 2007

- Our globe was warm almost everywhere, but the Northeast Pacific cooled with La Niña
- Argo observing system reaches design target
- Colder winter and warmer summer waters along the coast
- Ocean acidification: Local seas are most vulnerable
- The BC and Oregon zooplankton communities returned to 'cool-ocean' species in 2007
- Low returns of sockeye coast-wide, especially in the Fraser River
- Hake scatter in BC waters – can we blame jumbo squid?
- Sardines are back in BC, but herring, shrimp, and other species have declined

ASSESSMENT

Except for a brief warm period in summer, local ocean waters were cooler than normal through 2007 and into 2008, in contrast to warm waters of the previous four years. These cooler temperatures were associated with La Niña conditions in spring and autumn 2007, and also to a shift in the Pacific Decadal Oscillation to a cool state. This local cooling was the global exception. Most of the world was warmer than normal with record high temperatures over land and the most reduced extent and duration of Arctic sea ice on record. The Argo Observing System launched its 3000th ocean profiler in October 2007, providing for the first time ever, real-time observations of all the oceans from surface to 2000 metres depth. This network reveals a very strong North Pacific Current flowing eastward into BC and Alaskan waters in 2007-08, and a return to deep mixed layers and cold waters in the Gulf of Alaska. Other observations reveal the oceans to the west of Canada and USA are the most vulnerable to increasing ocean acidification due to global carbon dioxide emissions.

Very young and very small marine life respond rapidly to these changes in temperature in West Coast waters. Northern and sub-Arctic zooplankton dominated in 2007, largely replacing the southern species that prevailed in previous years of warmer waters in BC and Oregon. Deep-sea zooplankton growth in the Gulf of Alaska was very focussed in 2007 with most of the spring/summer biomass (73%) occurring in May and a second smaller peak in July. Catches of juvenile (yearling) coho in June 2007 off Oregon were among the highest during the 10 year time series, but by September, catches were among the lowest. High and low numbers might be due to cool and warm temperatures of spring and summer, respectively. Surveys along the west coast of Vancouver Island (WCVI) show average growth of juvenile coho in 2007, suggesting normal marine survivals for adult coho, Chinook, and sockeye. However, biomass of the euphausid *T. spinifera*, an important food source for juvenile salmon entering Barkley Sound, was low in 2007, indicating poor growth of salmon stocks that migrate through there and feed on this prey. The shift to a much stronger La Niña in winter 2007-08 anticipates improvement in growth and survival rates for WCVI coho, sockeye, and chinook migrating seaward in 2008.

General groundfish surveys, now into their fourth year, reported low catch weights per tow in 2007 in all regions. In Queen Charlotte Sound, in particular, an across-the-board decrease in biomass indices for almost all species was noted. Herring biomass was low in most BC waters, (except Strait of Georgia), attributed to less feed and more predators during previous warm years when herring were young and small in size. Low recruitment rates are expected in the next few years in all regions. Biomasses of pink shrimp, arrowtooth flounder, Dover sole, and Pacific halibut off the west coast of Vancouver Island in May declined, also attributed to warm waters of previous years. Hake were few in number off the west coast of Vancouver Island and scattered into many more regions in 2007 in BC waters. Reasons for the declines and scattering are not clear, but low *T. spinifera* biomass (a favourite hake food) and interactions with jumbo squid, a recent intruder are potential explanations. Interestingly, the 2007 hake survey captured these squid in Canadian waters only.

In the Strait of Georgia, surface waters were somewhat warmer than normal through the year, but deeper waters cooled to temperatures observed in 1999 to 2002. Phytoplankton biomass was higher in summer and lower in autumn. Its spring bloom arrived relatively early. Herring biomass declined from the very high levels of only a few years ago. Very few Fraser River sockeye returned to spawn in 2007, most likely due to very poor feeding conditions and/or increases in predators resulting from warm waters during the spring of 2005. Marine indicators of ocean productivity suggest that sockeye survivals in 2008 should be somewhat better than in 2007, but still below normal. Coho salmon returns to the Strait of Georgia in 2008 are predicted to be low, perhaps even lower than in 2006, based on very poor growth and low CPUE recorded in the 2007 survey in the Strait of Georgia. Chinook returns in 2008 are predicted to be below average - numbers of 5-yr olds returning from the disastrous 2005 sea entry year will probably be very low. Chum returns in 2008 are anticipated to be average, based on the average CPUEs in the July 2006 survey. It is expected that there will be a large abundance of juvenile pink salmon in the strait in 2008, which may put pressure on marine survival of other juvenile salmonids.

Our globe was warm almost everywhere, but the Northeast Pacific cooled with La Niña

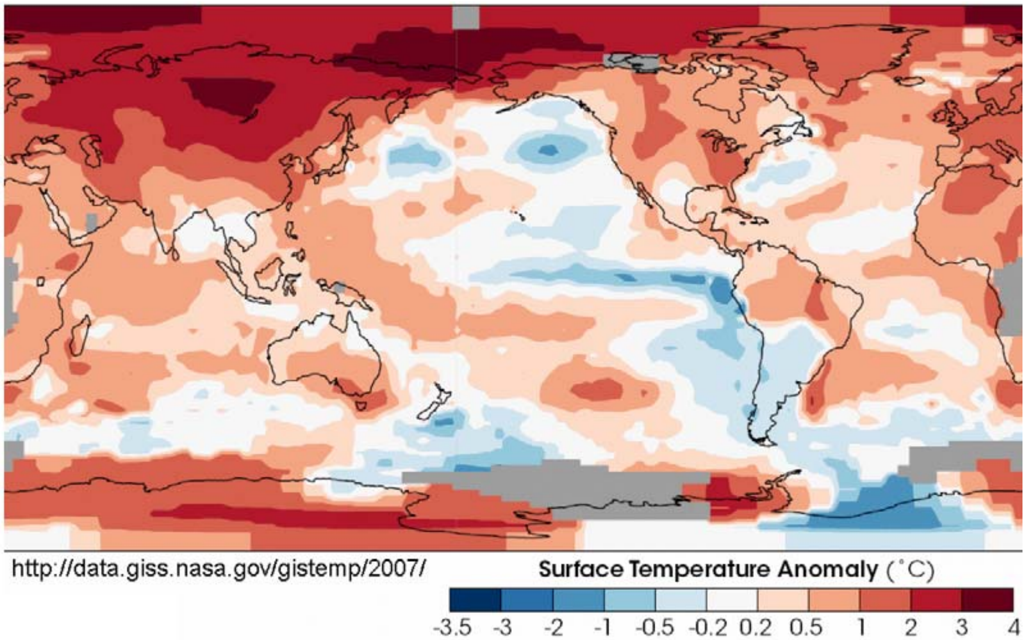


Figure 1. Surface temperature anomaly in 2007 relative to the 1951-1980 mean based on surface air measurements at meteorological stations, and ship and satellite measurements of sea surface temperature. Source: [NASA Goddard Institute for Space Sciences](#).

According to the NASA Goddard Institute for Space Studies, the temperature over land and ocean in 2007 was tied with 1998 for the second warmest year in the era of instrument data, which began in the late 1800s. Land temperatures in 2007 were the highest since the beginning of instrumental record as shown in the lower panel of Fig. 2.

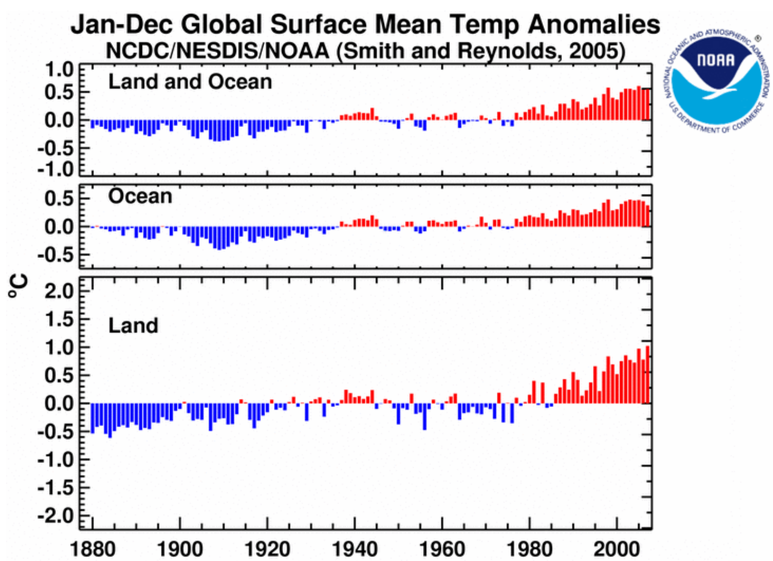


Figure 2. Time series of annual average temperature anomalies over the globe, reference to the period 1901 to 2000. Source: [NOAA National Satellite and Information Service, National Climatic Data Center](#).

The most anomalously warm ocean surface appeared in the Arctic Ocean north of Bering Strait, contributing to the record low ice coverage in the Arctic Ocean in late summer 2007. Land temperatures have risen steadily since the 1970s, and the moderating effect of ocean temperatures has kept the global average temperature over land and sea from rising as rapidly. But in the eastern Pacific from Cape Horn to Alaska, waters ran much cooler than normal in 2007.

So why did it happen in our waters? Blame it on La Niña. (Or thanks to La Niña if you love cold-water fish.) Other ocean indices such as PDO and its sister the Victoria Mode also track these cool waters. Wind patterns over the Gulf of Alaska often vary with the rise and decline of both El Niño and La Niña. The left panel of Fig. 3 shows an average winter, with the black arrow along isobars pointing in the direction of typical warm south-westerly winds. Winter winds in 2006-07 and 2007-08 blew from a more westerly direction, with colder temperatures. Coldest winds were in January 2008 (right panel), with isobars distorted by shifts in the Aleutian Low (**L**) and North Pacific High (**H**) in Fig. 3. Winds were forced to blow from the north-northwest.

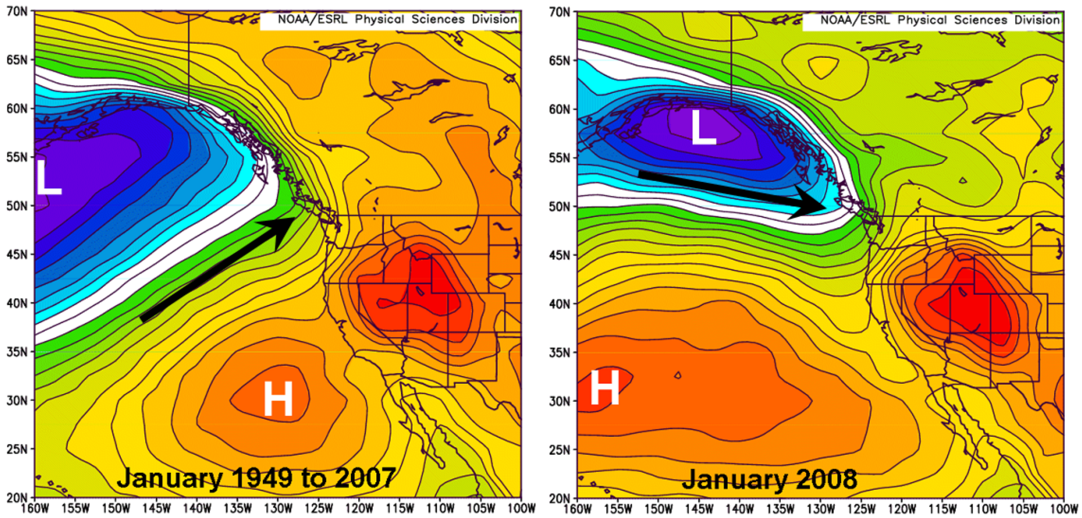


Figure 3: Average sea surface pressure for the January of 1949 to 2007 (left), and January 2008 (right).. Contours are at 1 mbar intervals, with the same scale for each panel. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado.

How cold was it? The figures below show ocean temperature anomalies in June 2007 and July 2007 from the tropical Pacific north to Alaska. Cooling near the West Coast in June 2007 did not extend to shore, due to weaker upwelling winds along the coast, but by January 2008 the entire coast from Mexico to Alaska was below normal temperatures. One analysis found the Gulf of Alaska to be the coldest in 35 years, predicting cold coastal waters into late spring 2008.

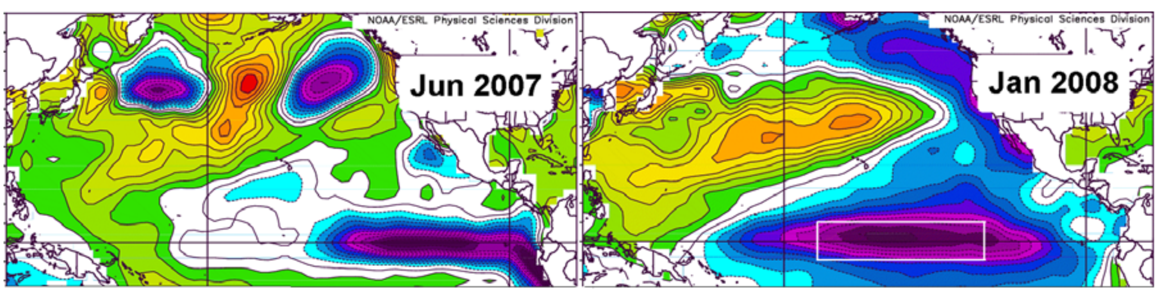


Figure 4. Anomalies of sea surface temperature over the North Pacific Ocean and tropics. Relatively cold water is shown in purple. The white box in the right panel is Niño 3.4 region along the Equator whose temperature anomaly defines El Niño and La Niña conditions. Coldest water in this box in January 2008 indicates La Niña was most intense in this month. Yellow and orange regions are warmer than normal. The pattern of warmer water between Indonesia and central North Pacific, together with cooler water in the northwest Pacific is a classic La Niña state. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado.

Argo Observing System reaches design target

The Argo Observing System reached its target of 3000 operating ocean profilers in October 2007; providing real-time observations of all the oceans from surface to 2000 metres depth. Canada has contributed about 3% of the total number of floats in global oceans. Each profiler is an autonomous instrument that drifts through deep-seas for up to five years. Most drift at 2000 metres depth. Every ten days they rise slowly, measuring temperature and salinity all the way to the ocean surface, where these data are transmitted to shore via satellite. All measurements are available to the public within days of reception. These data are immediately entered into weather and climate models, and also sent to oceanographers to detect significant changes in ocean currents. In the Gulf of Alaska (Fig. 5), these profilers revealed an unexpected strengthening of the North Pacific Current in 2007 and 2008 (flow across line ΔD_{NPC} below) and increased flow into the California Current (flow across line ΔD_{CC} below). Stronger flow into the California Current may have contributed to cooling of near shore oceans observed through 2007.

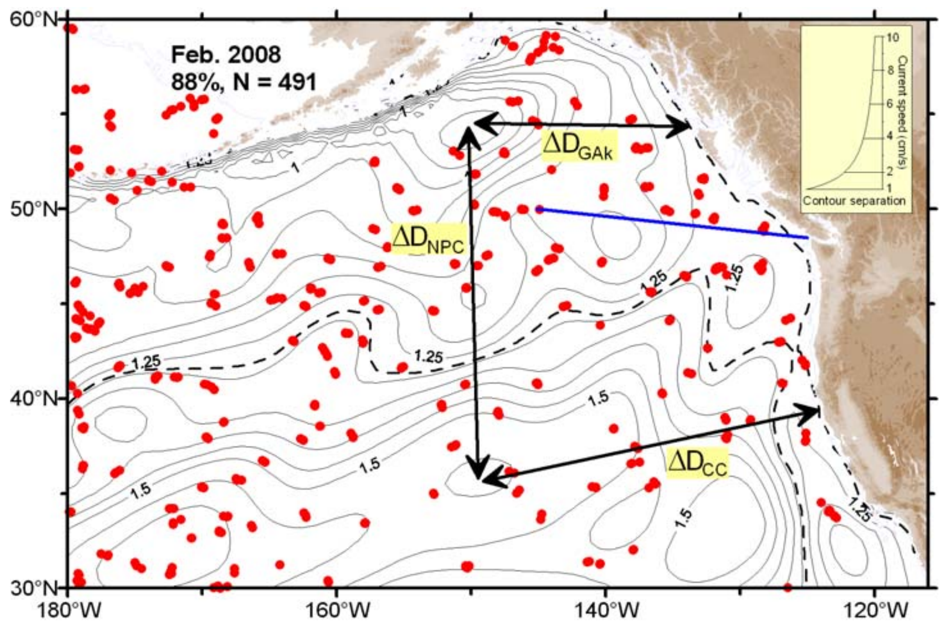


Figure 5. Each red dot is an Argo profiler. Most were launched by Fisheries and Oceans Canada and enable calculations of sea surface height and ocean current position and strength. Currents flow along contour lines with the bold-dashed line being the "dividing streamline" in the North Pacific Current that separates water that heads into the Gulf of Alaska from that which heads into the California Current system. Arrows show the points used to compute the differences in dynamic height, and so the strength of individual currents

In addition to Argo, DFO research cruises regularly sample the Gulf of Alaska. High concentrations of phytoplankton in large eddies were observed in June 2007. Sampling in February 2008 along Line P showed increased surface nutrient concentrations and a deepened mixed layer. If the mixed layer remains deep through spring (i.e. if spring remains stormy), then reduced light levels will decrease primary productivity in oceanic waters, but could enhance nutrient supply to coastal waters. This pattern was observed during the strong La Niña of 1999.

Colder winter and warmer summer waters along the coast

In normal winters the winds blow from the south, bringing warm seawater along the West Coast. In normal summers an offshore high pressure system reverses the prevailing winds, pushing warm water offshore. But weather systems weakened these forces in both summer and winter 2007, giving us colder winter waters and warmer summer along the outer coast from California to northern BC. Daily measurements at lighthouses in Canada tracked these changes, as shown in Fig. 6. These observations together with measurements at weather buoys revealed a warm-summer, cold-winter pattern of anomalies. It was different within the Strait of Georgia where temperatures at Chrome Island in mid-strait were mainly warmer than normal all year (See Fig. 6). Sea surface temperatures along the outer coast in summer (for example at Kains and Bonilla) generally cooled during northerly winds and clear skies. A sunny day at Tofino in summer will have colder ocean waters. Upwelled waters carry more nutrients, so the summer winds of 2007 that favoured warmer waters were likely poor for local marine life. Weaker upwelling winds in summer 2007 were found all along the coast from California to SE Alaska, as shown in Fig. 7. Based on ocean current data, it appears that the spring transition timing for the West Coast Vancouver Island current in 2007 was later than average. However the wind records suggest a later spring transition.

SeaWiFS satellite observations of phytoplankton off west coast Vancouver Island and Washington State showed no significant anomaly until May 2007, when values were two to three times the average.

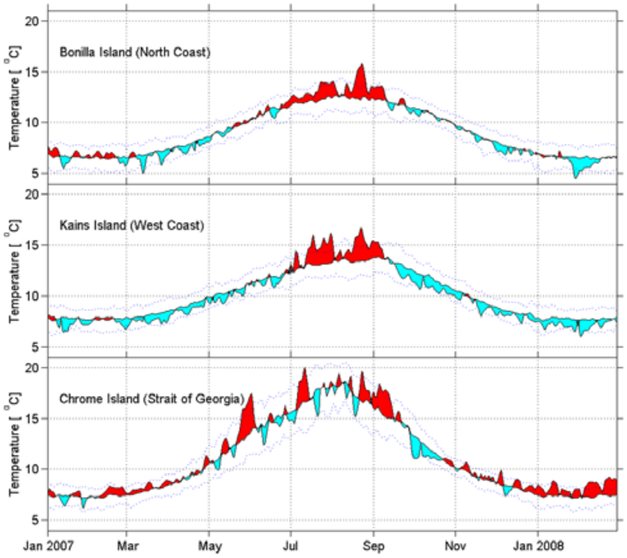


Figure 6. Temperature anomalies in 2007-08 (in red and blue), and the annual cycle from 1971 – 2001 at three BC shore stations.

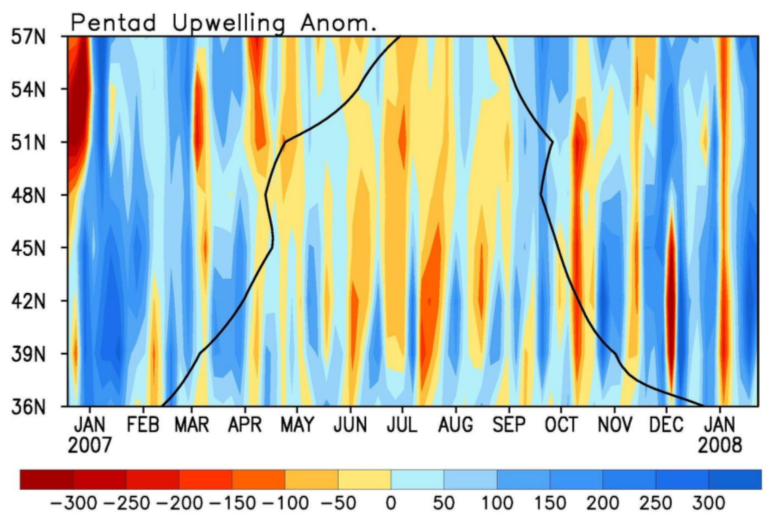


Figure 7. Upwelling anomaly between 36°N and 57°N along the West Coast of Canada and USA in 2007. The black line marks the transition between upwelling and downwelling in normal years. Note the negative upwelling anomalies at most regions in the spring-to-autumn upwelling season.

Ocean acidification: Local seas are most vulnerable

The North Pacific Ocean already has the most acidic water in the global ocean. All oceans are becoming more acidic due to increasing carbon dioxide. Much of the extra CO_2 released by burning fossil fuels ends up in the oceans, increasing the dissolved inorganic carbon concentration, resulting in an increase in acidity and a decrease in pH. At present the average pH of seawater has decreased by about 0.1. The decrease in pH means that pteropods, corals and shellfish that produce calcite and aragonite shells or structures are threatened. In fact the aragonite saturation depth (defined as the depth below which aragonite dissolves more readily than it can form) has shoaled between 50 and 200 metres in the last century. The Line P carbon program of Fisheries and Oceans Canada has contributed critical data to make these estimations of change in the carbonate system in the Gulf of Alaska, in regions most sensitive to acidification. Fig. 8 reveals global distribution of the saturation depth of two forms of calcium carbonate: aragonite and calcite.

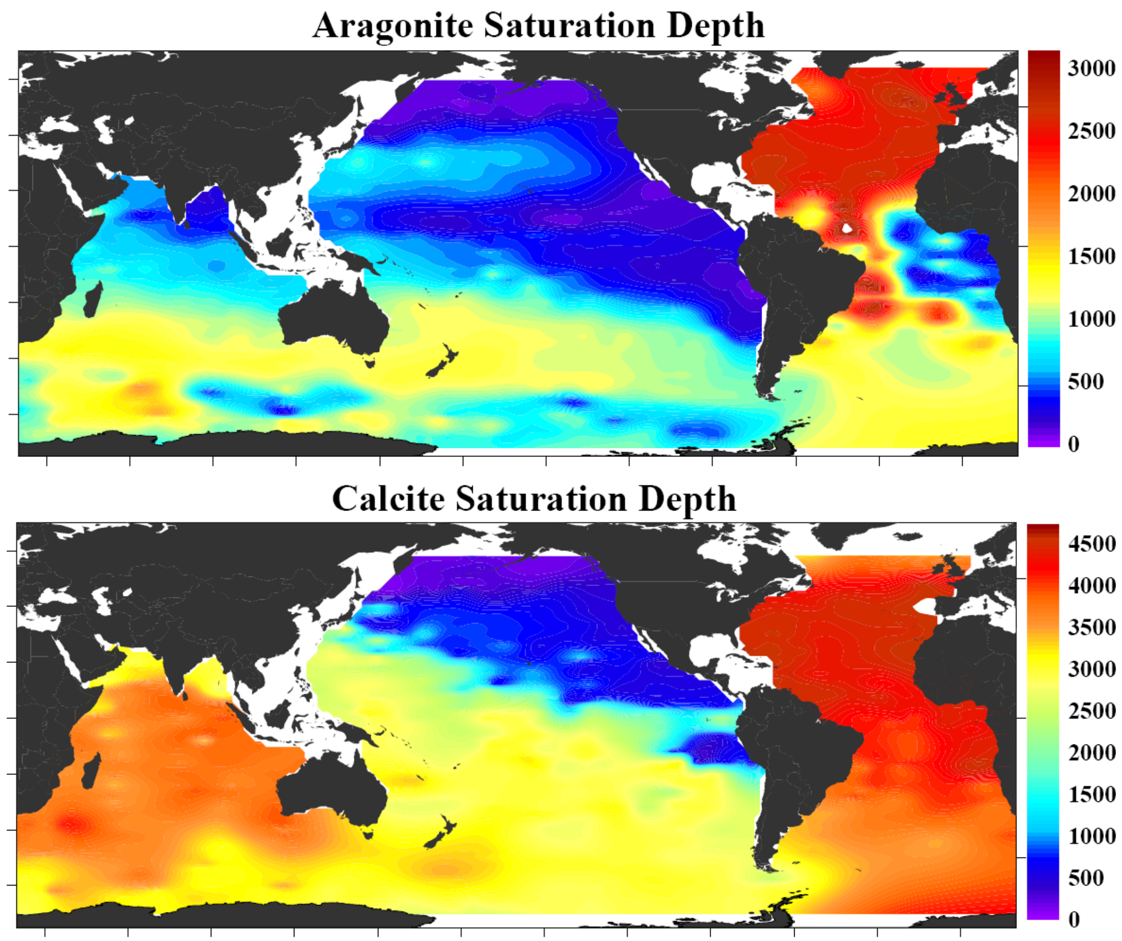


Figure 8. Saturation depth of aragonite and calcite in the global oceans. Colour scale at right denotes the depth in metres. White areas denote regions of little or no data. Figure courtesy of Richard Feely.

The BC and Oregon zooplankton communities returned to 'cool-ocean' species in 2007

Although cooling began in BC southern shelf waters in 2006, recovery of the boreal shelf copepods and northern chaetognaths and decline of the southern copepods and chaetognaths were delayed until 2007. Even in 2007, the return to cool ocean biomass levels and community mix was confined primarily to the continental shelf. Offshore waters off southern Vancouver Island remained relatively unproductive.

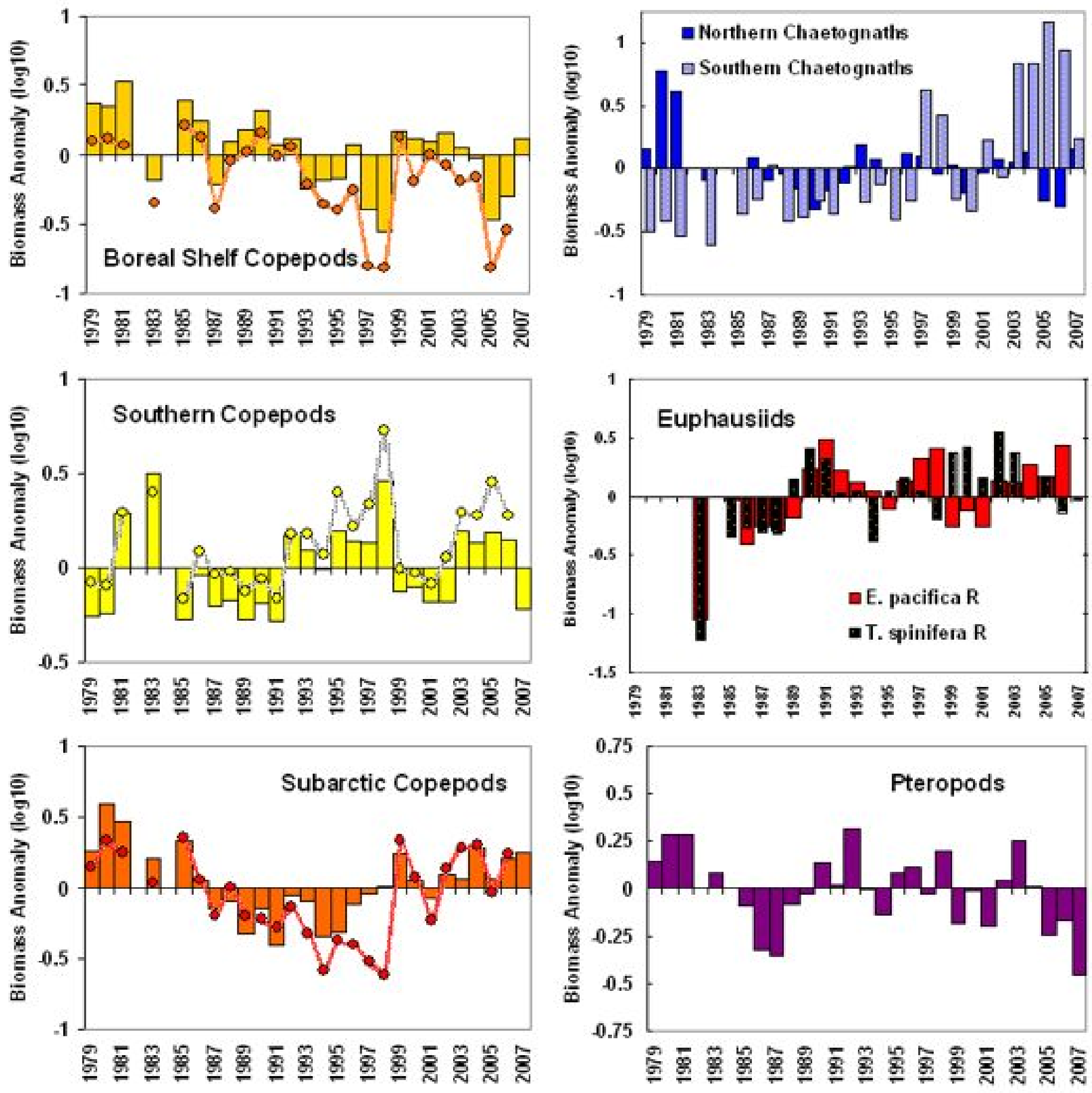


Figure 9. Zooplankton anomaly time series for southern Vancouver Island. Column bars are species group anomalies referenced to the full 1979-2005 baseline period. The years 1982 and 1984 are omitted because there were too few samples. Circles and lines in the 3 left panels show for comparison the older anomalies (1979-1991 baseline). Euphausiid anomalies have been corrected for day vs. night differences in capture efficiency, and are not reported for the first 3 years due to a change in sampling method after 1982.

The copepod community on the Oregon Shelf was a "cold water boreal" community and dominated by cold neritic species, from February through December 2007. This is in contrast to the previous three (warm) years during which warm neritic species were prominent (*Paracalanus parvus*, *Acartia tonsa* and *Calanus pacificus*), as shown in last year's "State of the Pacific Ocean" report.

The changes in zooplankton community composition in the past two decades appear to have had large effects on fish growth and survival, probably because the 'cool water' zooplankton are better fish food (larger individual body size and much higher energy content). Because much of the year-to-year variability of marine survival rate of harvested fish species occurs at early life stages (for salmon, in their first year after ocean entry), recent zooplankton anomalies provide a useful index of juvenile fish nutrition and a 'leading indicator' for subsequent adult fish recruitment.

Total mesozooplankton biomass for the deep-sea offshore BC region (from the continental slope out to 145 °W and between 48° and 55 °N) was very focussed in 2007 with most of the spring/summer biomass (73%) occurring in May and a second smaller peak in July. Although conditions were cooler, the time of peak biomass has not yet returned to June, where it was during cool conditions in 2000/01. The 2007 *Neocalanus plumchrus* peak, which makes up the bulk of the spring biomass, was later than it was during the warmer 2004-2006 period but not as late as in 2000/01. However, the copepod biomass in July 2007 was mostly made up of the larger *N. cristatus*; high numbers of this species have not been seen this late in the year since 2001.

Low returns of sockeye coast-wide, especially in the Fraser

With the exception of northern B.C., sockeye returns were generally low in 2007 (Fig. 10). Looking at the time series for various index stocks indicates:

- Since 1970, maximum returns for all populations occurred during the early 1990's immediately following the strong La Niña event of 1989.
- Central Coast, Vancouver Island (WCVI) and Fraser index-stocks all declined from early-1990s highs to persistent, sub-average returns since the mid-1990s.
- North Coast and Transboundary index-stocks declined from early-1990s highs to sub-average values by the late-1990s but since the year 2000 have exhibited a higher frequency of above-average returns than Central and South coast stocks.
- Populations entering continental shelf areas under stronger oceanic influences appear most responsive to La Niña-like (*anomalously cool, survival favourable*) and El Niño-like (*anomalously warm, survival less favourable*) conditions than stocks entering more protected estuarine waters.
- Persistence of strong El Niño-like conditions through the 2005 sea entry period by smolts was associated with low adult return rates in 2007 for Central Coast (Rivers and Smith Inlet), WCVI (Barkley Sound) and Fraser (Chilko Lake) sockeye index stocks.

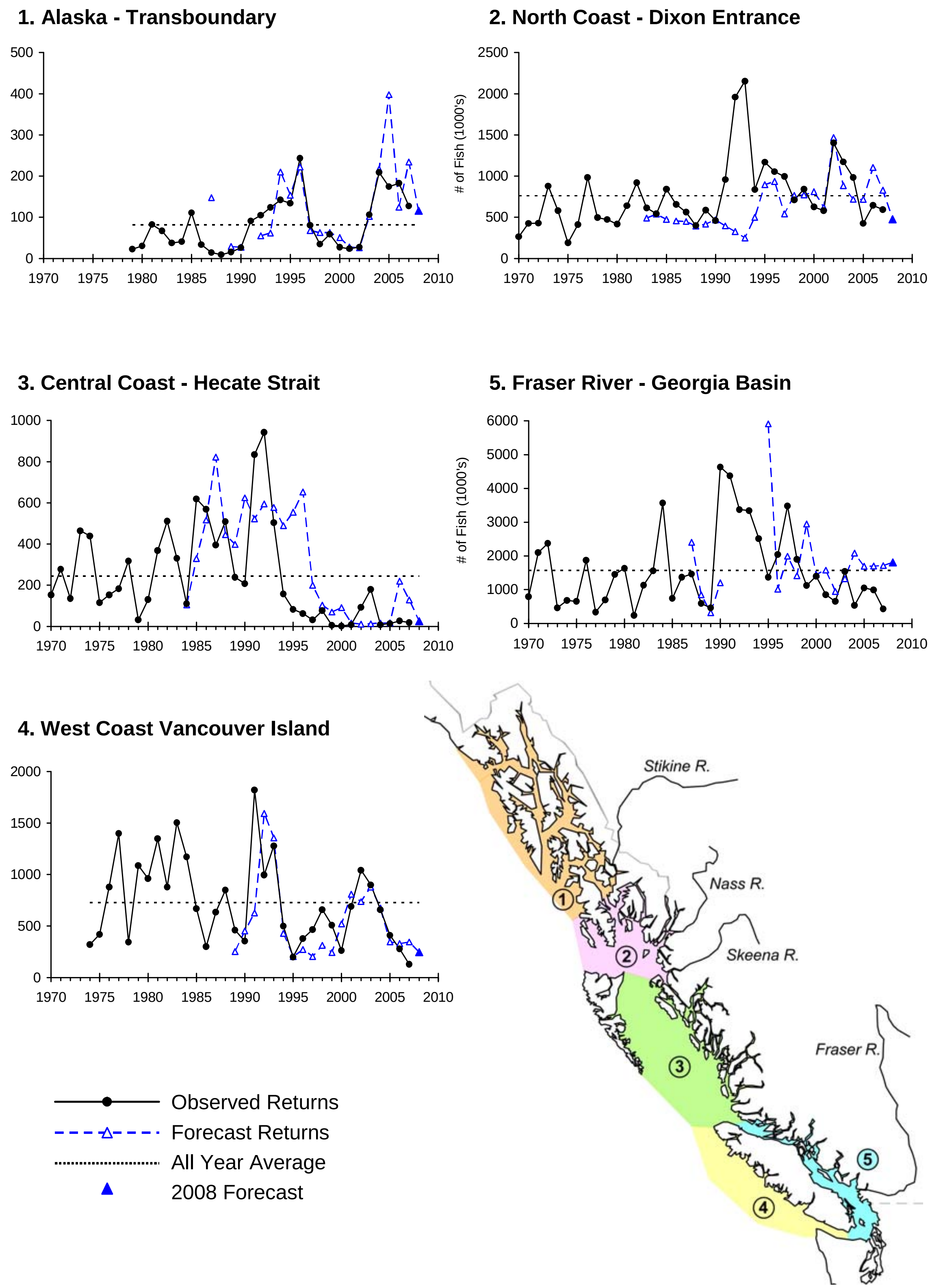


Figure 10. Trends in the total returns and forecasts for BC sockeye index stocks including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Barkley Sound, and 5. Chilko. Y-axis represents returns in thousands of fish.

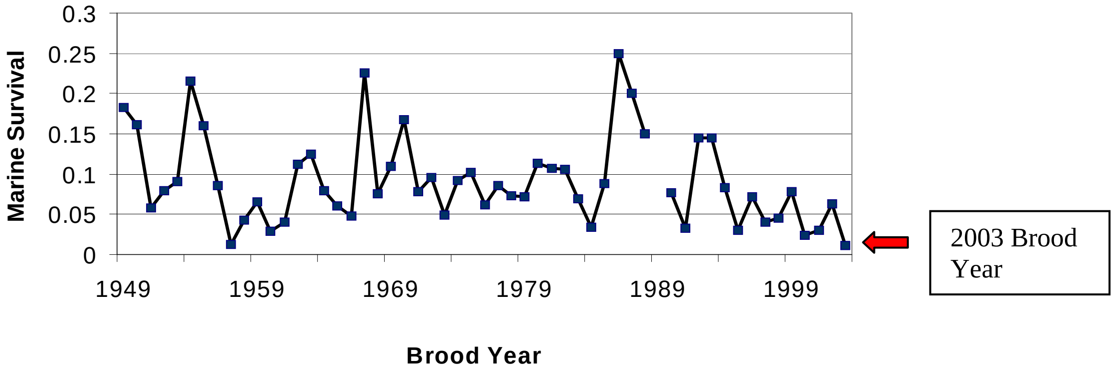


Figure 11. Marine survival of Chilko Lake run of Fraser River sockeye salmon. Data for 2003 brood year (2007 return year) are preliminary.

All four major run timing groups of sockeye salmon returned to the Fraser River in very low numbers in 2007. These low returns are almost certainly due to unusually poor ocean conditions after juvenile salmon left the river in spring 2005, a factor that hampered DFO predictions of returning numbers.

How bad were ocean conditions for Fraser River salmon? Fig. 11 shows a time series of marine survival for Chilko Lake Fraser River sockeye. The 2003 Chilko Lake brood year entered the ocean in 2005 and returned to spawn in 2007. Their marine survival was dismal, tied for the second lowest in more than 50 years of records.

Accurately forecasting salmon returns is difficult, and DFO forecast numbers were too high for all major Fraser sockeye populations in 2007, as revealed in Fig. 12. Forecast models like the ones used for Fraser sockeye assume average survival conditions based on the historical time series. Therefore, in years when survival conditions are less than what has been observed in the past, as occurred for the salmon that returned in 2007, forecasts under-estimate observed returns. Part of the challenge is to understand the relative importance of factors occurring in fresh water versus factors operating in the ocean. The Chilko stock is the only major sockeye population in the Fraser watershed where smolts are routinely counted en route to the ocean, and hence is the only population where we can separate the role of freshwater and marine factors affecting survival. Sockeye fry numbers are estimated in various lakes using hydroacoustic equipment (sounders), but significant freshwater mortality can occur between the time fry numbers are estimated and the sockeye migrate to sea nine months later as smolts. Sampling in the Strait of Georgia in June and September helps us understand what occurs during the early marine life of salmon. Observations of juveniles in the Strait of Georgia in 2005 indicated no problem with marine survival, suggesting normal returns in 2007. In 2005 relatively high surface ocean temperatures associated with reduced marine survivals existed, but higher temperatures in earlier years did not result in the extremely low marine survivals found for this brood year.

From the Georgia Basin, juvenile Fraser sockeye normally migrate through Johnstone Strait, Queen Charlotte Sound and northward along the continental shelf. It appears now that conditions in these waters were poor, based on low returns of sockeye and poor marine survival of seabirds near Vancouver Island.

Previous State of the Ocean Reports noted poor survival of juvenile coho and fledgling seabirds along the west coast of Vancouver Island in 2005, due to poor ocean conditions. Seabirds survival was the worst ever observed from California to Triangle Island off northern Vancouver Island. However, seabirds appeared fine north of this range in 2005, suggesting returns of sockeye in 2007 would be normal. Indicators of ocean productivity, such as PDO and coastal sea surface temperatures (Table 1), suggested reduced survivals for sockeye returning in 2007.

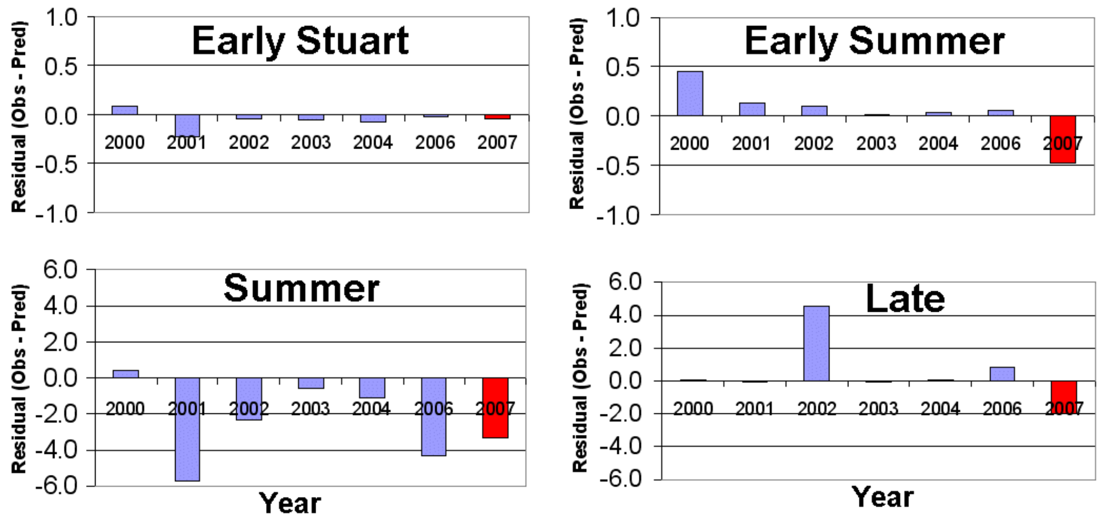


Figure 12. Forecasts success in past years for major run timing groups of Fraser River sockeye. Numbers for 2007 are highlighted – note that run forecasts were overly optimistic.

One analysis, reported in last year's report, compared Chilko Lake marine survival with ocean temperature observations for the brood years 1952-2002. These suggested that increased survivals were associated with a cooler Gulf of Alaska from January to August of ocean entry year and a warmer Gulf of Alaska from November to July of the return year. Conditions for the 2007 returning populations were just the opposite and quite extreme, pointing to poor returns. However, given past unreliability of using Chilko Lake sockeye in non-dominant years as indicators of other sockeye populations, it was not clear how to use this finding.

Future forecasts will consider how to more effectively use climatic, physical and biological oceanographic data to inform quantitative return forecasts. A possible approach presents data from previous State of the Pacific Ocean reports corresponding to the 2005 and 2006 entry years in a "report card" format (Table 1). Qualitatively, all indicators for 2005 were poor (below average), and this type of information could be used to recommend the acceptance of a conservative probability forecast. The good news is that 2006 marine indicators of ocean productivity suggest that the survivals of sockeye returning in 2008 should be somewhat better than for those that returned in 2007. Unfortunately, the number of spawners in 2004 was the lowest for this cycle year, indicating that even with near average survivals, that returns will be low in 2008.

Indicators of Ocean Productivity (State of the Ocean Reports 2005 & 2006)

	2005	2006
PDO	**warm** (0.95 Jan-Aug) **cool** (-0.77 to Dec)	**warm** (0.57 Jan-Jul) **cool** (-0.34 to Dec)
SST (Coast BC)	**warm**	**near/above avg** (Jan-Jun) **below avg** (Jul-Dec)
Vertical Stratification	**strong**	**average-weak** (storms)
Upwelling	**weak**	**strong** (in summer)
Spring transition	**delayed** (June)**	**average** (Early-April)
Zooplankton (warm-water spp.)	**high**	**high**
Large cold water euphasiids	**poor (peak Ap/May)**	**poor (peak May)**
WCVI Coho growth rates	**lowest on record**	**average**
Marine bird breeding success	**lowest on record**	**average**
Juvenile sockeye size (SOG)	**below average**	**largest in past 10 yrs**

Table 1. Ocean indicators for Fraser River and other southern BC sockeye salmon outbound in 2005 and 2006. The 2005 and 2006 indicators are relevant to sockeye returning in 2007 and 2008 respectively.

Hake scatter in BC waters. Can we blame jumbo squid?

Hake were distributed from Monterey Bay (36.8° N) northwards to Dixon Entrance (54.6° N) in 2007, with typical dense shelf-edge aggregations observed off of the Washington, Oregon, and northern California coasts (Fig. 13). Further north in Canadian waters, hake distribution was sparse, with most hake in well-separated pockets along the west coast of Vancouver Island and through Queen Charlotte Sound, Hecate Strait and Dixon Entrance. Total estimated biomass of hake aged 3 and older was 0.88 million metric tons in 2007, which is a 27% decline since 2005 and similar to the lowest estimated biomass of 0.78 million metric tons recorded in 2001. The 2007 survey was conducted by the NOAA Ship *Miller Freeman* because the CCGS *W.E. Ricker* suffered a catastrophic failure of the propeller shaft two weeks prior to joining the hake survey effort. The 2007 survey covered more than 12,000 nautical miles on 133 transects and conducted 92 sampling trawls.

Historically, the areas between the mouth of Juan de Fuca Strait (48.25° N) and La Pérouse Bank (48.8° N) are the most productive fishing grounds for the Canadian hake fishery. However, hake biomass in these areas has declined substantially since 2003 (Fig. 13), which is most clearly illustrated by the 2007 data, and as a result the fishery has shifted to Queen Charlotte Sound, at the northern end of Vancouver Island. These changes in distribution and abundance between surveys are not related to differences in survey timing or methods since standardized protocols have been followed since 1995 by both Canada and the United States. The recent decline in hake abundance on traditional Canadian fishing grounds might be related to a reduction in the abundance of *T. spinifera*, a preferred food of hake.

The 2007 survey was notable for the capture of 82 jumbo squid (*Dosidicus gigas*) during biological sampling at depths exceeding 300 m offshore of the continental shelf along Vancouver Island and the Queen Charlotte Islands. Jumbo squid underwent a rapid range expansion into the southern California Current between 2002 and 2006 (Field et al. 2007). Although previous surveys have captured jumbo squid, the 2007 survey was the first survey to capture jumbo squid exclusively in Canadian waters. Based on the acoustic data, hake appeared to be more widely dispersed or less densely aggregated when jumbo squid were captured and jumbo squid predation may have led to increased swimming activity and dispersal of hake.

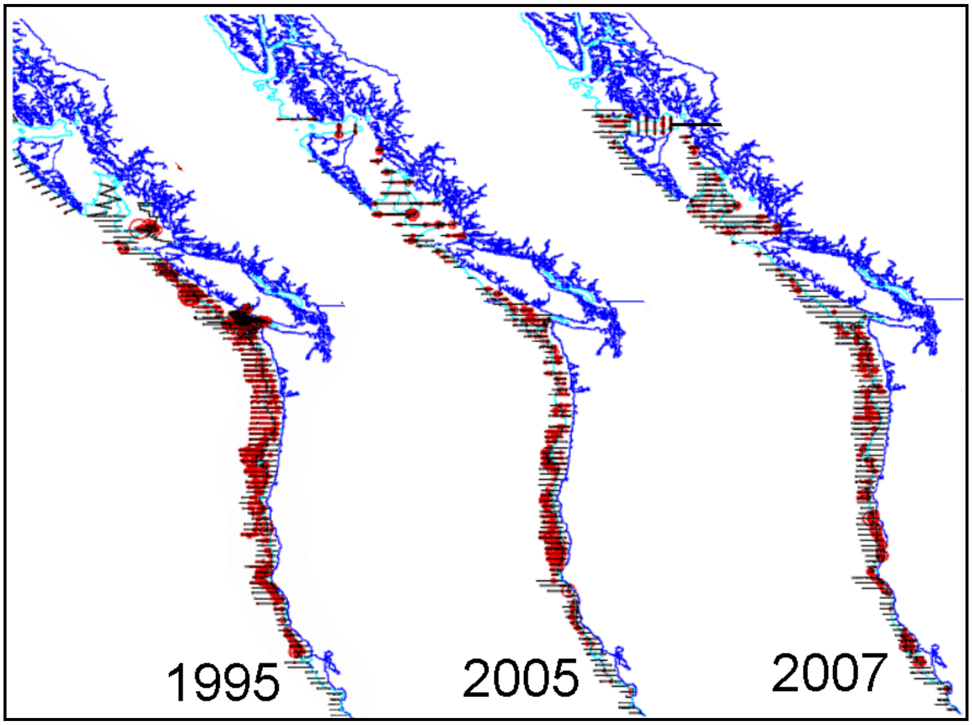


Figure 13. Offshore hake distribution and abundance estimated by the Canada-US Pacific hake acoustic-trawl survey, 1995, 2005 and 2007. Black lines show survey grid, cyan line is the 200 m depth contour (continental shelf-edge) and the red circles indicate hake acoustic backscatter along transects with size proportional to the maximum among years. Based on a figure provided by Rebecca Thomas (Nat. Marine Fish. Serv., Northwest Fish. Centre, Seattle, WA).

Sardines are back in BC, but herring, shrimp and other species have declined

Sardines reappeared off the west coast of Vancouver Island in 1992. During the 1990s their distribution expanded northward from southern Vancouver Island through Hecate Strait to Dixon Entrance. In 2003 and 2004 the distribution of sardines in B.C. was limited to the inlets of Vancouver Island and offshore areas in the south. Recent warm conditions and a very strong 2003 year-class have resulted in widespread distribution of sardines throughout southern Hecate Strait and Queen Charlotte Sound in 2006 and 2007.

However, herring on the West Coast of Vancouver Island is at an historically low level and will remain so unless ocean conditions resulting in a reduction in the abundance of predators in the area improve. Recent conditions have not been favourable for herring survival in 2004 and 2005, and we expect continued weak recruitment to the stock during the next couple of years.

Herring in the Hecate Strait area consist of migratory stocks from the Queen Charlotte Islands, Prince Rupert and Central coast areas. For the past decade, recruitment and abundance of Queen Charlotte Islands herring have been low while recruitment and abundance of Prince Rupert and Central Coast herring have generally been good. Recruitment of the 2003 and 2004 year-classes was weak in all three areas resulting in moderate declines in Prince Rupert and the Central Coast.

Herring survival conditions and recruitment have been unusually good in the Strait of Georgia for the last decade. Abundance of herring reached near historical high levels from 2002-2004 exceeding 100,000 mt. However, the 2003 and 2004 year-class are relatively weak resulting in a substantial decline in abundance in recent years. Nevertheless, the stock remains at a healthy level in the short term.

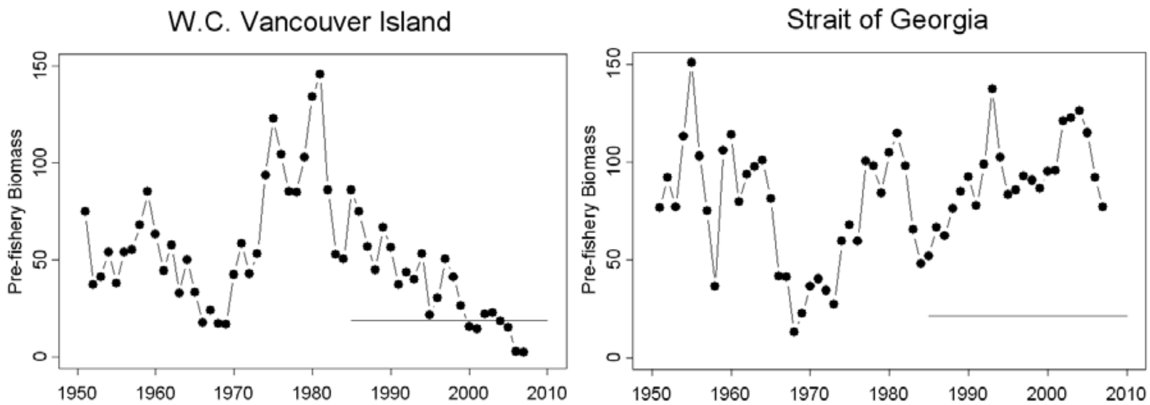


Figure 14. Herring abundance on the West Coast of Vancouver Island and in the Strait of Georgia to 2007. No commercial fishing is allowed when biomass drops below the horizontal lines in each panel. Central and North Coast biomasses were closer to this fishing limit.

Bottom trawl surveys using a small-mesh net (targeting the smooth pink shrimp *Pandalus jordani*) have been conducted during May since 1973. The survey in 2007 found that the biomass of *Pandalus jordani* shrimp off central Vancouver Island was low and similar to that from 2004 to 2006. Pink shrimp biomass continues to be affected by the warm ocean conditions from 2003 to 2005, likely a result of poor recruitment during this period and a 2-yr time lag to capture by the survey. Biomass of most other "key" indicator species continued to decline from record highs (for some species) in 2005; exceptions in 2007 were increases of both warm (Pacific hake) and cool (walleye pollock) water species.

Appendix 1. List of workshop participants

Steve Baillie	DFO[1]	Sonia Batten	SAHFOS[2]	Richard Beamish	DFO
Steve Bograd	NMFS[3]	Jim Boutillier	DFO	Edmundo Casillas	NMFS
Al Cass	DFO	Peter Chandler	DFO	Ken Cooke	DFO
Bill Crawford (Editor)	DFO	George Cronkite	DFO	Richard Dewey	VENUS[4]
Deborah Faust	DFO	Howard Freeland	DFO	Moira Galbraith	DFO
Elysha Gordon	DFO	Jim Gower	DFO	Sue Grant	DFO
Mark Hipfner	EC[5]	John Holmes	DFO	Roy Hourston	DFO
Karen Hunter	DFO	Kim Hyatt	DFO	Debby Ianson	DFO
Jim Irvine (Editor)	DFO	Krista Lange	DFO	Dave Mackas	DFO
Diane Masson	DFO	Sandy McFarlane	DFO	Skip McKinnell	PICES[6]
Cheryl Morgan	NMFS	Laurie Neil	EC	Chrys Neville	DFO
Dave O'Brien	DFO	Chuck Parken	DFO	Angelica Peña	DFO
Ian Perry	DFO	Bill Peterson	NMFS	Paul Rankin	DFO
Marie Robert	DFO	Kate Rutherford	DFO	Jake Schweigert	DFO
Frank Schwing	NMFS	Margot Stockwell	DFO	Rusty Sweeting	DFO
Ron Tanasichuk	DFO	Richard Thomson	DFO	Marc Trudel	DFO
Frank Whitney	DFO	Greg Workman	DFO	Yan Xue	NCEP[7]

[1]Fisheries and Oceans Canada
[2]Sir Alister Hardy Foundation for Ocean Science, Plymouth, UK
[3]United States National Marine Fisheries Service
[4]Victoria Experimental Network Under the Sea, University of Victoria
[5]Environment Canada
[6]PICES is the North Pacific Marine Science Organization
[7]United States National Centers for Environmental Prediction, NOAA

Appendix 2. Additional sources of information

DFO Links
Ocean Science Division: http://www-sci.pac.dfo-mpo.gc.ca/osap/default_e.htm
Marine Ecosystems and Aquaculture Division: http://www.pac.dfo-mpo.gc.ca/sci/aqua/default_e.htm
Salmon and Freshwater Ecosystems Division: http://www-sci.pac.dfo-mpo.gc.ca/fwh/index_e.htm
Canadian Hydrographic Service: http://www-sci.pac.dfo-mpo.gc.ca/charts/tides/home_e.htm
Pacific Scientific Advice Review Committee: http://www.pac.dfo-mpo.gc.ca/sci/psarc/Default_e.htm

Environment Canada Green Lane http://www.ec.gc.ca/default.asp?lang=En&n=FD9B0E51-1

USA National Marine Fisheries Service http://www.nmfs.noaa.gov/

USA National Centers for Environmental Prediction, NOAA www.**ncep**.noaa.gov/

VENUS University of Victoria http://www.venus.uvic.ca/

PICES (North Pacific Marine Science Organization) www.**pices**.int/

Appendix 3 – Individual reports

Global ocean conditions: Classical La Niña

Bill Crawford, Fisheries and Oceans Canada

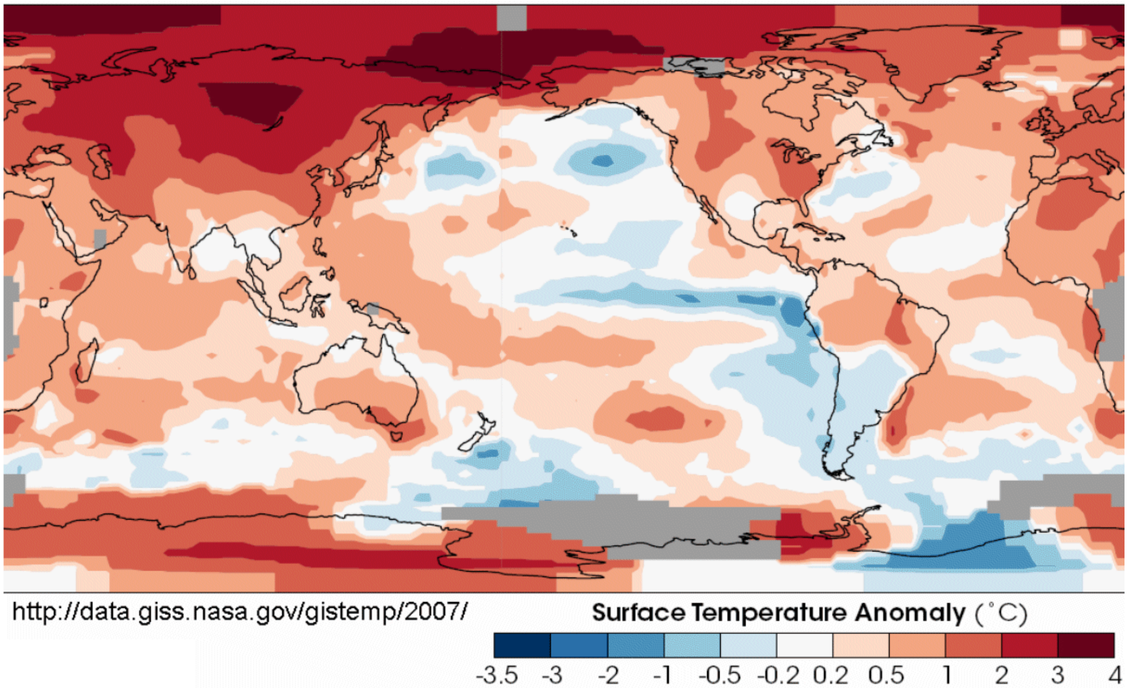


Figure 1. Surface temperature anomaly in 2007 relative to the 1951-1980 mean, based on surface air measurements at meteorological stations and ship and satellite measurements of sea surface temperature. Source: NASA Goddard Institute for Space Studies.

Ocean surface waters warmed almost everywhere in 2007, except in those parts of the Pacific Ocean that normally cool during La Niña conditions. The western tropical Pacific Ocean was warmer than normal, due to stronger trade winds of La Niña. Blue regions in Fig. 1 in the northeast Pacific Ocean and along the Equator near South America are cold waters associated with La Niña winds. The cold waters of the northeast Pacific Ocean extended all the way to the West Coast of Canada and USA, as noted later in this report, greatly impacting local marine life.

According to the NASA Goddard Institute for Space Studies, the temperature over land and ocean in 2007 was tied with 1998 for the second warmest year in the era of instrument data. Significantly this warming took place during a La Niña event when global temperatures are usually cooler. The most anomalously warm ocean surface appeared in the Arctic Ocean north of Bering Strait. This warming contributed to the record low ice coverage in the Arctic Ocean in late summer 2007.

Land temperatures in 2007 were the highest since the beginning of instrumental record in the later 1800s, as shown in the lower panel of Fig. 2 on the next page. Temperatures were well above normal in Europe and central Russia, parts of North America, North Africa and Brazil. Land temperatures have risen steadily since the 1970s, but the moderating effect of ocean temperatures has kept the global average temperature over land and sea from rising as rapidly.

Observations in Fig. 3 (next page) reveal patterns of sea surface pressure averaged over all Januaries from 1947 to 2007, and for January 2008. Both the North Pacific High (labelled H) and Aleutian Low (labelled L) were more intense than normal in Jan. 2008, and their location forced strong winds (black arrows) from the north-northwest, greatly cooling the eastern Gulf of Alaska.

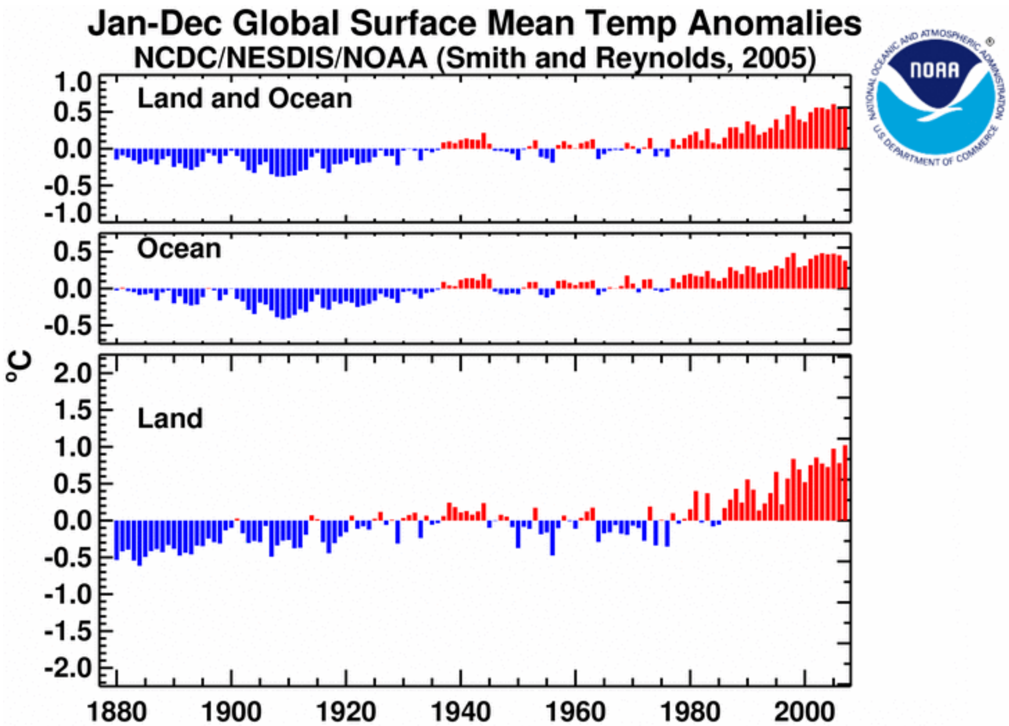


*Figure 2. Time series of annual average temperature anomalies over the globe, reference to the period 1901 to 2000. Source: [NOAA National Satellite and Information Service, National Climatic Data Center](). Details of analyses are given by Smith and Reynolds, 2005, A global merged land air and sea surface temperature reconstruction based on historical observations (1880-1997), J. Climate, **18**, 2021-2036..*

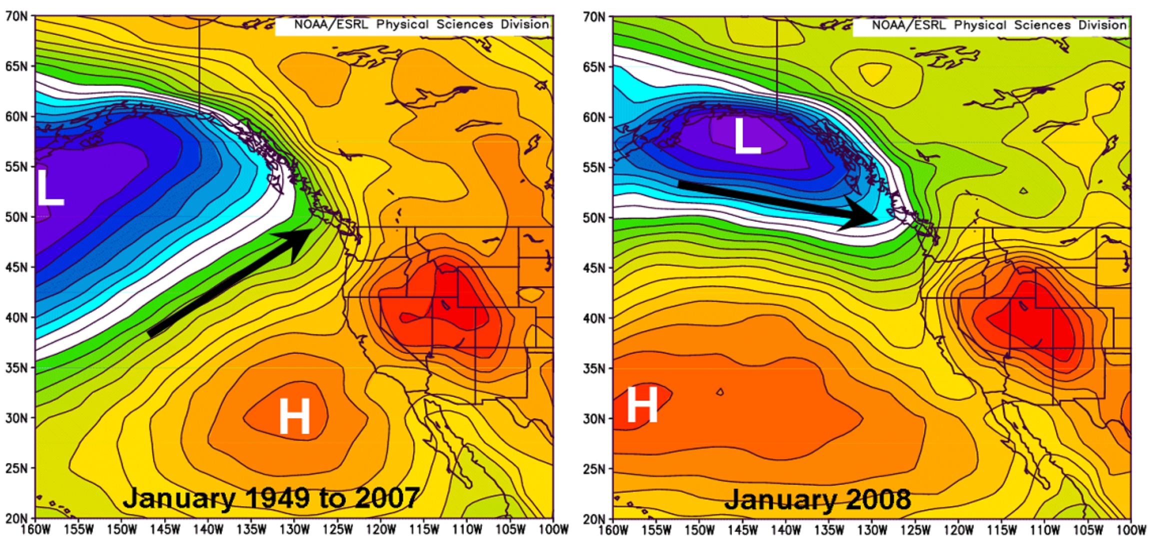


Figure 3: Average sea surface pressure for January from 1949 to 2007 (left), and January 2008 (right). Contours are at 1 mbar intervals, with the same scale for each panel. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder Colorado.

El Niño and La Niña periods are useful indicators of sea surface temperatures (SST) in the northeast Pacific Ocean and along parts of the West Coast of Canada and USA. Cooling in 1999-2002 and in 2007-08 accompanied Las Niñas. Los Niños of 2002 to 2004 led to very warm surface waters along Line P in 2004. The maps below (Fig. 4) show tropical Pacific sea surface temperatures from January 2007 to March 2008, revealing the evolution of this most recent La Niña.

Sea Surface Temperature

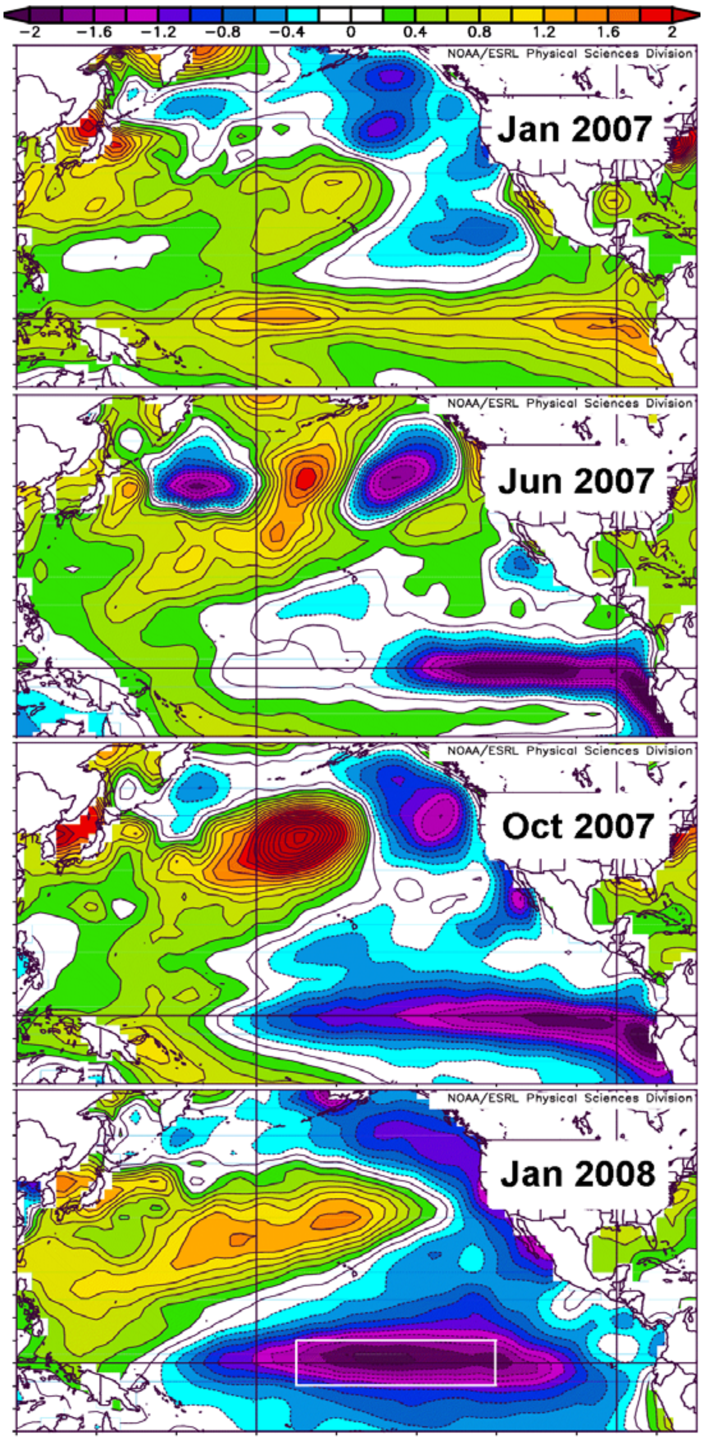


Figure 4. Monthly SST anomalies in the Pacific Ocean, from Jan. 2007 (top panel) to Jan. 2008 (bottom panel). Colour bar at top gives the anomaly scale in °C. The Niño 3.4 region is outlined in white in the bottom panel. The SST anomaly in this box defines the Oceanic Niño Index (ONI), an official indicator of strength of El Niño and La Niña (collectively denoted ENSO).

A weak El Niño developed in late 2006, and the warm tropical Pacific waters of this event are shown in the January 2007 SST anomalies in the top panel of Fig. 4. The blue and purple regions in the following months reveal the progression of relatively cool La Niña waters from the eastern Pacific toward the west. Coldest waters in Niño 3.4 arrived in early 2008, as shown in the January 2008 panel. By March 2008 the eastern tropical Pacific was warmer than normal, temperature in Niño 3.4 was less cool, and the peak of La Niña 2007-08 had passed.

Note the cool waters west of Canada and Washington State, and warmer waters in the central North Pacific. Both regions often respond in this manner during La Niña winters. Temperature anomalies were negative along the West Coast in all seasons except summer 2007.

To be classified as a full-fledged ENSO (El Niño or La Niña), the ONI must exceed a magnitude of 0.5°C for a period of at least 5 consecutive overlapping 3-month intervals. ONI is positive for El Niño, negative for La Niña. The ONI for January to March 2008 was -1.4 °C. The 2007-08 event met or exceeded 0.5°C in magnitude for all seven 3-month intervals since July to September 2007, and is an official La Niña.

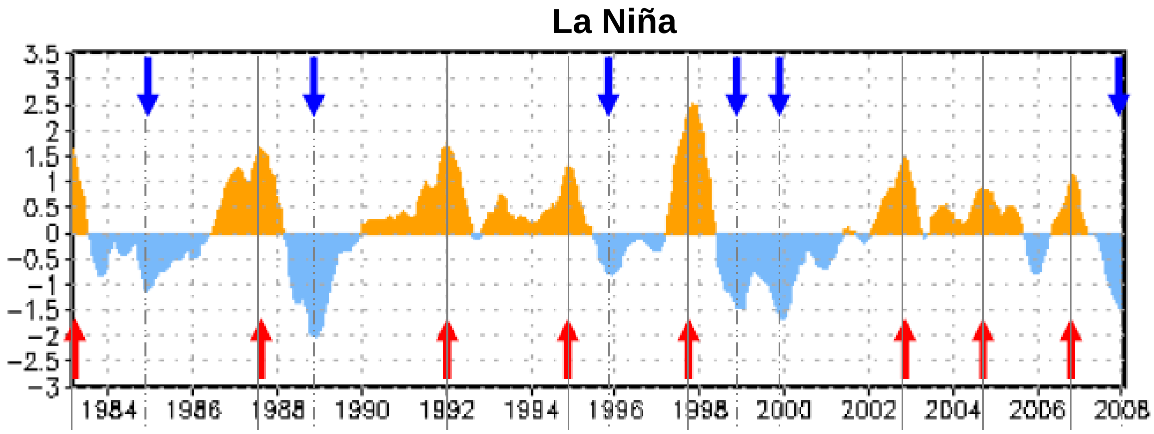


Figure 5. Time series of the Oceanic Niño Index (ONI), Red and blue arrows denote El Niño and La Niña events since 1983. ONI is positive for El Niño (red arrows), negative for La Niña (blue arrows).

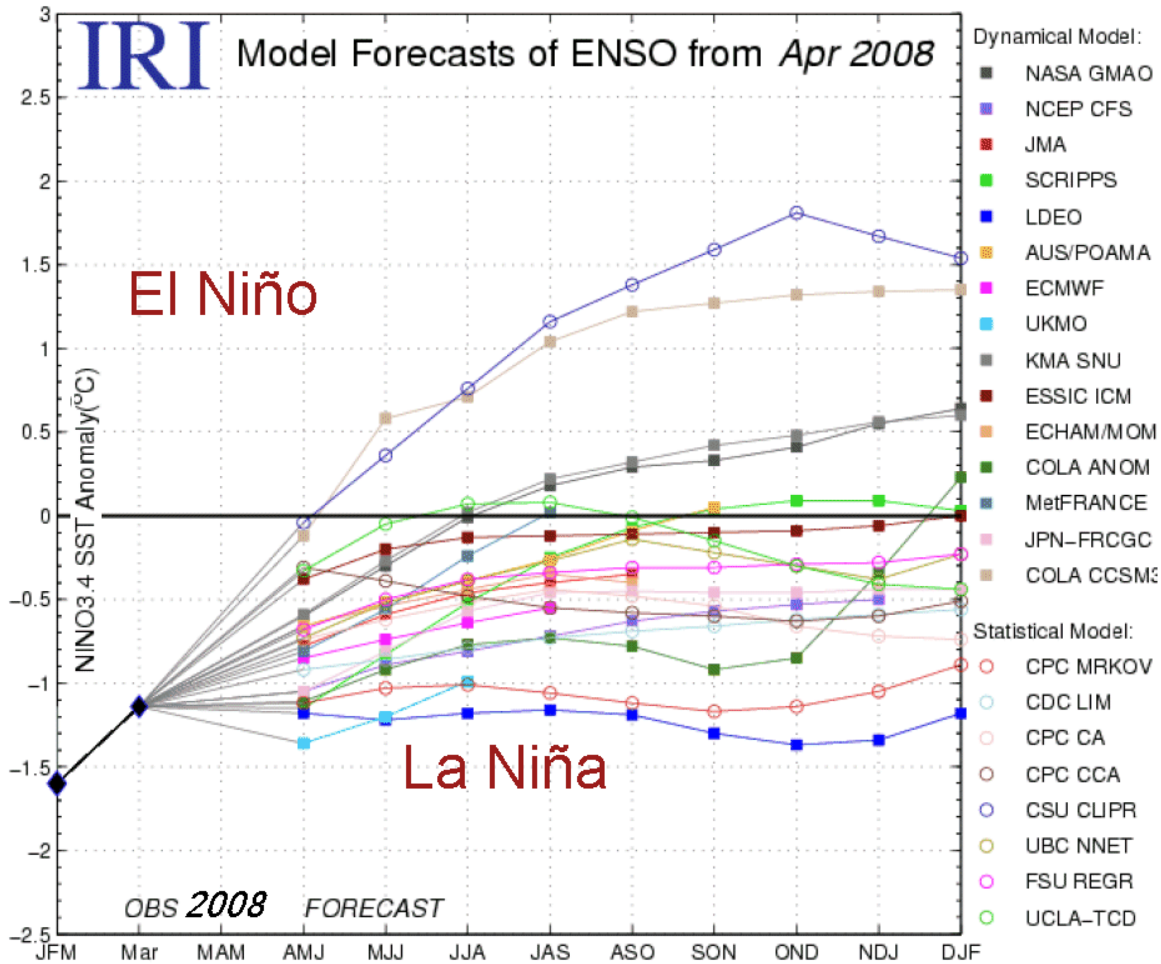


Figure 6. Predictions of Oceanic Niño Index by various ENSO models. Agencies providing predictions are listed along the right side of the figure. Although the accuracy of any one predictive model is difficult to assess, the ensemble of these predictions provides a useful indicator of events many months into the future. The present La Niña is decaying, and ONI should reach neutral values (± 0.5°C) by summer 2008.

Climate Indices and ocean temperature

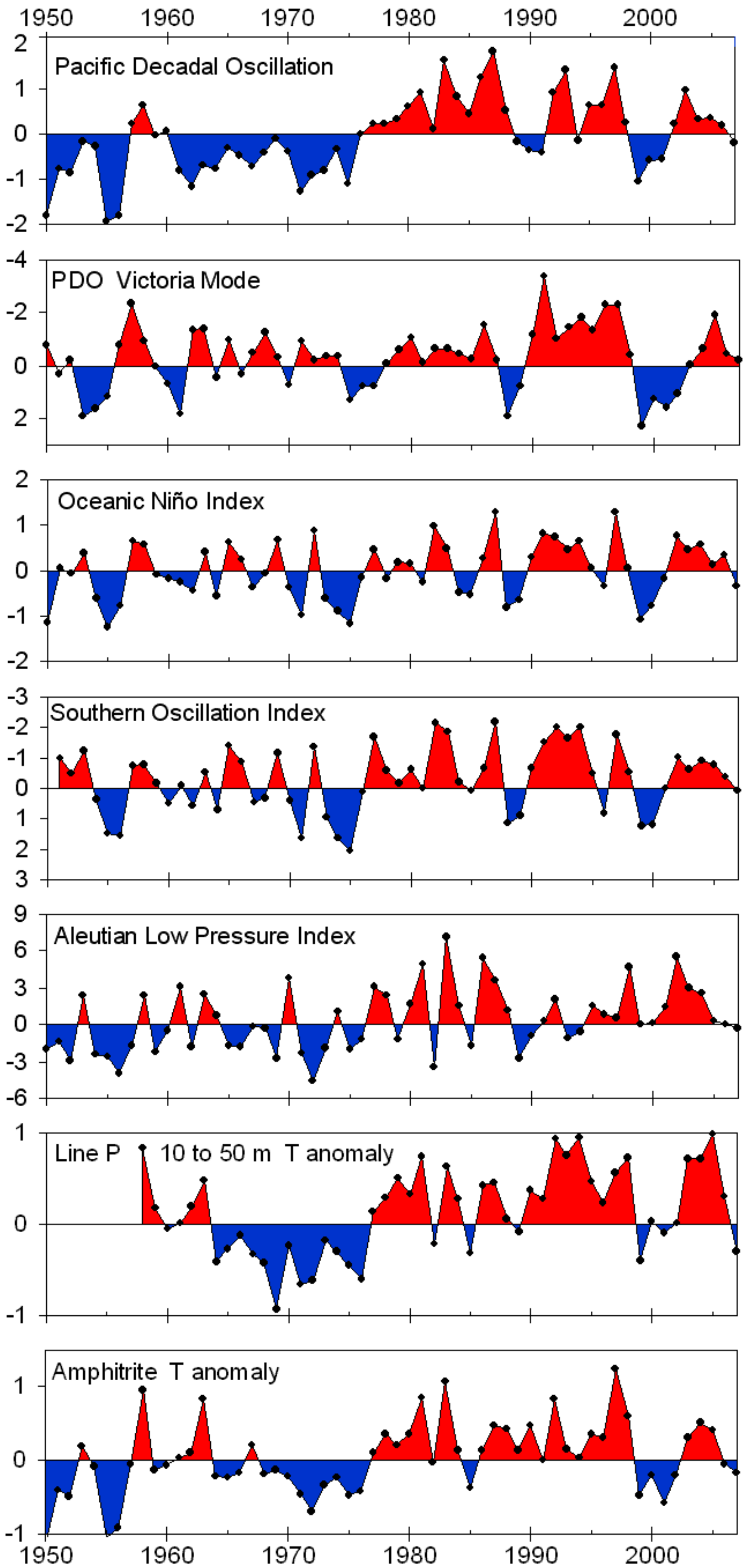


Fig. 7 at left displays a set 57-year time series representing climate of the North Pacific Ocean plus El Niño and the [Southern Oscillation Index (SOI).](#)

Figure 7. Indices of Pacific Ocean climate plus temperature anomalies (°C) of the Oceanic Niño Index and at [Amphitrite Point](#) and along [Line P](#). The Southern Oscillation Index and the [PDO – Victoria Mode](#) are inverted so their variability is in phase with other series.

Most of these series display common variability, with blue regions prevailing prior to the regime shift near 1977, and red regions after then.

All time series shift from blue toward red for several years centred on 2000. This shift indicates actual cooling in the eastern Gulf of Alaska (Line P) and along the west coast of Vancouver Island (Amphitrite Point), and in Niño 3.4 ([Oceanic Niño Index](#)). In general, this cooling aligns with La Niña, negative PDO and Aleutian Low Pressure Index, positive Victoria Mode, and Southern Oscillation Index.

Warming along Line P and at Amphitrite Point in 2002-2004 coincides with El Niño, positive PDO and negative PDO-Victoria Mode.

Cooling since 2005 accompanies La Niña, negative PDO and positive PDO–Victoria Mode.

These relationships generally hold, but there are several exceptions. For example, the El Niño of 1972 was a major event in the tropical Pacific, but Line P and Amphitrite remained cool.

Sources of data for time series

plotted at left are listed below.

Pacific Decadal Oscillation (PDO) is based on analysis of Mantua et al. (1997) and Zhang et al. (1997). The time series was provided at this Internet site of the Joint Institute for Studies of Atmosphere and Ocean of NOAA in Seattle: http://jisao.washington.edu/pdo/PDO.latest

Mantua, N.J. and S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis,1997: A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society, 78, pp. 1069-1079.

Zhang, Y., J.M. Wallace, D.S. Battisti, 1997: ENSO-like interdecadal variability: 1900-93. J. Climate, 10, 1004-1020.

PDO – Victoria Mode is first described by Bond et al. (2003). The time series was provided by Muyin Wang of JISAO/NOAA, in Seattle. For this analysis she computed the EOF patterns based on 1950-99 SST and then regressed the SST to the spatial patterns to get the entire time series. The advantage of doing this is that from now on, the old numbers won't change, and each year one can simply add one more new number at the end. The SST data used is the HadCRUT3v.

Bond, N. A., Overland, J.E., Spillane, M., Stabeno, P., 2003: Recent shifts in the state of the North Pacific. *Geophysical Research Letters*, 30(23), 2083, doi:10.1029/2003GL018597.

Oceanic Niño Index (ONI) is provided by the NOAA/ National Weather Service National Centers for Environmental Prediction Climate Prediction Center, Camp Springs, Maryland: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Southern Oscillation Index is available at: http://www.cpc.ncep.noaa.gov/data/indices/soi.

Aleutian Low Pressure Index (ALPI) is based on analyses by McFarlane and Beamish (1992) and Beamish et al. (1997). Updated indices are provided by Fisheries and Oceans Canada at this Internet site: http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/downloads/indices/alpi.txt

McFarlane, G.A., and R.J. Beamish, 1992: Climatic influence linking copepod production with strong year-classes in sablefish. *Canadian Journal of Fisheries and Aquatic Sciences*, 49(4), 743-753.

Beamish, R.J., C.E. Neville and A.J. Cass, 1997: Production of Fraser River sockeye salmon (*Oncorhynchus nerka*) in relation to decadal-scale changes in the climate and the ocean. *Canadian Journal of Fisheries and Aquatic Sciences*, 54, 543-554.

Line P temperature anomalies are based on Crawford et al. (2007) and are available at the Internet site: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/linep/linepselectdata_e.htm.

Crawford, W. R., Galbraith, J., Bolingbroke, N., 2007: Line P ocean temperature and salinity, 1956-2005. *Progress in Oceanography*, 75**,** 161-178, doi:10.1016/j.pocean.2007.08.017.

Monthly average **Amphitrite temperature** time series are provided by Fisheries and Oceans Canada at this Internet site:
http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm

Northeast Pacific and Gulf of Alaska

Cooling ocean from summer 2007 to winter 2008

Bill Crawford, Fisheries and Oceans Canada

Ocean surface temperatures this past winter from the Canadian coast to 160°W were among the coldest ever observed in the historical record. The very cold temperature anomalies of January to March 2008 are in direct contrast to conditions in the summer of 2005, when temperatures were close to record high levels. Although ocean surface temperatures in summer 2007 were close to long term averages, the strong westerly winds through autumn 2007 and into the winter of 2008 dropped surface temperatures below average winter levels.

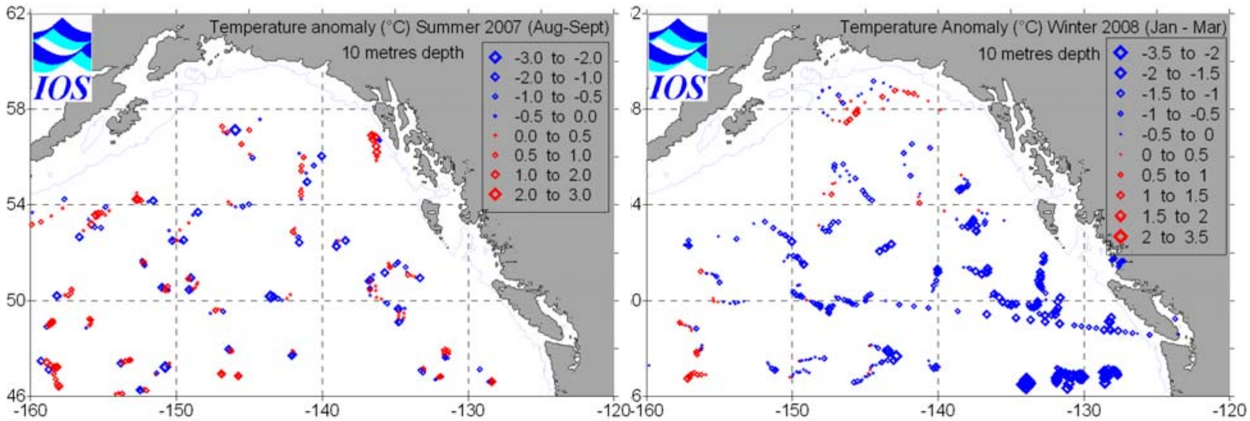


Figure 1. Temperature anomalies (relative to average conditions in historical data from 1931 to 2005) as measured by Argo profilers, and by DFO surveys in the Gulf of Alaska and coastal waters of British Columbia. Each symbol represents a measurement at 10 metres depth.

Surface waters of the Gulf of Alaska were fresher than normal through the summer of 2007, perhaps due to very high precipitation in British Columbia the previous winter. However, by winter 2008 the ocean surface salinity was at nearly normal levels. We suspect the very strong westerly winds in autumn 2007 and winter 2008 mixed high salinity water to the ocean surface from depths below the surface mixed layer.

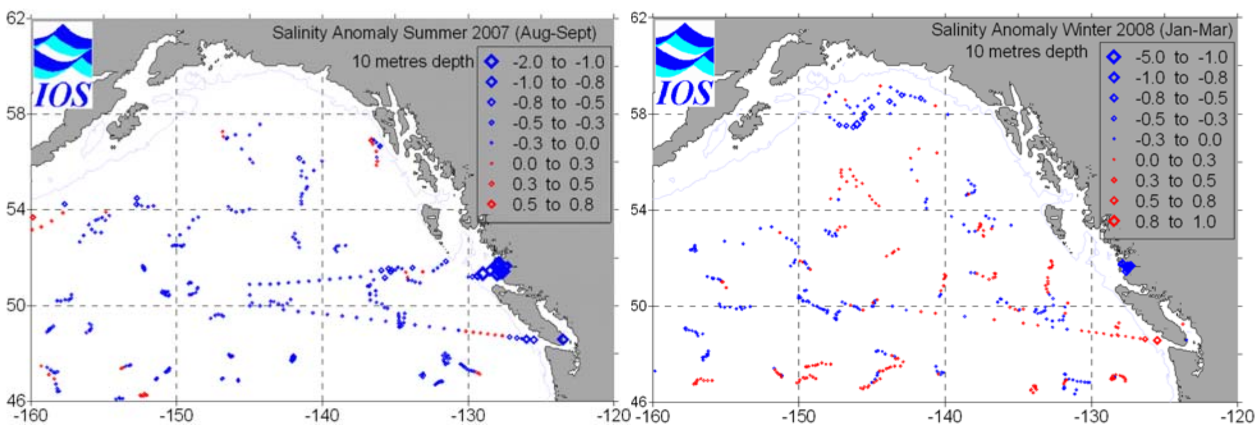


Figure 2. Salinity anomalies (relative to average conditions in historical data from 1931 to 2005) as measured by Argo profilers, and by DFO surveys in the Gulf of Alaska and coastal waters of British Columbia. Each symbol represents a measurement at 10 metres depth.

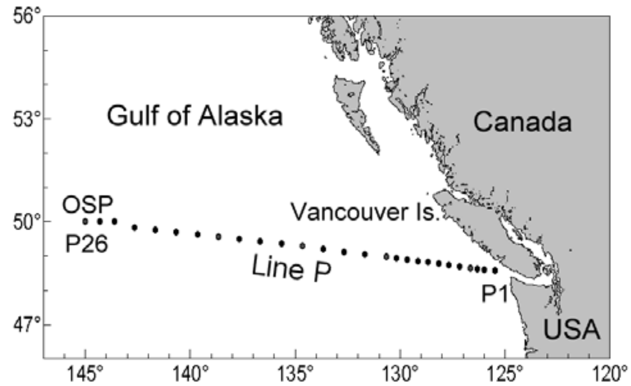


Figure 3 (at left).

Location of the Line P set of oceanographic sampling stations.

Figure 4 (below).

Changes in temperature along Line P. Colour contours present anomalies in temperature (°C) along Line P, in both space and time. Colour scale is at bottom of each panel.

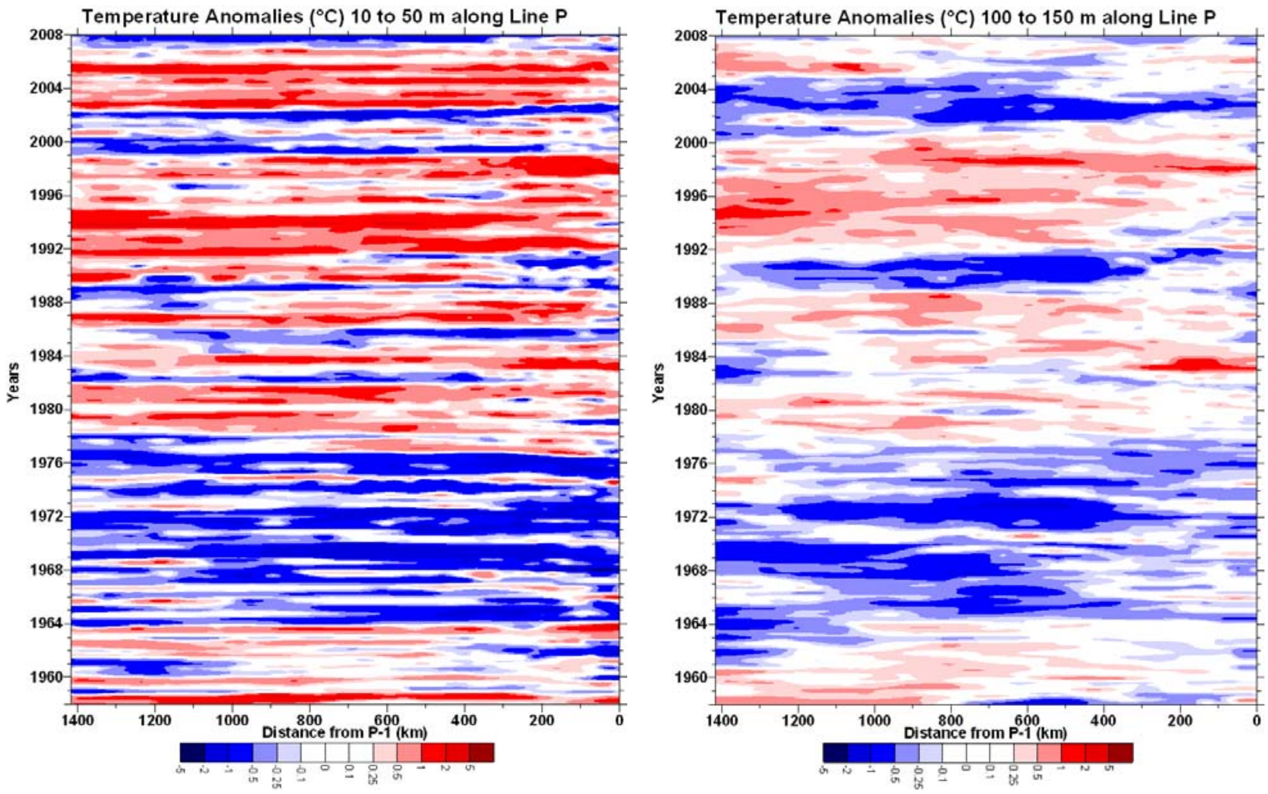


Fig. 4 displays changes in temperature anomalies in two layers near the ocean surface over the past 50 years along Line P. Most recent anomalies are presented at top of each panel. The right side of each panel reveals anomalies near the West Coast of Vancouver Island; the left side shows anomalies at Ocean Station Papa (OSP). These plots are based on thousands of measurements along Line P.

Temperature at 10 to 50 metres below the ocean surface was below normal level in late 2007, (left panel above) having fallen to levels last measured in 2002. Less cooling was observed at 100 to 150 metres below surface (right panel above).

Additional plots (and text files) are provided on the Line P Internet site.

http://www-sci.pac.dfo-mpo.gc.ca/osap/projects/linepdata/default_e.htm

Details of these plots are given by Crawford, W.R., Galbraith, J., Bolingbroke, N., 2007: Line P ocean temperature and salinity, 1956-2005, *Progress in Oceanography* 75, 161-178, doi:10.1016/j.pocean.2007.08.017.

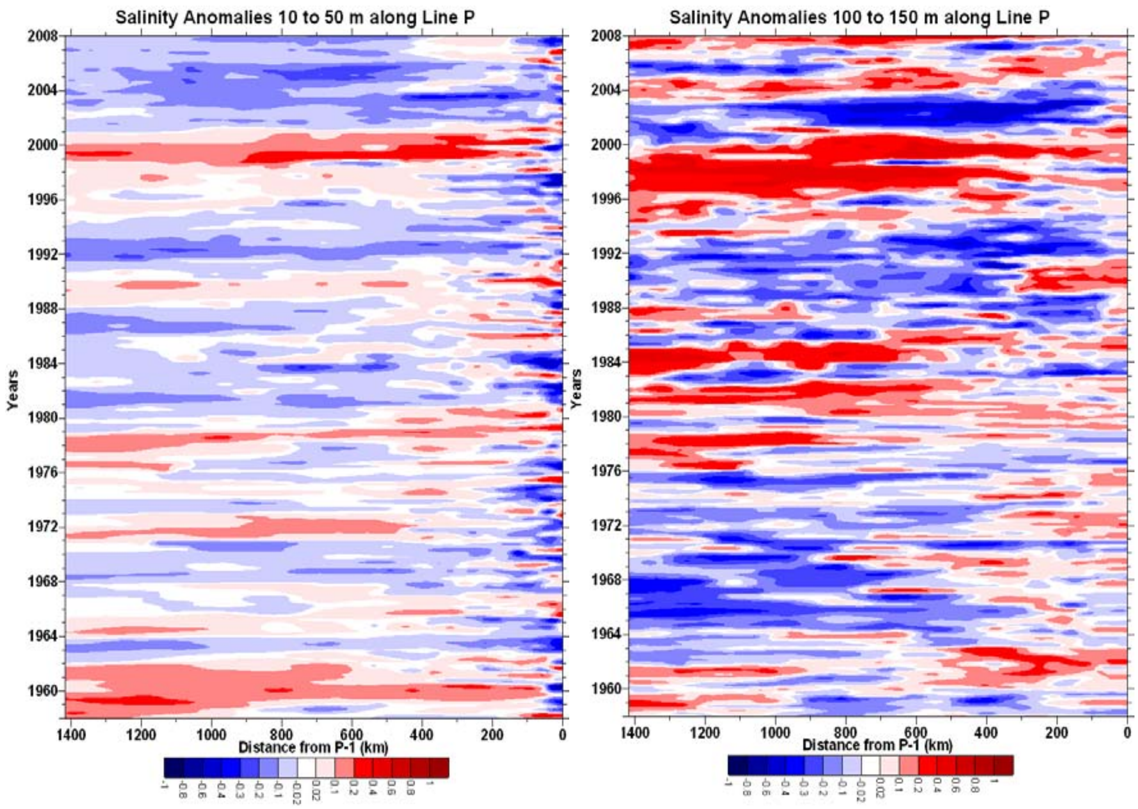


Figure 5. Changes in salinity along Line P. Colour contours present anomalies in salinity (psu) along Line P, in both space and time. Colour scale is at bottom of each panel.

Salinity has been relatively low since 2002 in the near-surface layer at 10 to 50 metres below ocean surface. Freshest near-surface waters were in 2005-06 midway along Line P. The salty waters in 1999 to 2000 in both layers appeared during the previous La Niña. This present La Niña has not carried such salty waters to the near-surface layer at 10 to 50 m depth.

Argo views the Gulf of Alaska in 2007

Howard Freeland, Fisheries and Oceans Canada

The Argo Observing System launched its 3000th ocean profiler in October 2007; providing real-time observations of all the oceans from surface to 2000 metres depth.

The observations recently revealed some very odd ocean conditions in the N.E. Pacific and most of it I can't explain. Argo has had a global array in place now for several years and has been able to map properties in the Gulf of Alaska for a much longer time. Most properties of the ocean are mapped using "objective analysis". One of the valuable byproducts of the Gauss-Markov theorem that underpins objective analysis is that it naturally supplies an error estimate that is independent of the property being estimated, this is shown in Fig. 1. Where the error estimate is low, confidence is high. This particular error estimate was derived from a computation of mixed-layer depths, but the only information required to find the error field is the correlation scale and the location of observations, the same error field would arise if we mapped temperature or salinity using the Gauss-Markov theorem and the same correlation scale.

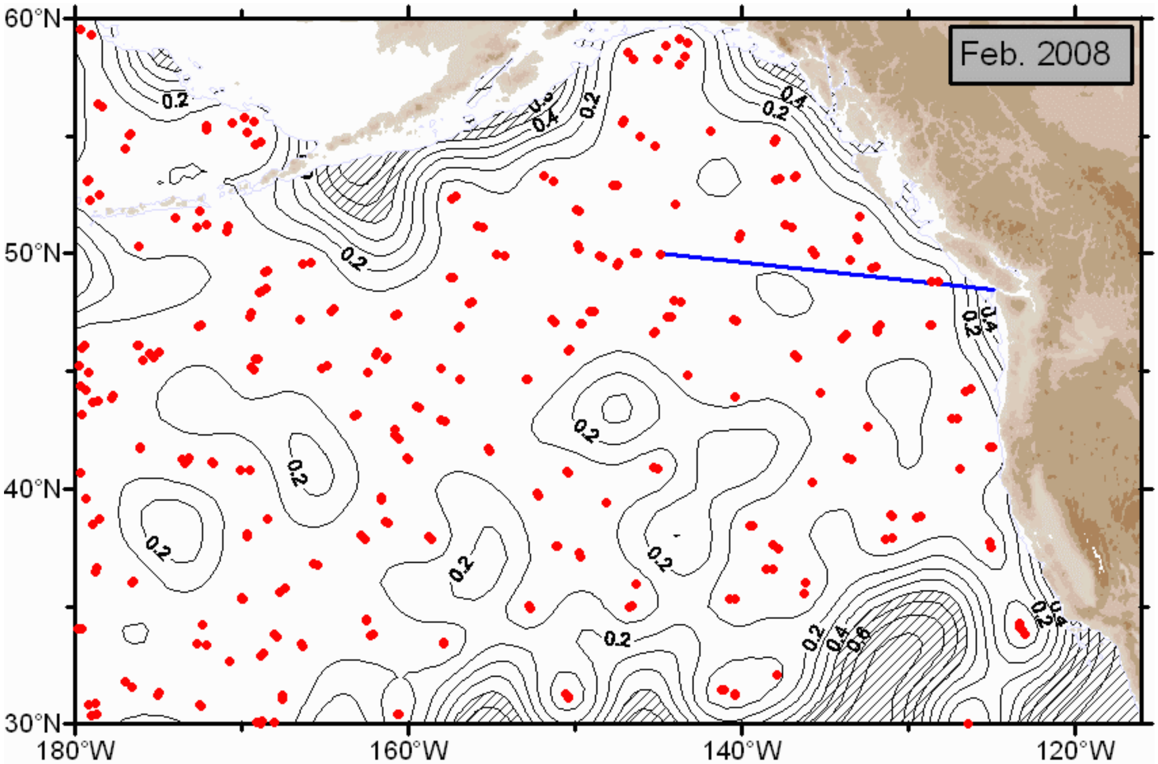


Figure 1: This shows the distribution of Argo float observations during February 2008 (red dots) and the expected error distribution assuming an objective analysis procedure using a Gaussian covariance function. Where expected error is low, confidence is high. Units are standard deviations. For example, on the 0.2 contour we can map mixed-layer depth to within ±0.2 standard deviations

Each month the data from Argo floats are interpolated onto the stations that comprise Line-P. We have an excellent climatological description of conditions along Line-P so this gives us the ability to map deviations from normal. None of the sections are presented here, but I note that early in 2007 a positive salinity anomaly appeared in the sections that intensified steadily through the year dominating observations along Line-P by the end of the year. In early 2008 this anomaly is still present and centred below the main pycnocline below 125 metres depth. The source of this becomes evident if we examine the variations in density at Ocean Station Papa.

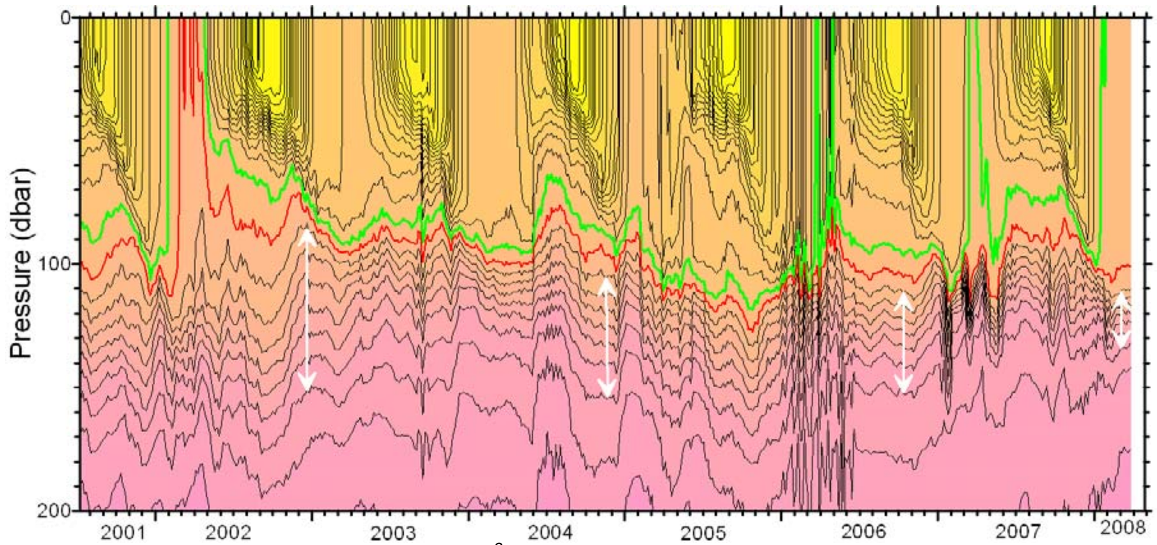


Figure 2: Sigma-t (density minus 1000 kg/m^3) versus pressure and time interpolated from Argo to Ocean Station Papa.

In Fig. 2 we show how density has varied at Station Papa from 2001 to 2008. Two density surfaces are highlighted, sigma-t = 25.8 in green and 25.9 in red. This shows that mixing occurred down to a deep level during the winter of 2001/02, then followed three winters with extremely weak vertical mixing and a return to normal in recent winters. Still, in the winter of 2008, mixing has not been deep enough to raise the sigma-t = 25.9 value to the surface but it is close, one big storm in March should accomplish that for the first time since the winter of 2001/02. What is very striking is the steady decrease in separation of some of the deeper density surfaces, as shown by the white arrows. In late 2002 the density surfaces 26.0 and 26.6 were separated vertically by 80 metres, in late 2004 this had decreased to 50 metres and continuing to 35 metres and 25 metres in late 2006 and early 2008 respectively. This could be caused by a change in the winds. It is known that deep vertical velocities are related to the curl imparted by large-scale winds. It might also be related to changes in the major current systems. At the moment we don't know which of these is causing the change in the large scale density structure of the ocean in the N.E. Pacific.

Fig. 3 shows a specimen circulation map for the N.E. Pacific. All maps show flow crossing the dateline at left from the western Pacific in a broad current system. As this flow approaches the West Coast it splits into two branches, one heading northwards and forming the circulation of the Gulf of Alaska, and the other heading south into the California Current. Following methods developed in Freeland and Cummins (2005) we identify permanent highs and lows to make objective measures of the strength of various current systems and these current strength indicators are plotted in Fig. 4.

Fig. 4 shows that the North Pacific Current had a relatively low flow in mid 2004, but since that time, though there has been a lot of low frequency variability, the amount of water transported to the east has been steadily increasing with record high flows (record since 2002 when Argo was first able to map current systems) in late 2007. Since then there has been a small decrease in the flow rate in the early months of 2008. At the same time we have seen an increase in the flow in the California Current, suggesting that not much of the increased flow from the N. Pacific Current seems to be showing up in the Gulf of Alaska. But clearly, as we explore the causes of the changes in the distribution of deep density layers and the changes in dissolved oxygen reported elsewhere in this volume, we must remember that the distribution of currents has changed significantly over the last few years. It is odd that the strongest flow in the North Pacific Current during the last 6 years occurs at the same time as the tightening of the separation between density surfaces at Station Papa. Can these two observations be linked?

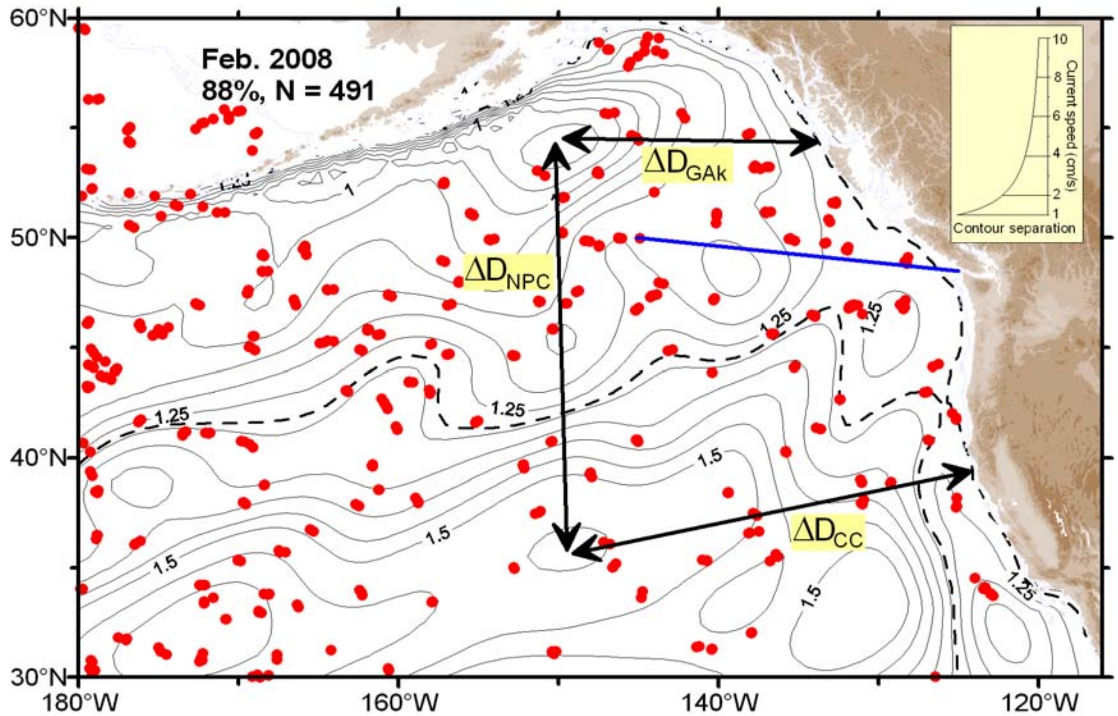


Figure 3: A typical circulation map for the N.E. Pacific. The blue line shows Line-P for reference. Flow is along contour lines with the bold-dashed line being the "dividing streamline" that separates water that heads into the Gulf of Alaska from that which heads into the California Current system. Arrows show the points used to compute the differences in dynamic height, and so the strength of individual currents.

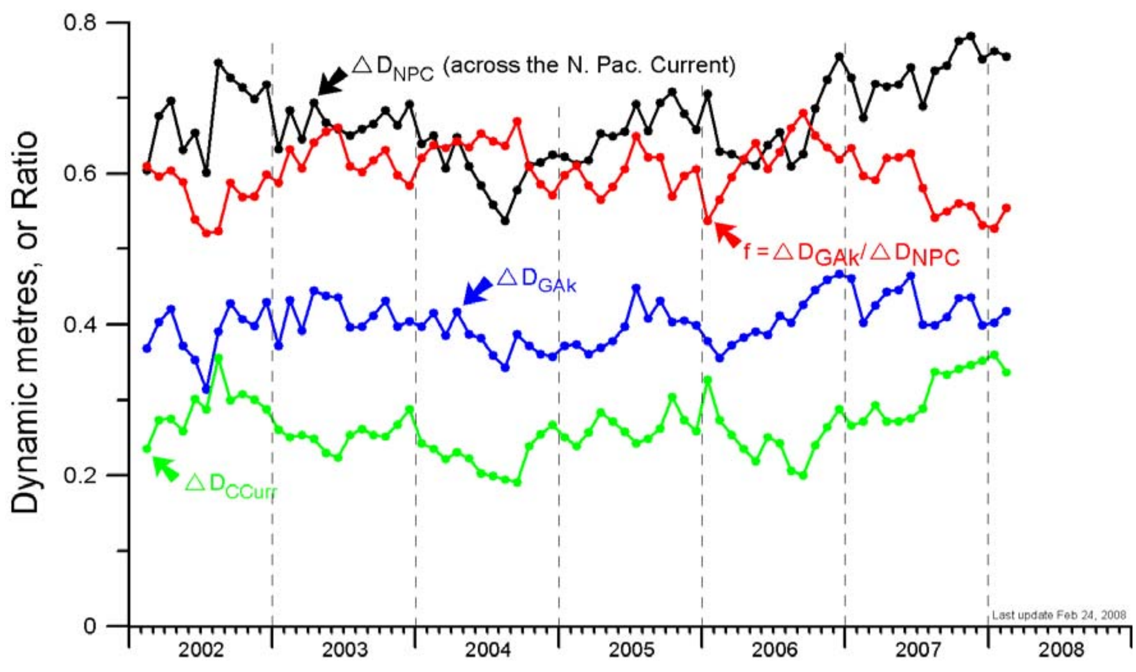


Figure 4: Current strength indicators for the strength of the North Pacific Current (black), the Alaska Gyre (blue) and the California Current (green). The red line shows the fraction of water from the North Pacific Current that heads into the Gulf of Alaska.

Finally, Argo allows us to observe the variations in mixed-layer depth over the last few years. In Fig. 5 four maps of the mixed-layer depth are shown for February of each of a few recent years.

The first two, 2004 and 2005 show data for winters under the influence of the period of high near-surface stratification. Mixed layers are produced by wind action at the surface which generates turbulence which then starts to mix the near-surface waters. As mixing occurs dense water is moved upwards in the water column. Thus the depth of mixing is effectively a balance between the amount of energy used to generate turbulence and the increase in potential energy of the water column. The result is that mixing is less deep when stratification is high and the deep nutrient sources are then less available for biological production.

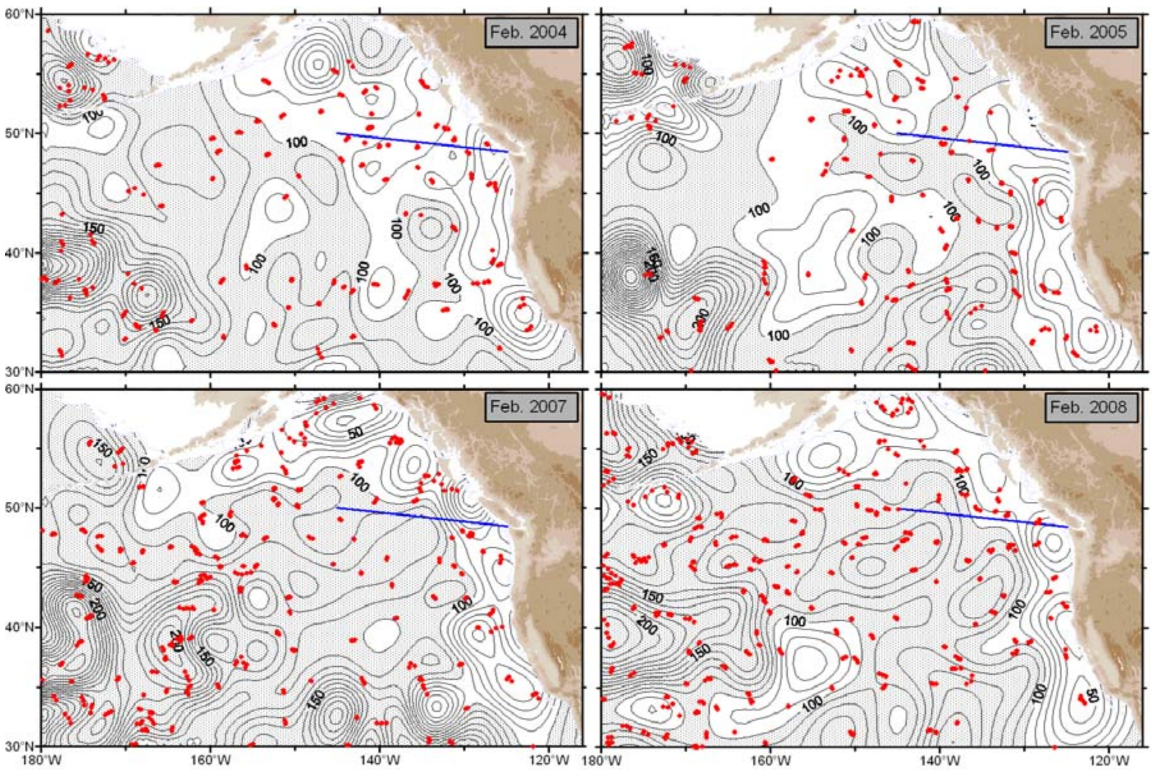


Figure 5: Mixed layer depths in February for each of 4 representative recent years. The red dots show where observations are available, the blue line shows Line-P for reference and contours are at intervals of 5 metres. Areas with mixed-layer depths greater than 100 metres are shaded.

During the winter of 2003/4 the winds had supplied insufficient energy to develop mixed layers of 100 metres depth in the eastern Gulf of Alaska. There was a slight return towards normal conditions in the winter of 2004/5 but it was not until the two most recent winters that normal conditions truly prevailed again. The mixing in the winter of 2007/8 has been intense and should result in a high supply of macro and micro nutrients to the surface waters.

Reference:

Freeland, H. J. and P. Cummins. 2005. Argo: a new tool for environmental assessment and monitoring of the world's oceans. Progress in Oceanography 64(1), 31-44.

Seasonal nutrient drawdown by phytoplankton: Line P and Skaugran cruises

Frank Whitney and Marie Robert, Fisheries and Oceans Canada

Scientists of Fisheries and Oceans Canada manage observation programs on research vessels along Line P in the northeast Pacific Ocean, and on the commercial vessel *Skaugran* across the North Pacific Ocean. Both the Line P and *Skaugran* programs measure nitrate concentrations in surface waters in late winter and late summer. Measurement from these two seasons allows us to estimate the spring and summer drawdown of nutrient from various regions in this domain. Differences in nitrate concentration between February and September provide a reasonable estimate of spring and summer new production (primary production supported by nitrate), but do not account for either additional nutrient supply from mixing or for the depth range over which production occurs. Because coastal waters are strongly mixed and can have high inputs of nutrient from estuarine circulation, nutrient drawdown estimates are meaningless in these regions. In fact, nitrate is often higher in summer, due to upwelling or other coastal processes. Therefore we discuss only deep-sea measurements below.

Fig. 1 shows the spring and summer drawdown of nitrate, averaged over many years. More nitrate is supplied to the ocean surface in the Alaska Current (AC) region than in other regions, with most of this nutrient being consumed by phytoplankton, resulting in the highest rate of drawdown (Top left red box, 12.5 µM). To the southeast, less nutrient is supplied along Line P and iron limitation is severe. As a consequence, nitrate drawdown is lower (Blue boxes, 6.8 to 7.1 µM).

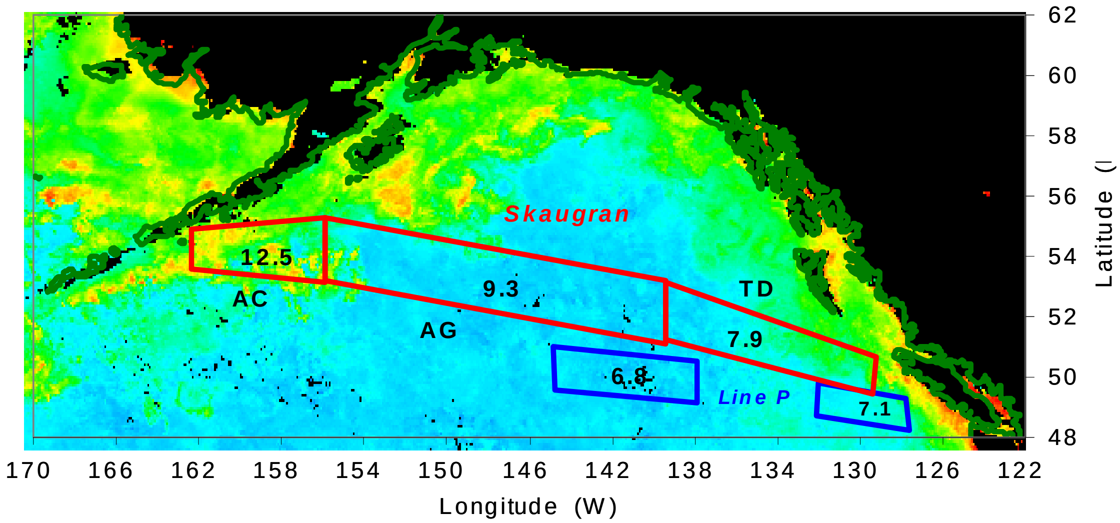


Figure 1. Average nitrate drawdown (µM) in spring and summer in five regions within the subarctic northeast Pacific (Alaska Current, AC; Alaska Gyre, AG; Transitional Domain, TD; and two regions along Line P which represent TD and High Nutrient-Low Chlorophyll waters). The background is a MODIS image (http://oceancolor.gsfc.nasa.gov/) of chlorophyll at the ocean surface in the spring of 2007.

Line P surface nutrients have been measured most years since 1988, and the Skaugran sampling program has been underway since 1995. (Unfortunately, *Skaugran* missed sampling in 2007.) Using all years with available data (17 for Line P and 12 for *Skaugran*), averages of nitrate drawdown were calculated and annual anomalies computed (Fig. 2). These data show that both 2006 and 2007 were fairly average years, with perhaps slightly higher nutrient drawdown in the Transitional Domain and slightly lower in open ocean. Such a trend is characteristic of a cool (La Niña) period. Sampling in February 2008 along Line P showed increased surface nutrient concentrations and a deepened mixed layer. If the mixed layer remains deep through spring (i.e. if spring remains stormy), then reduced light levels will decrease primary productivity in oceanic waters, but could enhance nutrient supply to coastal waters. This pattern was observed during the strong La Niña of 1999.

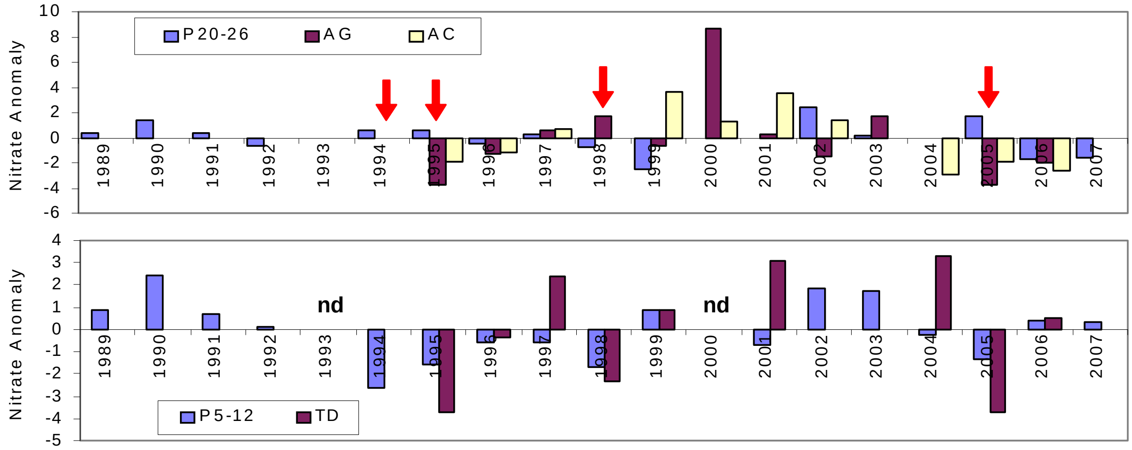


Figure 2. Estimates of nitrate drawdown anomalies (µM) for open ocean (top panel) and transitional domain (bottom panel) waters. Red arrows indicate warm (El Niño) years during which nitrate supply to the surface ocean was limited by upper ocean stratification. No data (nd) were available in some years.

Mesozooplankton in the Gulf of Alaska in 2007: Cooler conditions are evident in species composition

Sonia Batten, Sir Alister Hardy Foundation for Ocean Science

Total mesozooplankton biomass for the offshore BC region (from the continental slope out to 145°W and between 48° and 55°N) was very focussed in 2007 with most of the spring/summer biomass (73%) occurring in May and a second smaller peak in July. Although conditions were cooler, the time of peak biomass has not yet returned to June, where it was during cool conditions in 2000/01. The *Neocalanus plumchrus* peak, which makes up the bulk of the spring biomass, was later than it was during the warmer 2004-2006 period but not as late as in 2000/01. However, the biomass in July 2007 was mostly made up of the larger *N. cristatus* and numbers have not been seen this late in the year since 2001.

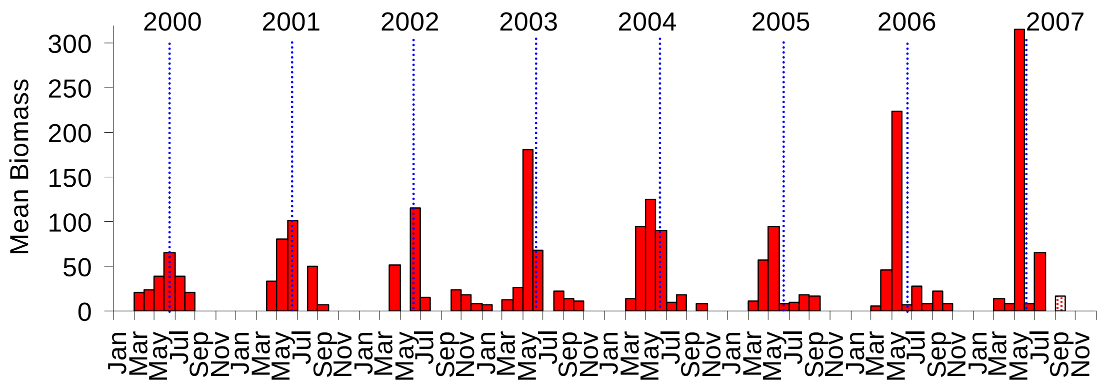


Figure 1. Time series of mesozooplankton biomass, presented as mean monthly biomass in mg dry weight per sample (~3m^3) from Continuous Plankton Recorder sampling (which occurs approximately monthly 6 times per year between March and October) in the off-shore Gulf of Alaska area. Data for Sept 2007 are preliminary. Dashed blue lines indicate June of each year.

Subtropical copepods are found further north in warmer years (Fig. 2) with a very strong correlation between the Subtropical Copepod Index and spring sea surface temperature (r = 0.99), but in 2007 none were found north of 48°N in the summer, as was also the case in 2002.

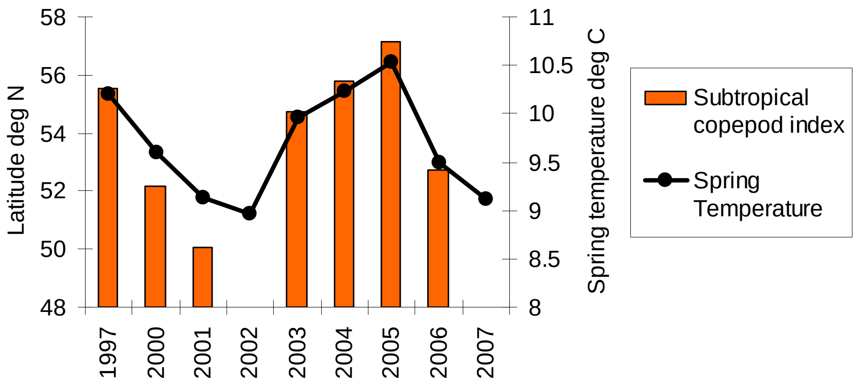


Figure 2. The latitude at which 75% of the cumulative abundance of sub-tropical copepods was reached in July/August of each year, together with the spring temperature (mean of March to May) at Amphitrite Point.

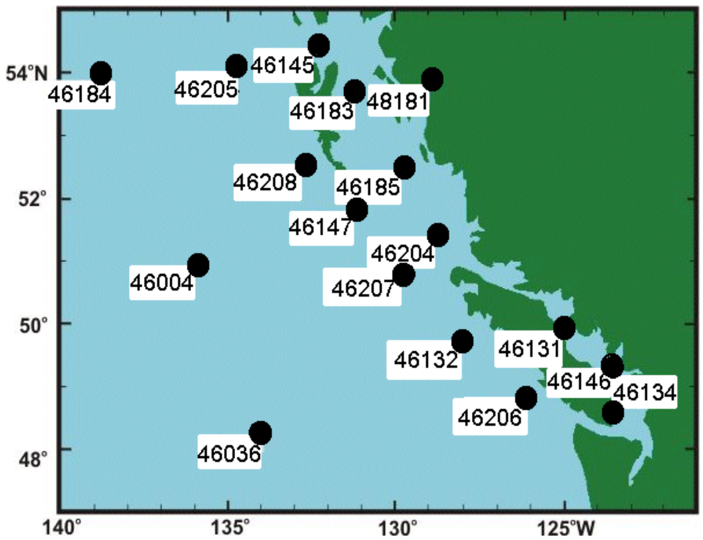
Numbers of *Calanus pacificus,* a more southern copepod, were also lower in 2007 than during 2003-2006, more similar to 2000/2001. These species composition changes are consistent with the cooling that occurred in 2007. The seasonality of the spring biomass peak did not completely return to the pattern of the last cool period but it may well do so if cool conditions continue.

See http://pices.int/projects/tcprsotnp/default.aspx for data and more information.

West Coast

Ocean temperature at weather buoys

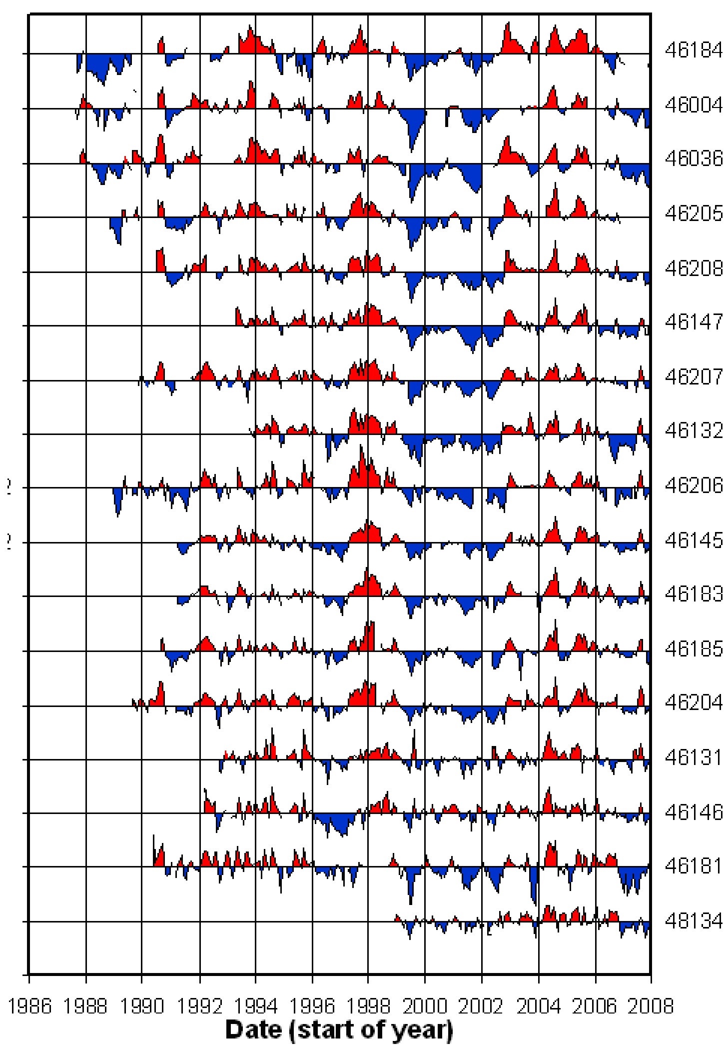
Jim Gower, Fisheries and Oceans Canada



Weather buoys have been maintained off the west coast of Canada for two decades, providing a continuous record of sea surface temperature. Positions of these buoys are presented in Fig. 1, and time series of temperature anomalies are shown below in Fig. 2.

Figure 1 (Left) Positions of weather buoys, maintained by Environment Canada and Fisheries and Oceans Canada

Figure 2 (Below left). Time series of monthly temperature anomalies at each weather buoy. Anomalies are based on average monthly temperatures over the entire record. Spaces between horizontal lines represent a temperature difference of 4 °Celsius.



Time series in Fig. 2 reveal that 2007 was cooler than average in most months, but warmer in summer, leading to an average anomaly for the year (wrt "all data" climatology) of -0.5C. The offshore Nomad buoys alone showed an annual average anomaly of -0.9C. The 10 coastal exposed buoys showed an annual average of -0.4C, with averages of -0.6 ± 0.1C for Jan to June and October to December, but 0.0, 1.0 and 0.0 in July, August and September.

In Fig. 2, the top three time series are measured at larger Nomad buoys, moored about 400 km off the BC coast. All others are 3-meter discus buoys. All measure SST at a nominal 1-meter depth. Buoys 46205 to 46206 (north to south) are in exposed waters 10 to 40 km offshore. Buoy 46145 is in Dixon Entrance, buoys 46183 to 46204 (north to south) are in Hecate Strait. Buoys 46131 and 46146 are in the Strait of Georgia. 46181 is in Douglas Channel near Kitimat and 46134 is in Saanich Inlet. Data gaps occur between times of instrument breakage and the next service cruise.

The graph in Fig. 3 below reveals the dominant changes in West Coast ocean temperatures over the past 20 years. This shows the average anomaly measured by the 10 coastal buoys (46205 down to 46204 in the above multiple plot). In 2007 SST was about 0.5C below average in most months, with a warm spike due to SST being 1 degree above average in August and near-average in July and September. The ocean surface temperature increased from 1988 to a maximum in late 1997 and early 1998 at the time of the most recent major El Niño. Waters cooled immediately after this El Niño and remained cool until early 2002. Although El Niño of 2002 to 2003 was weak, the winds off the west coast accompanying this event followed a classic El Niño pattern, bringing warm air and water from the south. Very strong westerly winds in the winters of 2006-07 and 2007-08 reduced ocean surface temperatures again.

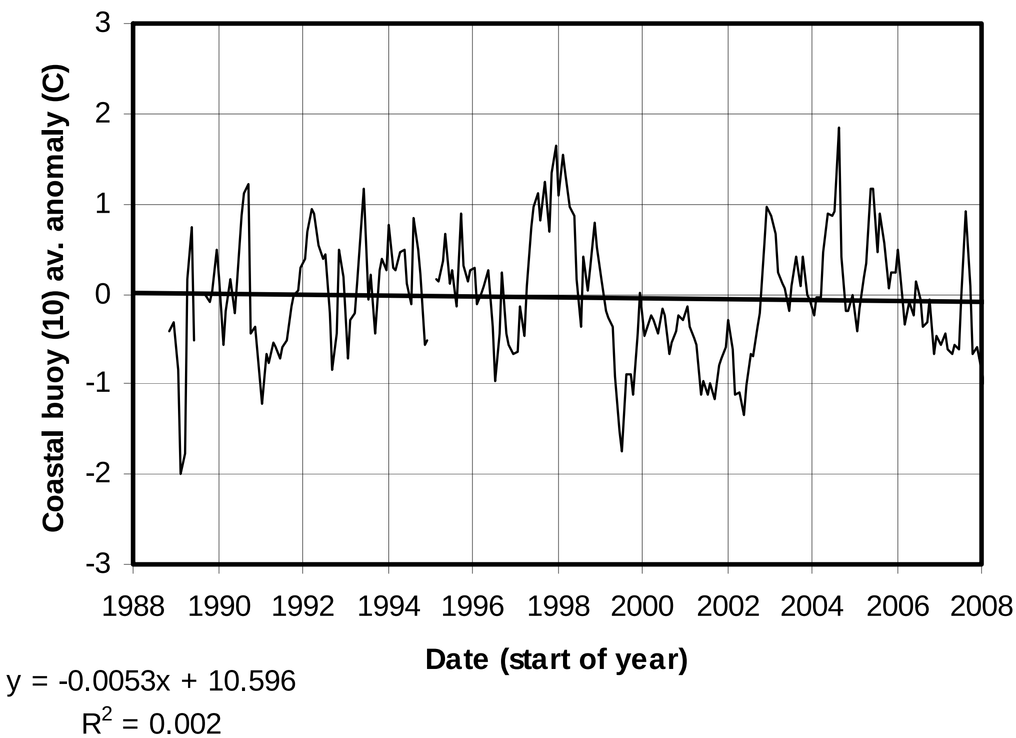


Figure 3 Average sea surface temperature for the 10 exposed, coastal buoys, 46205 to 46204. The linear trend is plotted. This average shows no significant temperature change over the length of record, but cooling since 2004.

Ocean acidification off the West Coast

Debby Ianson, Fisheries and Oceans Canada

Global oceans are becoming more acidic due to increasing carbon dioxide (Orr et al. 2005). Much of the extra CO_2 released by burning fossil fuels ends up in the oceans, increasing the dissolved inorganic carbon concentration (DIC). As DIC increases, the relative proportions of carbon species shift (specifically from the carbonate ion to the bicarbonate ion), resulting in an increase in acidity and a decrease in pH (Strum and Morgan, 1981). At present the pH of seawater has decreased by about 0.1 due to oceanic uptake of anthropogenic carbon and is projected to decrease by 0.4 by the year 2050 (Orr et al. 2005). The decrease in pH (and concurrent decrease in carbonate ion) means that organisms that produce calcite and aragonite shells or structures, such as pteropods, corals and shellfish, are threatened (The Royal Society, 2005).

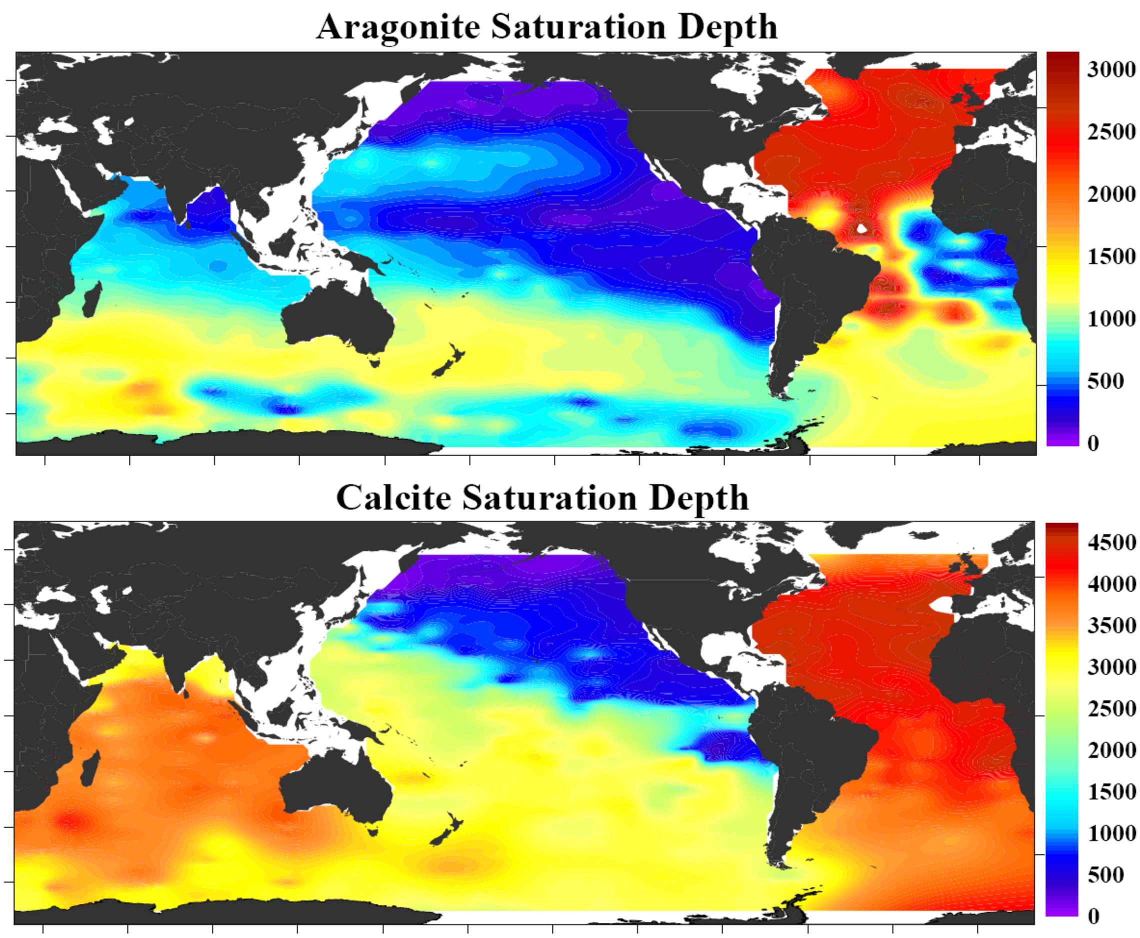


Figure 1. Saturation depth of aragonite and calcite in the global oceans. (Feely et al. 2004). Colour scale at right denotes the depth in metres. White areas denote regions of little or no data. Figure courtesy of Richard Feely.

The North Pacific Ocean already has the most acidic water in the global ocean. In fact the aragonite saturation depth (defined as the depth at which aragonite dissolves more readily than it can form) has shoaled by between 50 and 200 metres in the last century, and is now found at depths of only 100 to 300 metres below the ocean surface (Feely et al. 2004; Fig. 1). The Line P carbon program of Fisheries and Oceans Canada has contributed critical data to make these estimations of change in the carbonate system in the Gulf of Alaska.

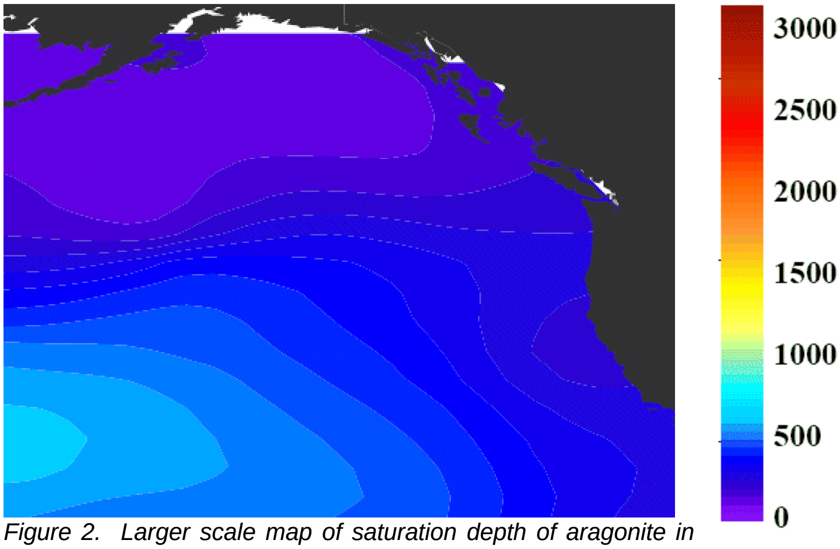


Figure 2. Larger scale map of saturation depth of aragonite in the northeast Pacific Ocean shown in Fig. 1. Colour scale at right denotes the depth in metres. White areas denote regions of little or no data.

Very few data from the carbonate system have been collected on the Canadian west coast; however these few observations show that Juan de Fuca Strait and the Vancouver Island Coastal Current experience high pCO_2 water due to tidal mixing in the Strait, which brings water high in DIC and low in pH to the surface (Ianson et al. 2003). An additional study with high spatial resolution confirms the high surface pCO_2 (400 -- 800 ppm; Nemcek et al, in press) in this area estimated by Ianson et al. (2003) but has no complimentary measurements (such as DIC) with which to determine pH in the Strait.

Summer upwelling causes intermediate depth water from 100 to 200 metres below surface to come onto the shelf and up into the ocean surface layer. The upwelled water is high in nutrients and DIC and so is lower in pH. However this DIC is quickly drawn down by primary producers, and so the exposure of the shelf to low pH water is expected to be intermittent. To date there have been no *in situ* studies of the effect of this exposure on the local organisms. There are no complimentary winter observations at present, although because of colder temperatures, winter mixing, higher DIC and lower primary production, there may be corrosive water over the shelf at this time of year. The Ianson and Allen (2002) model suggests surface pCO_2 of up to 400 ppm in winter.

References:

Feely, R. A., Sabine, C. L., Lee, K., Berelson, W., Kleypas, J., Fabry, V. J. and F. J. Millero. 2004 Impact of Anthropogenic CO2 on the CaCO3 System in the oceans, Science 305: 362.

Ianson, D., Allen S. E., Harris S. L., Orians K. J., Varela D. E. and Wong C. S. 2003. The inorganic carbon system in the coastal upwelling region west of Vancouver Island, Canada. Deep Sea Research I. 50: 1023-1042.

Ianson D. and S. E. Allen. 2002. A two-dimensional nitrogen and carbon flux model in a coastal upwelling region. Global Biogeochem. Cycl. 16(1):10,1029/2001GB00145.

Nemcek, N., D. Ianson, and P. D. Tortell, 2008. A high-resolution survey of DMS, CO2, and O2/Ar distributions in productive coastal waters. Global Biogeochem. Cycles, doi:10.1029/2006GB002879, in press.

Orr J. C. et al. 2005. Anthropogenic ocean acidfication over the twenty-first century and its impact on calcifying organisms, Nature 437: 681.

Royal Society, Ocean acidification due to increasing atmospheric carbon dioxide (The Royal Society, 2005).

Strum W. and J. Morgan, 1981. Aquatic Chemistry, 2nd Ed. Wiley.

Mesoscale eddies are regions of high phytoplankton biomass in spring

Frank Whitney and Marie Robert, Fisheries and Oceans Canada

June surveys carried out in 2007 reconfirm that mesoscale eddies are offshore centers of high primary production. Eddies form along the continental margin of B.C. and Alaska in late winter, then transport coastal waters and their nutrients (especially iron) away from shore. When conditions are favourable in spring, these waters experience spring blooms similar to coastal waters (Crawford et al., 2007).

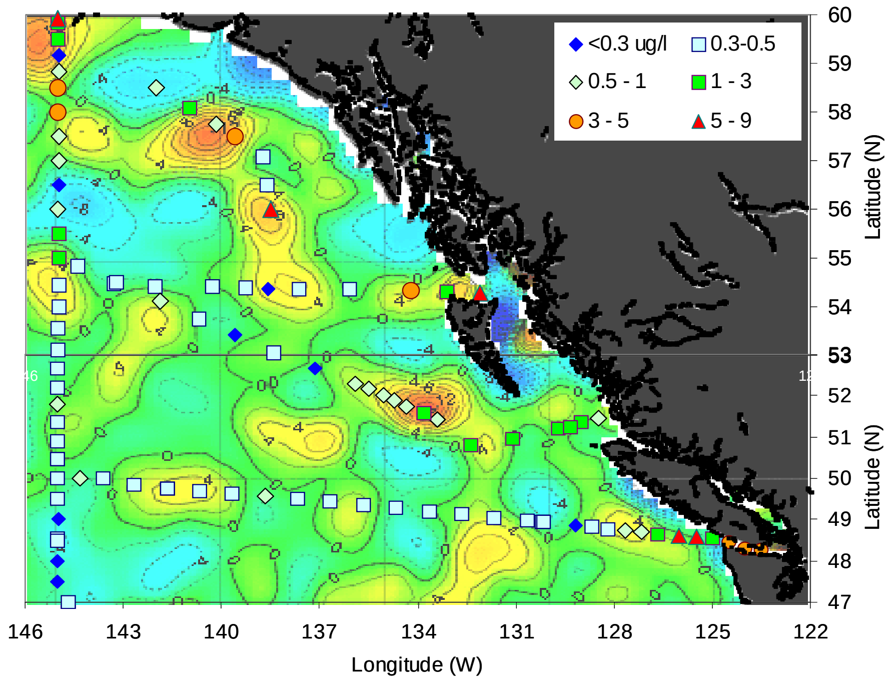


Figure 1. Sea surface chlorophyll a (plotted symbols) as measured on the Canadian Coast Guard Ship John P. Tully in June 2007. Scale for chlorophyll symbols is in the box at top right of figure. Background contours shading presents sea surface height topography as measured on June 10, 2007 by satellites. Orange and red shading in regions of positive heights; blue shading in low elevation regions; contours in cm with labels every 4 cm. Satellite image was downloaded from CCAR (http://argo.colorado.edu/~realtime/welcome/).

Of the many surveys undertaken to sample eddies over the past decade, this survey is perhaps the best for measuring chlorophyll levels during spring growth. Each of the eddies sampled had some amount of nitrate left in its waters, suggesting growth had not yet reached its maximum. A previous cruise with NOAA in April 2005 found high nutrient levels in more northern eddies, but apparently preceded spring growth (Ladd et al., submitted). Mesoscale eddies are likely important feeding areas for marine species able to locate them, and may be important regions of carbon dioxide uptake by oceans.

Ladd, C., Crawford, W.R., Harpold, C.E., Johnson, W.K., Kachel, N.B., Stabeno, P.J., Whitney, F., submitted. A synoptic survey of young mesoscale eddies in the Eastern Gulf of Alaska. *Deep-Sea Research* Part II.

Crawford, W.R., Brickley, P.J., Thomas, A.C., 2007: Mesoscale eddies determine phytoplankton distribution in northern Gulf of Alaska, *Progress in Oceanography* 75, 287-303, doi:10.1016/j.pocean.2007.08.016.

SeaWiFS satellite images of phytoplankton

Jim Gower, Fisheries and Oceans Canada

Monthly composite image data from the SeaWiFS satellite sensor of surface chlorophyll and water brightness at 555 nm (green light) extracted from global “Level 3” data provided by NASA at http://daac.gsfc.nasa.gov, shows the patterns of these variables off the west coast (Fig. 1 and 2).

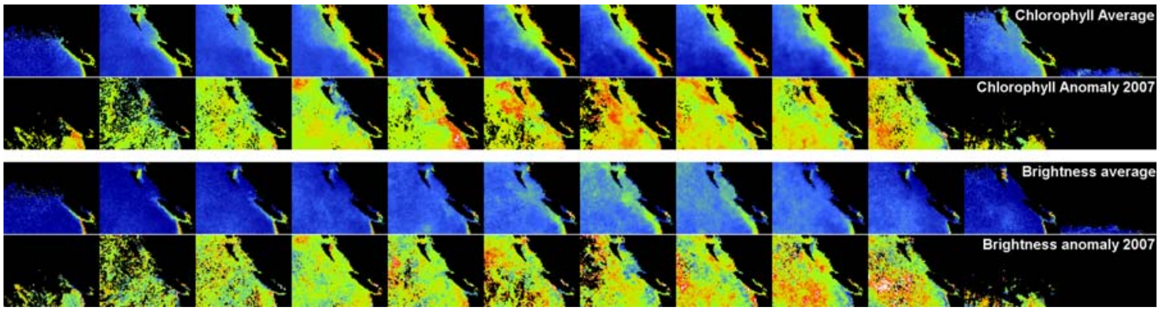


Figure 1. Averages (top and third rows) and anomalies (second and fourth rows) for 2007 in chlorophyll, upper two rows, and water brightness, lower two rows. Images have 9 km spatial resolution and are derived from SeaWiFS satellite data. Each row shows left to right the months January to December. The anomaly images (second and fourth rows) have more gaps due to cloud cover, since they rely on cloud-free data for the one year (2007). The pattern of missing data due to cloud cover in 2007 is identical in rows two and four.

We use the global composite monthly image data at 9 km spatial resolution, computing an average image for 1997 (where months are available, otherwise 1998) to 2006 and comparing this to 2007 by computing a difference image. The chlorophyll data are stored logarithmically in these data, so differences show multiples. Results are shown in Fig. 1 and 2. Red colours in the chlorophyll anomaly images indicate concentrations more than 3 times the 1997-2006 average values. Dark blue colours indicate concentrations less than half the average.

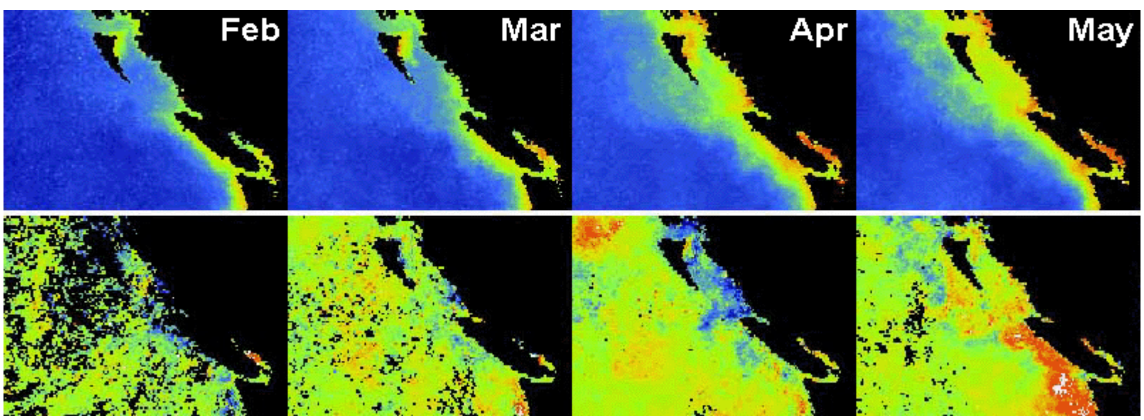


Figure 2. Chlorophyll distributions shown in the top two rows of Figure 4, but for the months February to May only.

The average chlorophylls in the top row of Fig. 2 show the increase in surface chlorophyll values from February to April associated with the spring bloom. Most of the increase is between the March and April images. The May average (top right) shows no clear increase above the values in April. The February 2007 image shows high values (twice to three times average) in the Strait of Georgia, reflecting an early start of the spring bloom in these waters, and the April image shows low values (half of average) in northern coastal waters. Waters off Vancouver Island and Washington State area show no significant anomaly until May, when values are two to three times the average.

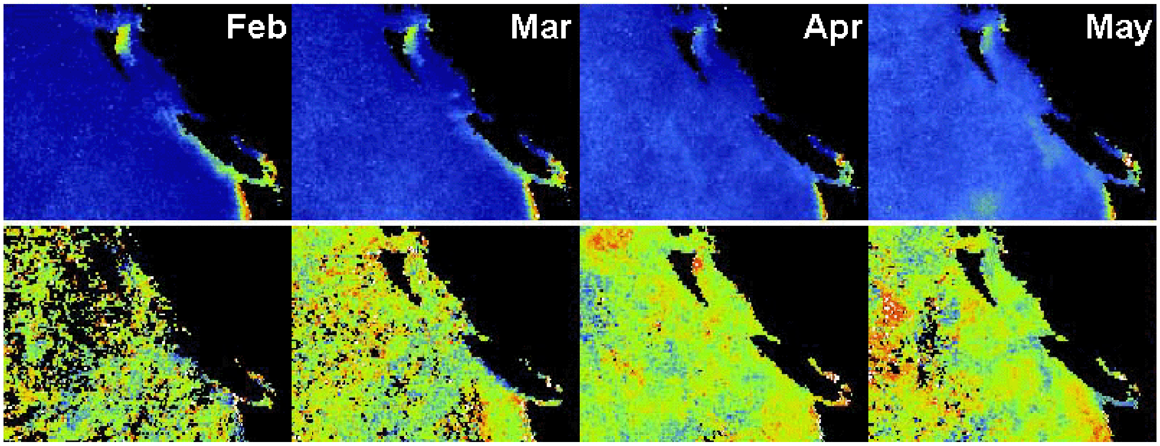


Figure 3. Water brightness distributions shown in the lower two rows of Figure 4, but for the months February to May only.

Water brightness data are shown for comparison in the two lower rows of Fig. 1 and in Fig. 3. Resuspension of bottom sediments due to winter storms results in bright water east of the Queen Charlotte Islands in north-western Hecate Strait. Sediment is evident in water along the west coast of Vancouver Island in February and March, but has vanished in April and May. The anomaly images show patches of brightness further offshore in April and May. These are usually due to coccolithophorid blooms.

Long-term temperature and salinity at BC lighthouses

Peter Chandler, Fisheries and Oceans Canada

Temperature and salinity are measured daily at daylight high tide by light keepers at 13 stations as part of the DFO Shore Station Oceanographic Program that began in early 1900s.

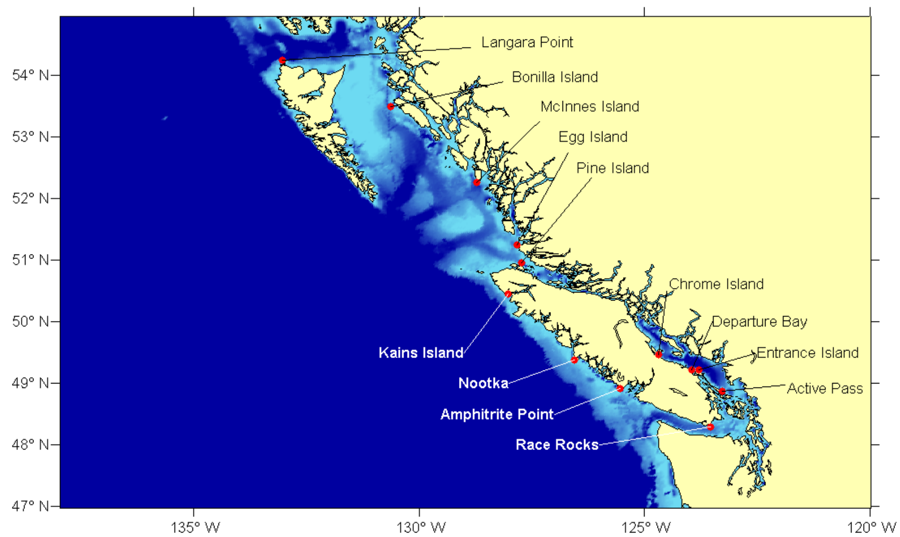


Figure 1. The 13 stations presently in the network

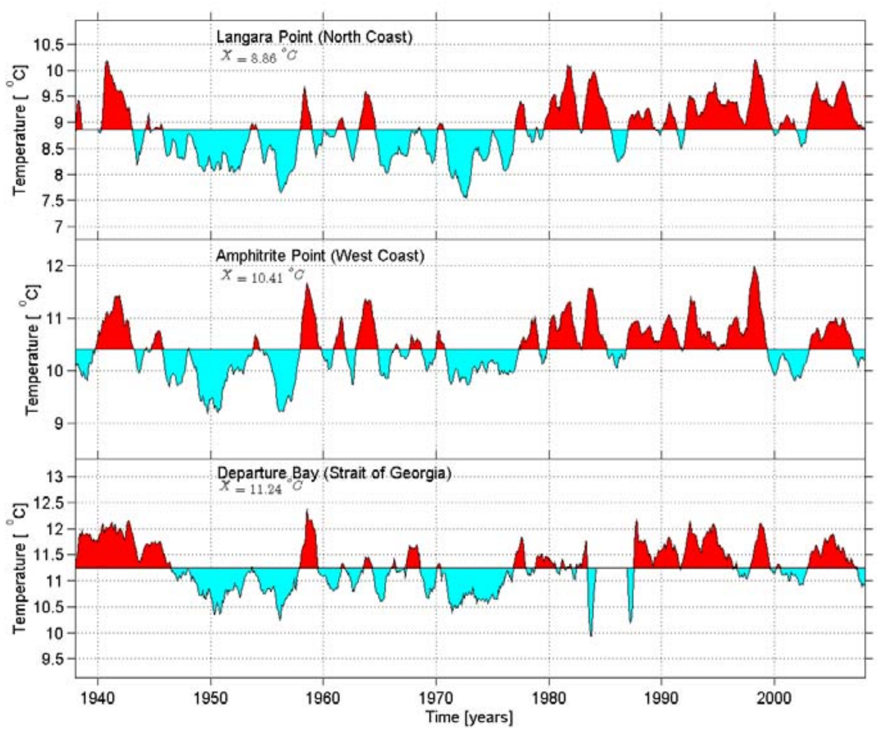


Figure 2. Long-term time series of annual-average temperature at representative stations in BC. Observations show temperatures in 2007 close to or below the long term average (where the average is calculated over the time period shown, 1940 – present).

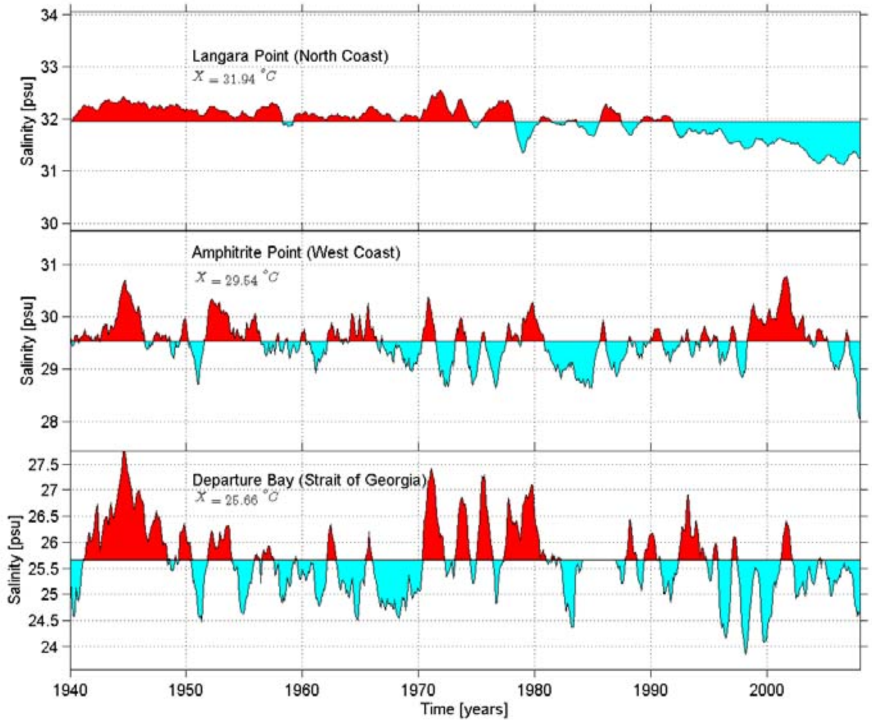


Figure 3. Long-term salinity time series at representative stations. Surface waters show a continuing freshening trend in recent years, especially at Langara Point.

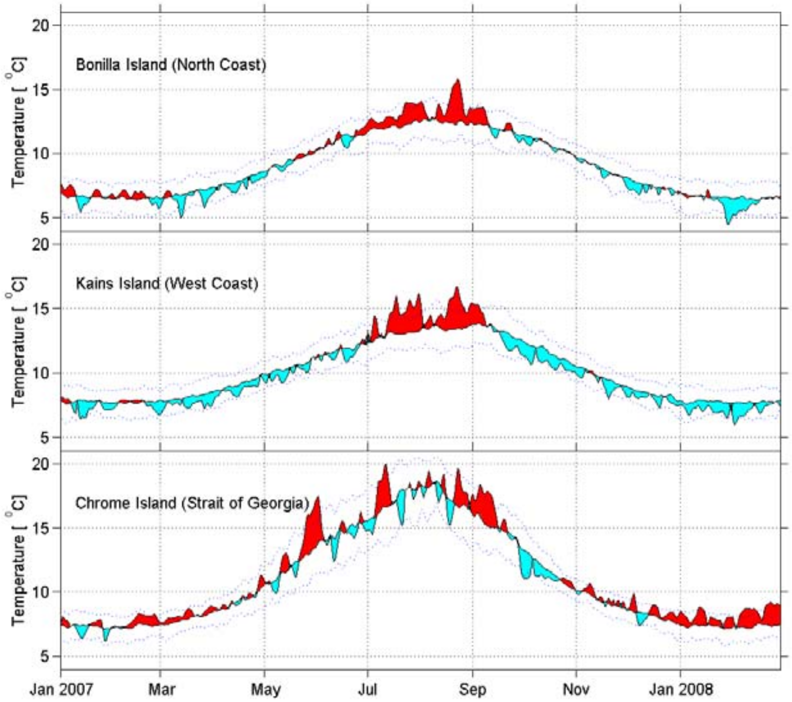


Figure 4. Temperature anomalies and the annual cycle (calculated from the 1971 – 2001 sea surface temperature data) at representative stations. Surface waters on the North and West Coasts show above-average temperatures in July and August, followed by cooler temperatures. Conditions in the Strait of Georgia show a recent trend to above-average ocean temperatures at surface near shore.

Temperature Anomalies - 2007.

A mid-summer warming anomaly in July and August 2007 is evident in all regions. Later in 2007 below average sea surface temperatures are observed at all stations with the exception of two in the Strait of Georgia; Active Pass and Chrome Island.

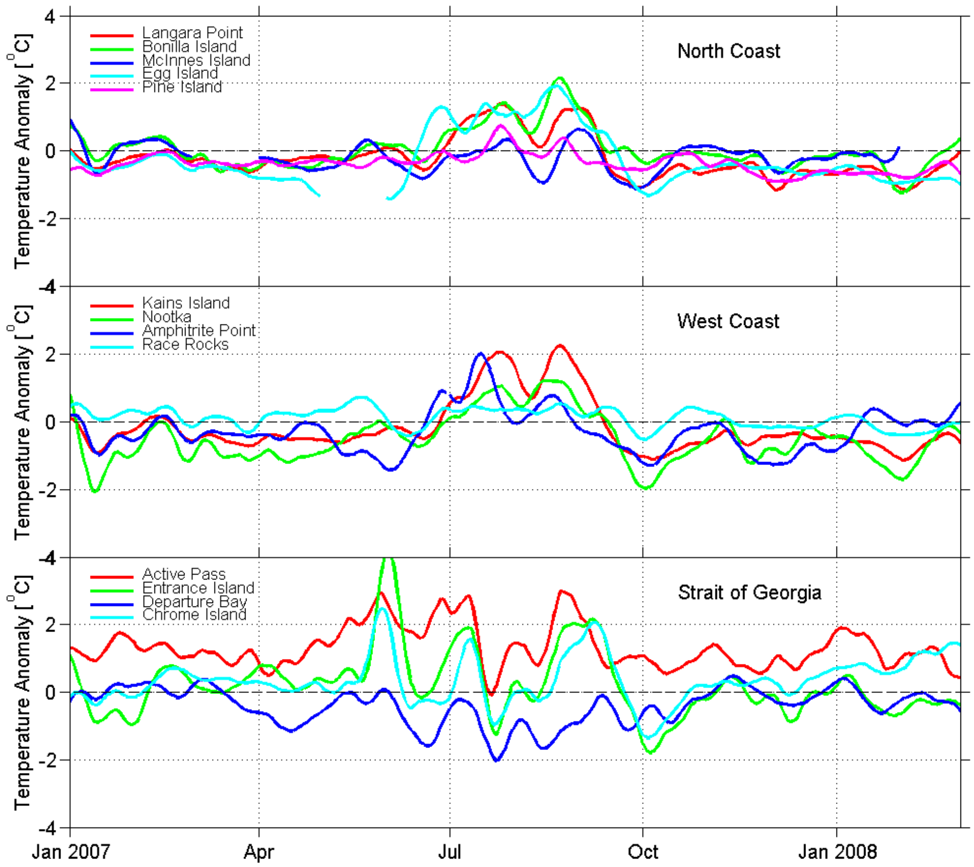


Figure 5. Time series of daily sea surface temperature anomalies where the long-term average is calculated from daily observations made between 1971 – 2001.

Salinity Anomalies - 2007.

Observations of sea surface salinity anomalies show below average values in all regions, with fresher waters evident throughout the year generally. As observed last year, there remains considerable variability in the salinity observed at Nootka, and the Egg Island data remain consistently fresher than the long-term average. Most stations in the Strait of Georgia show a July event which resulted in surface waters saltier than the average, but, as with the other stations along the coast, a generally fresher-than-average year.

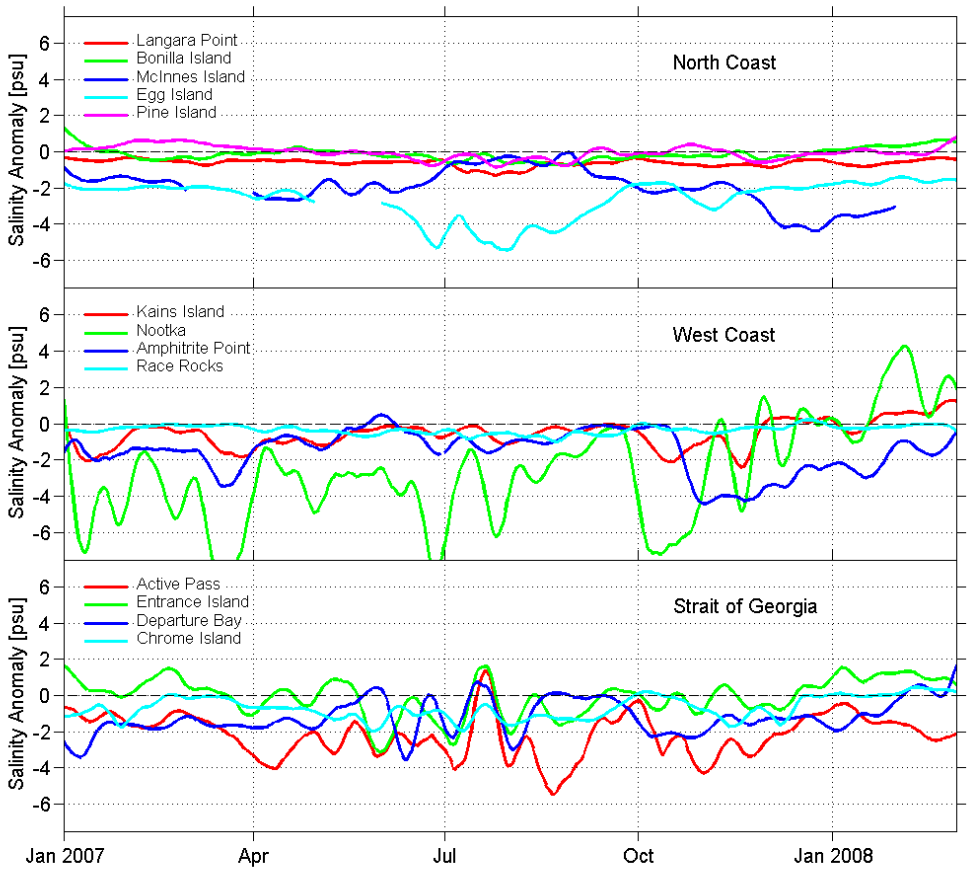


Figure 6. Time series of daily sea surface salinity anomalies where the long-term average is calculated from daily observations made between 1971 – 2001.

Links:
BC Seawater sampling at Lighthouses
(http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm)

Ocean temperature to be cooler along the BC coast in 2008

Skip McKinnell, North Pacific Marine Science Organization (PICES)

A La Niña climate pattern intensified through 2007, and during the past winter was accompanied by stronger westerly winds in the North Pacific Ocean west of Canada, bringing cooler waters toward the British Columbia coast in winter and spring 2008. We have observed similar links in the past 50 years between La Niña and ocean temperatures in British Columbia. La Niña events are usually accompanied by lower air pressure in the Western Tropical Pacific, and the linkage is illustrated by plotting air pressure over the Solomon Sea (Western Tropical Pacific) versus sea surface temperatures at the Kains Island lighthouse on Vancouver Island, plotted below in Fig. 1. Kains Island is very representative of average sea temperatures along the B.C. coast.

Cooler waters along the British Columbia coast were also reflected by a shift in McKinnell & Mantua's high resolution Pacific Decadal Oscillation (HR-PDO) to strongly negative values beginning in October, 2007. Much of the Gulf of Alaska sea surface was cooler in winter 2008 than has been seen since the late 1960s and early 1970s (Fig. 2). These cool surface waters will likely persist for a few years.

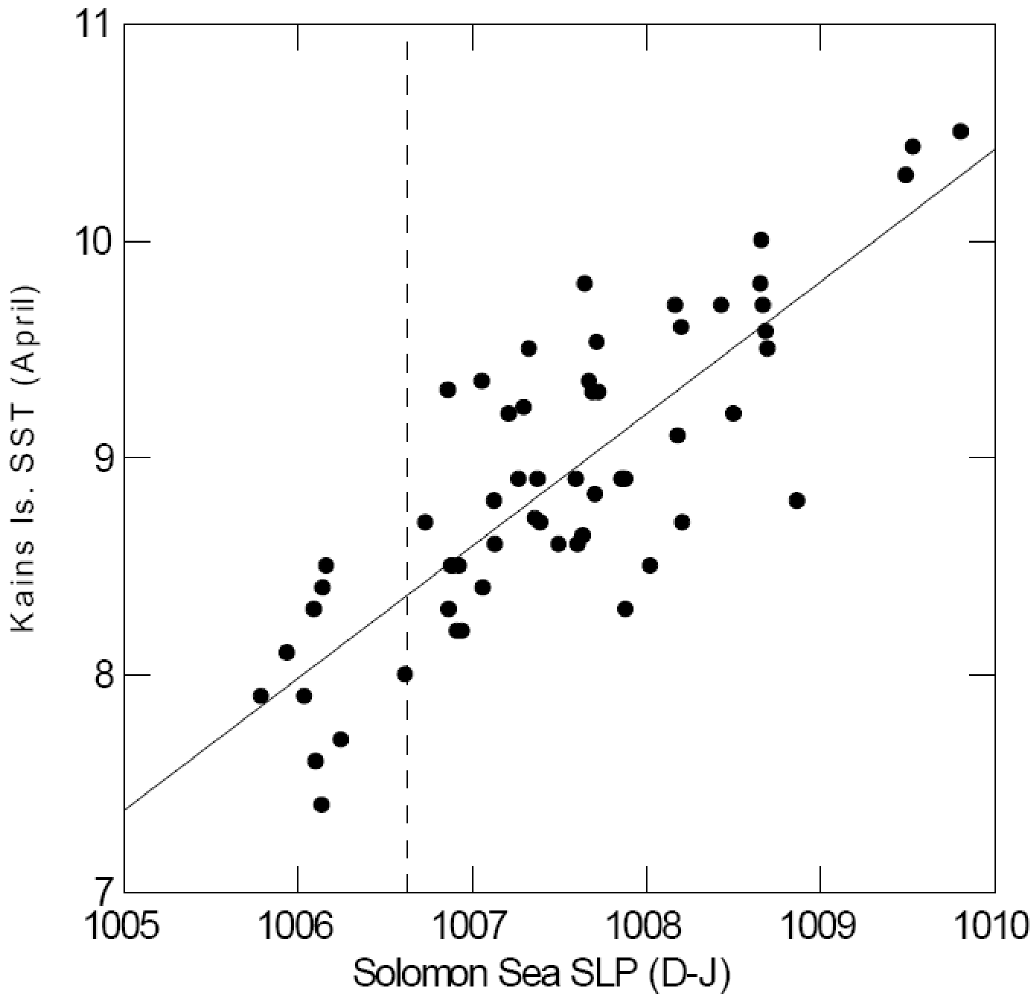


Figure 1: Kains Is. temperature in April versus the December/January average sea surface pressure (SSP) at a grid point over the Solomon Sea (east of Indonesia) from 1948 to 2007. Each year provides one data point. The vertical line passes through the SLP for December/January 2007/08. Kains Island lighthouse data are provided by Fisheries and Oceans Canada; SLP data are from NOAA/NCEP reanalysis.

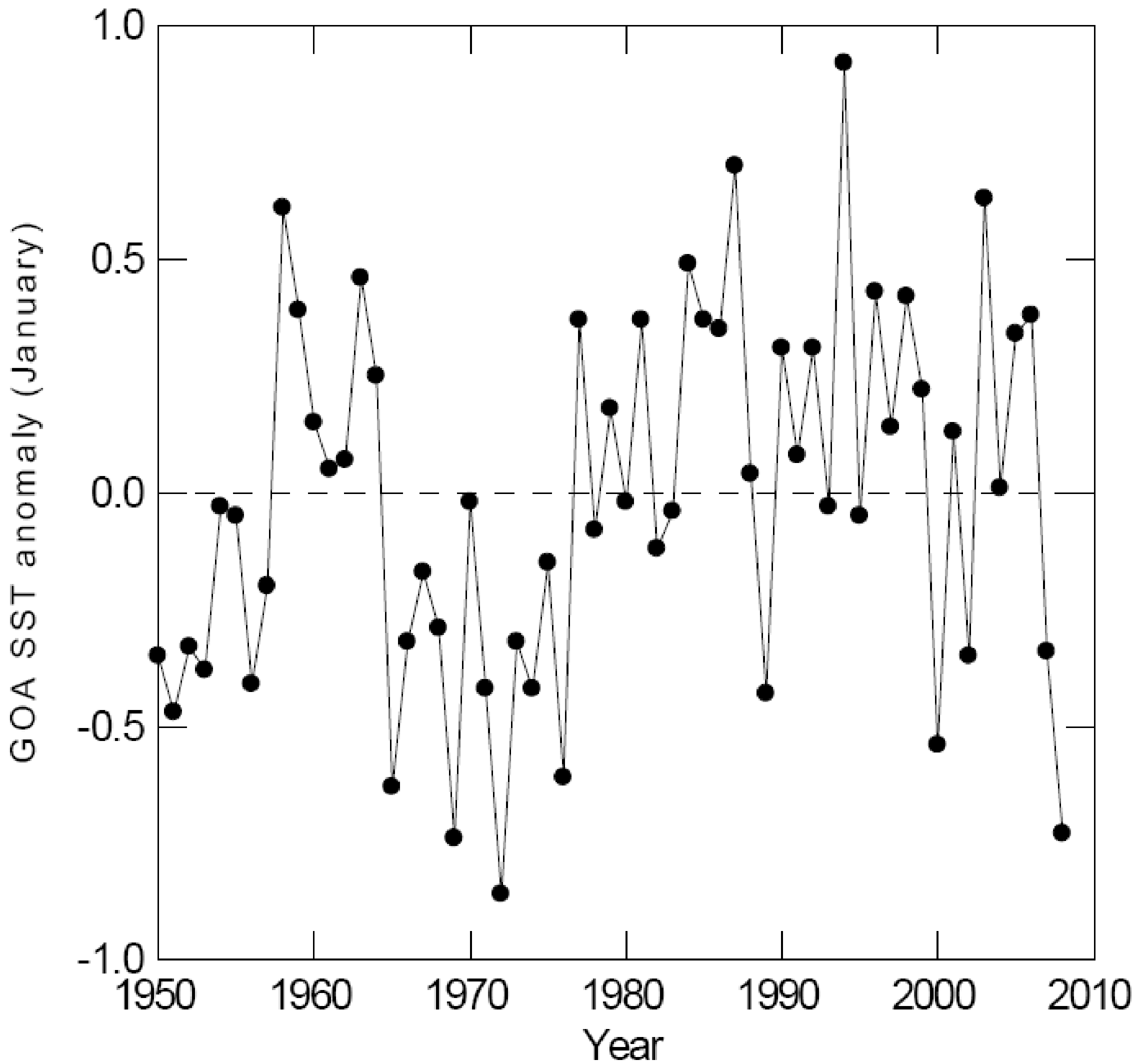


Figure 2: Average sea surface temperature in the Gulf of Alaska during January from 1950 to the present. Data are from the NOAA Extended Reconstructed SST database.

Oxygen levels on the Vancouver Island Shelf

Bill Crawford, Fisheries and Oceans Canada

Very low oxygen concentrations have killed shellfish along the Oregon continental shelf in several summers since 2002. In 2006 these low levels were also observed on the continental shelf of Washington State, close to the Canada-USA border. Although such low oxygen levels have been seen previously in Oregon deep waters, in the 21st century these hypoxic regions moved closer to shore, into depths less than 50 m. We find no evidence of low concentrations on the Vancouver Island continental shelf (<1 ml/litre) in waters less than 90 m deep as noted below. Levels below 0.5 ml/l have not been recorded in offshore waters less than 500 m deep.

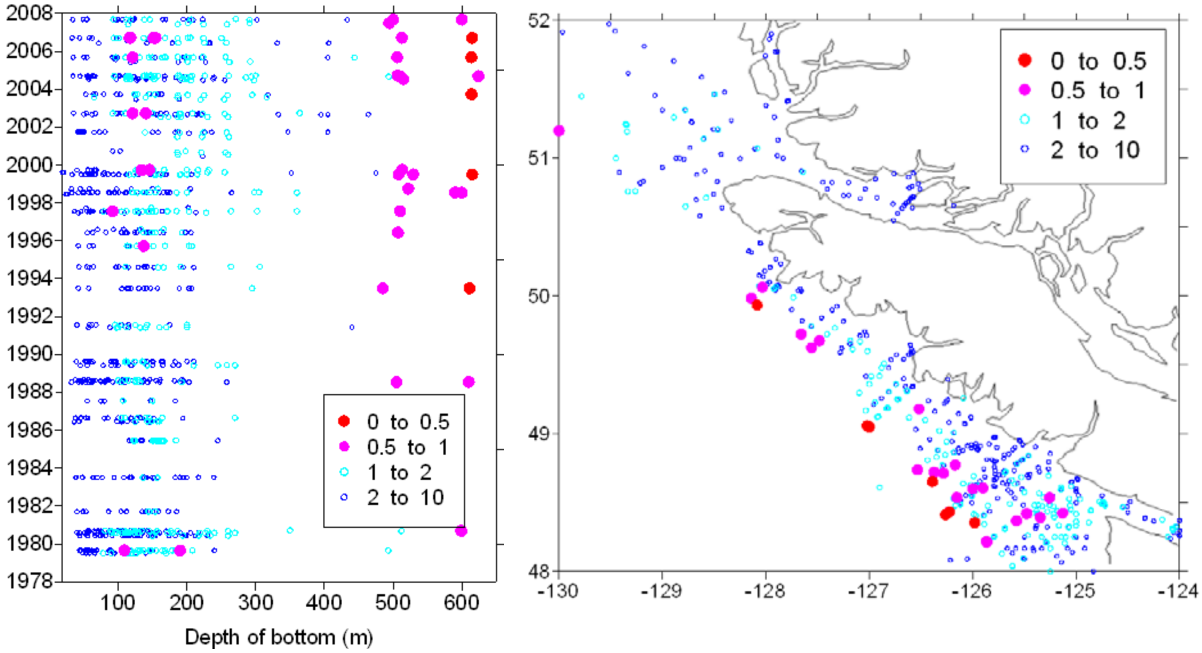


Figure 1 Concentration of oxygen (ml/litre) measured within 20 metres of ocean bottom in months of July to September. (Left) Concentrations plotted versus depth of ocean bottom. (Right) Concentrations plotted on map of sample locations.

Normally the oxygen concentrations are low in deep waters off the West Coast, due to oxidation of organic matter on the continental shelf, and to low concentrations of oxygen in deep waters that move onto these shelves.

We examined all historical reports of measured oxygen levels along the West and North Coasts of Vancouver Island for the months of July, August and September, a time of year when deep-ocean waters upwell farthest onto the continental shelf, bringing lowest O_2 levels. All data examined are from seawater samples collected within 20 metres of ocean bottom and titrated using the Winkler method or one of its successor methods. Although recent years have seen electronic sensors measure oxygen, we rely here on titrated values only.

The two figures show where these samples were collected over the years (right panel) and near-bottom oxygen concentrations over the past 30 years, from shallow waters out to 650 m depth (left panel). Levels below 1 ml/litre were seldom observed on the shelf (depths less than 200 m).

These observations derive mainly from regular DFO research cruises to the Vancouver Island continental shelf. Regular summer sampling will continue on Fisheries and Oceans Research vessels in these waters.

Coastal sea levels: Below normal in 2007 in southern BC.

Bill Crawford, Fisheries and Oceans Canada

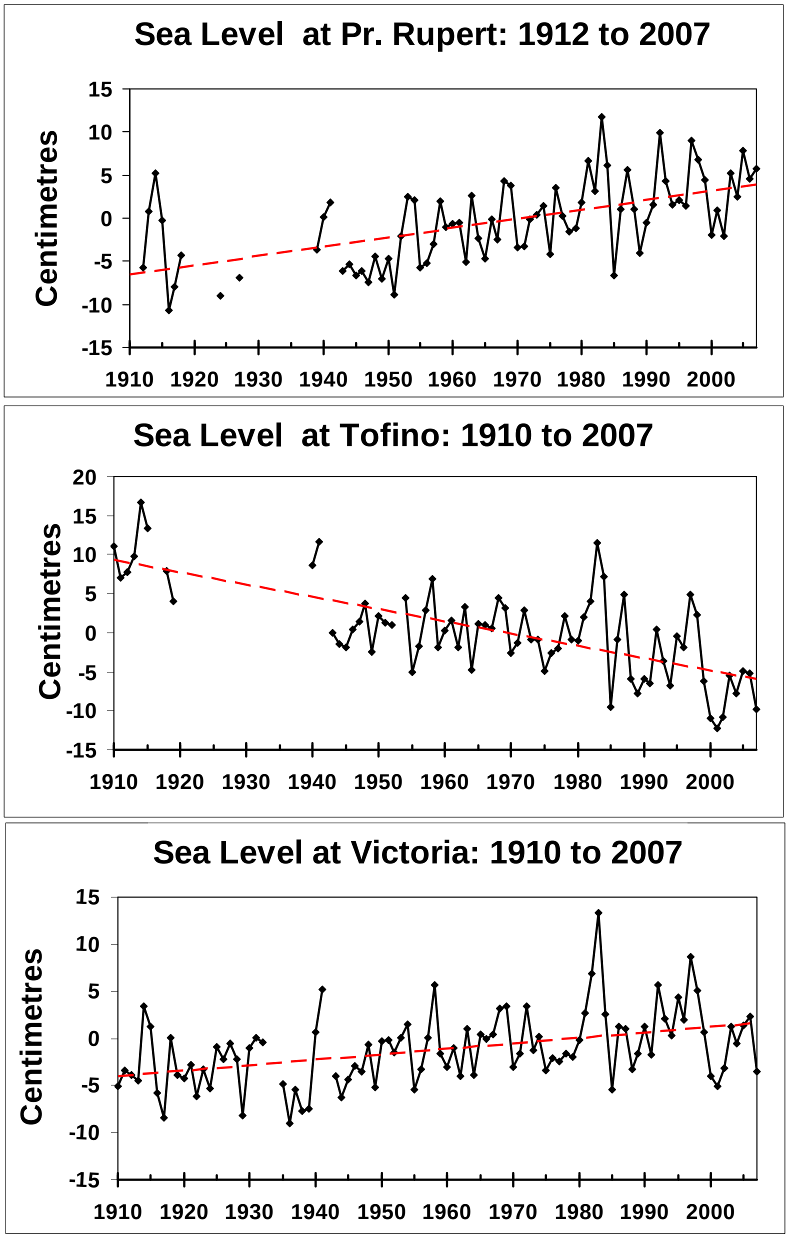


Figure 1. Graphs of annual-averaged sea levels at three British Columbia ports. Long-term linear trends are plotted as red dashed lines.

The Canadian Hydrographic Service monitors levels along the BC coast. The records at left show deviations from long-term average levels at three BC ports. Strong winter winds from the west dropped sea levels below normal in southern BC in 2007.

Dashed red lines show the linear trend over the record length. These trends are listed below (in cm/century):

Prince Rupert	+11
Victoria	+6
Tofino	-16

Tectonic motion is lifting the land at Tofino faster than sea level is rising, so local sea level is actually dropping at a rate of 16 cm per 100 years. The next Cascadia Subduction Zone earthquake will drop the land at Tofino and along the west side of Vancouver Island by 60 cm or so, and send a major tsunami toward the BC coast.

Global sea levels rose by 17± 5 cm in the 20th century. Satellite observations since 1993 indicate a global rise of 0.3 cm per year. The Intergovernmental Panel on Climate Change (IPCC 2007) predicts sea level to rise by 20 to 60 cm over the 21st century, but cautioned than they could not determine confidence limits for the upper limit of sea level rise. Recent observations of ice melt in Greenland and Antarctica suggest the upper limit of 60 cm might be too low.

Winds, currents and temperatures

Richard Thomson and Roy Hourston, Fisheries and Oceans Canada

Current velocity, along with water temperature and salinity, have been measured at mooring A1 - located at 48° 32' N 126° 12' W in 500 m of water on the continental slope seaward of La Pérouse Bank - continuously since 1985 (Fig. 1). Sea surface temperature, wind velocity, and other meteorological properties have been measured at a nearby Environment Canada buoy 46206 (48° 50' N 126° 00' W) since 1988. These records enable us to characterize the interannual variability in surface and subsurface meteorological and physical oceanographic conditions off the West Coast of Vancouver Island.

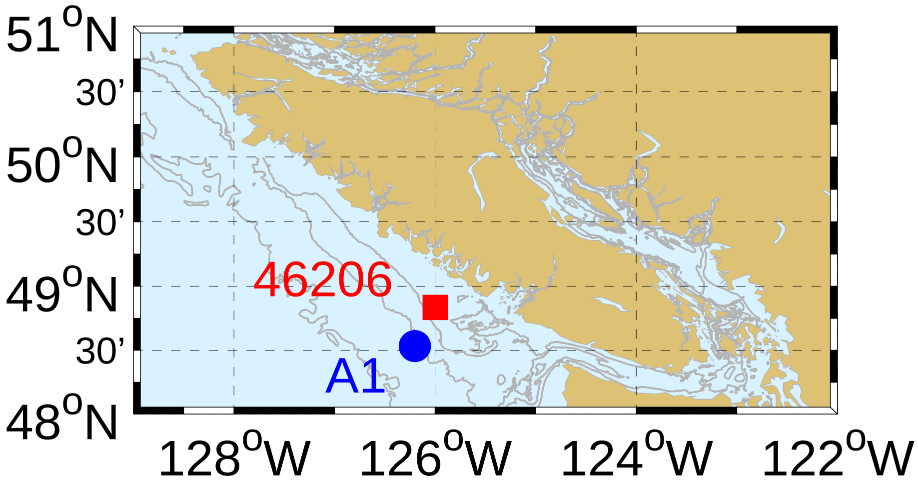


Figure 1. Locations of current meter mooring A1 and meteorological buoy 46206.

Fig. 2 shows monthly mean anomalies of the alongshore component of wind stress together with the alongshore component of ocean current velocity and associated water temperatures from the surface to 400 m depth for the period 1985 to 2007. Alongshore winds at buoy 46206 were weaker than average in 2007, with weaker downwelling-favourable winds in winter and weaker upwelling-favourable winds in summer. Alongshore current velocities observed at mooring A1 during the early 2000s were characterized by negative alongshore current anomalies (weaker poleward and/or stronger equatorward velocities, depending on the season) at 35 and 100 m below ocean surface, while at 175 and 400 m depth, velocity anomalies were positive (stronger poleward and/or weaker equatorward) peaking in 2005. Although the mooring was destroyed by a fishing vessel in late 2006 and most of the winter data lost, it appears that velocity anomalies at all depths returned to near or slightly below zero during the first half of 2007. Temperatures at all depths warmed through 2004/05, probably due to El Niño effects, but began cooling substantially through 2007-2008 coincident with the present La Niña event.

Fig. 3 shows the timing of the spring transition based on the alongshore current velocity at A1 at 35 m depth and the alongshore surface wind stress at meteorological buoy 46206. Spring transition marks the shift from poleward to equatorward ocean current and the beginning of biologically productive spring-summer upwelling conditions. The wind and current estimates are closely linked, with the ocean current typically *leading* the wind by roughly two and a half weeks. Years having a late spring transition, such as 2005 have been characterized by poor or significantly altered productivity in plankton, fish, and birds, as documented in earlier State of the Ocean Reports. Based on ocean current data, it appears that the spring transition timing for the coastal ocean current in 2007 was one of the latest on record, like 2005 - the previous year for which there are data.

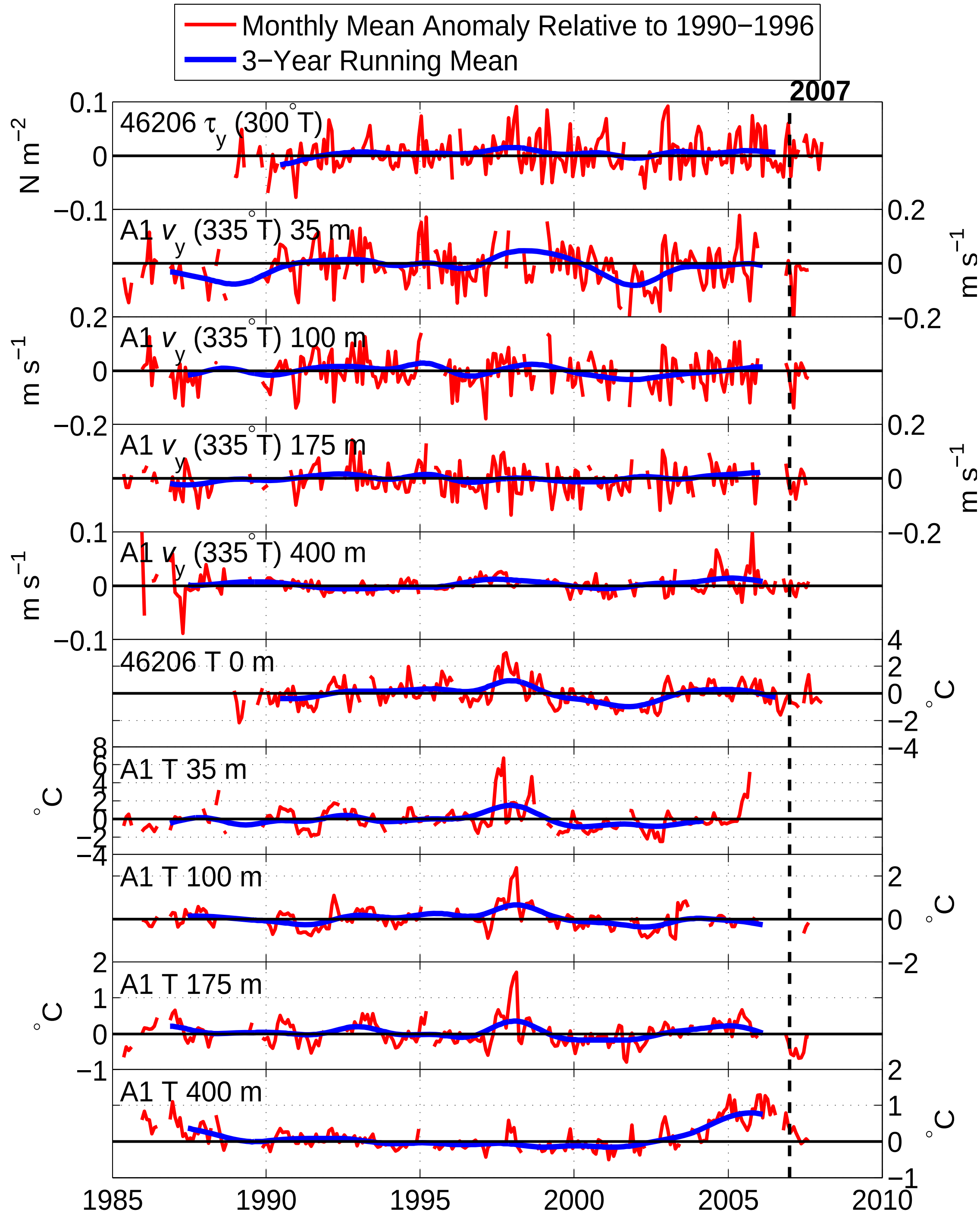


Figure 2. Monthly mean anomalies and corresponding five-year running-means for alongshore wind stress at 46206, a longshore velocities at A1, and temperatures at 46206 and A1.

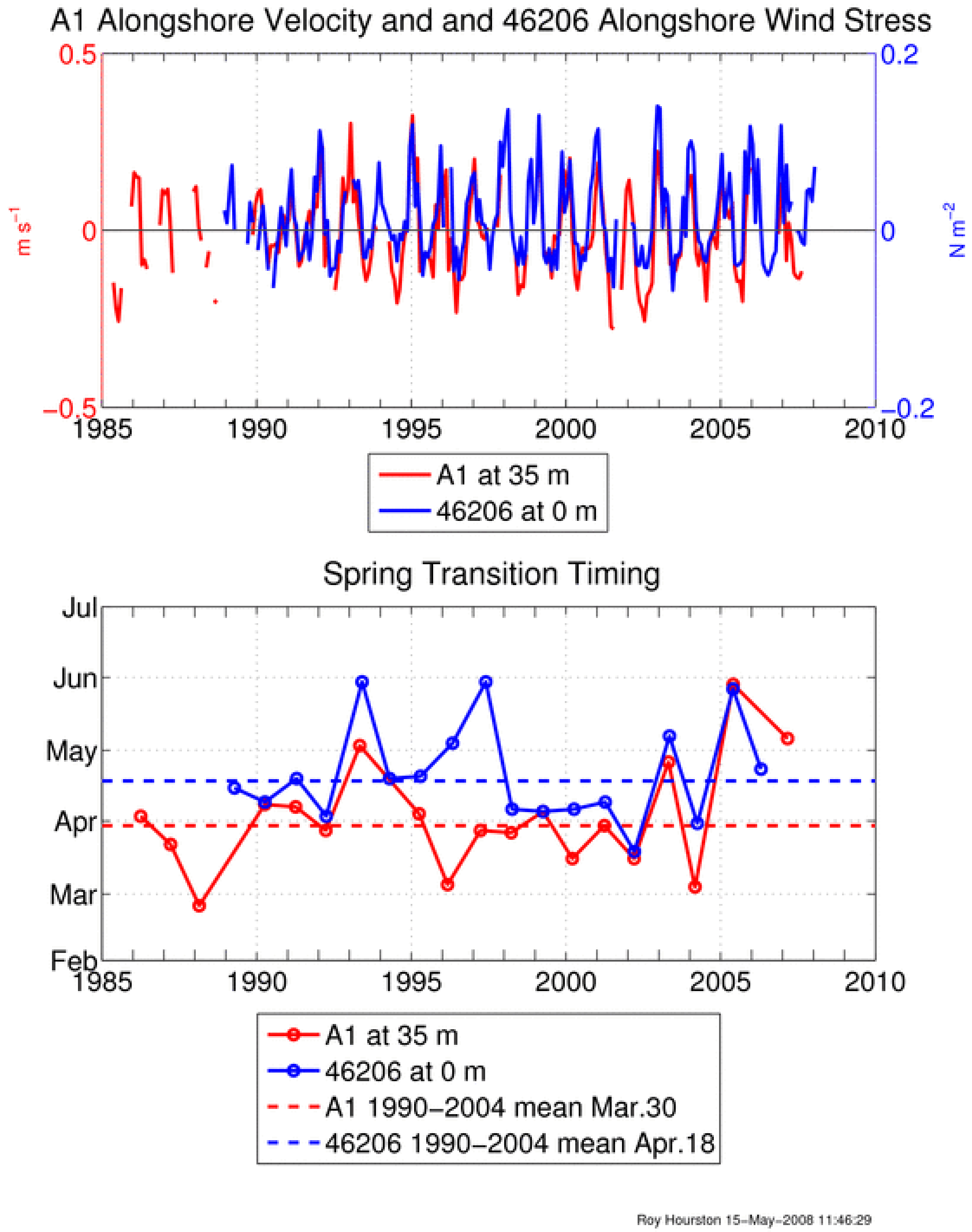


Figure 3. Spring transition timing of alongshore current velocity at mooring A1 at 35 m depth and alongshore wind stress at met buoy 46206. Timing was derived from when the monthly mean time series crossed the zero line (poleward to equatorward) in the spring. In the case of multiple crosses in one year, the times were averaged to obtain one value per year. The timing estimate for 46206 wind stress in 2007 is poor due instrument failure in the spring.

The duration and intensity of upwelling-favourable winds are generally considered indicators of coastal productivity. To examine low-frequency variability in coastal productivity, we have summed upwelling-favourable-only winds (from NCEP/NCAR Reanalysis) by month along the west coast of North America from 45°-60° N latitude.

Monthly mean anomalies smoothed using a five-year running mean for the period 1948-2007 are shown in Fig. 4. Results clearly show the regime shift in the late 1970s as a sharp transition from stronger to weaker than average upwelling-favourable winds. Upwelling-favourable winds have been stronger than average throughout the 2000s, but if history repeats itself, our results suggest that there is to be another dramatic shift to weaker than average upwelling in the near future.

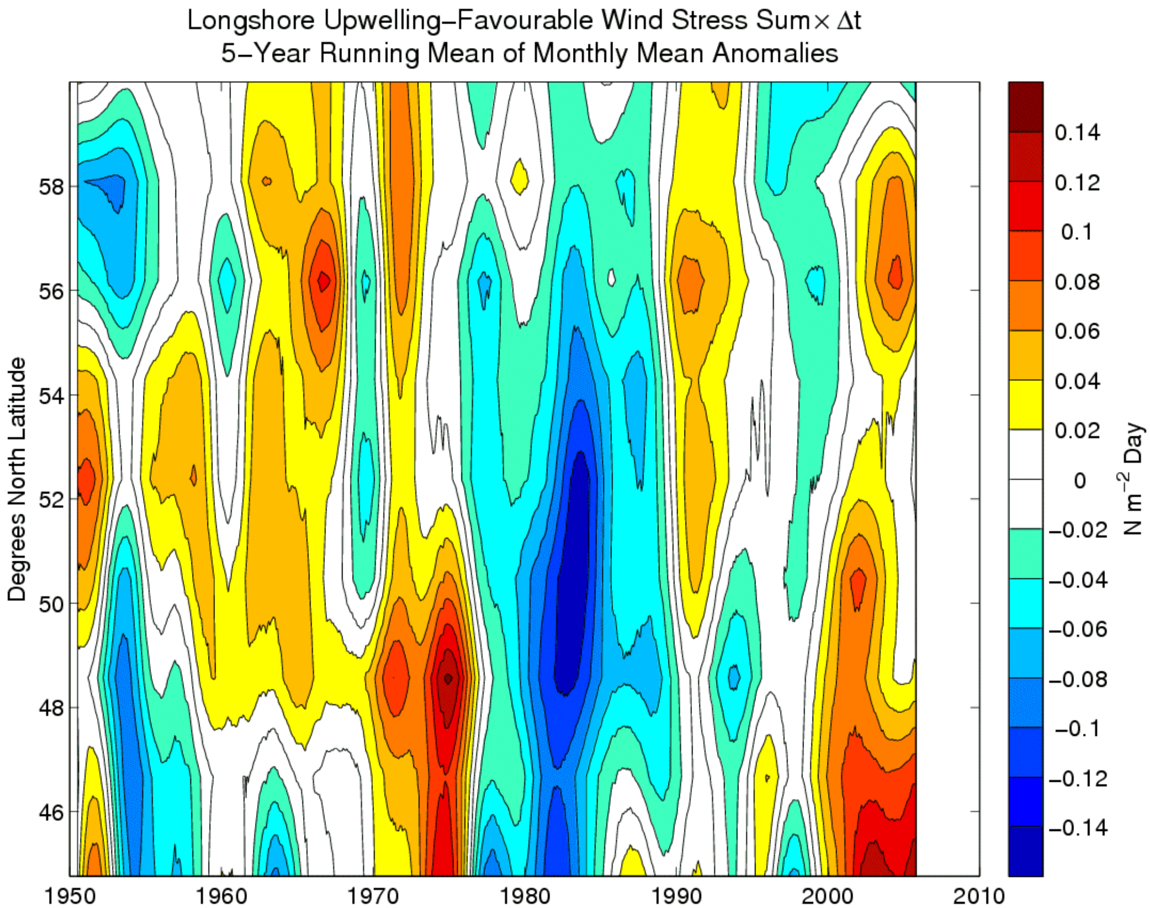


Figure 4. Five-year running means of monthly mean anomalies of monthly sums of longshore upwelling-favourable (equatorward) wind stress at coastal grid points from 45°-60° N. NCEP Daily Global Analyses data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/

Weak upwelling along the West Coast in summer 2007

Frank Schwing, Steve Bograd, NOAA Env. Research Division, NMFS, SWFSC

Yan Xue, NOAA NCEP

Much of the biological variability along the West Coast of USA and Canada arises from persistent anomalies in alongshore winds. Northerly winds push warm waters southward, and the rotation of the earth carries these waters away from shore, allowing cooler, nutrient-rich waters to upwell and stimulate phytoplankton growth. The images below reveal changes in upwelling winds along the West Coast between San Diego and southeast Alaska. The normal upwelling season progresses from March to July along the west coast of North America from 36ºN to 57ºN. It begins in April between Oregon and central BC (45°N to 51°N). Upwelling was weaker than normal through most of the summer of 2007, providing fewer nutrients for marine plant growth.

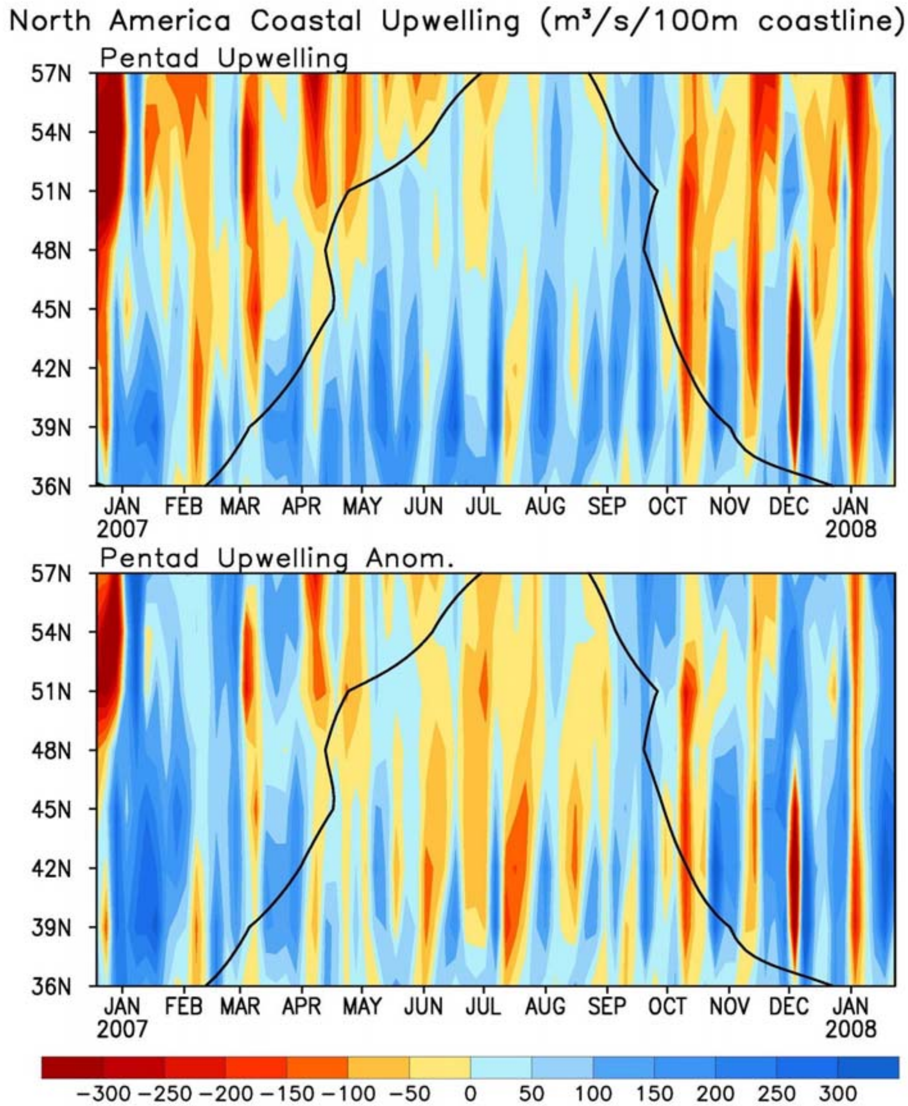


Figure 1. Upwelling (top panel) and upwelling anomaly (lower panel) between 36°N and 57°N along the West Coast of Canada and USA. (Upwelling is positive with winds from the North.) The black line marks the transition between upwelling and downwelling in normal years. Note the negative upwelling anomalies at most regions in the normal spring-to-autumn upwelling season.

Zooplankton community returns to 'cool-ocean' pattern off Vancouver Island in 2007

David Mackas, Moira Galbraith, Deborah Faust, Fisheries and Oceans Canada

Zooplankton time series coverage of the Vancouver Island continental margin extends from 1979-present for southern Vancouver Island, and from 1990-present (but with low sampling intensity and taxonomic resolution 1991-1995) for northern Vancouver Island. The grid of standard sampling locations is shown in Fig. 1; additional locations are included in within-time-period averages when they are available. Sampling consists of vertical net hauls with black bongo nets (0.25 m^2 mouth area, 0.23 mm mesh aperture) from near-bottom to surface on the continental shelf and upper slope, and from 250 m to surface at deeper locations. Mackas, Thomson & Galbraith (2001) provide more detailed descriptions of sampling and data analysis methods.

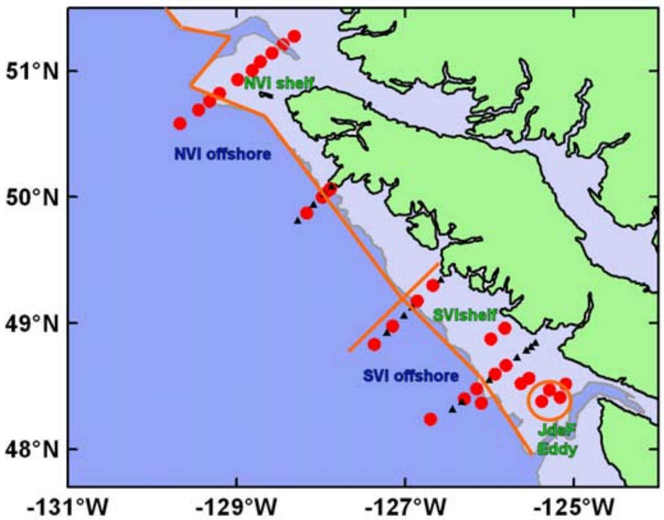


Figure 1 Standard zooplankton sampling stations off the Vancouver Island continental margin (circles), and their spatial classification into statistical areas. Triangles show supplementary CTD stations.

We calculate annual anomalies for more than 50 zooplankton taxa relative to their long-term average annual seasonal cycle within each statistical area. To summarize these results, we further average the anomalies within groups of species sharing similar ecological niches and zoogeographic ranges.

Our previous reports of zooplankton anomalies (Mackas, Thomson & Galbraith, 2001; Mackas, Batten & Trudel 2007; previous State of the Ocean reports) were referenced to 1979-1991 baseline averages for southern Vancouver Island (SVI), and to a 1990-2001 baseline for northern Vancouver Island (NVI). In 2007, we updated our average seasonal cycles to include the years to 2005, and to give finer resolution (monthly) of the seasonal cycle (Fig. 2). The main effect of this change in baseline period is that we now include the warm years of the 1990s and 2004-2006 in the long term averages for Southern Vancouver Island.

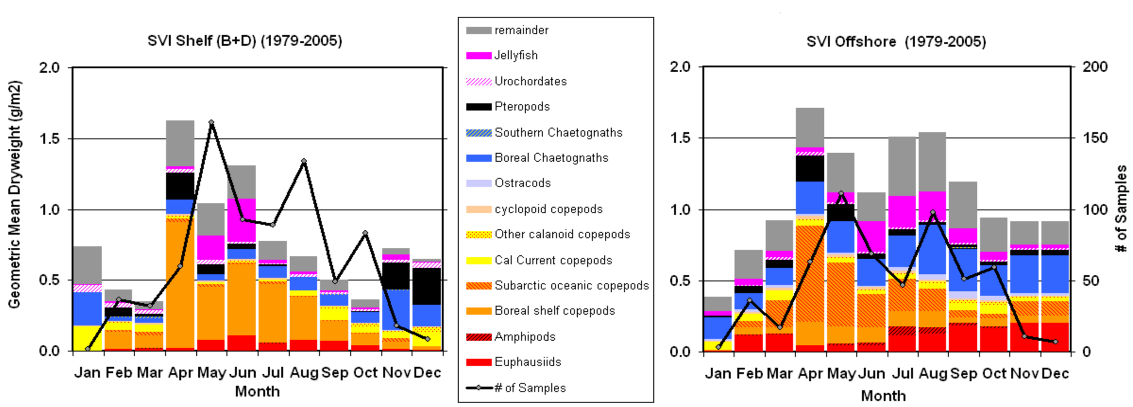


Figure 2. Updated average seasonal cycles (geometric mean of dryweight biomass) for the Southern Vancouver Island Shelf and Offshore regions shown in Fig. 1. Columns show cumulative amount for each month within 14 summary taxonomic groups. Black lines show the number of samples included in each monthly and regional average.

This shifts the SVI anomaly time series vertically, so that the complete time series are now centred around a zero mean (see comparison of 'old' and 'new' anomaly time series in Fig. 3).

Fig. 3 below (Southern Vancouver Island) and Fig. 4 on the next page (Northern Vancouver Island) show the cross-shore and annually averaged biomass anomalies for several important zooplankton species groups. Zooplankton anomalies are logarithmic: an annual anomaly of +1 means that the zooplankton were on average ten times more common than their within-region average seasonal cycle; an anomaly of –1 means they were one tenth as common.

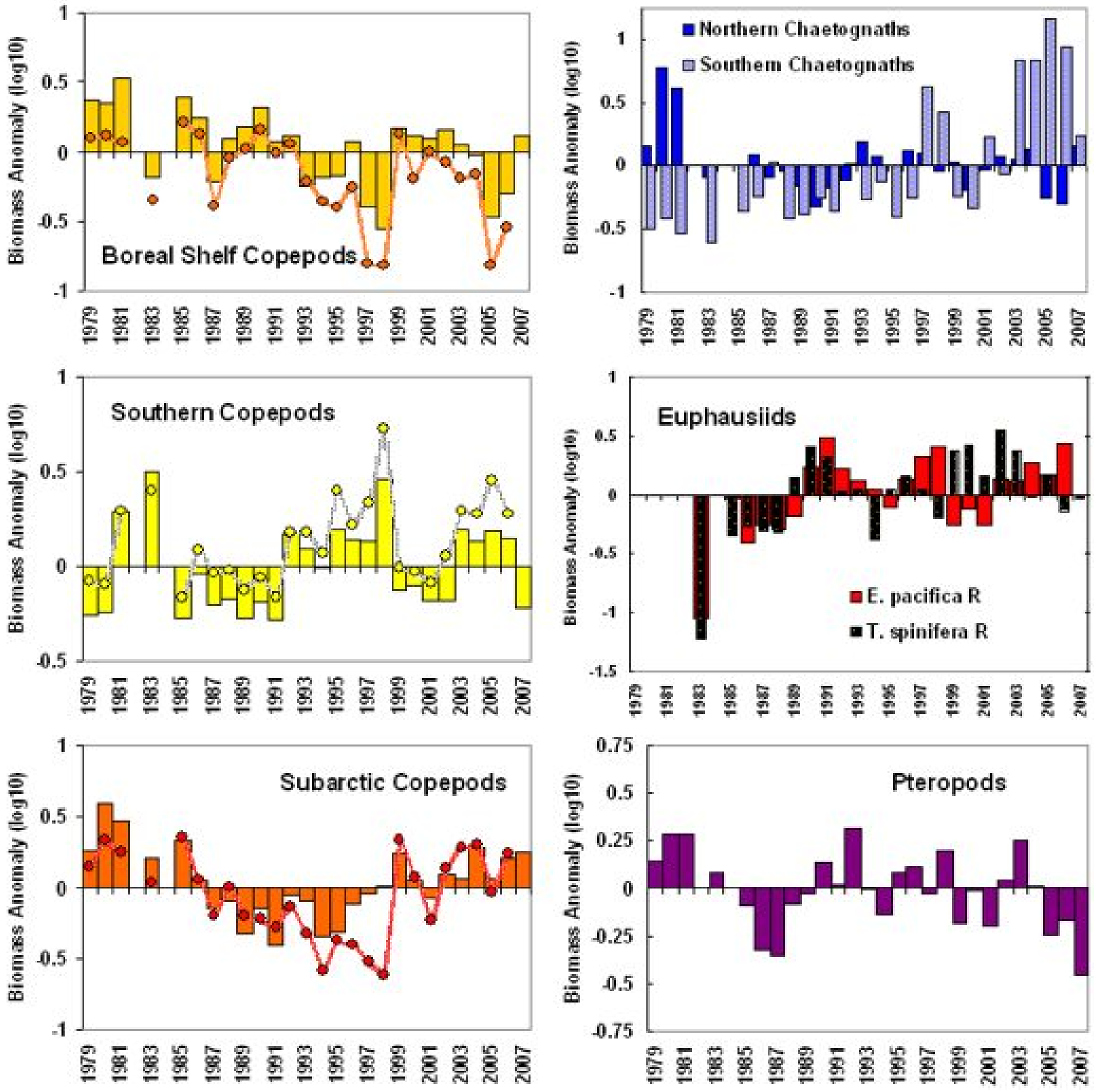


Figure 3. Zooplankton anomaly time series for southern Vancouver Island. Column bars are species group anomalies referenced to the full 1979-2005 baseline period. The years 1982 and 1984 are omitted because there were too few samples. Circles and lines in the 3 left panels show for comparison the older anomalies (1979-1991 baseline). Euphausiid anomalies have been corrected for day vs. night differences in capture efficiency, and are not reported for the first 3 years due to a change in sampling method after 1982.

Positive anomalies of energy-rich 'boreal shelf' and 'subarctic oceanic' copepods and of 'northern chaetognaths' are correlated with cool ocean conditions and high overall productivity. Positive anomalies of 'southern copepods' and 'southern chaetognaths' are correlated with warm ocean conditions and lower productivity. Euphausiids are important prey for hake, herring and juvenile salmon. Pteropods (planktonic snails) have aragonite shells and are likely to be among the taxa most vulnerable to increasing ocean acidification from higher CO2 levels of the future climate.

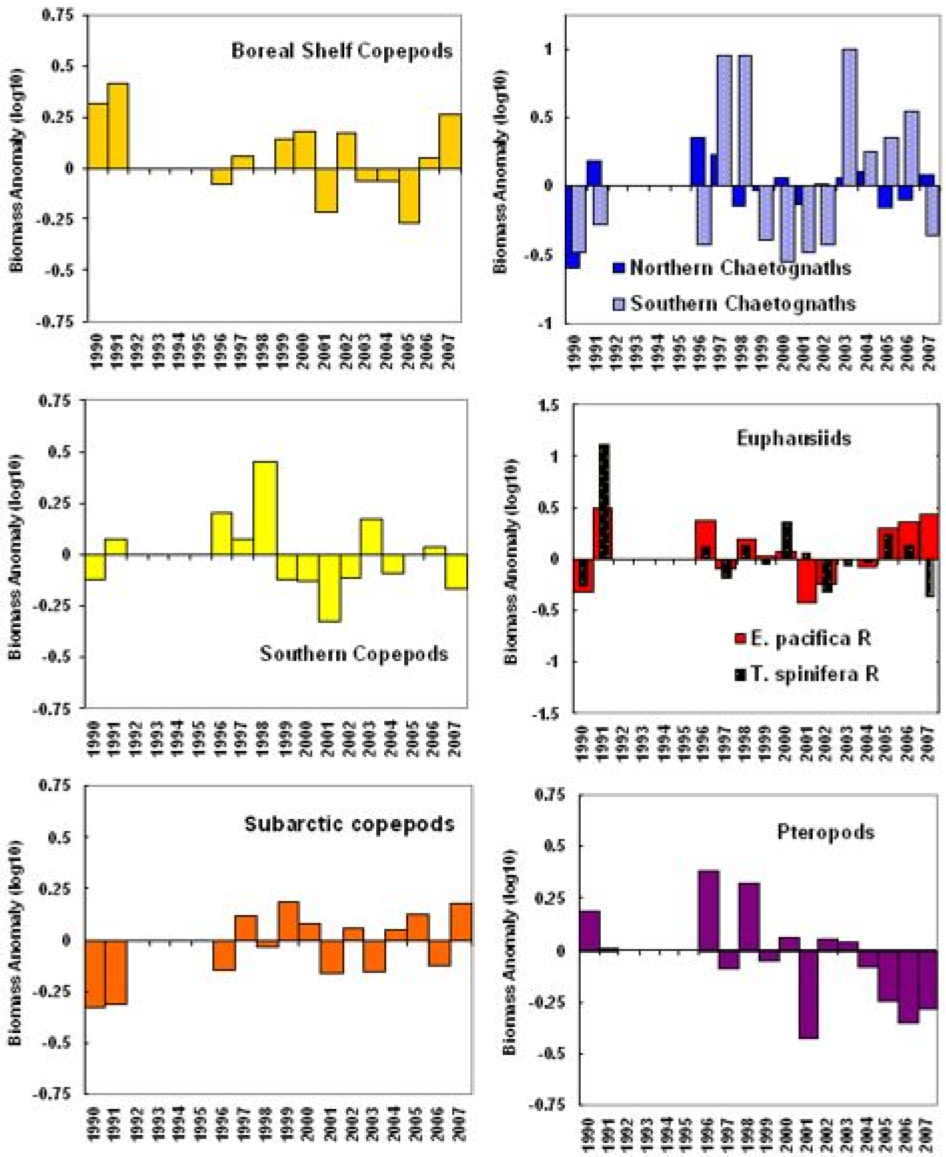


Figure 4. Zooplankton anomaly time series for northern Vancouver Island. The years 1992-1995 are omitted from the plots because there were too few samples to give reliable estimates.

Anomalously warm upper-ocean temperatures (compared to historical norms) were frequent in the NE Pacific during the past 15 years. Warm temperatures have direct effects on biota, and are correlated with other important environmental factors such as strong vertical stratification, resistance to wind-mixing and upwelling, reduced nutrient supply from deep water, reduced plankton productivity, and poleward anomalies of transport and migration. All of these push the zooplankton community toward reduced growth and survival of resident species, and toward increased abundance of their 'warm-water' competitors and predators, leading to shifts in community composition and food web pathways. These changes are evident in the zooplankton anomaly time series. During most of the 1990s, there was a strong shift to a more 'southerly' copepod fauna, and a reduction of abundance for the normal resident 'boreal shelf' and 'subarctic oceanic' copepod species groups. The trend reversed sharply in 1999, following the 1999 La Niña event. From 1999-2002, when upper ocean temperatures were relatively cool in the NE Pacific, the biomass and community composition of zooplankton along the Vancouver Island continental margin was similar to the 1980s. However, warm conditions resumed 2003-2005, and zooplankton anomalies reverted to a 'warm water' pattern in which many of the 'southern' origin copepod species were significantly more abundant than average, and the resident 'northern' copepods much less abundant than average. Northward shifts in distribution were seen in other zooplankton groups, most notably in the chaetognaths, with the formerly-dominant boreal chaetognath (*Parasagitta elegans*) being almost completely replaced in 2004-2005 by the California Current resident *Parasagitta euneritica*. Cooler ocean conditions returned in early 2006, but recovery of the boreal shelf copepods and northern chaetognaths and decline of the southern copepods and chaetognaths were delayed until 2007. Even in 2007, the return to cool ocean biomass levels and community mix was confined primarily to the continental shelf. Offshore waters off southern Vancouver Island remained relatively unproductive.

The changes in zooplankton community composition in the past 2 decades appear to have had large effects on fish growth and survival (Mackas, Batten & Trudel 2007; Trudel this report), probably because the 'cool water' zooplankton are better fish food (larger individual body size and much higher energy content). Because much of the year-to-year variability of marine survival rate of harvested fish species occurs at early life stages (for salmon, in their first year after ocean entry), recent zooplankton anomalies provide a useful index of juvenile fish nutrition and a 'leading indicator' for subsequent adult fish recruitment.

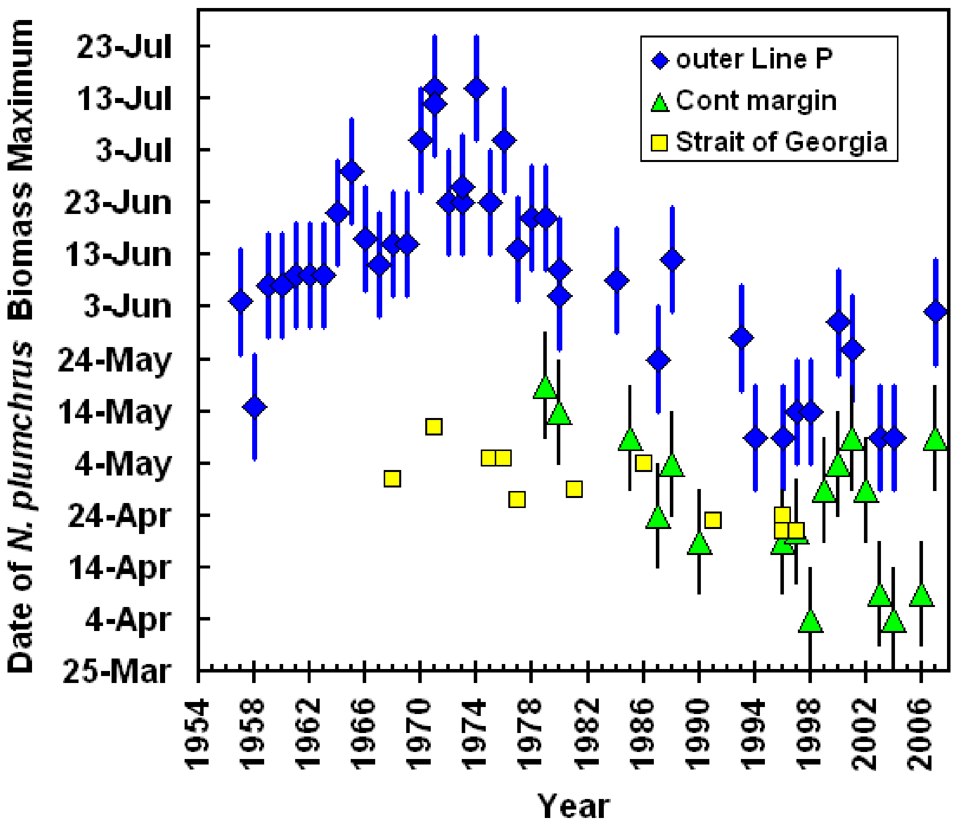


Figure 5. Changing seasonal timing of the dominant subarctic oceanic copepod Neocalanus plumchrus (Line P and continental margin time series updated from Mackas et al. 1998; Strait of Georgia time series from Bornhold 2000). In all three areas, early timing is strongly associated with warm upper ocean temperature during the spring growing season.

The briefer northern Vancouver Island region anomaly time series are qualitatively similar to SVI (bad for endemic species and good for southern species during warm years), but anomaly amplitudes off NVI are in general smaller. In 2007, the two biggest differences between SVI and NVI were that positive anomalies of the cool water taxa were similar in both shelf and offshore areas, and that *Euphausia pacifica* biomass increased rather than decreased from 2006.

Biomass and abundance of the 'subarctic oceanic' copepods (*Neocalanus* spp.) were higher in

2003-2006 than during the late 1990s. However, both warm periods were accompanied by large changes in *Neocalanus* life history timing (Fig. 5). These large copepods make up most of the zooplankton biomass in the oceanic subarctic Pacific, and have an annual life cycle that includes a brief growing season from spring into early summer followed by departure from the surface layer for a prolonged dormancy much deeper in the water column (between 400-1500 m). The annual biomass maximum, and maximum availability as food for upper ocean predators, is therefore brief (about 3-4 weeks) and occurs just before the start of this dormant period. The biomass peak and onset of dormancy occur early in the year if spring season temperature of the upper ocean is warm, and late if the water is cool. The years 2003-2006 were among the earliest recorded, both along the Vancouver Island continental margin, (Fig. 5) and in the Alaska Gyre (the North Pacific Continuous Plankton Recorder surveys had similar results). Timing in 2007 was near the long-term average, as indicated in Fig. 5.

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Oregon zooplankton off to a great start in 2007--cool winter and spring, but upwelling fizzled in June --however deep shelf waters were cold and salty all summer long

Bill Peterson, NOAA-Fisheries, Newport OR

The winter of 2006-2007 was relatively free of storms along the Oregon continental shelf. A period of calm conditions in early February resulted in a phytoplankton bloom (3 µg chl-*a* L^{-1}) which led in turn to a spawning event by the euphausiids *Thysanoessa spinifera* (at a mid-shelf station, NH 05, 360 eggs m^{-3}) and *Euphausia pacifica* (at a shelf-break station, NH 25, 340 eggs m^{-3}). This is noteworthy for two reasons: the first spawning of *T. spinifera*, a spring spawner, is usually not observed until March, and *E. pacifica* ordinarily does not spawn until summer months.

Upwelling was initiated in March but was intermittent and weak through early May; the spring transition to persistent upwelling winds was initiated on 7 May 2007. SST anomalies at the NOAA Buoy 46050 (off Newport Oregon) posted an average – 0.94°C anomaly in May. However strong northerly upwelling winds never developed during summer, resulting in very warm SST anomalies off Newport of +0.5° C, +2.9° C and +1.5° C in June, July and August respectively (Fig. 1). Similar conditions are reported for the British Columbia outer coast

Unusual ocean conditions were related to the Pacific Decadal Oscillation (PDO). The PDO was near zero in winter/spring 2007, turned positive in summer 2007, then strongly negative in Sept. 2007 (Fig. 1). It remained negative at least through March 2008. Note from Fig. 1 that both SST and species richness track changes in the PDO and Multi-Variate-ENSO Index (MEI).

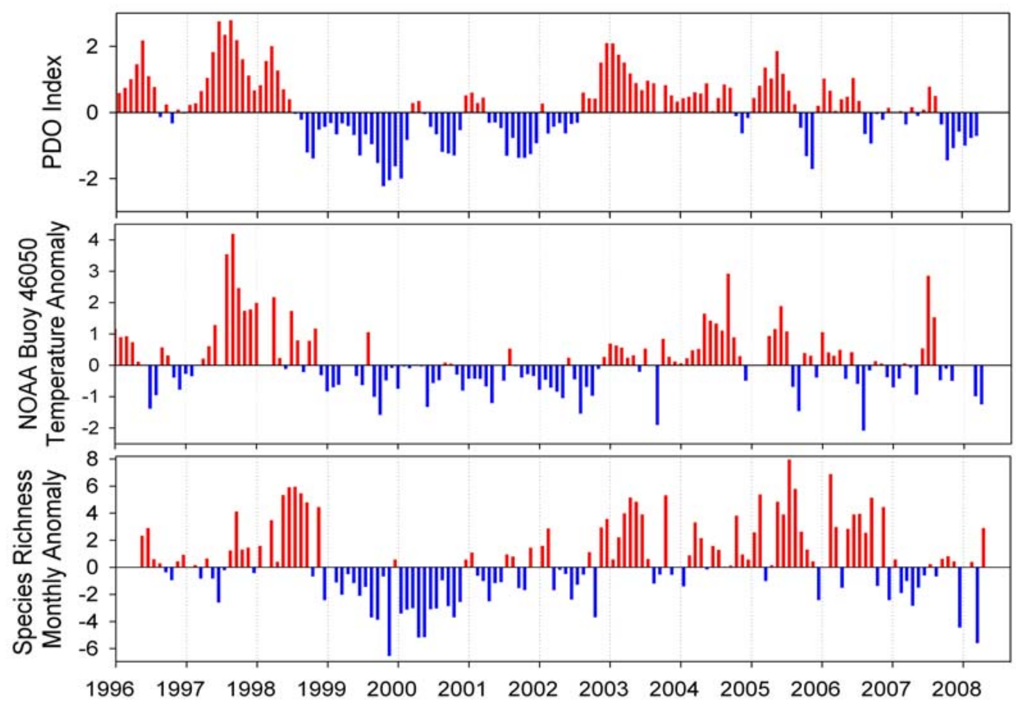


Figure 1. Monthly values of the PDO, MEI, and monthly anomalies of SST at NOAA Buoy 46050 off Oregon, and copepod species richness at nearby Oregon station NH-05. Species richness is the number of species in a plankton sample. Note (1) the three red bars in SST during summer 2007: values similar to those observed during the summer of 2005, but (2) copepod species richness remained low in 2007 as compared to the warm summer months of 2004-2006.

Based on multivariate ordinations and cluster analysis, the copepod community was a "cold water boreal" community and dominated by cold neritic species, from February through December 2007 (not shown). This is in contrast to the previous three (warm) years during which warm neritic species were prominent (*Paracalanus parvus*, *Acartia tonsa* and *Calanus pacificus*), as shown in last year's "State of the Pacific Ocean" report. Only *P. parvus* appeared in our plankton samples in 2007, and only in late summer. Perhaps the most notable item related to the copepod community was the presence of large numbers of *Neocalanus cristatus* and *N. plumchrus* in our samples (not shown). Abundances of *N. plumchrus* at our shelf break station (NH 25) were about five times higher in spring 2007 than in any other year of our time series.

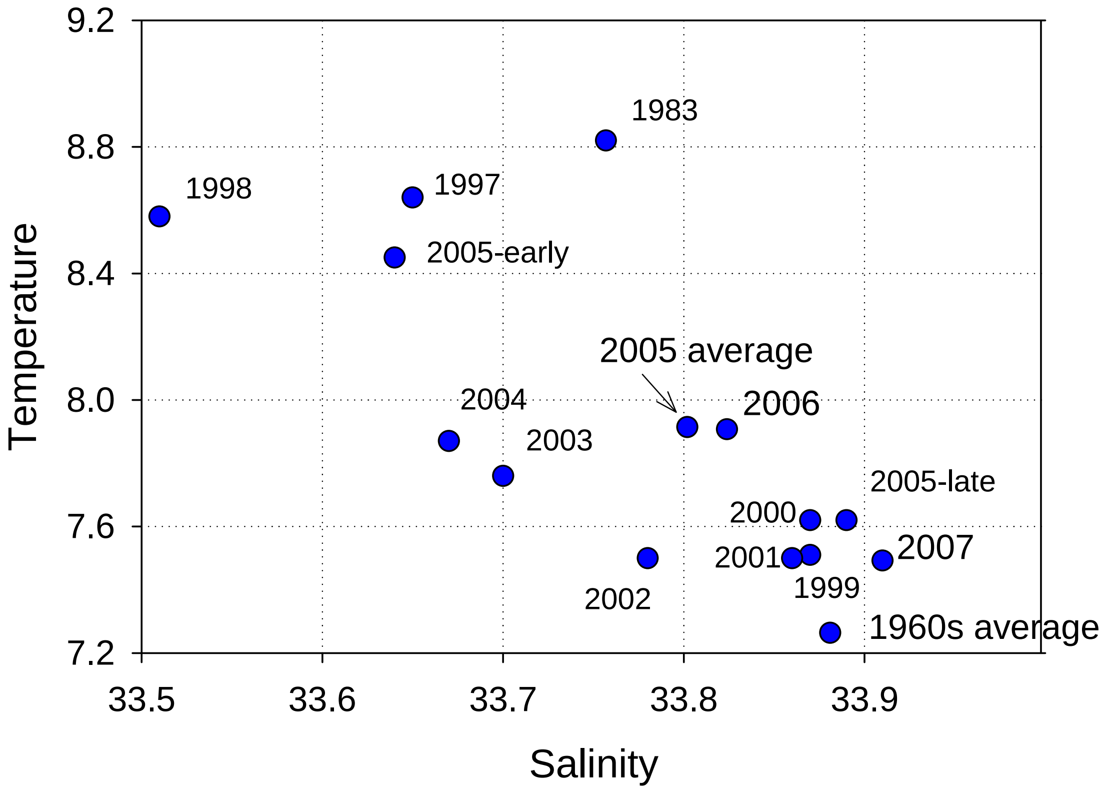


Figure 2. Temperature and salinity measured at a depth of 50 m at a mid-shelf station (NH 05: station depth 62 m) off Newport OR, averaged for May-September. Note that the summer of 2007 was as cold as the summers of 1999, 2001 and 2002, but saltier than any of these summers, and saltier than the average from the 1960s.

The presence of unusually high numbers of *Neocalanus* suggests greater transport of sub-arctic and/or Gulf of Alaska waters to the northern California Current during the winter and spring of 2007. Alternatively, transport of subarctic water into the northern California Current could have been "normal" but abundances of *Neocalanus* spp in these waters were anomalously high due to better than normal recruitment in spring 2006 or lower than normal mortality during summer/autumn of 2006.

The other unique characteristic of coastal waters off Oregon in 2007 was the presence of very cold and salty water in deep shelf waters (Fig. 2). Thus, although the surface waters were as warm as the summers of 2004 and 2005 (Fig. 1), the deep water temperature and salinity more closely resembled the summers of 1999-2002. Cold salty water overlain by warm and fresher waters suggests increased stratification in coastal waters in summer 2007.

Seabird reproductive performance on Triangle Island in 2007: A late and unsuccessful breeding season

Mark Hipfner, Environment Canada

Triangle Island Background and Species Natural History

Marine birds can be effective indicators of the state of marine ecosystems because they gather in large aggregations to breed and because, as a group, they feed at a variety of trophic levels (zooplankton to fish). Seabird breeding success is closely tied to the availability of key prey species, and as a result, can vary widely among years, depending on ocean conditions. Triangle Island (50°52' N, 129°05' W) in the Scott Island chain off northern Vancouver Island, supports the largest and most diverse seabird colony along the coast of British Columbia. Since 1994, researchers from the Centre For Wildlife Ecology (a partnership between Environment Canada's Canadian Wildlife Service and Simon Fraser University), have visited Triangle Island between late March and late August to collect annual time-series information on seabird demography and ecology. This report presents key indicators of seabird breeding at Triangle Island in 2007, and places 2007 results within the context of the 1994-2006 time series and earlier measurements back to mid-1970s.

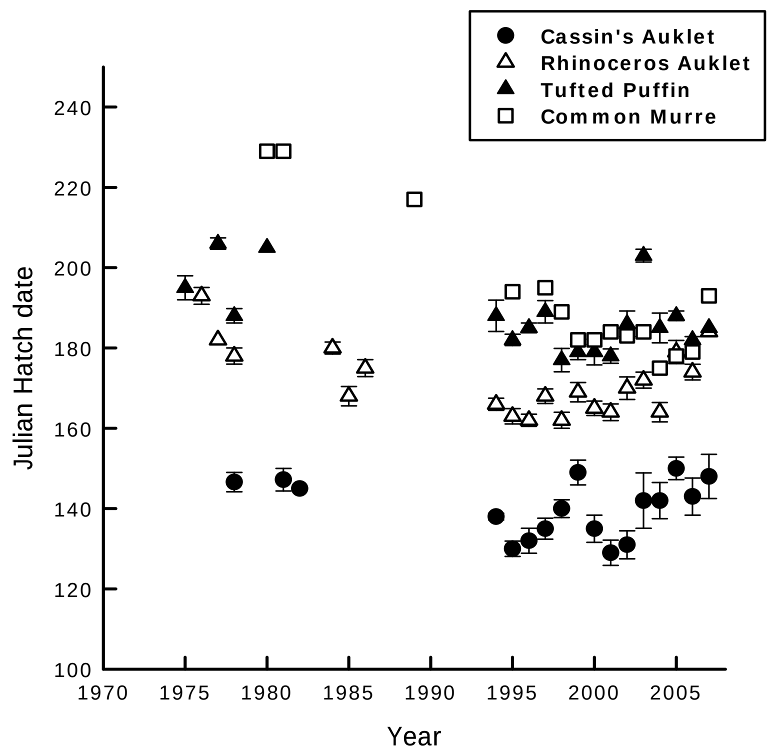


Figure 1. Timing of breeding for seabirds on Triangle Island, British Columbia, 1975-2007. Reported are mean hatching dates, with 95% confidence intervals, for Cassin's Auklets, Rhinoceros Auklets and Tufted Puffins, and dates when nestlings were first seen for Common Murres. Note that the timing of breeding in 2007 continued to revert back toward long-term averages in all species.

Timing of breeding

Variation in the timing of avian breeding is determined primarily by female condition prior to and during the period of egg formation, which is itself related to food availability early in the season. In general, the timing of breeding among the alcids continued to revert back towards long-term averages in all species (Fig. 1). Of note, Common Murre hatching began considerably later in 2007 than in other recent years.

Breeding success

For all species, breeding success was average or below average at Triangle Island in 2007. In Cassin's Auklet, success in 2007 was close to values predicted from the cold March sea-surface temperatures recorded at Pine Island (Fig. 2). In contrast, success was extremely low for Rhinoceros Auklets (the lowest in the time series), and much lower than predicted from sea-surface temperature in April. The representation of Pacific sandlance, a preferred prey species, in Rhinoceros Auklet nestling diets was extremely low in 2007 (< 10% of biomass), continuing a very dramatic eight-year decline. Success was the lowest on record for Common Murres as well, although the time series for that species goes back only to 2003. On the whole, 2007 was a poor year for breeding for the seabirds on Triangle Island.

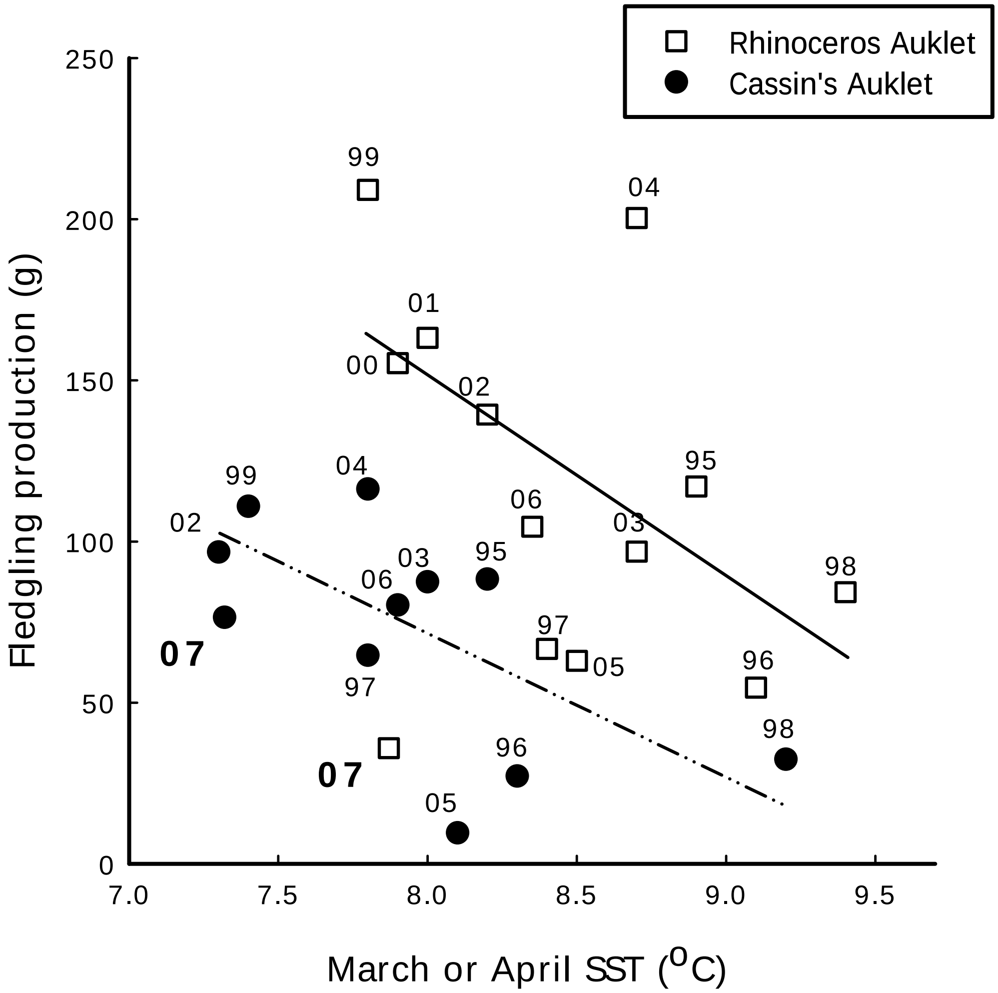


*Figure 2. Consequences of April sea surface temperatures, measured at the Pine Island Lightstation (50°35'N 127°26'W), for Cassin's and Rhinoceros Auklets breeding on Triangle Island, in 2007, compared to the trend for 1994-2006. Fledgling production is calculated as: hatching success * % fledging success * mean fledging mass; or in other words, the mean mass of fledged chick produced per egg laid.*

Links

[Scott Islands Marine Wildlife Area]

[Canadian Wildlife Service bird monitoring in BC]

Small-mesh bottom-trawl surveys in May: biomass of smooth pink shrimp continues to be low since 2004

Ian Perry, Jim Boutillier, Dennis Rutherford. Fisheries and Oceans Canada

Bottom trawl surveys using a small-mesh net (targeting the smooth pink shrimp *Pandalus jordani*) have been conducted during **May** since 1973. The survey in 2007 found that the biomass of *Pandalus jordani* shrimp off central Vancouver Island was low and similar to that from 2004 to 2006. Pink shrimp biomass continues to be affected by the warm ocean conditions from 2003 to 2005, likely a result of poor recruitment during this period and a 2-yr time lag to capture by the survey. Biomass of most other "key" indicator species continued to decline from record highs (for some species) in 2005; exceptions in 2007 were increases of both warm (Pacific hake) and cool (walleye pollock) water species. Diversity indices (not shown) indicate that the distribution of biomass among 33 key vertebrate and invertebrate taxa has returned to "normal" after being concentrated into fewer taxa in 2005 and 2006 compared with 1997-2004.

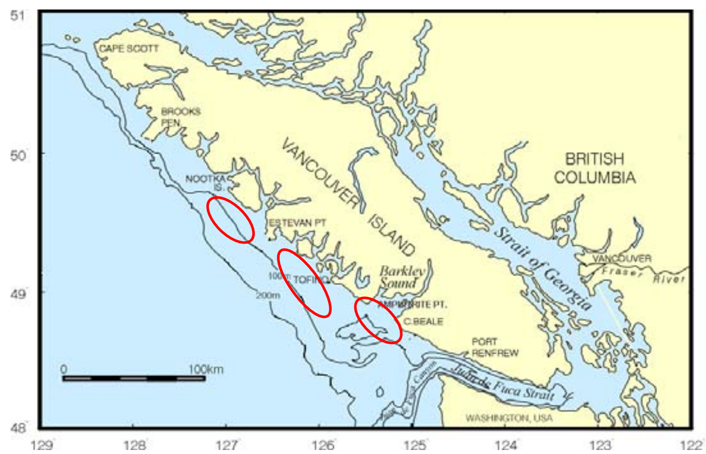
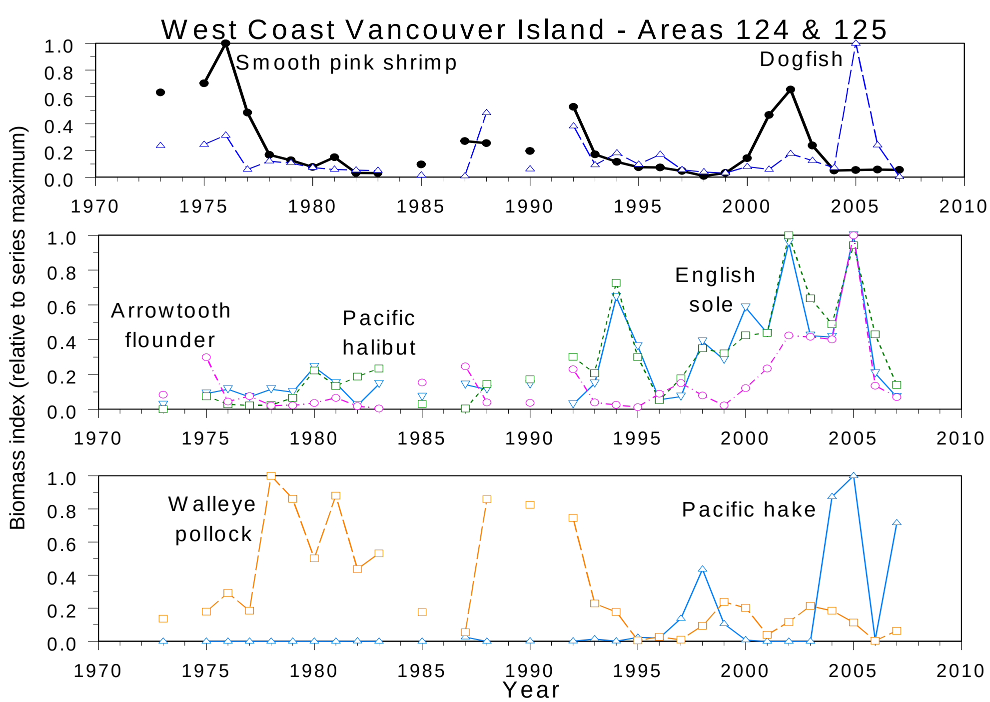


Figure 1 (left) Map showing the three main shrimp (Pandalus jordani) survey grounds off Vancouver Island (red ovals). The Nootka (Area 125) and Tofino (Area 124) Grounds are the northern and middle ovals, respectively.

Figure 2 (below): Time series of normalised (to maximum biomass) survey catches of smooth pink shrimp, dogfish, Pacific halibut, Arrowtooth flounder, English sole, Pacific hake and walleye pollock.



Small pelagic fishes

Jake Schweigert, Fisheries and Oceans Canada

West Coast of Vancouver Island

Herring abundance off the west coast of Vancouver Island decreased from 1977 through to the present to levels not seen since the late 1960s. Abundance in 2007 was similar to 2006 and well below the fishery threshold. Warm ocean temperatures appear to be associated with poor recruitment for herring (the opposite of herring stocks in the Strait of Georgia), and an increase in summer biomass of predators. Apart from predation, ocean conditions (temperature) appear to be warming, especially from 2002 to 2006, resulting in poor herring survival that may result in continued reduced recruitment to the stock in 2008 and 2009.

Sardine returned to southern Vancouver Island waters in 1992 after a 45 year absence, and expanded their distribution northward throughout the west coast of Vancouver Island, Hecate Strait and Dixon Entrance by 1998. Sardine spawning was reported off the west coast of Vancouver Island in 1997 and 1998. In 2007 sardines appeared in Canadian waters in late June. The distribution was similar to that in 2006 and concentrated north of Vancouver Island in southern Hecate Strait and Queen Charlotte Sound. The exceptionally strong 2003 year-class continues to be an important factor in the widespread distribution of smaller sardines throughout the area.

North Coast

Exploitable herring biomass in the north coast area is an amalgamation of migratory stocks from the Queen Charlotte Islands, Prince Rupert and Central Coast areas. Recruitment in the Queen Charlotte Islands stock has been reduced for the past decade, resulting in low abundance, while recruitment in the Prince Rupert and Central Coast stocks has been generally good, because of sporadic very strong year classes. However, both of the most recent year-classes (2003 and 2004) have been weak in these areas resulting in further decline in abundance from the previous year.

Small pelagic fishes: detailed analyses

Herring

Since about 1977, the recruitment of herring off the west coast of Vancouver Island has been generally poor, interspersed with a few good year-classes (Fig. 1). As a result, the productivity of the west coast of Vancouver Island herring stock (Fig. 2) has been declining since the early 1980s (Fig. 1). Research studies have shown that herring recruitment in this region tends to be negatively correlated with temperature probably reflecting: 1) poor feeding conditions for herring larvae and juveniles during their first growing season; and 2) a general increase in the mortality rate of the larvae and juveniles, due to an increase in the intensity of invertebrate and fish predation in the rearing area in warm years. Studies to measure the predation rate confirm that the negative correlation between herring recruitment and hake biomass could be caused by predation or competition for food. Ocean conditions have warmed in the last few years (2002 to 2006), impacting herring survival in 2004 and 2005 and could result in continuing reduced recruitment to the stock in 2007 and 2008.

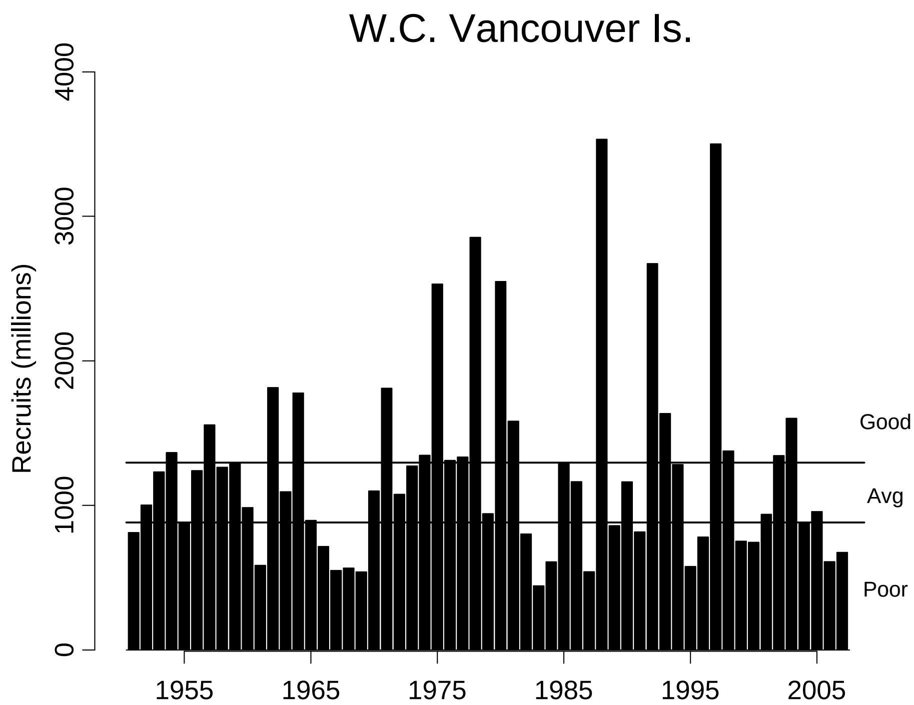


Figure 1. Interannual variability and decadal trends in recruitment to the west coast of Vancouver Island herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 4 of the last 10 recruitments have been 'poor'.

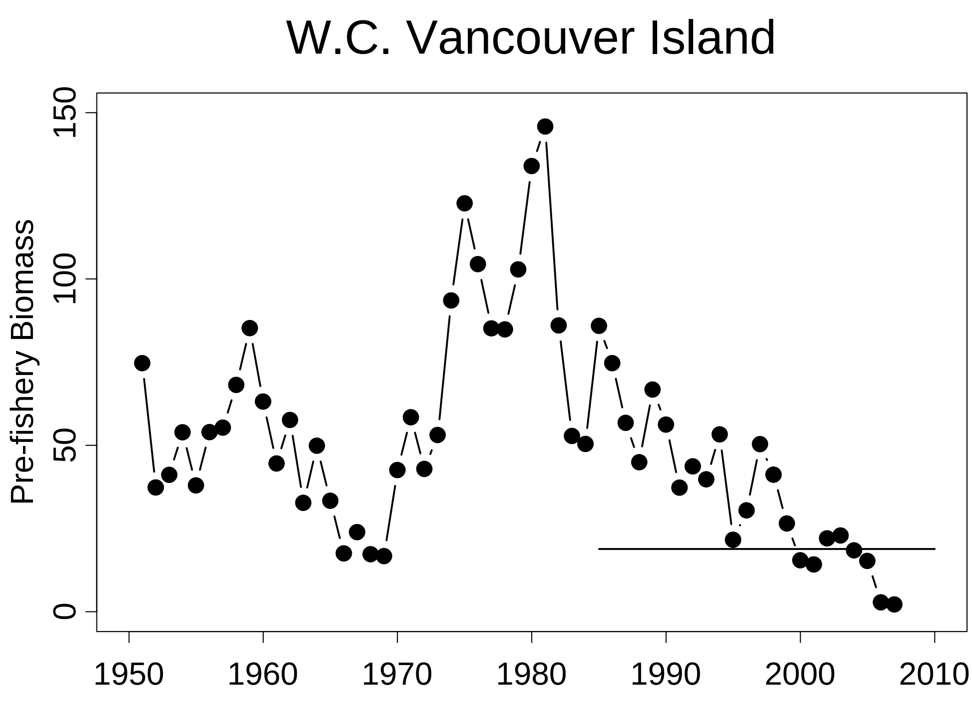


Figure 2. West Coast Vancouver Island herring abundance.

Pacific Sardine

Pacific sardine is a migratory species and when the population is healthy and ocean conditions are favourable, sardines migrate to British Columbia in the summer to feed. Most of these summer migrants make a return spawning migration in the fall to the waters off central and southern California. The sardine fishery in Canadian waters collapsed in 1947 without warning and by the early 1950s off California due to unfavourable environmental conditions. After a 45-year absence from British Columbia waters, sardines reappeared off the west coast of Vancouver Island in 1992. From 1992-1996, their distribution was limited to the southern portion of Vancouver Island.

In 1997, their distribution expanded northward and by 1998 sardines inhabited waters east of the Queen Charlotte Islands throughout Hecate Strait and up to Dixon Entrance. Spawning was reported off the west coast of Vancouver Island in 1997 and 1998. In 1999 during La Niña, sardine distribution again contracted southward. The most recent U.S. assessment suggests that coast wide abundance peaked in 2000 and has declined since, decreasing to less than 1 million tonnes in 2007 (Fig. 3). During 2006 and 2007, sardines appeared in Canadian waters in late-June and were distributed offshore and largely north of Vancouver Island into southern Hecate Strait and Queen Charlotte Sound (Fig. 4).

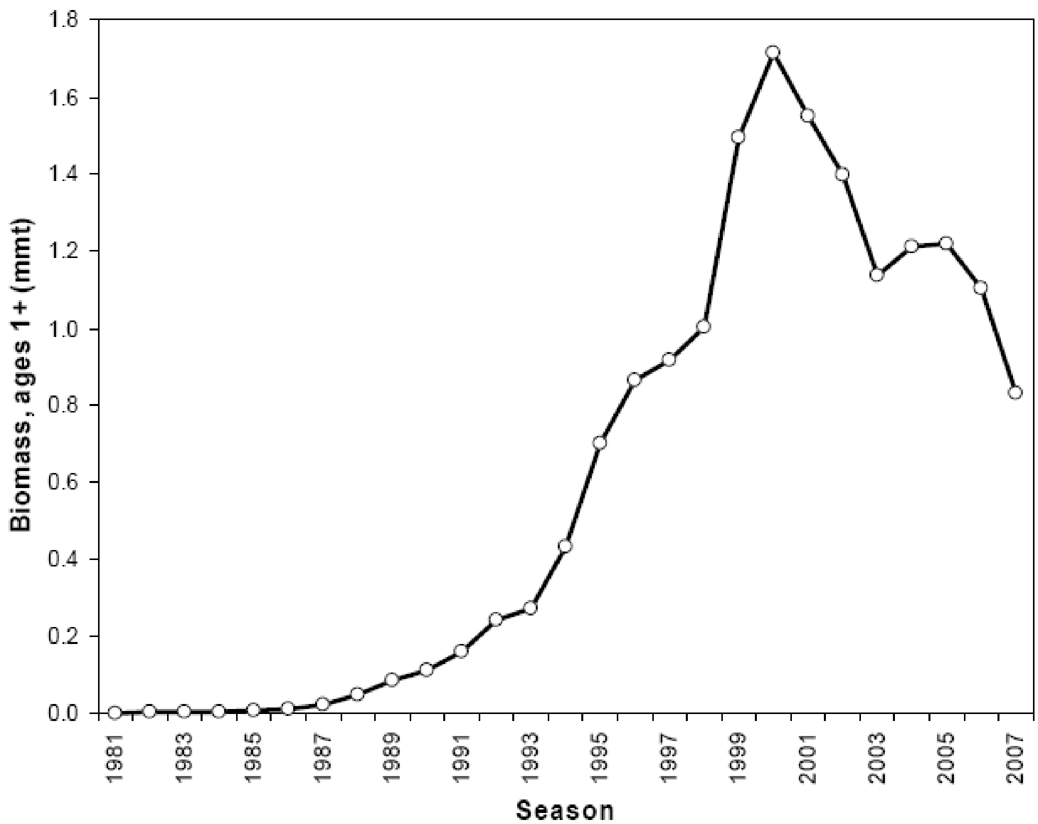


Figure 3. Time series of Pacific sardine stock biomass (x1,000 mt) of age 1 and older fish, estimated from an age-structured stock assessment model (data from Hill et al. 2006).

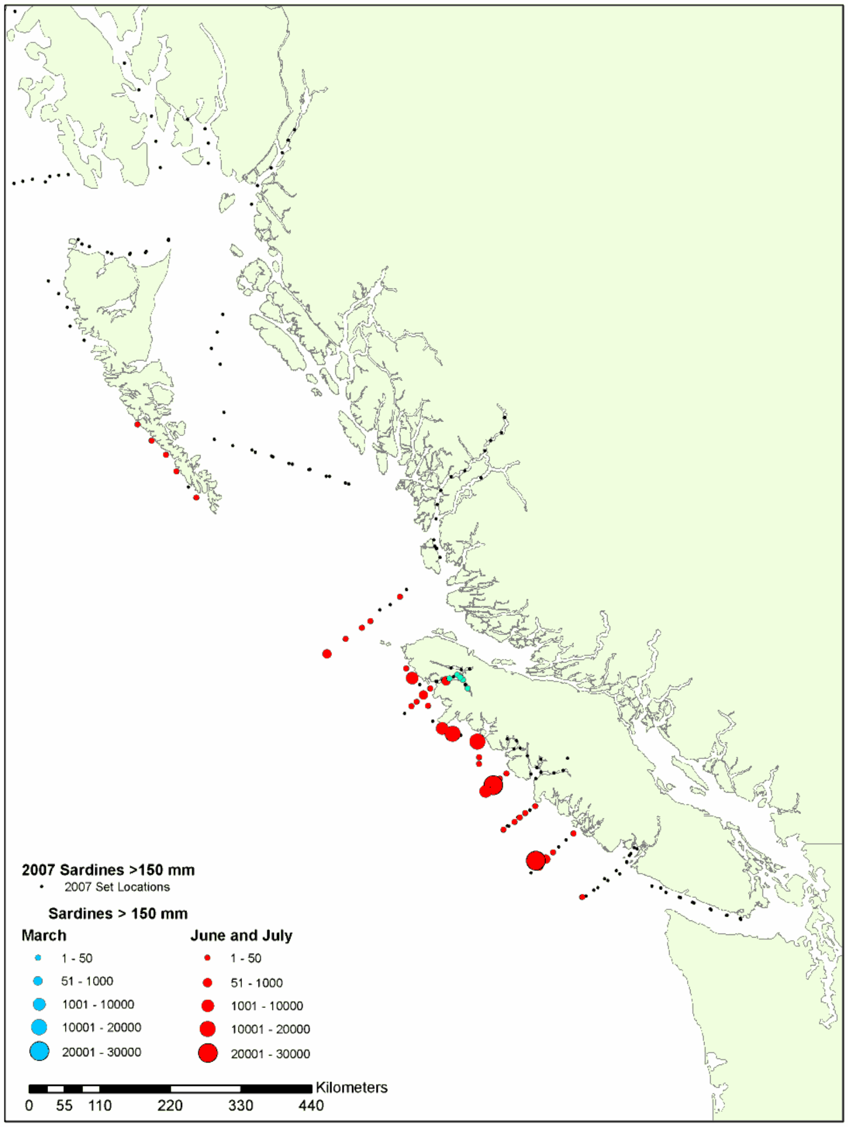


Figure 4. Distribution of Pacific sardine in BC waters during 2007 based on by-catch in the high seas salmon surveys.

Herring in Hecate Strait

The exploitable biomass of herring in the Hecate Strait area is an amalgamation of the three major migratory stocks in the Queen Charlotte Islands, Prince Rupert, and in the Central Coast. Over the past decade, abundance in the Queen Charlotte Islands has been depressed whereas abundance in both Prince Rupert and the Central Coast has remained at healthy levels (Figs. 5,7,9). Levels of recruitment to the Queen Charlotte Islands have been depressed (Fig. 6) with only 2 of the past 10 year-classes being above average, while the Prince Rupert stock (Fig. 8) has experienced a good recruitment at least every 4 years since 1980. Recruitment to the Central Coast stock (Fig. 10) has been less regular but the 'good' year-classes that have occurred were very strong. Indications are that the most recent recruitments (2003 and 2004 year-classes) are poor and resulted in declines in the Prince Rupert and Central Coast stocks while the Queen Charlotte Islands increased slightly.

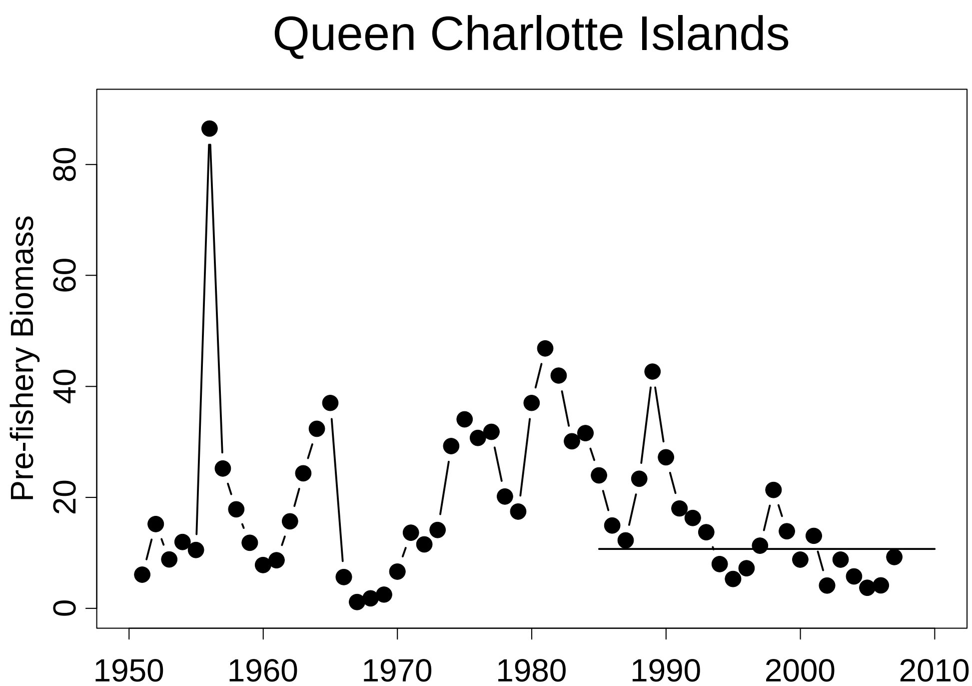


Figure 5. Queen Charlotte Islands herring abundance.

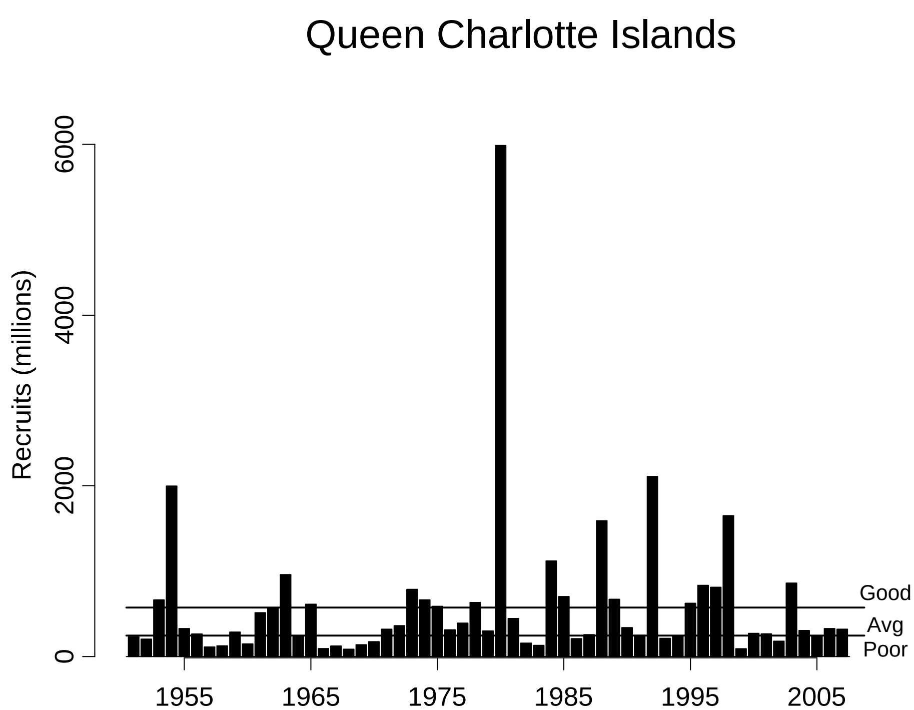


Figure 6. Interannual variability and decadal trends in recruitment to the Queen Charlotte Islands herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that only 2 of the last 10 recruitments have been 'good'.

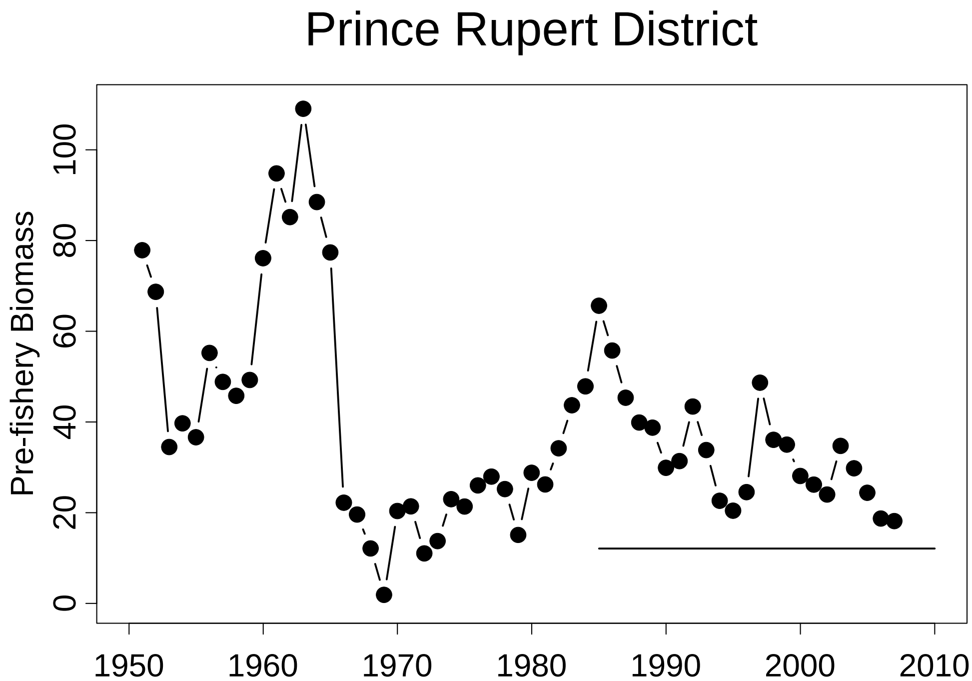


Figure 7. Prince Rupert District herring abundance.

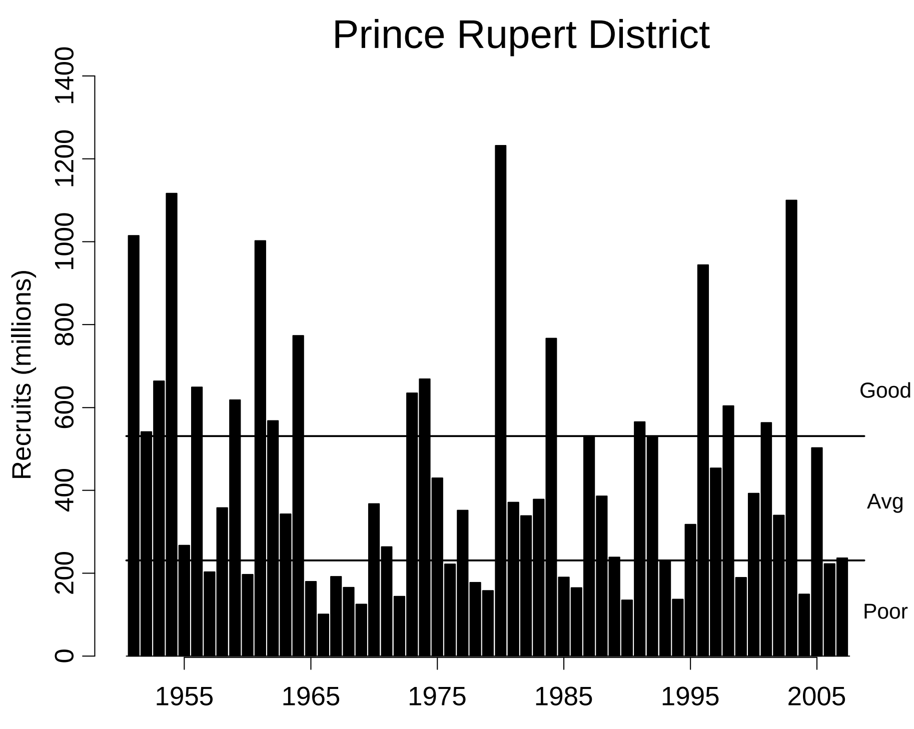


Figure 8. Interannual variability and decadal trends in recruitment to the Prince Rupert District stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 'good' recruitments have occurred almost every four years since 1980.

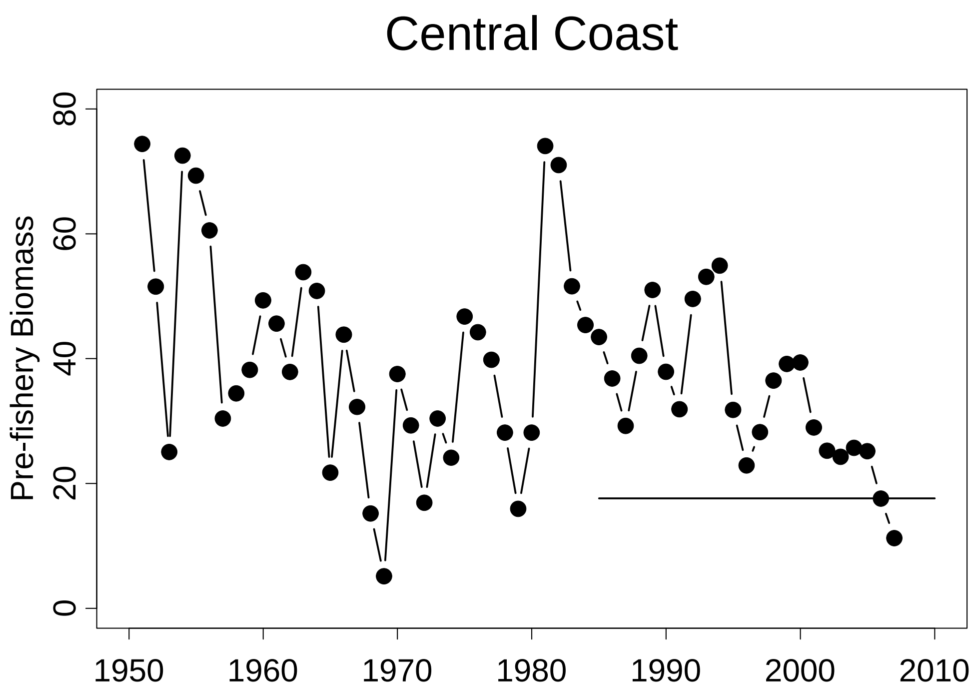


Figure 9. Central Coast herring abundance.

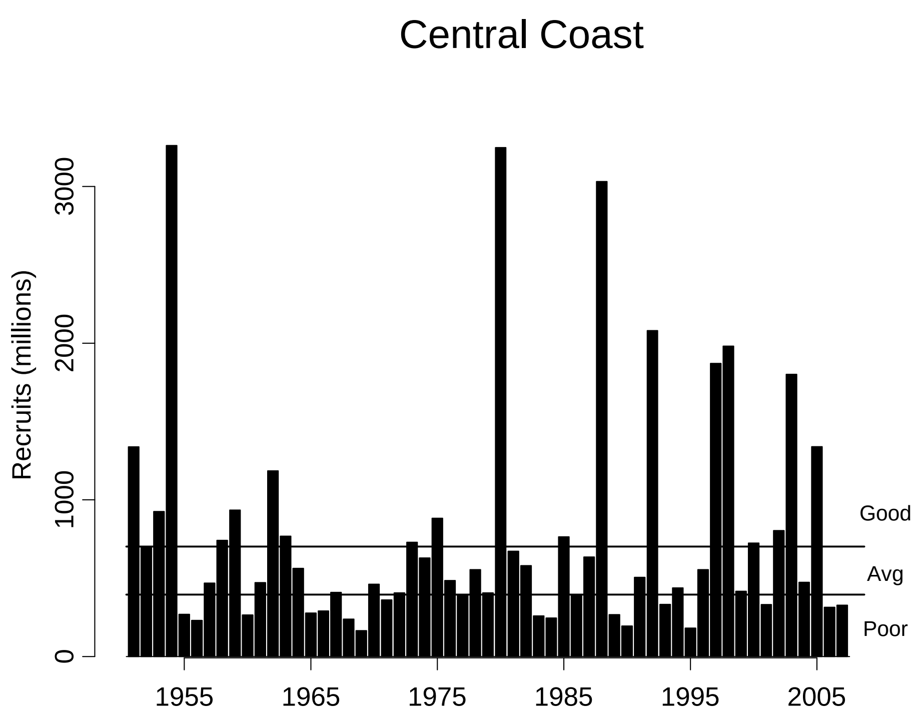


Figure 10. Interannual variability and decadal trends in recruitment to the Central Coast stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

Small Pelagic Fishery Interpretation and Speculative Results

West Coast Vancouver Island

Herring: Herring on the west coast of Vancouver Island is at an historically low level and will remain so unless ocean conditions resulting in a reduction in the abundance of predators in the area improve. Recent conditions have not been favourable for herring survival in 2004 and 2005, and we expect continued weak recruitment to the stock during the next couple of years.

Sardine: Sardines reappeared off the west coast of Vancouver Island in 1992. During the 1990s their distribution expanded northward from southern Vancouver Island through Hecate Strait to Dixon Entrance. In 2003 and 2004 the distribution of sardines in B.C. was limited to the inlets of Vancouver Island and offshore areas in the south. Recent warm conditions and a very strong 2003 year-class has resulted in widespread distribution of sardines throughout southern Hecate Strait and Queen Charlotte Sound in 2006 and 2007.

North Coast Major

Herring: Herring in the Hecate Strait area consist of migratory stocks from the Queen Charlotte Islands, Prince Rupert and Central coast areas. For the past decade, recruitment and abundance of the Queen Charlotte Islands stock has been low while recruitment and abundance of the Prince Rupert and Central Coast stocks have been generally good. Recruitment of the 2003 and 2004 year-classes was weak in all three areas resulting in moderate declines in Prince Rupert and the Central Coast. Warming ocean conditions resulting in increased hake abundance in this area may be expected to negatively impact herring recruitment and stock abundance over the short term.

Sockeye salmon index stocks – Regional overview of trends and 2007 returns

Kim Hyatt, Karen Hunter, Margot Stockwell and Paul Rankin,
Fisheries and Oceans Canada.

Results from recent studies (Mueter et al. 2002a, 2002b, Pyper et al. 2005) suggest that associations between Pacific salmon survival and near coastal environmental variables (*upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]*) are strongest at local spatial scales (distances of less than 500-800 km) for adjacent stocks and exhibit little to no co-variation at spatial scales larger than 1000 km. Among three variables examined (*upwelling, SST and SSS*), correlation scales for SST in summer most closely matched the correlation scales for salmon survival. Furthermore, regional averages of SST appeared to be better predictors of survival rates than large-scale measures of SST variability such as the Pacific Decadal Oscillation (PDO; Mueter et al. 2002b). This suggests regional-scale variations in SST along the coast are related to the processes causing the observed co-variation in survival rates of neighbouring salmon stocks. Thus, neighbouring stocks are likely to exhibit stronger similarities in survival and production variations than stocks separated by larger distances. In addition, species comparisons suggested geographical overlap of salmon species during freshwater and early marine life stages are more important in determining shared environmental effects on survival rates (*and ultimately on stock productivity*) than are species differences (Pyper et al. 2005).

Comparisons of forecasts and observed total returns of sockeye salmon for major rivers and fisheries throughout coastal British Columbia have been completed annually by DFO stock assessment personnel for decades (Fig. 1). Given the observations noted above, production trends for major sockeye populations or stock aggregates (i.e. “index-stocks”) may reflect environmental changes and anticipate production trends for several salmon species originating from areas of the coast constituting separate production domains. Comparisons of trends for several sockeye index-stocks permit the following generalizations:

- Annual variability in total returns for all stocks is large with maximum annual returns ranging between 10 to 90 times the minimum return.
- Since 1970, maximum returns for all stocks occurred during the early 1990’s immediately following the strong La Niña event of 1989.
- Central Coast, Vancouver Island (WCVI) and Fraser index-stocks all declined from early-1990s highs to persistent, sub-average returns since the mid-1990s (Fig. 1).
- North Coast and Transboundary index-stocks declined from early-1990s highs, exhibited by all sockeye index-stocks, to sub-average values by the late-1990s (Fig. 1) but since the year 2000 have exhibited a higher frequency of above-average returns (*43% of return years*) than Central and South coast stocks (*only 7% of return years*).
- Index-stocks entering continental shelf areas under stronger oceanic influences (*i.e. areas 3 and 4 of Fig. 1*) appear more responsive to alternations in La Niña-like (*anomalously cool, survival favourable*) and El Niño-like (*anomalously warm, survival less favourable*) conditions (*see detailed analysis for WCVI and Central Coast areas below*) than stocks entering more protected estuarine waters (*i.e. areas 1, 2, and 5 of Fig. 1*).
- As anticipated (Hyatt et al. 2007), persistence of strong El Niño-like conditions through the 2005 sea entry period by smolts was associated with low adult return rates in 2007 for Central Coast (Rivers and Smith Inlet), WCVI (Barkley Sound) and Fraser (Chilko Lake) sockeye index stocks.
- Expectations for near-average to above-average returns of North Coast and Alaska Transboundary stocks respectively were also borne out.
- Observed returns were notably lower than “formal” numeric forecasts for sockeye stocks throughout coastal B.C. and Southeast Alaska in 2007 (Fig. 1).
- Low return rates in 2007 appear to reflect anomalous environmental conditions (high SST, lower food quality, elevated losses to predators) influencing juvenile salmon survival several weeks before to several weeks after sea entry in 2003, 2004 and 2005 (DFO 2006, 2007).

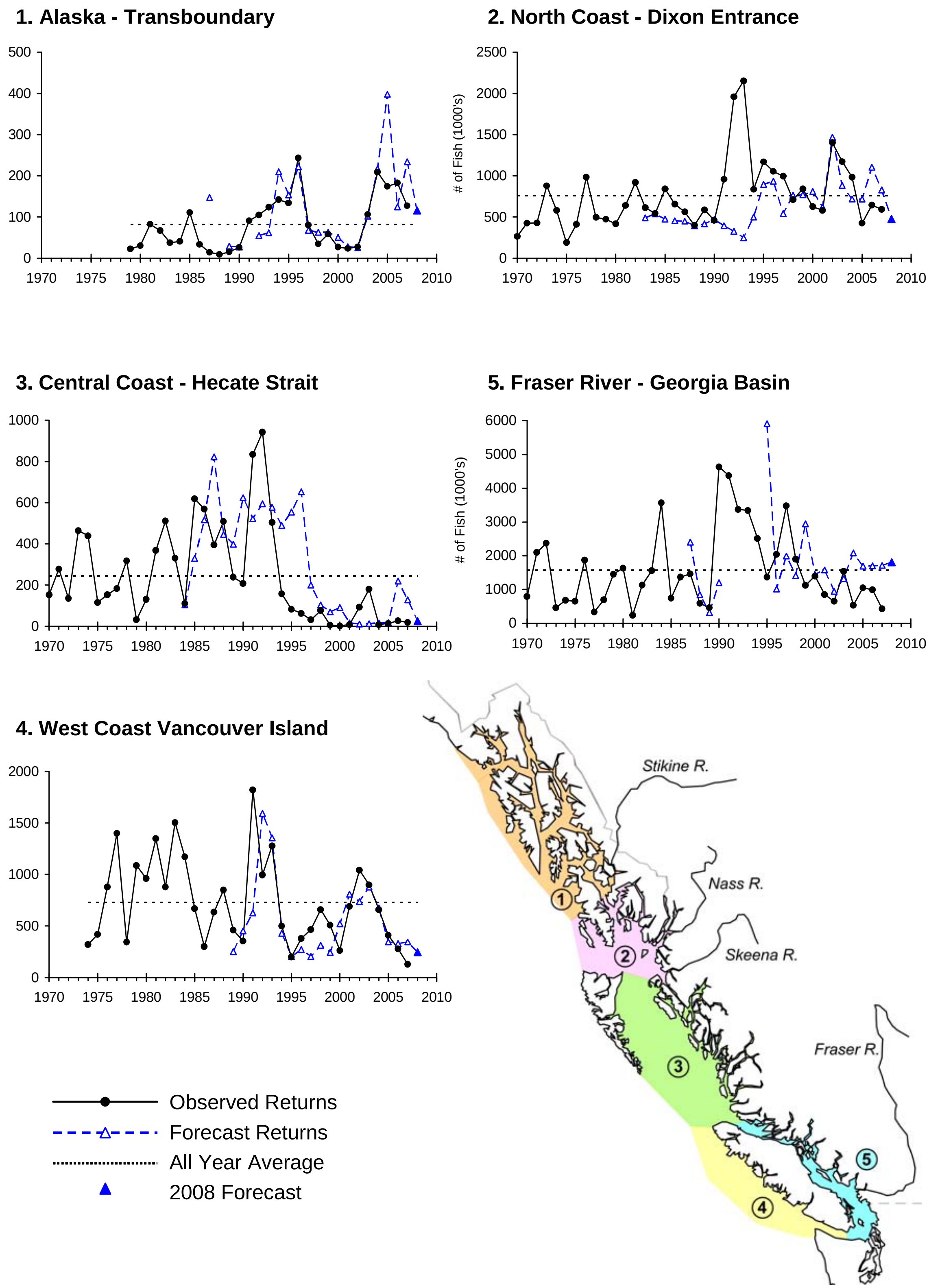


Figure 1. Trends in the total returns and forecasts for British Columbia sockeye index stocks including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Barkley Sound, and 5. Chilko sockeye salmon. Y-axis represents returns in thousands of fish.

West Coast Vancouver Island

Barkley Sound Sockeye Salmon: Continued low returns

Barkley Sound (BkSd) sockeye on the West Coast of Vancouver Island exhibit annual recruitment variations that alter abundance patterns by more than a factor of ten within intervals as short as 2-3 years (Fig. 1, Area 4). Studies of these variations have supported the use of a simple two-state, “survival-stanza”, model since 1988 (SStM, Hyatt and Luedke 1999) to successfully predict multiyear intervals of stock collapse (late 1980’s, mid-1990’s, 2004-2007) and recovery (early 1990’s, 2001-2003). SStM forecasts rely on the concept that continental-shelf ecosystems alternate between two states which support either high or low marine survival of juvenile sockeye respectively (Hyatt and Steer, 1988). Thus, “La Niña-like” conditions (*SST < 30 yr average during smolt migration, low northward transport, average to below average sea level*) are associated with relatively high marine survival (5 %) and “El Niño-like” conditions (*SST > 30 yr average, elevated sea level, high northward transport*) with lower marine survival (2.5 %).

2007 Observations:

Barkley Sound sockeye salmon returns remained well below the long term average in 2005, 2006 and 2007 as predicted by the SStM model (Fig. 1, Area 4). Lower marine survivals experienced by WCVI juvenile salmon during their 2003-2005 ocean entry years (adult returns in 2005-2008) were anticipated by positive SST and ENSO indices respectively (DFO, 2005, 2006, 2007).

Outlook for 2008 and beyond:

In spring 2006, sea surface temperature anomalies at Amphitrite Point and the NOAA multivariate ENSO index were average and weakly La Niña-like respectively (DFO 2006, 2007). Consequently, 2008 return rates for Barkley Sound sockeye and several other salmon stocks (all WCVI origin sockeye stocks, Carnation Creek coho, Robertson Creek coho and Chinook) are expected to improve. However, even if survivals are average, because stock sizes are depressed, we expect below average run sizes in 2008 (Fig. 1, Area 4).

By contrast, the shift to a much stronger La Niña state in winter 2007-08 anticipates significant improvement in survival rates for WCVI coho and sockeye migrating seaward in 2007 and returning as adults in either 2008 (coho) or 2009 (sockeye) respectively.

Central Coast – Queen Charlotte Sound

Rivers and Smith Inlet Sockeye Salmon: Returns in 2007 were much lower than the “stationary” numeric forecast but should come closer to the forecast in 2008.

Rivers and Smith Inlet sockeye supported one of the most valuable fisheries on the Central Coast of BC until severe stock declines in the early to mid-1990s forced their closure. Time series assessments permitting partitioning of marine versus freshwater production stages support the view (McKinnell et al. 2001) that the steep decline and low returns of sockeye to Rivers and Smith Inlets since the 1990s are due to persistently low marine survival. By contrast, a strong compensatory response of increased egg-to-fall-fry survival in freshwater (Smokehouse River and Long Lake, Fig. 2b) accompanied major reductions in spawner abundance for the 1997 to 2001 brood years and buffered Smith Inlet sockeye from even more severe declines.

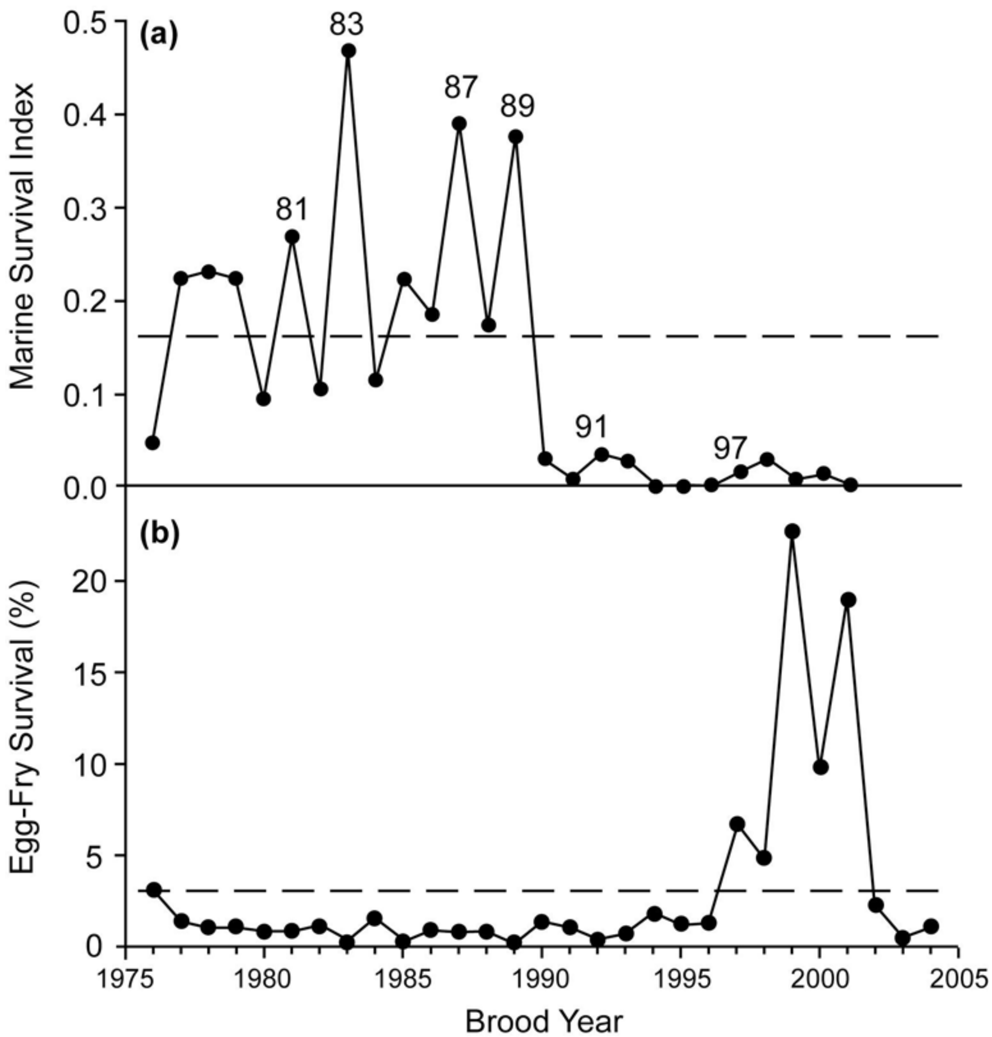


Figure 2. Trends in marine (smolt-to-adult) and freshwater (egg-to-fall-fry) survival of 1976 - 2004 brood year sockeye salmon from Smith Inlet (Long Lake). Dashed line represents all-year mean.

Returns to Smith Inlet in 2007 were strongly sub-average and, as in 2006, much lower than the pre-season forecast (Fig. 1, Area 2).

Production trends for Central Coast sockeye appeared to share little in common with stocks from other areas prior to the mid-1980s. However, starting in the late 1980s both Barkley Sound and Central Coast index stocks (Fig. 1) appear to reflect signature effects of alternating El Niño and La Niña-like events on production variations (*i.e. shared peaks in 88, 91-93, 98, 02-03 associated with relatively cool SSTs during smolt migrations two years earlier; shared troughs in 89-90, 95-97, 02, 05-07 associated with relatively warm SSTs two years earlier*). Thus, changes in ocean conditions within the past 15-20 years may have resulted in a northward expansion of common marine mechanisms controlling production variations for salmon stocks in the relatively open coastal waters of Barkley Sound (WCVI) and Queen Charlotte Sound (Central Coast). Application of a non-stationary, multi-state, survival model (SStM, Hyatt and Steer 1988) triggered by changes in SST has yielded relatively reliable forecasts of variations in Barkley Sound sockeye returns compared to the stationary models applied to Smith Inlet sockeye over a comparable interval (compare panels 3 and 4 in Fig. 1). Given the low forecast of Barkley Sound sockeye returns in 2008 expected under a variable-state, survival model and the depressed state of sockeye escapements in 2004 it is likely that predictions for strongly sub-average returns to Smith Inlet in 2008 are reliable.

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Coho and Chinook salmon in shelf waters off Washington and Oregon

Bill Peterson, Cheryl Morgan and Edmundo Casillas

NOAA Fisheries (BP and EC) and Oregon State University (CM)

Juvenile salmonids are surveyed in June and September along eight cross-shelf transects extending from La Push Washington (48°N) south to Newport Oregon (44°40'N). Transect spacing is approx 30 nautical miles; the trawl is an NET Systems Nordic 264 rope trawl.

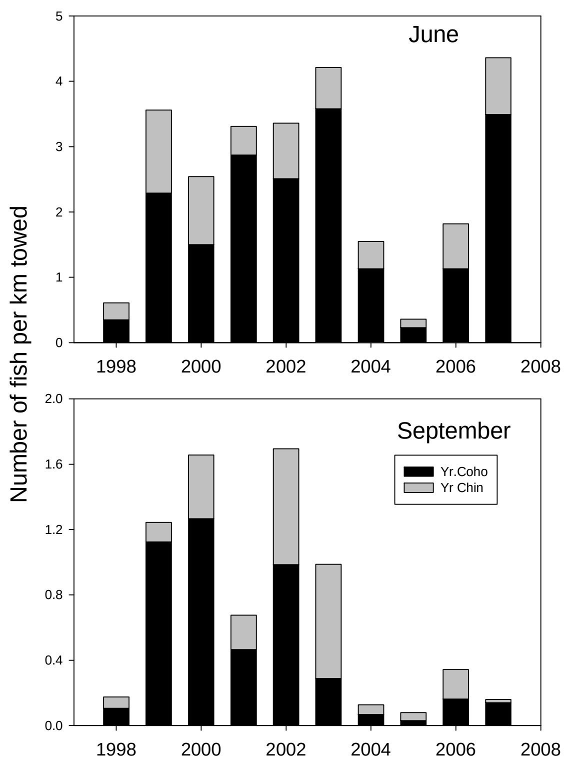

Figure 1. Catches of yearling coho (black) and Chinook (grey) salmon in trawl surveys, in June (upper) and September (lower).

Catches of juvenile (yearling) coho in June 2007 were among the highest catches of our 10 year time series. This may reflect the presence of good ocean conditions (cold water and a boreal zooplankton community) during the winter and spring pre-conditioning period before the salmon arrived at sea. However, note that by September, yearling coho salmon catches were among the lowest in 10 years. We think that this reflects the anomalously warm SSTs observed in the northern California Current in July and August. We speculate that juvenile coho salmon, which are surface-oriented animals, found poor feeding conditions in warm surface waters and either starved or were eaten, resulting in high mortality during summer 2007.

A similar situation seems to have existed for the juvenile yearling Chinook salmon. Catches in June 2007 were the 3rd highest in 10 years but catches in September 2007 were the lowest in 10 years. However, it is difficult to evaluate this observation since the June yearling Chinook are primarily upper Columbia River Chinook which migrate out of our area rapidly whereas the yearlings caught in September are from stocks with different rivers of origin.

We have also found that catches of yearling spring Chinook salmon in June are correlated with the number of jack salmon that return to the Columbia River the following spring (Fig. 2). (Jack salmon are those that return a year earlier than expected.) This relationship suggests that June catches (and subsequent returns of adults 2-3 years later) are somewhat dependent upon ocean conditions at and near the time of ocean entry. Note in Fig. 2 that relatively high jack returns are expected in spring 2008.

The catches of yearling coho salmon in September are correlated with the abundance of adult coho that return to hatcheries the following year (Fig. 3). Given that we have not found any correlation between coho catches in June and adult coho survival or number of spawners that return the following year, we suggest that year-class strength for spring Chinook may be set earlier in the summer than it is for coho, for example.

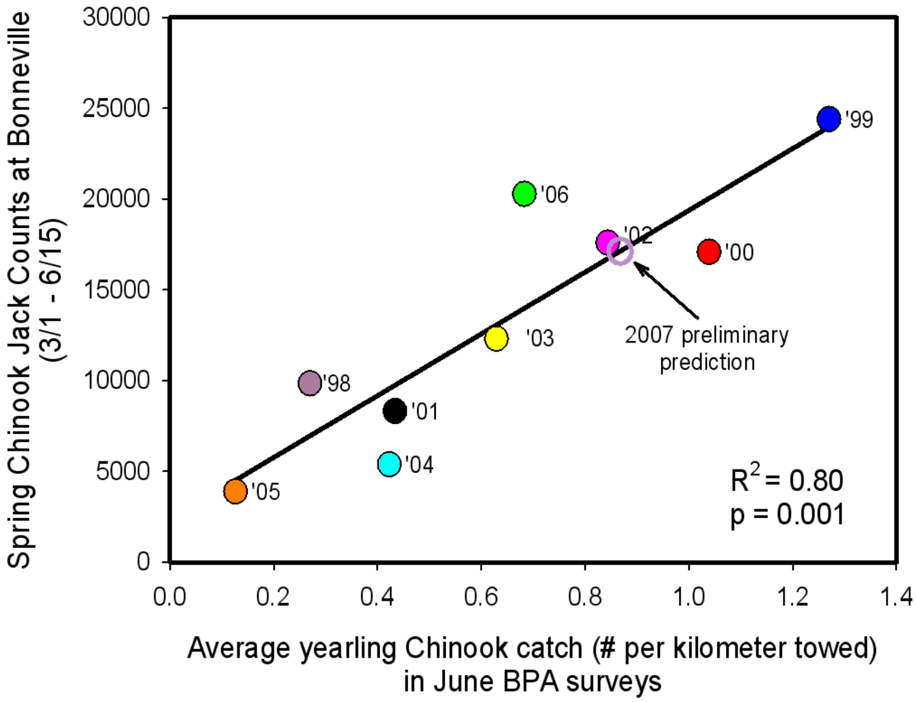

Figure 2. Regression of the 1998 – 2006 Spring Chinook salmon jack counts at Bonneville Dam on the average CPUE (Catch per Unit Effort, number per km towed) of yearling Chinook salmon caught during each of our June cruises. The open point indicates the observed 2007 June CPUE (0.87) and predicted OPIH from the regression (17,082).

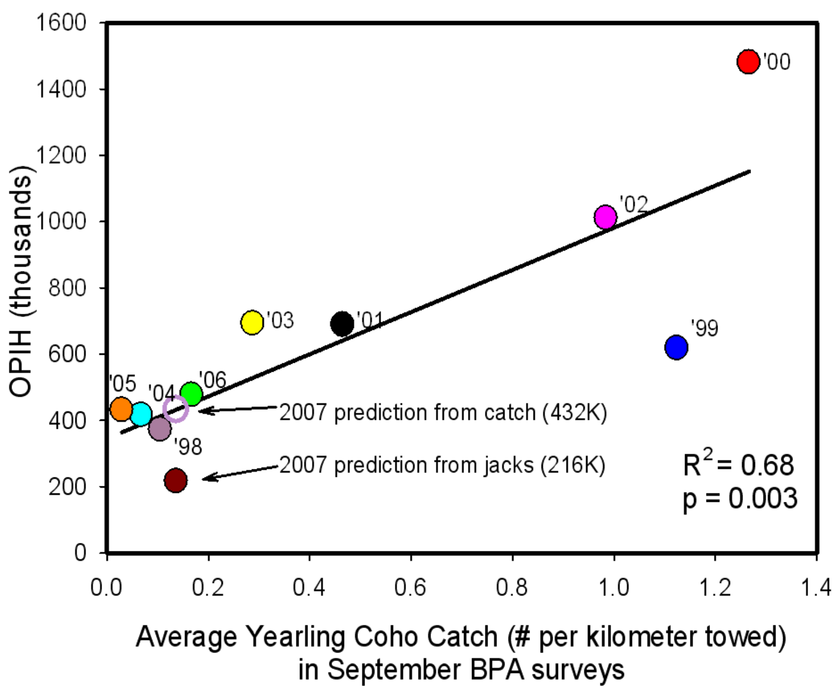

Figure 3. Regression of OPIH (Oregon Production Index Area Hatchery) adult coho salmon abundance on the average CPUE (Catch per Unit Effort, number per km towed) of juvenile coho salmon the previous September. The years indicated are for the catches of the juvenile fish. Adult production from the 2007 smolt year is a prediction based on jack returns. The open point indicates the observed 2007 September CPUE (0.14) and predicted OPIH from the regression (432 thousand).

Euphausids and hake – Linkages to coho, herring, sockeye, and chum

Ron Tanasichuk, Fisheries and Oceans Canada

One of our research activities focuses on evaluating simultaneously the influences of egg deposition levels, food, competition, and predation on the productivity of Pacific herring (*Clupea pallasi*), and coho (*Oncorhynchus kisutch*), sockeye (*O. nerka*), and hatchery chum (*O. keta*) salmon along the southwest coast of Vancouver Island (WCVI). Our diet analysis indicates that herring and salmon select the euphausiid (krill) *Thysanoessa spinifera* over other potential prey species. Herring and coho consume prey longer than about 17 and 19 mm respectively. Most krill fed upon by sockeye were 3-5 mm while those consumed by chum were 3-4 mm. The 1991-2007 time series of *T. spinifera* biomass (Fig. 1) indicates low levels in 2007. Pacific hake (*Merluccius productus*) dominates the pelagic biomass in summer and is potentially the most important predator on young herring and salmon. Hake can also be a competitor because *T. spinifera* is also a key prey item for them. The 1999 hake yearclass was quite strong. In 2004, hake from this yearclass became large enough to start consuming fish. Results from our 2005 hydro-acoustic survey suggested that hake piscivorous (fish-eating) biomass remained relatively high and total hake biomass was increasing. Preliminary results from the 2007 hydro-acoustic survey indicate that hake biomass is declining because of gradual disappearance of the 1999 yearclass and no strong subsequent recruitments.

Evidence suggests that herring recruitment (production of new spawners) varies as a result of egg deposition, *T. spinifera* biomass and/or hake biomass effects. Interestingly, WCVI euphausiid biomass appears to be a useful predictor for major herring stocks in other areas. Recruitment variation for northern BC (Queen Charlotte Islands, North Coast, Central Coast) herring results from the effects of egg deposition and competition with hake during herring's second year of life. For Strait of Georgia herring, recruitment varies in response to egg deposition and hake predation when, as young-of-the-year, these herring move to offshore feeding areas along the WCVI. Recruitment variability for WCVI herring is caused by variations in *T. spinifera* biomass and competition with hake when herring are in their first year of life. *T. spinifera* biomass variability also helps explain changes in growth of WCVI herring, and variation in adult natural mortality rates for WCVI, Strait of Georgia, Central Coast, and North Coast herring. WCVI euphausiid biomass also appears to be a useful predictor for some salmon stocks. For instance, WCVI wild coho return variability is affected by smolt production and *T. spinifera* biomass variability early in marine life. Much of the Barkley Sound (Sproat and Great Central lakes) and Central Coast (Long Lake) sockeye return variability can be explained by variations in *T. spinifera* biomass early in marine life. Nitinat hatchery chum productivity, as indexed by returns of ages 4 and 5 fish, is affected mostly by variations in hake biomass, but *T. spinifera* biomass early in marine life also affects the return of age 3 chum.

The status of *T. spinifera* prey biomass in 2007 for a given predator may not reflect the trend for larval or adult biomass. This is a consequence of: 1) each predator selecting a specific size range of the *T. spinifera* biomass, and 2) a possible mismatch between the seasonality of *T. spinifera* production and the critical period within which a given predator depends on energy from *T. spinifera*.

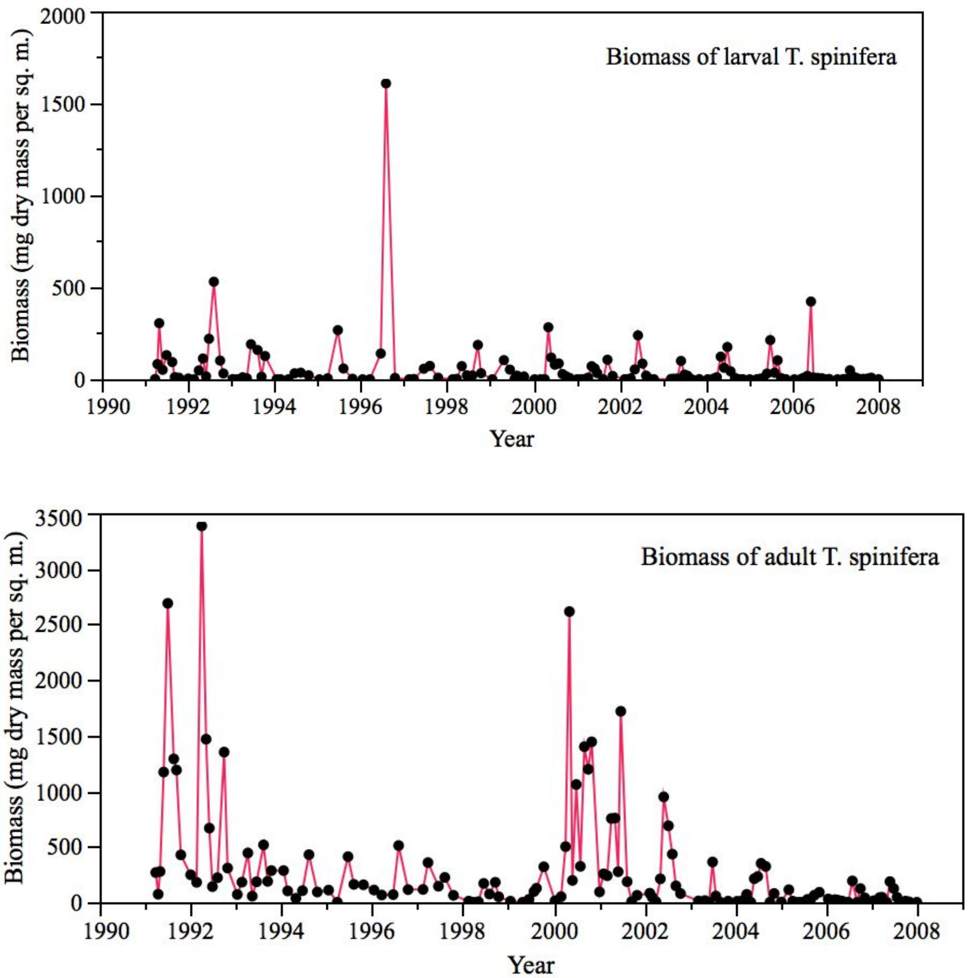

Figure 1. The 1991-2007 time series of ***larval*** *(top panel, <10 mm long) and* ***adult*** *(bottom panel > 9 mm long) T. spinifera biomass. Median larval and adult biomasses in 2007 were the second and fourth lowest respectively in the time series; larval biomass decreased by 48% and adult biomass increased by 62% from 2006.*

The following are the anticipated consequences of 2007 prey and predator biomass levels;

- Herring: recruitment to all major BC stocks will continue to decline in 2008 because of the hake predation/competition effect, but begin to increase in 2009 because of a reduction in hake biomass as of 2006 (this may be tempered somewhat by low *T. spinifera* prey biomass for WCVI herring); growth of WCVI herring will decline and WCVI, Strait of Georgia, Central Coast, and North Coast adult natural mortality rates will increase because of low *T. spinifera* prey biomass in 2007;

- WCVI wild coho: marine survival is forecast to remain relatively low, about 3%, for the 2008 return year because of reduced *T. spinifera* prey biomass in the 2007 smolt year;

- Barkley Sound/Central Coast sockeye: returns in 2008 will be poor because of low *T. spinifera* prey biomass in the 2005 and 2006 smolt years but begin to increase in 2009 because of higher *T. spinifera* biomass in 2007;

- Nitinat River Hatchery chum: a decline in returns is expected to reverse in 2009 as a consequence of reduced hake predation that would have begun in 2006.

Average growth for coho salmon in southern BC

Marc Trudel, Steve Baillie, Chuck Parken, and Dave O'Brien,
Fisheries and Oceans Canada

Ocean surveys for juvenile salmon have been used to assess the distribution, growth, condition, and survival of Pacific salmon in different parts of the British Columbia coastal ecosystem since 1998. These surveys are usually conducted in late spring-early summer (June-July) and in the fall (October-November). In addition, juvenile salmon have been collected during winter (February-March) since 2001. The general assumption of this work is that marine survival is expected to be high when salmon are rapidly growing and are in good condition and low in years of poor growth and condition. Hence, marine survival is expected to be positively correlated to indicators of juvenile salmon growth rate.

These surveys indicate that juvenile coho salmon are generally growing faster in Southeast Alaska than off the west coast of Vancouver Island (Fig. 1). This could potentially explain the higher marine survival of Southeast Alaska coho salmon compared to southern British Columbia stocks. In 2007, the growth rate of juvenile coho salmon was near the 1998-2007 average value off the west coast of Vancouver Island, but was the lowest on record for Southeast Alaska (Fig. 1).

Our analyses indicate that the marine survival of west coast of Vancouver Island coho, Chinook, and sockeye salmon is strongly correlated to the growth conditions for coho salmon in this region. Hence, marine survival is expected to be average for west coast of Vancouver Island coho salmon in 2008 and Chinook salmon in 2009 relative to 1999-2006, but slightly below the 1999-2004 average for Barkley Sound sockeye salmon in 2009 (Fig. 2).

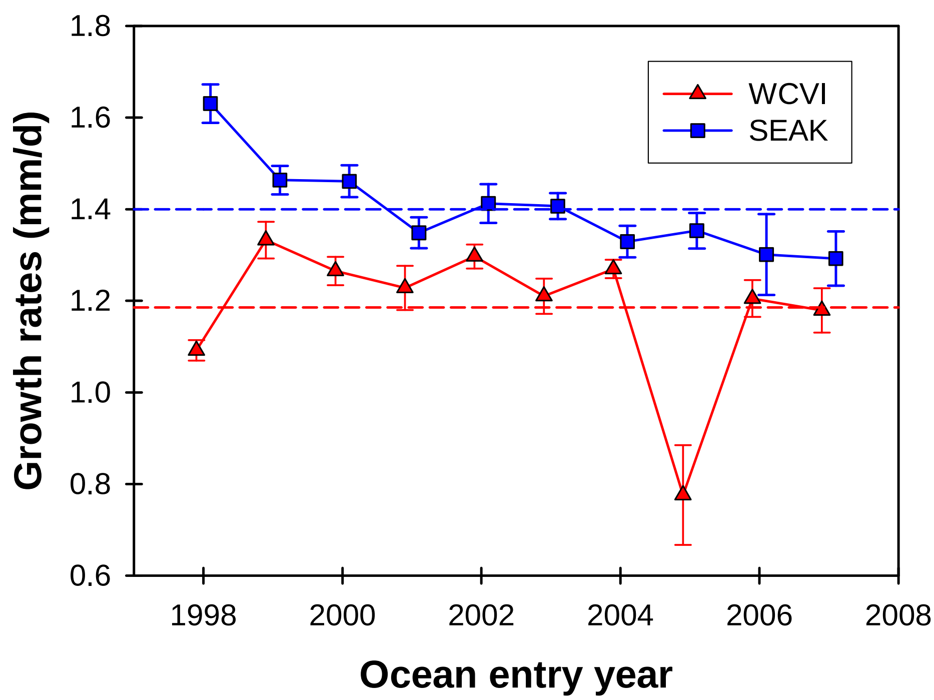

Figure 1. Growth rates (May-October) of juvenile coho salmon off the West Coast of Vancouver Island (red triangles) and Southeast Alaska (blue squares). The blue and red dotted lines represent the 1998-2007 average values for Southeast Alaska and the west coast of Vancouver Island, respectively. The error bars are 2 x SE. Details on the procedure used to estimate growth rate are provided in Trudel et al. (2007).

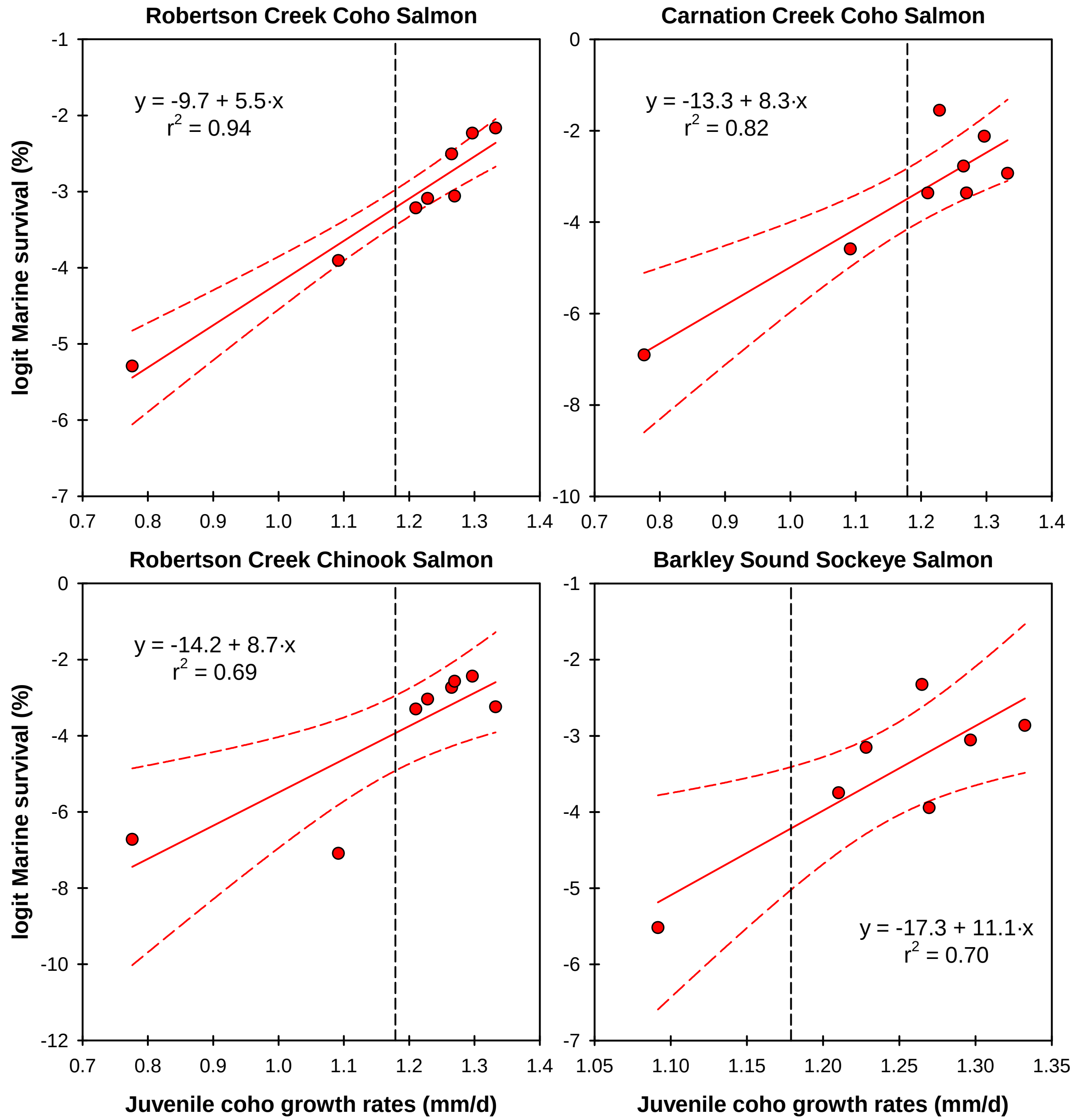

Figure 2. Marine survival of Robertson Creek coho and Chinook salmon, Carnation Creek coho salmon, and Barkley Sound sockeye salmon in relation to the May-October growth rates of juvenile coho salmon off the west coast of Vancouver Island. The dotted black line represents the observed growth rate for the 2007 ocean entry year. Marine survival data are for the 1998-2005 ocean entry years for coho and Chinook salmon, and for the 1998-2004 ocean entry years for sockeye salmon. Note that the marine survival data were transformed using the logit transformation prior to fitting the linear regression model.

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Multi-species groundfish bottom trawl surveys: Smaller catches in 2007

Greg Workman and Kate Rutherford, Fisheries and Oceans Canada

Groundfish researchers at the Pacific Biological Station initiated a series of random-depth-stratified multi-species bottom trawl surveys in the summer of 2003. The program has since grown to include four biennial area specific surveys. In 2007 the program completed three surveys: one in Hecate Strait/Dixon Entrance (HS), one in Queen Charlotte Sound (QCS), and one off the West Coast of the Queen Charlotte Islands (WCQCI) (Table 1, Fig. 1).

Table 1. Summary of results for three areas surveyed in 2007.

Survey	QCS	QCS	QCS	QCS	HS	HS	WCQCI	WCQCI
Year	2003	2004	2005	2007	2005	2007	2006	2007
Timing	July to early August				Late May to June		September	
Area Surveyed (km^2)	25654				16252		5571	
Sets	235	233	224	257	226	143	110	112
Km^2 per Set	109	110	115	100	72	114	51	50
Total Catch (mt)	89	113	101	69	96	41	104	89
Mean Catch Per Set (kg)	378	485	449	269	426	290	946	799
Species Identified	235	233	224	257	226	143	110	112
Average N Species	17	21	25	19	20	19	24	17
Samples	1413	1819	2028	1475	1907	1103	969	784
Specimens	30769	34487	48230	34839	63935	26491	27339	18475
Funding Agency	CGRCS	CGRCS	CGRCS	CGRCS	DFO	DFO	CGRCS	DFO

***CGRCS = Canadian Groundfish Research and Conservation Society**

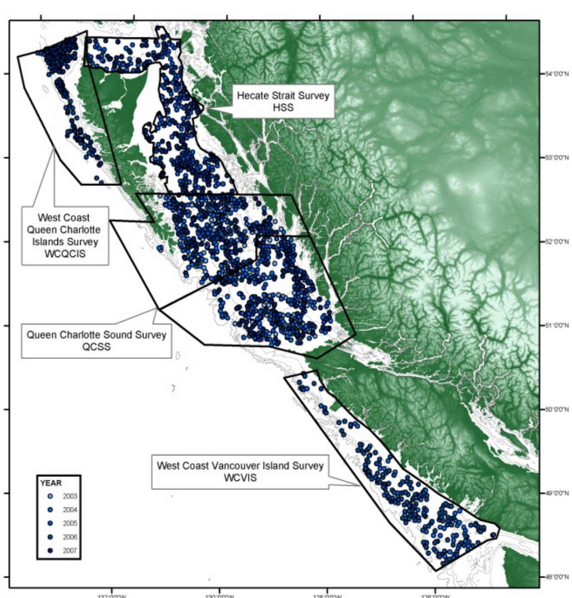

Figure 1. (left) Map of the four groundfish survey areas, and locations of all successful sets (blue dots) from 2003 to 2007.

Mean catch weight per tow and biodiversity were down in 2007 in all regions relative to previous survey observations. In Queen Charlotte Sound in particular we noted decreases in biomass indices for 44 of 53 species (Fig. 2). Possible explanations include changes in abundance, catchability, environment, technology, fish behaviour or random chance. Since the program's inception, temperature-depth (SBE 39) loggers have been mounted on the net. Starting in 2006 a portable CTD (SBE 16/19+) was also deployed, adding salinity and dissolved oxygen observations.

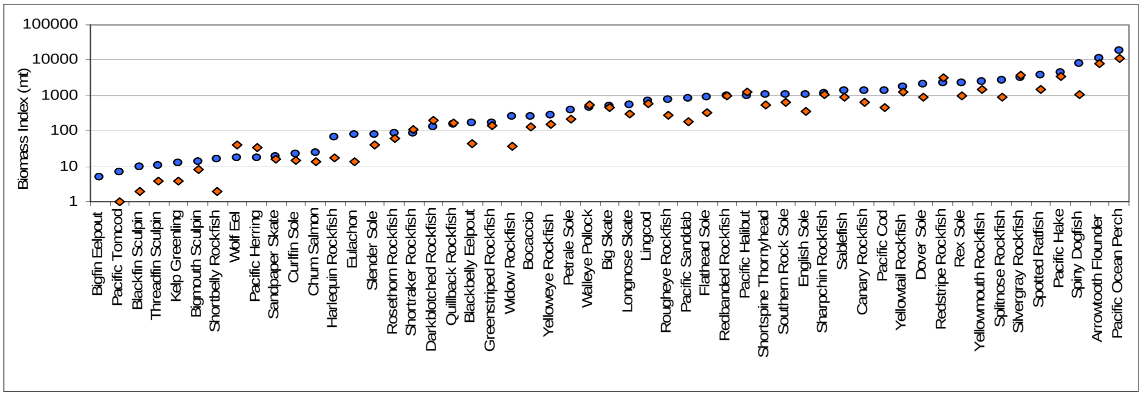

Figure 2. 2007 Queen Charlotte Sound species biomass indices for 2007 (red) compared to the mean of 2003-2005 (blue).

To gain some insight into what might be driving changes in catch rates, we looked at the mean depth and temperature of capture. 2007 was relatively cool; mean temperatures at depth were similar to 2003 (Fig. 3).

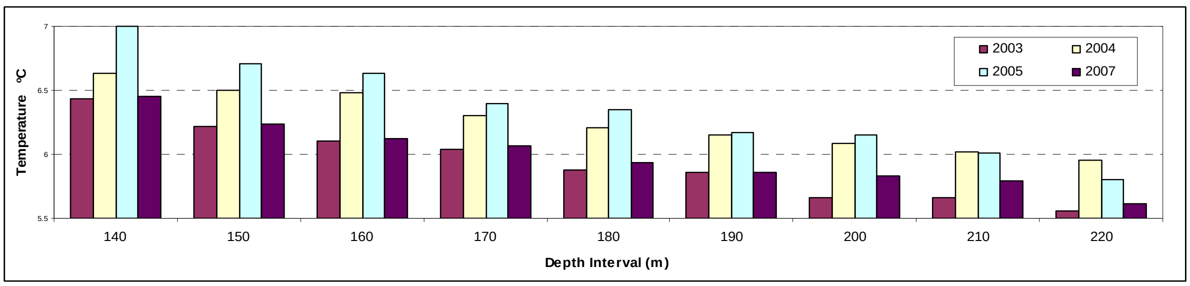

Figure 3. Mean temperature at depth by year. Each bar represents one year, each cluster of 4 bars represents a separate 10 m depth interval; the value shown is the start of the depth interval.

Despite a temperature regime similar to 2003, mean depth of capture in 2007 was significantly shallower (Fig. 4). There is a clear trend in all four years of the QCS survey towards decreasing depth of capture across all species. The average decrease is 8%; the maximum is 26% (Pacific Hake). If it were not for the 2007 observations one might speculate that temperature was driving the changes, but with the cooling observed in 2007 that is clearly not the case. It is more likely that the recently observed decreasing depth of the hypoxic boundary is forcing fish to shallower depths. Unfortunately with only one year of *in situ* salinity and dissolved oxygen measurements in each of the survey areas we are unable to contrast these data for this report. After the 2008 field season we will have two years' data for two areas, allowing us to start looking at the relationships among dissolved oxygen, salinity and catch rates.

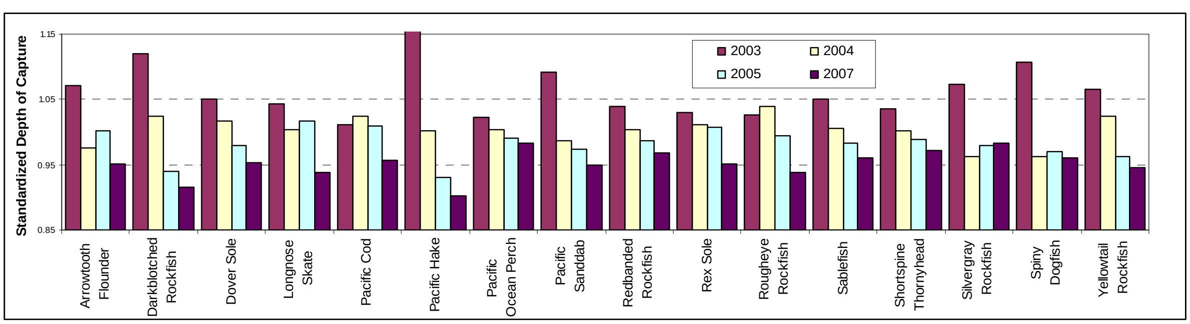

Figure 4. Standardized depth of captures for 16 species over the four surveys conducted in Queen Charlotte sound.

Pacific Hake (*Merluccius productus*) distribution along West Coast of Canada and the United States, 1995-2007

John Holmes, Ken Cooke and George Cronkite, Fisheries and Oceans Canada

Between June 19 and August 24, 2007, Canada and the United States conducted a joint acoustic-trawl survey to assess the distribution and abundance of the offshore Pacific hake (*Merluccius productus*) stock. Here we present the results of the 2007 survey and discuss these results in the context of the hake survey time series from 1995 to 2005.

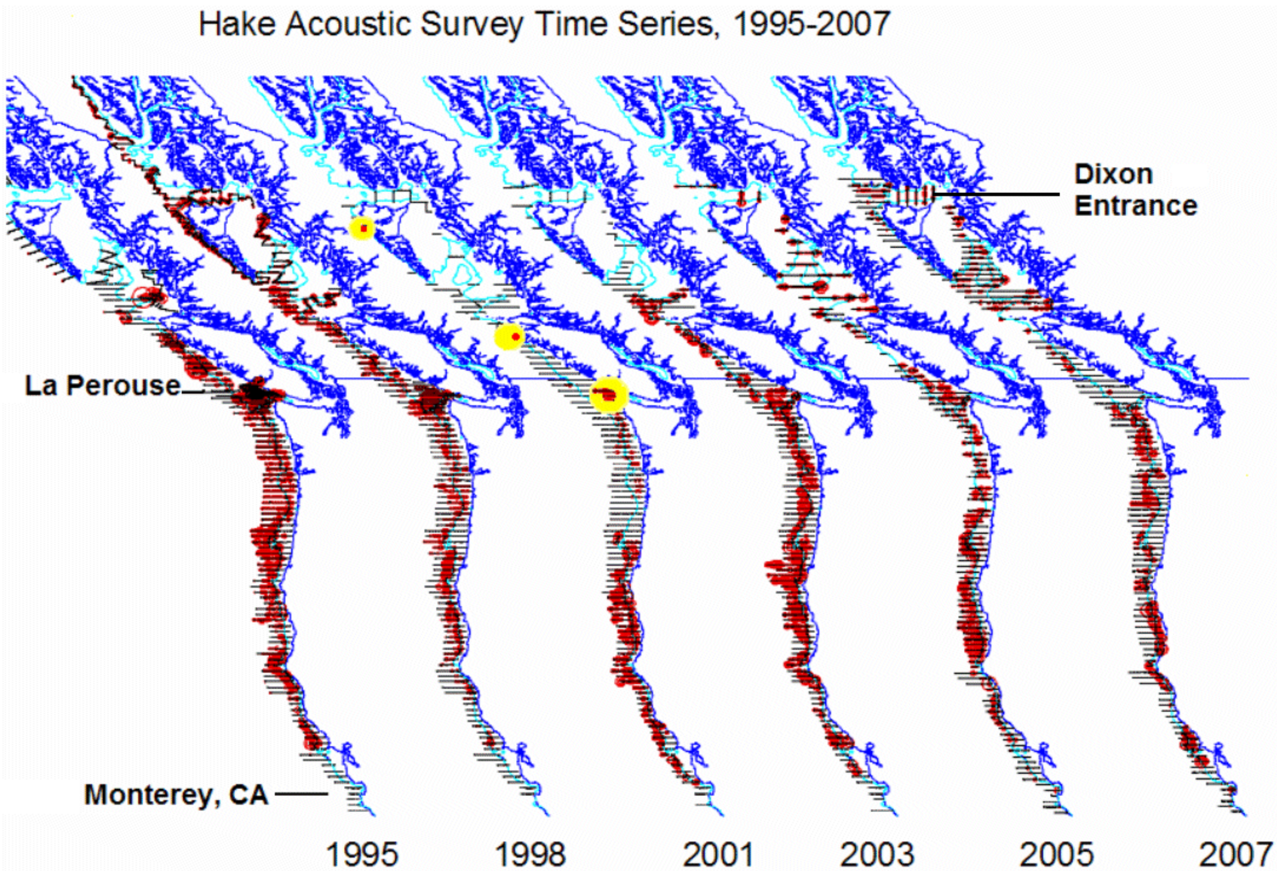

Figure 1. Offshore hake distribution and abundance time series estimated by the Canada-US Pacific hake acoustic-trawl survey, 1995-2007. Black lines show survey grid, cyan line is the 200 m depth contour (continental shelf-edge) and the red circles indicate hake acoustic backscatter along transects with size proportional to the maximum among years. Yellow areas show isolated aggregations of hake in 2001. Figure provided by Rebecca Thomas (Nat. Marine Fish. Serv., Northwest Fish. Centre, Seattle, WA).

The offshore hake stock - the largest of three hake stocks along the west coast - is the most abundant groundfish in the California Current system and is an important commercial species in both Canada and the United States (Ressler et al. 2008). Hake disperse from winter spawning grounds off southern California to northern feeding areas off the coasts of northern California, Oregon, Washington and British Columbia during the summer months where they form dense midwater W-shaped aggregations at depths of 150-300 m along the edge of the continental (200 m depth contour) during daylight hours (Dorn 1995). The coastal region is characterised by upwelling at the edge of the continental shelf (200 m isobath) that mixes deep, cold, nutrient rich waters with warmer, oxygenated surface waters and provides favourable conditions for euphasiid production, the primary food resource of hake.

Acoustic trawl surveys to assess the distribution and abundance of hake have been conducted since 1977 by the United States and jointly with Canada since 1992, under the auspices of the International Hake Treaty, which recognizes that this stock is a transboundary resource. These surveys have covered the full distribution of hake since 1992 using standardized protocols and sonar equipment. The 2007 survey was conducted by the NOAA Ship *Miller Freeman* because the CCGS *W.E. Ricker* suffered a catastrophic failure of the propeller shaft two weeks prior to joining the hake survey effort. The 2007 survey covered More than 12,000 nautical miles on 133 transects were surveyed in 2007 and 92 trawls were towed to confirm species composition and to obtain measurements of length, weight, sex and age samples during 68 days of ship time.

Hake were distributed from Monterey Bay (36.8° N) northwards to Dixon Entrance (54.6° N) in 2007, with typical dense shelf-edge aggregations observed off of the Washington, Oregon, and northern California coasts (Fig. 1). Further north in Canadian waters, hake distribution was sparse, with most hake located in well-separated pockets along the west coast of Vancouver Island and through Queen Charlotte Sound, Hecate Strait and Dixon Entrance. Total estimated biomass of hake aged 3 and older was 0.88 million metric tons in 2007 (Fig. 2), which represents a 27% decline since the 2005 survey and is near the lowest estimated biomass of 0.78 million

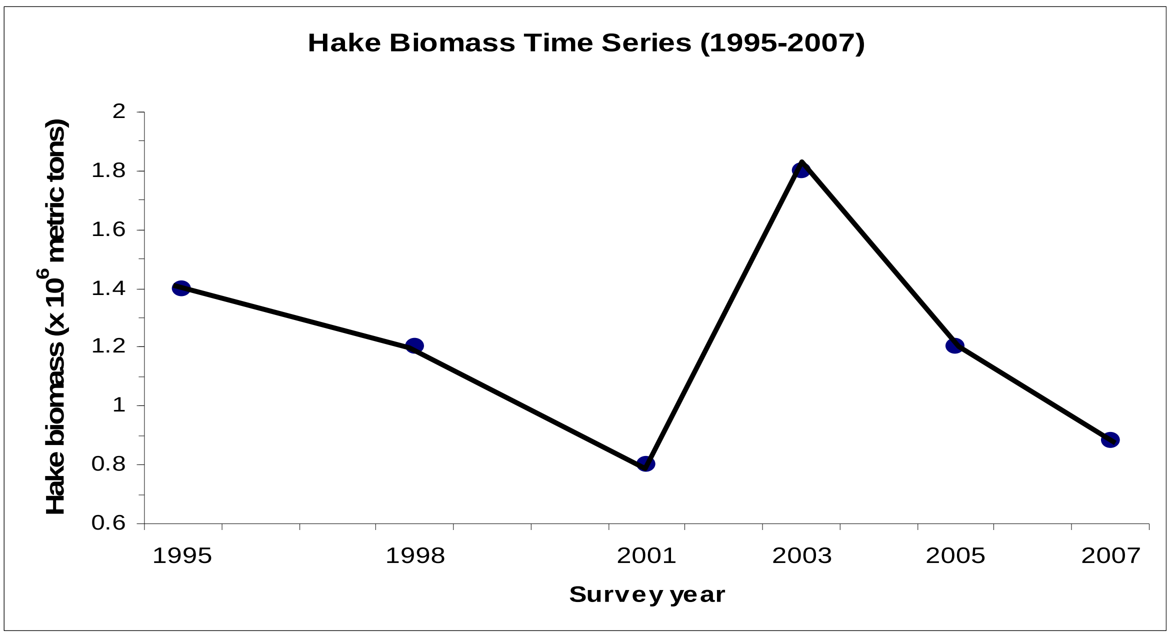

Figure 2. Pacific hake biomass time series based on coast-wide acoustic-trawl surveys from 1995 to 2007. Data taken from Wilson and Guttormsen (1997), Wilson et al. (2000), Guttormsen et al. (2003), and Fleischer et al. (2005, 2008).

metric tons recorded in 2001 (Fig. 2; see Guttormsen et al. 2003). Hake between 45 and 49 cm fork length were the dominant size mode in trawl catches in 2007 and are comprised primarily of 8-year old fish from the 1999 year-class, which has been the dominant year-class in this stock and has supported the fishery since recruiting as 3 year old fish in 2002. Hake biomass has exhibited a declining trend since 1995, with the exception of a peak in biomass of 1.8 million metric tons in 2003 (Fig. 2; Fleischer et al. 2005). The 2003 biomass peak may be associated with the entry of the 1999 year-class into the survey time-series.

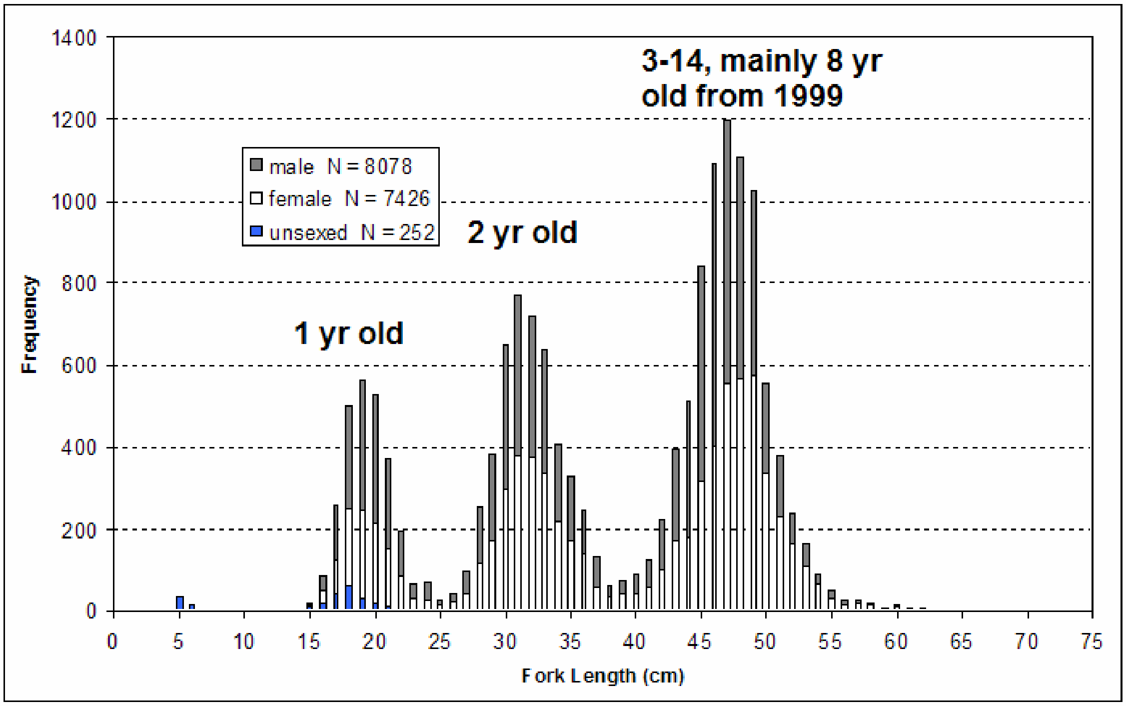

Figure 3. Size-frequency (fork length, cm) of Pacific hake captured during the 2007 acoustic survey in U.S. waters. Modal sizes of 18-20 cm, 30-33 cm, and 45-49 cm correspond with 1 year-old (2006 year-class), 2 year-old (2005 year-class) and 3-9 year-old fish, dominated by 8 year-old hake from the 1999 year-class. Figure provided by Rebecca Thomas (Nat. Marine Fish. Serv., Northwest Fish. Centre, Seattle, WA).

The distribution of hake clearly shifts northward and southward between surveys in response to climate-related changes in ocean conditions, particularly sea surface temperature (SST) during the northward migration (Mar-July) and coastal upwelling. In 1998, hake were found in Alaskan waters to 58° N as a result of the strong 1997-98 El Niño event (Wilson et al. 2000), which warmed coastal waters and enhanced poleward current flow during the winter and early spring. In contrast, few hake were found north of 48° N in 2001 owing to the 1999-01 La Niña event (Guttormsen et al. 2003), which cooled coastal surface waters and reduced poleward transport in spring. That these differences in distribution represent a shift in stock location rather than summer range extensions is illustrated by the fact that 49% of hake biomass was observed in Canadian waters in 1998 (Wilson et al. 2000), but only 10% (in three isolated spots – Fig. 1) in 2001 (Guttormsen et al. 2003). Historically, the area from the mouth of Juan de Fuca Strait (48.25° N) to La Pérouse Bank (48.8° N) were the most productive fishing grounds for the Canadian hake fishery. However, there has been a substantial decline in hake biomass in this area since the 2003 survey (Fig. 1), which is most clearly illustrated by the 2007 data, and as a result the fishery has shifted to Queen Charlotte Sound, at the northern end of Vancouver Island. Hypotheses to explain this decline in hake abundance on traditional Canadian fishing grounds are not clear at present, but are not related to differences in survey methodology or timing as all surveys since 1995 have followed standardized protocols and were conducted between June and September when hake have completed their annual northward migration and are fully available to the survey (Nelson and Dark 1985).

The 2007 survey was notable for the capture of 82 jumbo squid (Dosidicus gigas) during biological sampling at depths exceeding 300 m offshore of the continental shelf along Vancouver Island and the Queen Charlotte Islands. Jumbo squid underwent a rapid range expansion into the southern California Current between 2002 and 2006 (Field et al. 2007), but this was the first hake survey that captured jumbo squid exclusively in Canadian waters and these captures were associated with unusual hake acoustic signs. Based on the hake acoustic signs, hake exhibited diffuse, less dense aggregation patterns when jumbo squid were captured and we hypothesize that jumbo squid predation led to increased swimming activity and dispersal of hake, resulting in these atypical patterns observed near the shelf-break (Holmes et al. 2008). The implications of this hypothesis for hake acoustic surveys are significant since the acoustic signs associated with mixed hake-squid catches likely would be attributed to small meso-pelagic fishes (e.g., myctophids or lanternfishes) in the absence of evidence to the contrary, i.e., hake in these mixtures may not contribute to overall biomass estimates (Holmes et al. 2008). If our hypothesis is true and jumbo squid alter the aggregation pattern of hake, then additional ship time and trawling effort may be required in future surveys to identify and verify acoustic sign attributable to hake.

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Use of satellite-derived winds

Laurie Neil, Meteorological Service of Canada

Space-borne synthetic aperture radars (SAR) on earth satellites provide a new source of information on surface wind speed over marine areas. Of particular value is the high spatial resolution of this data, in the order of tens or hundreds of metres. No other dataset currently provides wind information at this resolution.

Meteorologists at the Pacific Storm Prediction Centre have evaluated and used almost a thousand SAR datasets over the past two years, in a project to determine the utility of this information. Data from both Canada's RadarSat-1 and the European Space Agency's Envisat satellite were used in this work.

The satellites carry out active microwave imaging of earth's surface in the C-band (5.4GHz), from sun-synchronous orbits of around 800 km. Their orbital period is about 100 minutes, but because of the narrow swaths not all areas can be scanned on every satellite pass (except in polar regions). These radar signals penetrate clouds and operate day and night. Because SAR is most sensitive to backscatter from small, wind-driven ocean waves at 5 to 20 cm wavelengths, they can be used for providing wind speeds over water. Accuracy is best for winds under 50 knots, and datasets are particularly useful for picking out variation of winds in narrow coastal areas. Several datasets that show the ability to detect small-scale wind features are shown below.

Wind speeds from SAR are indicated by colour, with blue representing winds less than 25 knots, yellow from 25 to 35 knots, and orange and red in the 35 to 50 knot range. Wind barbs provide corresponding model forecasts from the Canadian Meteorological Centre's GEM-LAM model, at 2.5 km horizontal resolution. White barbs are weather buoy measurements corresponding to the closest time of satellite pass.

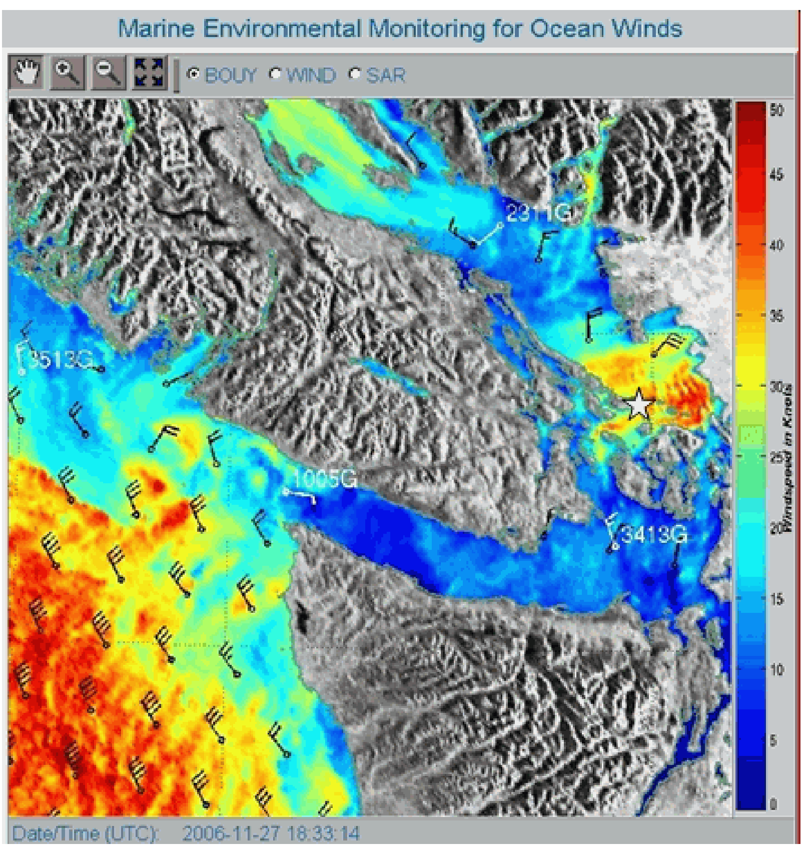

Figure 1. A SAR wind image from 18:33Z on 2006-11-27 shows the extreme wind variability that sometimes occurs even over relatively small areas such as the Strait of Georgia. In this case we see moderate north-westerly winds over the northern strait, light outflow from Howe Sound, and strong to gale force, gusty winds in the southern strait. The East Point automatic station, indicated with a star, was the only weather station that recorded these strong winds, (reported at 29G35 kts during this time). Even though this wind event was close to Greater Vancouver, SAR data provided the only report of its spatial extent and strength. Personal observations by a meteorologist in Tsawwassen later confirmed that these winds continued for several hours, and resulted in very rough sea conditions - "it looked like a tsunami in the distance".

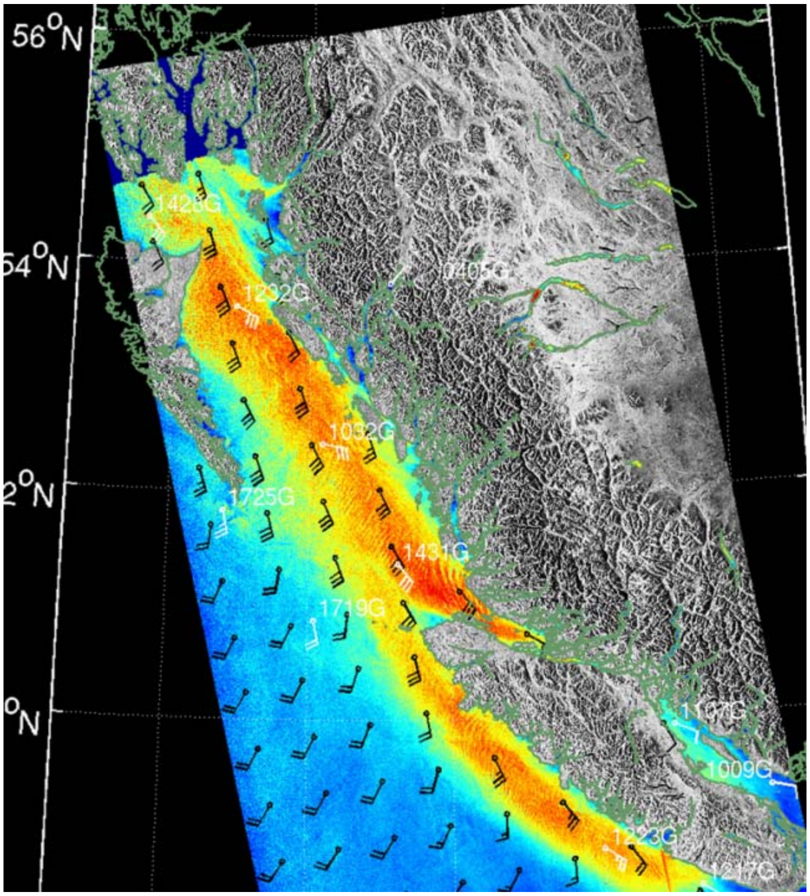

Figure 2 This SAR wind image from 0200Z on 17 February 2007 *shows a barrier jet, which is a narrow band of strong winds running parallel to a topographical barrier, hugging the western Vancouver Island coast and extending to the mainland coast. Barrier jets can form with particular pressure gradient patterns and atmospheric stability profiles. Buoy reports shown in white confirm the strong winds, but provide limited insight into their extent and sharp western boundary, especially off Vancouver Island. In this case the GEM-LAM model (winds shown in black wind barbs), with its 2.5 km horizontal resolution, represented the feature quite well.*

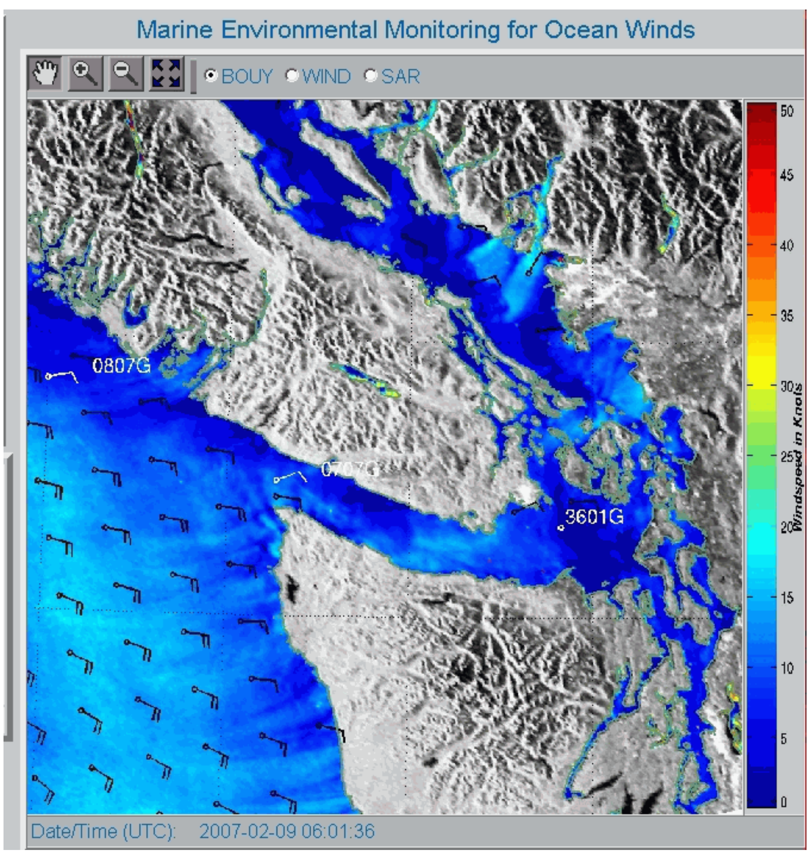

Figure 3. This image shows the extent of outflow from Howe Sound at 0600Z on 9 February 2007. Pam Rocks anemometer, located just east of Bowen Island at the mouth of Howe sound, reported outflow at 24 kts, but this SAR image provided the only information about its strength and extent over the Strait of Georgia. Clearly, in this case outflow north easterlies of 15 to 20 kts extended more than half way across the strait towards the Gulf Islands.

Meteorologists use SAR data available in near real-time to improve timing of their forecasts, as for example accurately identifying frontal location in the above example. These datasets provide additional information on wind speeds, helping forecasters provide more accurate marine warnings, and also to better verify those warnings. They show whether conventional surface observing stations accurately represent winds over nearby waters under differing pressure regimes. The data also help forecasters create and refine conceptual models of wind flow in complex terrain, which facilitates a better understanding of wind patterns even when no current SAR data is available. This data is also very useful for development and validation of mesoscale atmospheric models, since it provides the only observational data at a horizontal resolution sufficient to assess the fine scale details shown in these very high resolution models. Its only major limitation pertains to reduced accuracy for storm and hurricane force winds. This presently limits it to being a compliment to the coastal marine buoys, rather than a replacement for them. However research is being conducted to improve the ability of SAR data to accurately represent extremely strong winds.

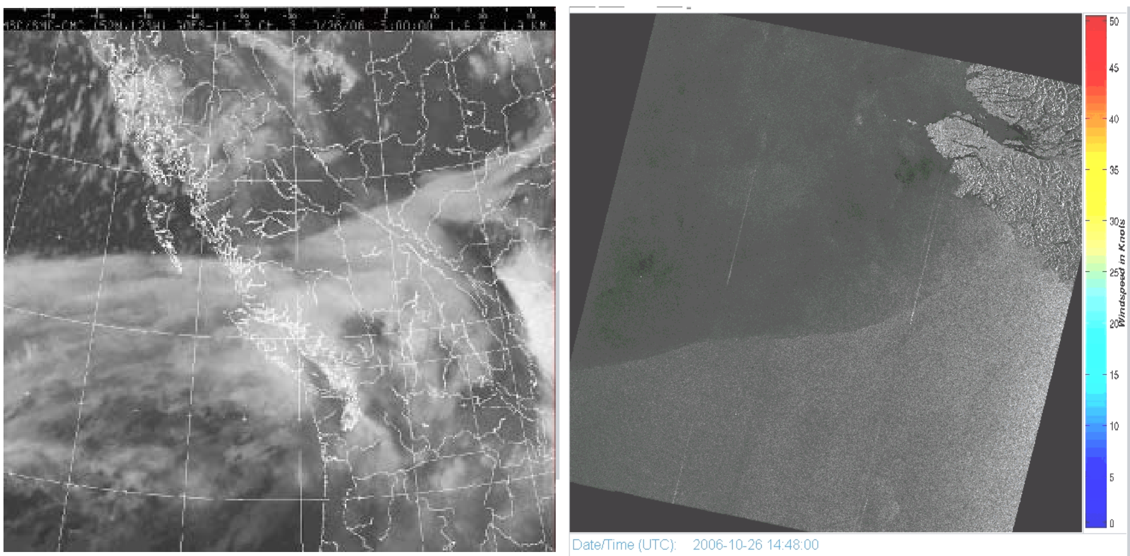

Figure 4. The final pair of satellite images shows how a cold front, which can be difficult to identify on standard GOES IR imagery (left side), stands out clearly on the raw SAR (monochrome) image on the right. This front was located on a northeast to southwest line off northwest Vancouver Island on the morning of 23 July 2006. GOES IR shows the temperature of the top of radiating cloud layers (colder and therefore higher are shown whiter to represent clouds). The IR sensor sees only the "top" of the radiating clouds, and can't see through that cloud to lower atmospheric layers or the sea surface. Consequently the surface front, with its wind shift that is so evident on the SAR image, is not obvious in the IR image.

It is hoped that with the launch of RadarSat-2 on 18 December 2007, SAR data will become more freely available in Canada. All SAR datasets processed during this project can be viewed on the MSC development site at http://yxy1.pyr.ec.gc.ca/~mentor/ . New SAR data will continue to be provided on this site in near real-time as they become available.

Strait of Georgia – Juan de Fuca Strait

Cooling in the Strait of Georgia

Diane Masson, Fisheries and Oceans Canada

The relatively warm conditions prevailing in the Strait of Georgia since mid 2003 subsided in 2007. Fig. 1 shows temperature contours measured at the Nanoose station located in the central deep basin of the strait (49° 18.7' N, 124° 2.7' W). In the spring and early summer of 2007, sub-surface intrusions of colder water reduced the temperature throughout the water column. The sub-surface temperature remained relatively cold for the rest of the year.

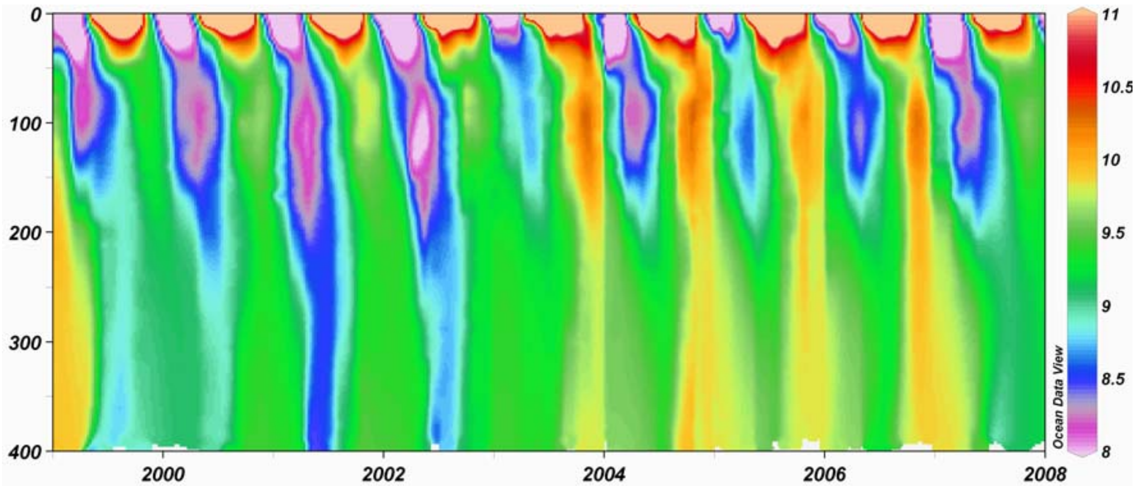

Figure 1: Contours of temperature (°C) measured at the Nanoose station (central Strait of Georgia). Depth is in metres. Labels along the lower axis denote the start of the year.

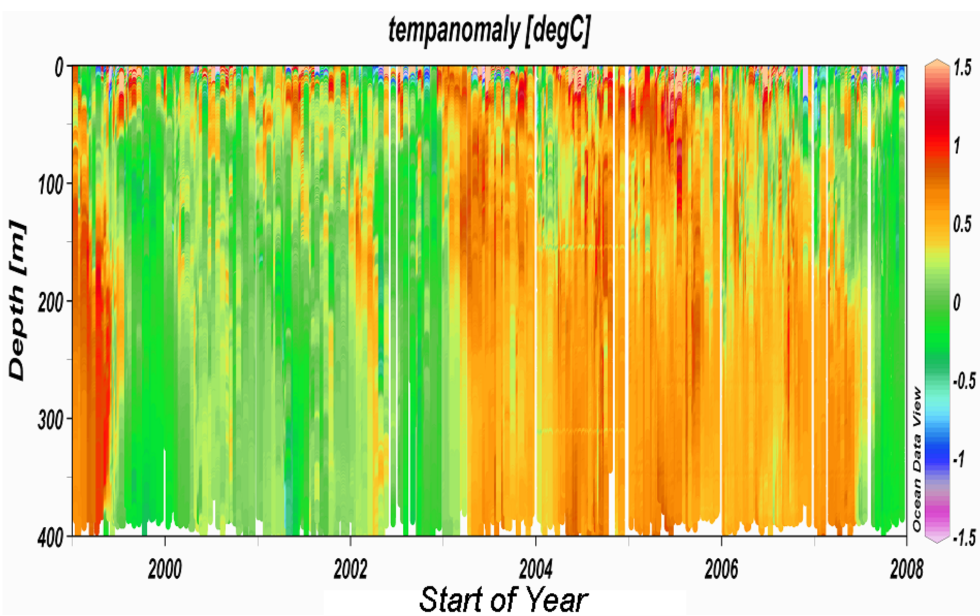

Figure 2: Temperature anomalies measured at the Nanoose station, for the period 1999-2007.

Fig. 2 gives the temperature anomalies at the Nanoose station relative to the average computed over the period 1979-2008. Positive anomalies associated with the strong 1997/98 El Niño were replaced in 1999 by near normal temperature. A warm period began in mid-2003 and continued until mid 2007 when the water returned to nearly average values.

Phytoplankton in the Strait of Georgia

Angelica Peña, Fisheries and Oceans Canada

Phytoplankton and nitrate concentrations are measured seasonally along a 20-station transect in the Juan de Fuca Strait / Strait of Georgia Basin (Fig. 1). The distribution of phytoplankton and nitrate concentration during winter and spring of 2007 was similar to those observed in previous years (2002-2006). However, in summer 2007, phytoplankton concentrations were higher at most of the stations, whereas in fall 2007 phytoplankton concentrations were lower, and nitrate concentrations higher than in previous years.

Figure 1: Location of sampling stations in the Juan de Fuca Strait/ Strait of Georgia region. The thick, shaded line shows the transect of stations used in Figure 2, with the numbers giving the distance in km from the mouth of Juan de Fuca Strait.

In general, nitrate concentrations are lower and chlorophyll fluorescence values (an indicator of phytoplankton biomass) are higher and more variable in the Strait of Georgia sector than elsewhere in this region (Fig. 2). Seasonally, chlorophyll concentrations are highest during the spring bloom (March-April), low during the summer, increasing again at the end of the summer/early fall, and lowest during winter.

In 2007, upper layer (0-15 m) chlorophyll concentrations during summer were higher than those measured in the fall (Fig. 2). Relative to previous years, chlorophyll concentrations in 2007 were higher during summer and lower during fall. Otherwise, the distribution and concentration of chlorophyll were within the range of values observed in previous years. In comparison, nitrate concentrations in the upper layer (0-15 m) during fall of 2007 were higher at most stations than the average of those measured in the five previous years. At the mouth of Juan de Fuca Strait, nitrate concentrations in November were higher than those observed in 2002-2005 but similar to those observed in 2006. At other locations, nitrate concentrations were similar to those observed in previous years.

The higher chlorophyll concentrations measured during the survey in June of 2007 were confirmed by numerous reports of significant phytoplankton blooms in the Strait of Georgia at the end of May and June. In addition, blooms that turned areas in the water a bright orange colour were reported in many areas from southern Hornby Island to Quadra Island, causing public concerns. Without information on phytoplankton composition, we cannot address the significance of the increased summer abundance of phytoplankton to food web production, since the transfers of phytoplankton production to higher trophic levels are mediated by the species composition of the phytoplankton – diatoms, flagellates, harmful algal blooms.

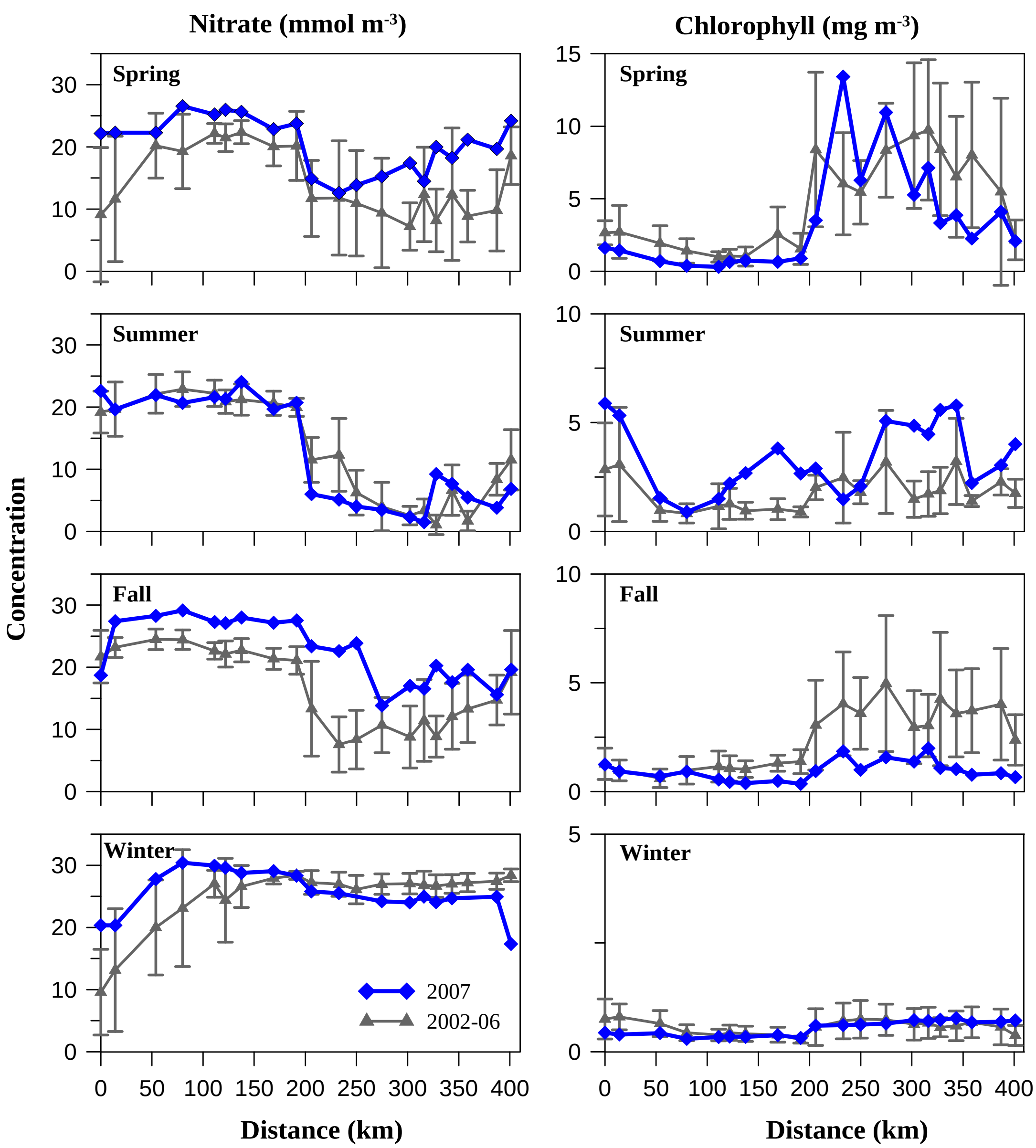

Figure 2. Upper layer (0-15 m) concentration of nitrate (left panel) and chlorophyll (right panel) along a transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring, summer, fall, and winter. Blue diamonds are observations in 2007. Grey triangles and bars denote averages and standard deviations of 2002 to 2006. Numbers along lower axes are cumulative distance from the mouth of the Juan de Fuca Strait (see Fig. 1)

Satellite images of the spring bloom in the Strait of Georgia

Jim Gower, Fisheries and Oceans Canada

In most West Coast waters the longer days of spring trigger faster growth of phytoplankton, whose numbers increase from very few in winter to highest numbers in spring, an event called the “spring bloom”. Eventually the phytoplankton growth consumes available ocean nutrients and their numbers quickly decline. The strong green colour of chlorophyll in phytoplankton can be observed by instruments on some ocean buoys and on several satellites, and used to determine timing and strength of this spring bloom.

We can observe the start of the spring bloom in local waters using the Saanich weather buoy time series (1 and 8 metre depth fluorometers recording hourly) or SeaWiFS satellite water-colour data. NASA provides a tool (Giovanni) that will compute area-averages of surface chlorophyll concentrations derived from SeaWiFS data and produce time series for any location with 8-day time steps. From this we estimate spring bloom dates as the date when chlorophyll first exceeds a threshold value.

Susan Allen of the Department of Earth and Ocean Sciences at UBC produces forecasts and hindcast dates for the spring bloom in the Strait of Georgia based on a numerical model, estimating the peak of the spring bloom as the date at which phytoplankton growth is first stopped by lack of nitrates. Phytoplankton are at the bottom of the marine food chain, providing feed for most marine life in the Strait of Georgia. It is suspected that timing of this spring bloom is critical for juvenile salmon descending the Fraser River and entering the Strait of Georgia in spring.

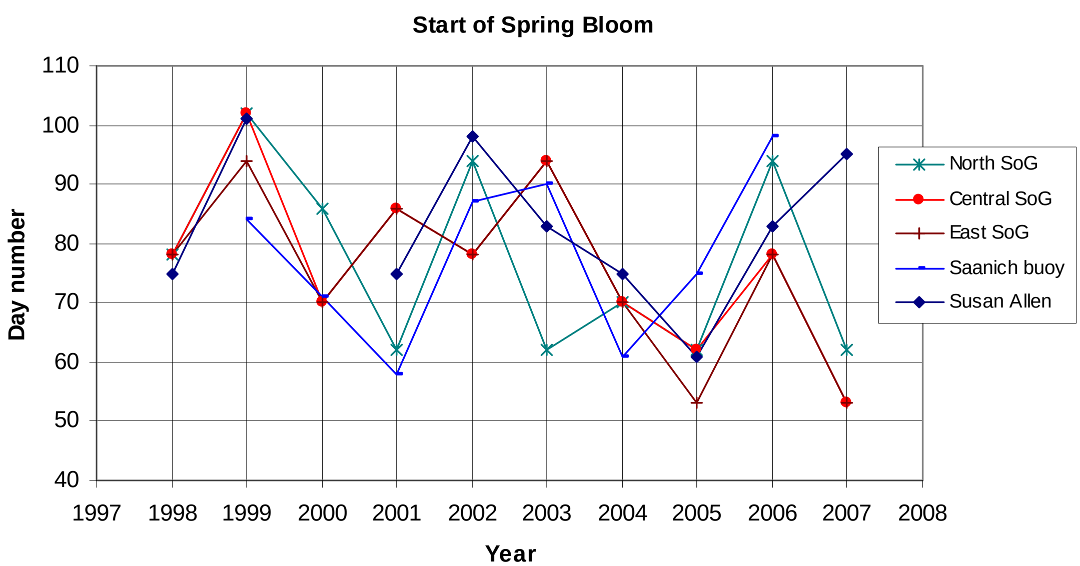

Figure 1. Estimates of the date of the spring bloom in Saanich Inlet as measured by the weather buoy, and at three locations the Strait of Georgia as determined from SeaWiFS satellite data by Giovanni. The final estimate derives from the model of Susan Allen. A threshold value for timing of 5 mg/m^{-3} was applied to SeaWiFS observations.

In Fig. 1, agreement with Allen’s model is good for all years except 2007. Saanich Inlet buoy data are not available for the spring of 2007. Most dates fall between March 1 (day 61) and April 1 (day 92). Central and East Strait of Georgia dates are identical in many years.

A VENUS perspective in Saanich Inlet

Richard Dewey, VENUS Associate Director, Research

The VENUS cabled ocean observatory has been operating in Saanich Inlet now for 2 years. Installed in February 2006, a suite of standard oceanographic instruments has been collecting data from a depth of 100 meters. Fig. 1 reveals variations in temperature, salinity, density, and dissolved oxygen. These sensors are all on the VENUS Instrument Platform, connected to the VENUS Node in Saanich Inlet.

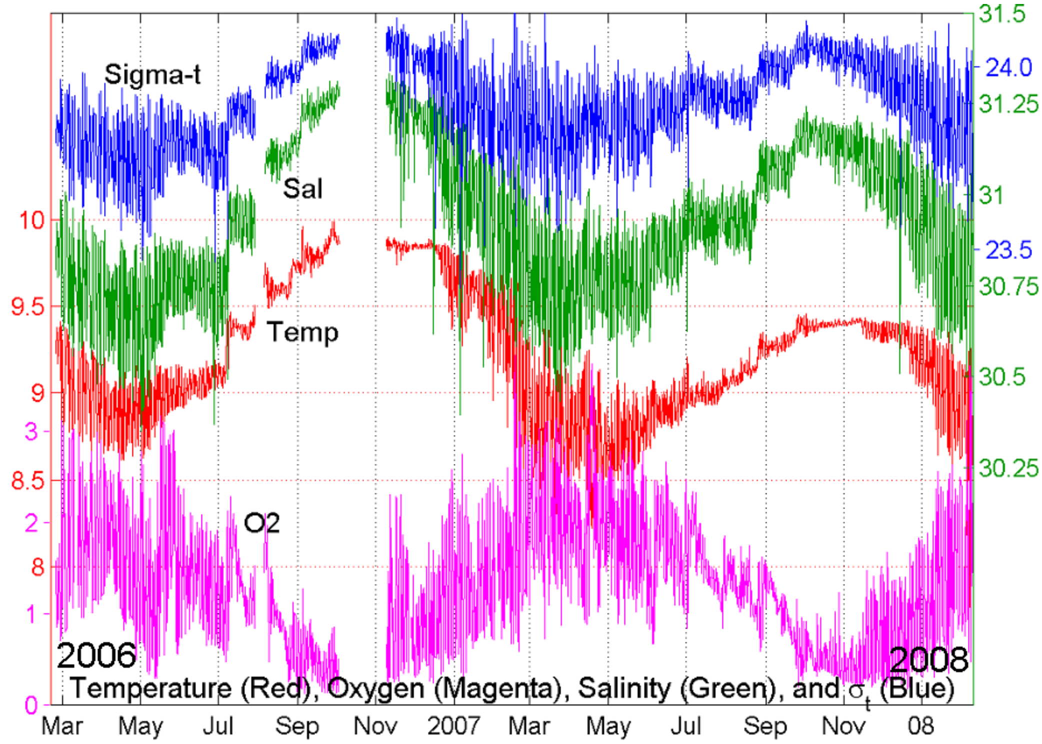

Figure 1. The entire two year record of temperature, salinity, density (in the form of sigma$_t$) and dissolved oxygen at 96 metres depth, from late February 2006 through early February 2008. The instrument samples every minute, resulting in over 500,000 samples per year. To reduce the data density on these plots, both the minimum and maximum values are plotted for every 24 hour period.

Fig. 1 reveals both short and long term variability, while ensuring that extreme values are captured. Key signals include the winter cooling, which progresses into May, followed by summer warming that extends through to the end of October. Salinity values at this location are correlated with temperature. There is a slight inversion in the vertical temperature profile near the bottom, with density stratification supported by a strong salinity gradient. At 96m, the salinity trend over winter (Nov-May) is a gradual freshening, followed by increased salinity during the up-welling season from May through September. Oxygen too is tied to both temperature and salinity, with fresher and cooler water having higher dissolved oxygen concentrations [ml/l] than saltier and warmer water. Deep water renewal events are evident at one month intervals, in agreement with Masson (2002). During these density-driven renewal events, salinity, temperature, and oxygen all increase. However, the displacement of anoxic water from deeper in the Saanich Inlet basin upwards past the VENUS site forces a longer term trend of decreasing oxygen during the renewal period, which is July through October. The summer weather of 2007 was particularly cool, and this is reflected in the cooler peak temperatures in late 2007.

There is one ping every second, recording over 800 echo-return intensities per profile. It is particularly well suited for revealing zooplankton and fish. Key features in Fig. 2 (next page) include the diurnal migration of the zooplankton, most likely dominated by *Euphausia pacifica,* from depth to the surface at dusk, retreating at dawn back to the bottom and depths below the VENUS Instrument Platform. Long nights and short days during the winter give way to short nights and longer days in the summer. During the spring bloom (April, second panel), phytoplankton densities are sufficiently high to enhance the near surface echo-intensities throughout the surface layer. By February 2008, we see the return of significant zooplankton populations, as well as schools of small fish, possibly herring. VENUS is working on summary statistics that will show the trends and seasonal timings of these characteristics.

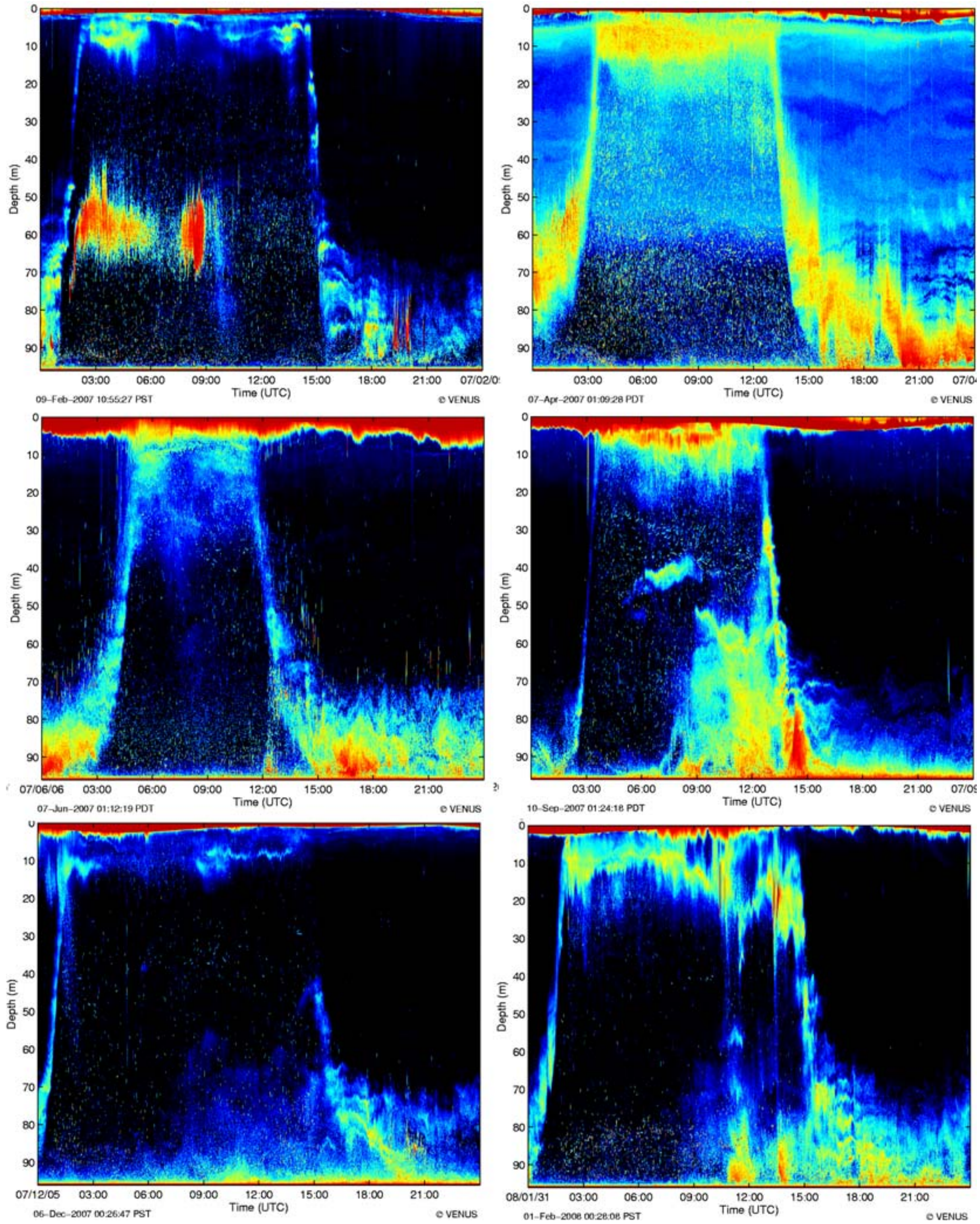

Figure 2. A composite of echo-grams from early 2007 to early 2008 Each panel represents one day of 200 kHz echo-sounder record, scaled in relative [db], from top right to lower left: Feb 8. 2007, April 6, 2007, June 6, 2007, Sept. 9, 2007, Dec. 5, 2007, and Jan. 31, 2008.

Herring in the Strait of Georgia

Jake Schweigert, Fisheries and Oceans Canada

Herring survival conditions and recruitment have been unusually good in the Strait of Georgia for the last decade. Abundance of herring reached near historical high levels from 2002-2004 exceeding 100,000 mt. However, the 2003 and 2004 year-classes are relatively weak resulting in a substantial decline in abundance in recent years. Nevertheless, the stock remains at a healthy level in the short term.

Detailed analysis

The Pacific herring stock in the Strait of Georgia migrates inshore in the fall and leaves the Strait in the spring following spawning. Survival conditions for juvenile herring in the Strait of Georgia have been unusually good during the last decade. Abundance of herring in the Strait of Georgia reached near historic high levels from 2002-2004 at over 100,000 tonnes (Fig. 1). Recruitment to this stock has been very strong with 8 of the last 10 year-classes being average or better (Fig. 2). The strongest recruitment occurred in 2000 and subsequent year-classes have been progressively smaller. The most recent recruitment in 2006 was poor and 2007 only slightly better. Juvenile rearing conditions within the Strait of Georgia appear to be an important determinant of recruitment success for this stock since most juveniles do not leave the area until their second summer. Initial indications are that the recruitments for the next couple of years may also be weaker based on surveys of juvenile abundance and could to lead further declines in overall abundance.

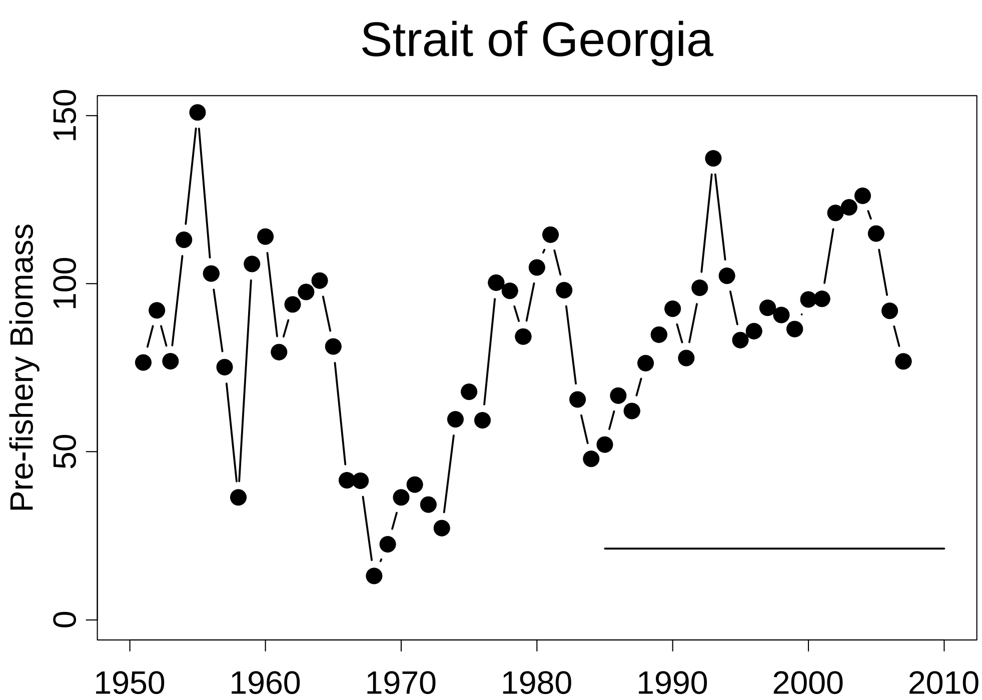

Figure 1. Strait of Georgia herring abundance.

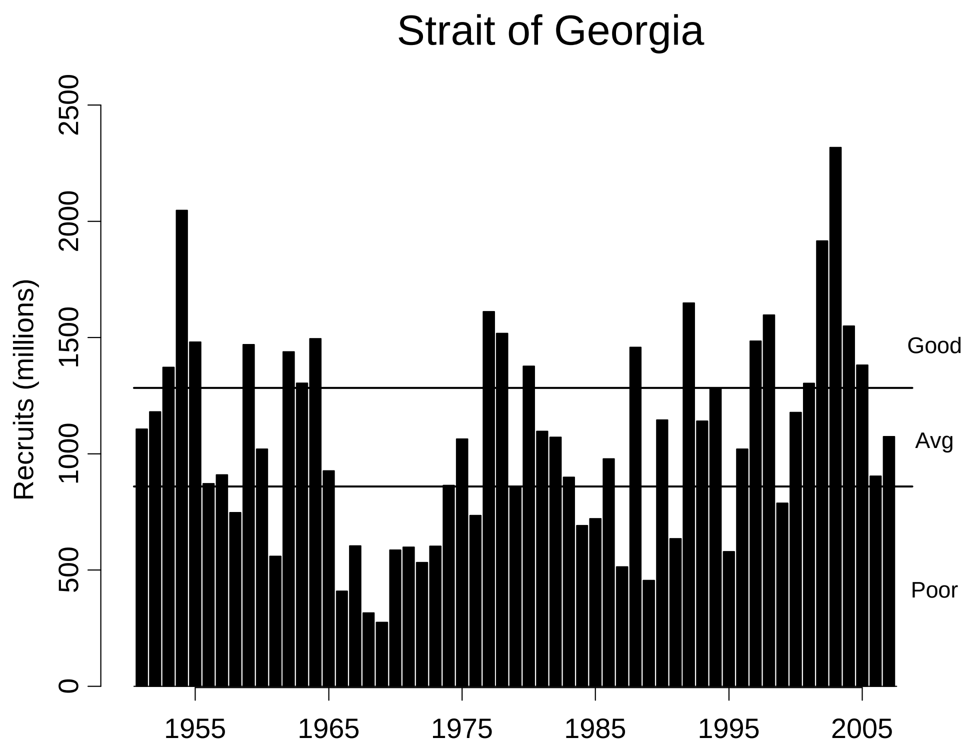

Figure 2. Interannual variability and decadal trends in recruitment to the Strait of Georgia stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

Interpretation and Speculative Results

Herring: The abundance of herring in 2006 and 2007 declined substantially from the near historic high levels of more than 100,000 tonnes in 2002-2004. The declining trend in recruitment over the past four years will translate into reduced mature abundance levels over the next few years. Fall surveys of juvenile herring also project reduced recruitment in the next few years.

Strait of Georgia juvenile salmon: The same in 2007, only different

R.M. Sweeting, R.J. Beamish, C.M. Neville, E. Gordon, K. Lange

Fisheries and Oceans Canada

The Strait of Georgia in 2007 in many ways exhibited continuation of long-term trends, but with several significant differences that may strongly impact brood year survival of juvenile salmon. The two major factors controlling the physical state of the Strait are Fraser River discharge and water temperature. Total annual discharge in 2007 was lower than the previous two years. However, the flow in April was the 2nd highest since 1965. April flows are considered crucial for setting up the physical state of the Strait of Georgia when the majority of juvenile coho, Chinook and chum salmon enter the marine environment. A change in timing of peak flows can be seen by examining the date at which 25% of the total annual flow has been achieved. Since 1913, this date has moved forward approximately 6-8 days (Fig. 1). If we examine the flow by month over this period (Fig. 2), it is clear that the majority of this change has occurred in April, May and June, critical months for early marine survival of salmon in the Strait of Georgia.

Water temperature also plays a major role in marine survival. The Strait has been warming but in 2007 the Nanoose sampling program recorded lower temperatures than the previous 5-8 years, at the surface, at 10 meters and at 390 meters depth. This temperature trend was also seen using the IOS Lighthouse surface temperature database (Table 1). Note that the slopes are all similar, even for Race Rocks in Juan de Fuca, which is generally under different physical forcings than the Strait of Georgia. Taken together, 2007 was a year of lower water temperatures, particularly in the surface layers (0-30 meters) where we catch the vast majority of juvenile salmon in our surveys.

Data	Equation (number before the x indicates the slope)	R^2 values
NANOOSE	Y = 0.0289x + 10.45	0.465
CHROME ISLAND	Y = 0.0365x + 10.42	0.638
SoG combined	Y = 0.0394x + 10.52	0.724
Race Rocks	Y = 0.0353x + 8.65	0.628

Table 1. Warming trends in the Strait of Georgia and Juan de Fuca (Race Rocks), using annual values from 1969-2007. The Strait of Georgia combined includes data from Departure Bay, Entrance Island, Chrome Island and Sisters Island.

We conducted 74 sets in July 2007. Major findings were average to low catches of juvenile coho and Chinook, with very low catches of chum and sockeye (Table 2). Catch per unit effort (CPUE) for Chinook and coho was approximately equal to the long-term (1997-2007) average. While neither CPUE was as low as observed in 2005, in 2007 we caught a disproportionately large percentage of juvenile coho of American origin (determined from coded-wire tags). This suggests that the Canadian coho survival was lower than the CPUE might predict. The CPUE for juvenile chum salmon was the lowest since 1997. Interpreting sockeye CPUE is complicated, due to extreme dominance cycles exhibited by this species. Furthermore, we were unable to conduct our survey in 2003, so it is difficult to assess from the previous brood year for this cycle.

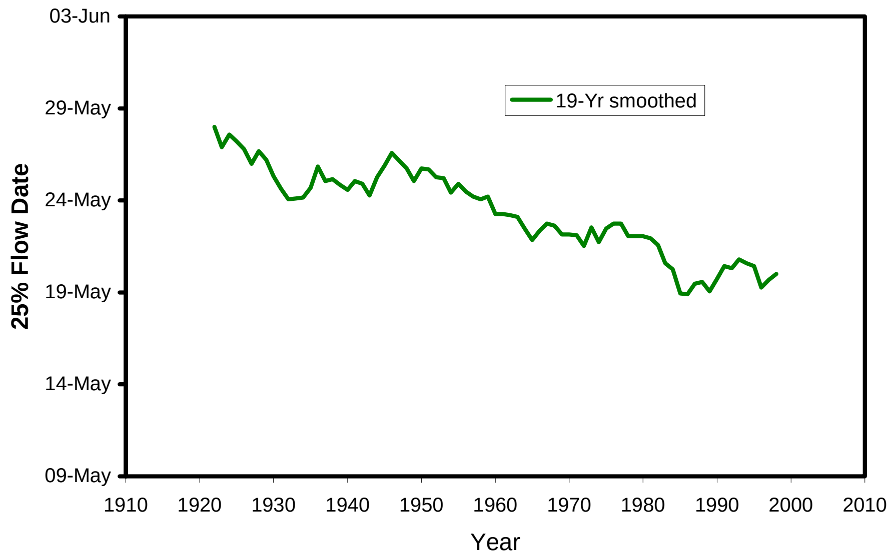

Figure 1. Date at which 25% of the annual Fraser River flow is achieved (data from Hope station - 08MF2005), using a 19 year smoothed curve.

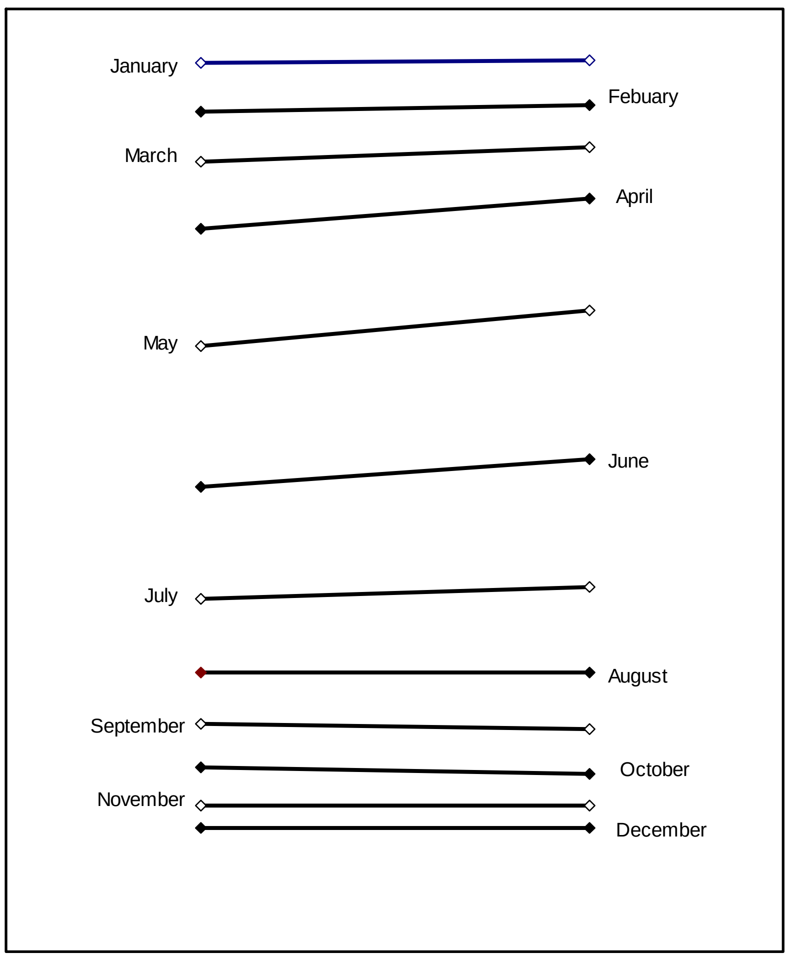

Figure 2. Slopes of average flows for the Fraser River at Hope 1913-2007.

	Catch (July 2007)	CPUE (July 2007)	Average CPUE (97-07)	"Trend"
COHO	1293	41.6	40.3	Average
CHINOOK	2023	59.7	54.8	Average
CHUM	561	21.9	195.8	Very low
PINK	0	-	-	Not a pink year
SOCKEYE	65	2.54	19.40	Very low

Table 2. Catch and CPUE data for the July 2007 juvenile salmon survey in the Strait of Georgia. The average CPUE is calculated from 1997-2007 (no survey in 2003). Note that 2007 was not a year for juvenile pink salmon from the Fraser River stocks.

In September 2007 we conducted 71 sets, with some intriguing results (Table 3). Coho CPUE was low, about 1/3 the long term average, whereas both Chinook and chum CPUEs were closer to average values. Particularly interesting were the very high sockeye catches and CPUE. The literature suggests that most juvenile sockeye depart the Strait of Georgia prior to September. We found an inverse correlation between our September sockeye CPUE and marine survival (Fig. 4), suggesting that the longer sockeye remain in the Strait of Georgia in their entry year, the poorer their marine survival will be ($R^2 = 0.44$).

	Catch (Sept 2007)	CPUE (Sept 2007)	Average CPUE (97-07)	"Trend"
COHO	328	10.2	28.9	Very low
CHINOOK	1124	32.7	38.1	Average
CHUM	2182	80.1	110.7	Low to average
PINK	30	-	-	Not a pink year
SOCKEYE	1858	68.4	22.4	Very high

Table 3. Catch and CPUE data for the September 2007 juvenile salmon survey in the Strait of Georgia. The average CPUE is calculated from 1997-2007 (no survey in 2003). Note that 2007 was not a year for juvenile pink salmon from the Fraser River stocks.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
COHO											
Fork L	159.2	172.8	167.6	199.7	185.7	170.3	-	178.9	190.9	194.0	153.6
St Dev	22.54	23.27	22.31	23.33	21.31	22.84	-	28.19	24.28	23.66	23.17
N	520	1213	1646	3359	3502	2184		2257	641	2327	1236
CHINOOK											
Fork L	140.3	120.9	138.2	142.7	145.2	139.7		119.6	134.4	131.0	106.4
St Dev	33.83	36.73	28.28	37.25	31.09	25.59		32.16	26.78	36.70	20.24
N	1585	1411	1664	1827	2647	2411		3073	641	2586	1809

Table 4: Average fork lengths (mm) (standard deviation and sample size N) for juvenile coho and Chinook salmon captured in July midwater trawls surveys in the Strait of Georgia from 1997-2007. No survey conducted in 2003.

In addition to CPUE, we have shown that marine survival is also related to the average size of juvenile salmon in our July surveys. This is particularly true for coho salmon (for hatchery coho, R^2 = 0.196; for wild coho, 0.542; total coho, 0.360). In our July 2007 surveys, average fork lengths for both coho and Chinook were the lowest seen in the 11 years of this program (Table 4). For Chinook salmon, the low average size is in part due to the absence of the upper size mode usually observed in the July surveys (Fig. 3). These bimodal peaks may represent ocean-type and stream-type populations within the Strait. Future work will determine this.

Another way to examine this early marine growth is to determine the amount of growth between July and September (Fig. 5). This plot shows that the greater the growth between July and September, the lower the marine survival. This may be a reflection of the conflict between growth (i.e., achieving large size to avoid predation) and energy storage (i.e., over-winter survival).

<u>PREDICTIONS</u>:

1. Coho salmon returns to the Strait of Georgia in 2008 will be low, perhaps even lower than in 2006, based on the very poor growth and low CPUE observed in the 2007 survey.
2. Chinook returns in 2008 will be average to poor. The return of 5-yr olds from the disastrous 2005 entry year will probably be very low. Data from the 2007 surveys suggest that returns in 2009 do not look promising.
3. Chum returns in 2008 will be average, based on the average CPUE in the July 2006 survey. Since the CPUE in July of 2007 was very low, we expect returns in 2009 may be poor.
4. Sockeye returns in 2008 will probably be above average (based on 2006 data), but returns in 2009 may be extremely poor.
5. There will be many juvenile pink salmon in the Strait in 2008, which may put pressure on marine survival of other juvenile salmonids. Adult returns in 2008 will be average to good, based on 2006 CPUE data.

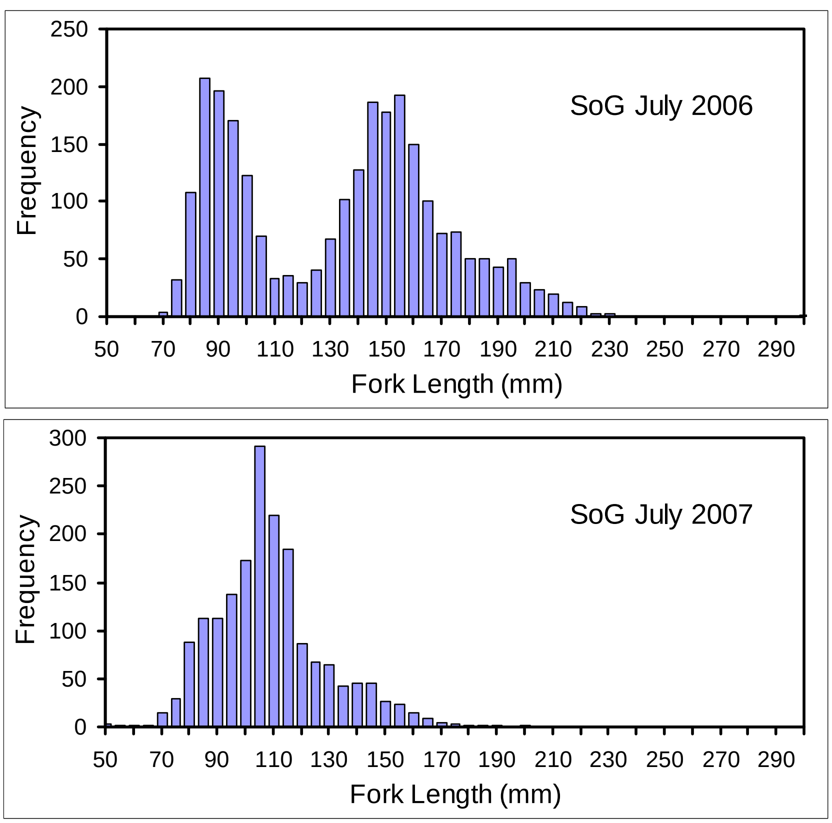

Figure 3. Histogram of Chinook salmon fork lengths (mm) from July surveys in the Strait of Georgia, 2006 and 2007. Note lack of second size peak in 2007.

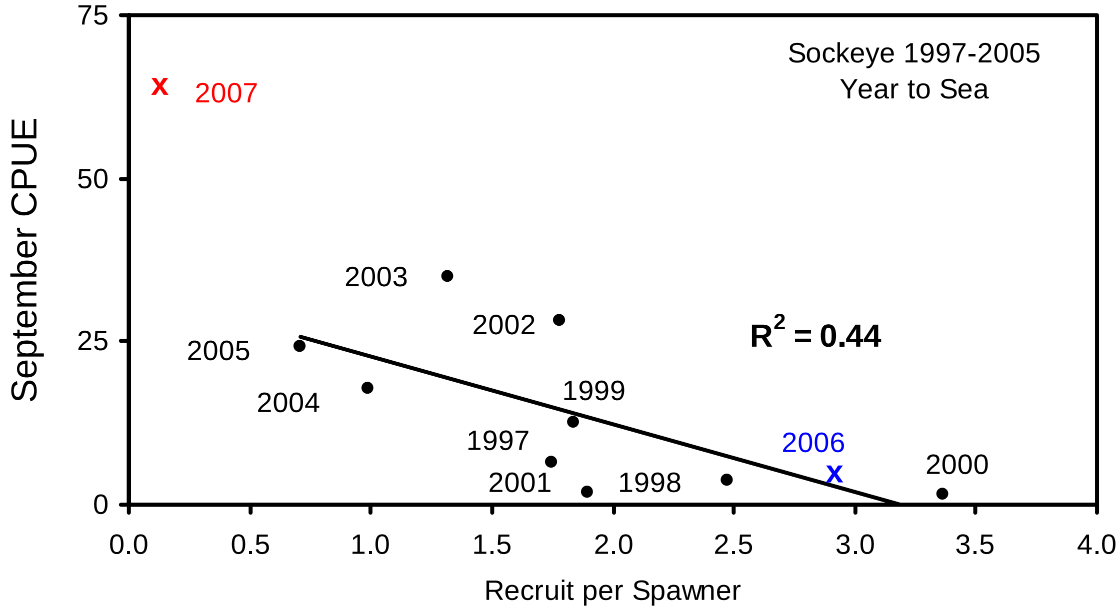

Figure 4. Relationship between September CPUE for juvenile sockeye in the Strait of Georgia and the resulting recruit per spawner for that brood year. Note the extremely high CPUE in 2007 and the resulting low projected survival predicted for 2009.

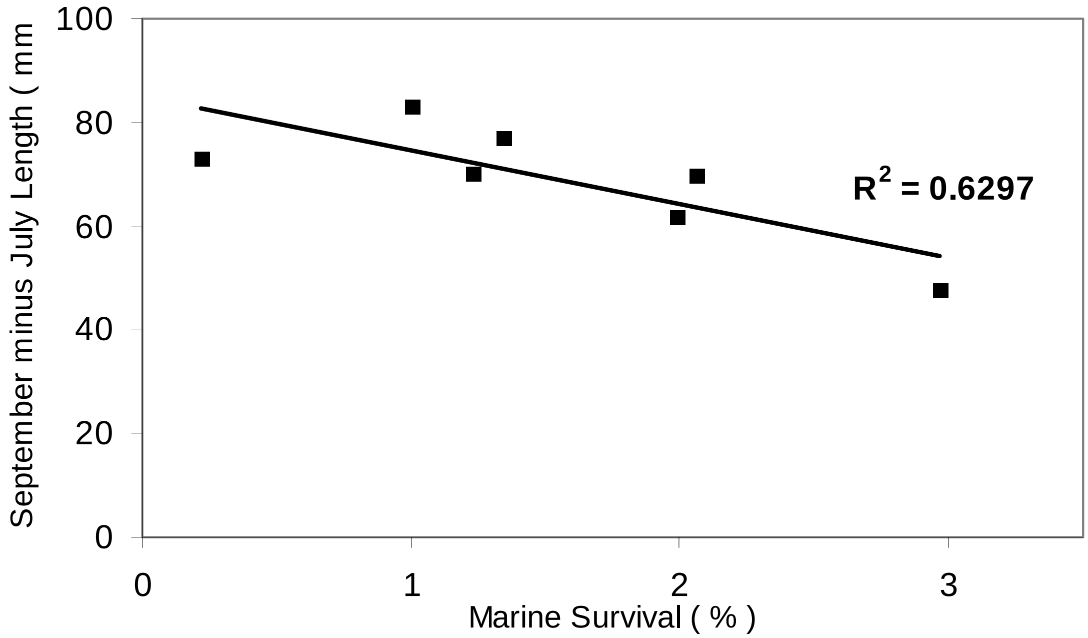

Figure 5. Relationship between summer growth (average fork length in September survey – average fork length in July survey) and marine survival. High summer growth may reduce available stored energy for overwinter survival.

Fraser River sockeye pre-season forecasts for 2008

Sue Grant and Al Cass, Fisheries and Oceans Canada

Background: Pre-season abundance forecasts for Fraser River sockeye salmon are reviewed annually and a series of reports are publicly available: http://www.dfo-mpo.gc.ca/csas/csas/Publications/Pub_Index_e.htm. Data available to generate forecasts for most Fraser River sockeye stocks (19 stocks presented in the forecast tables--Tables 2 & 3) include stock and recruitment data. A subset of these 19 stocks also have jack return and juvenile data available. Environmental data have also been included as a covariate in biological models for these stocks and broadly these variables include sea surface temperature, Fraser River discharge, and various climate indices such as the Pacific Decadal Oscillation (PDO). A number of "miscellaneous" stocks only have stock data available. Depending on the data available for a particular stock, various models can be used to generate forecasts that range from naïve (e.g. average past return across all cycles) to biological models (e.g. Ricker stock-recruitment model); naïve models do not use predictor variables such as brood year escapement or juvenile abundance or include, as covariates, environmental data to forecast returns. For each stock, the "best" model is selected to forecast returns based on how each model performs retrospectively. Generally, biological models that include environmental data as a covariate have not performed as well as other models. Therefore, only a small number of stocks may include environmental data to generate a forecast in any given year. Detailed methods, results, and model performance are documented in Cass et al. 2006.

Forecast Performance: Sockeye abundance forecasts are associated with high uncertainty as revealed in Fig. 1 below.

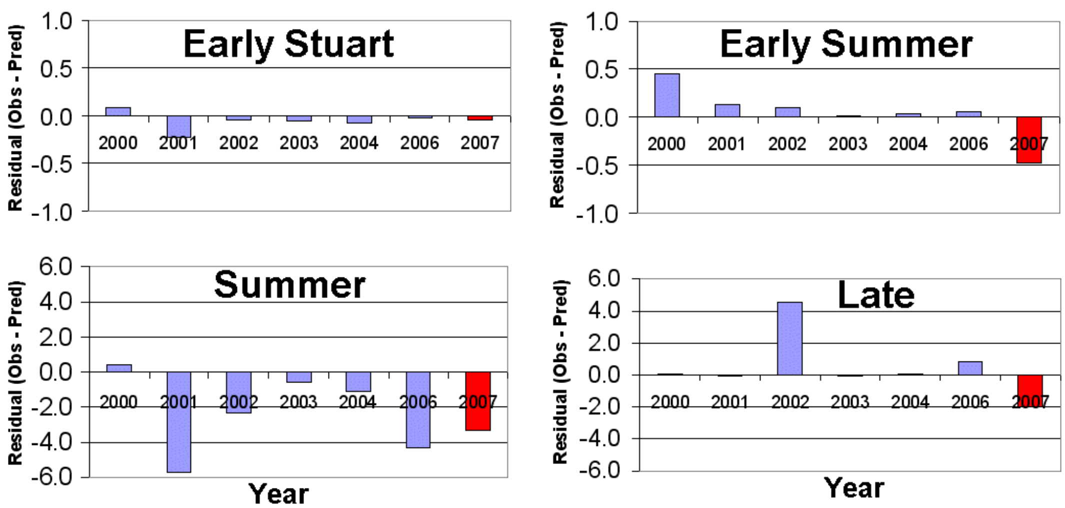

Figure 1. Observed returns (Obs) minus forecasted returns at the 50% probability level (Pred) for each of the four major run timing groups for Fraser sockeye (Positive values indicate the forecast under-estimated observed returns and negative values indicate the forecast over-estimated returns)

Models used to date to forecast sockeye return assume average survival conditions based on the historical time series. Therefore, in years when survival conditions are greater or less than what has been observed in the past, forecasts respectively over- or under-estimate observed returns. Chilko sockeye, the only indicator stock for Fraser sockeye where we can partition survival between marine and freshwater environments, indicated that marine survival was particularly low for the 2003 brood year (1%) relative to the long term average (9%). Sockeye stocks are largely comprised of 4_2 fish (4 years total age, 2 years freshwater age) and, therefore, most sockeye from the 2003 brood year migrated to the ocean in 2005 and returned to spawn in 2007. Forecasts for most stocks that returned in 2007 over-estimated observed returns attributed largely to anomalously poor marine survival conditions for juvenile sockeye.

4_2 Sockeye Life-History Cycle:

2003 brood year (adult spawning year) ⟶ 2005 smolt migration to ocean ⟶ 2007 adults return to spawn.

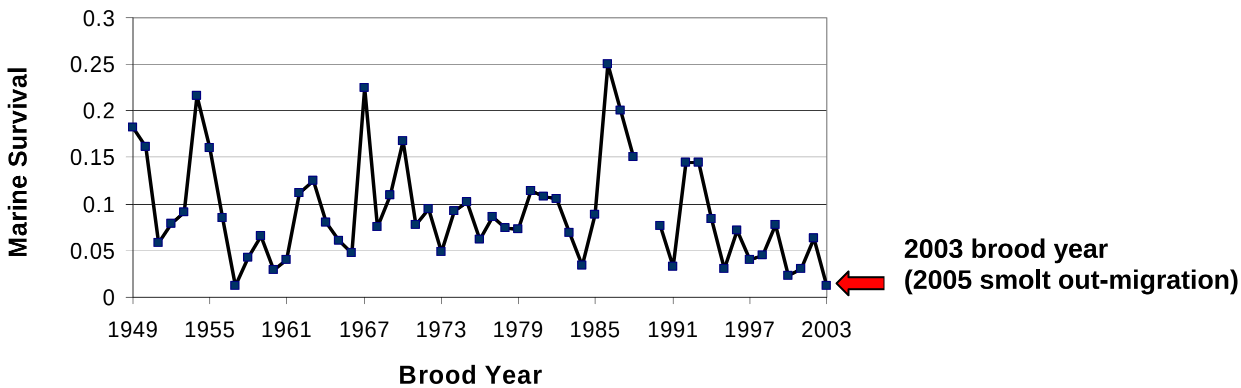

Figure 2. Marine survival for Chilko sockeye, where the final data point is the preliminary four year old survival for the 2003 brood year (equals 2005 smolt migration to the ocean and 2007 adult returns).

The first few months at sea when they are relatively small is when sockeye are generally most vulnerable to mortality mechanisms such as predation and starvation. Therefore, ocean conditions that reduce growth rates and energy reserves (e.g. higher water temperatures, limited food availability etc.) can decrease survival for juvenile fish. However, when comparing individual oceanographic variables in 2005, conditions were not sufficiently poor for any one quantitative variable to explain the poor sockeye marine survival observed for the 2003 brood year (see plots below). For instance, in 2005, the year of low smolt survivals, PDO was low and the SST was high, but lower PDOs and higher SSTs in earlier years did not result in as low marine survivals.

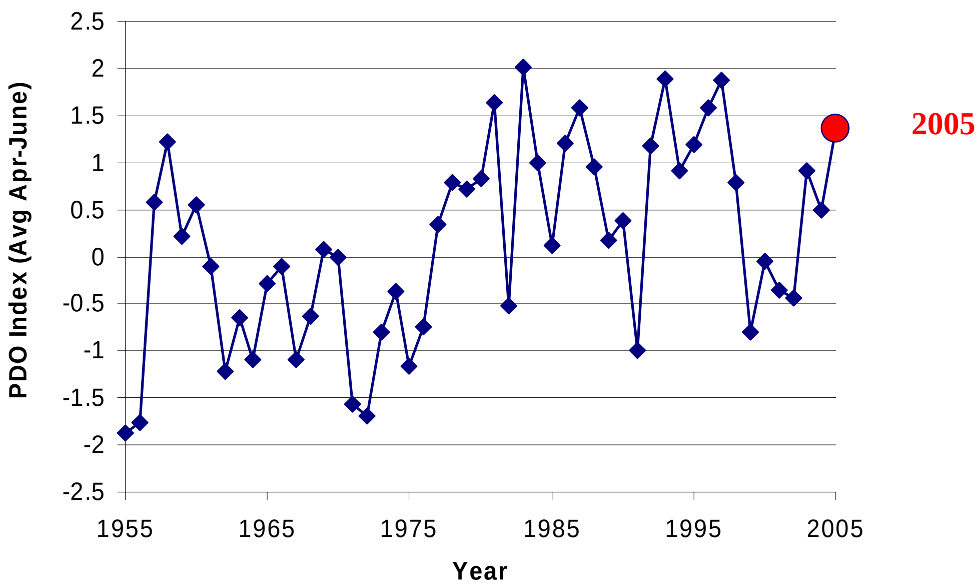

Figure 3. Time series of the Pacific Decadal Oscillation (PDO) averaged over April to June of each year.

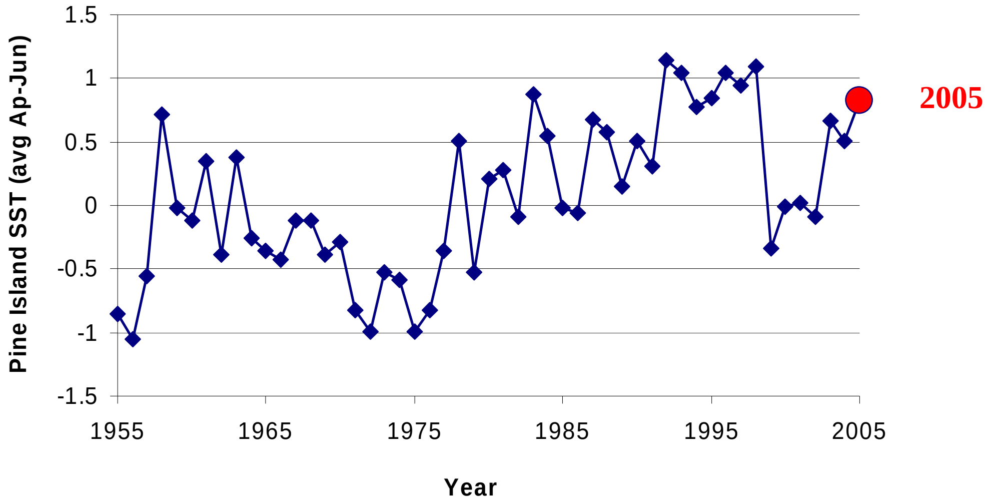

Figure 4. Time series of annual average temperature at Pine Island, BC.

Individually, none of the environmental variables when included as a covariate in the forecast models would have predicted the poor sockeye returns observed in 2007 at the 50% probability level (most probable return given average survival conditions). An alternative approach proposed for future forecasts is to track qualitatively a range of climatic, physical and biological oceanographic variables for each smolt outmigration year. This suite of information presented below compiled from corresponding "State of the Pacific Ocean" reports should inform the quantitative return forecasts that are presented over a range of probabilities from the more conservative 90% probability level to the less conservative 10% probability level. The presentation of this information could be in a "report card" format similar to what is presented by Northwest Fisheries Science Centre, NOAA, re-worked below using "State of the Pacific Ocean" 2005 and 2006 reports. Since indicators for the 2005 smolt outmigration year were poor (below average), this would have been informative for 2007 forecasts since forecasts generally over-estimated returns.

Table 1. Ocean indicators for Fraser River sockeye salmon outbound in 2005 and 2006. The 2005 and 2006 indicators are relevant to sockeye returning in 2007 and 2008 respectively.

Indicators of Ocean Productivity (State of the Ocean Reports 2005 & 2006)

	2005	**2006**
PDO	↓ **warm** (0.95 Jan-Aug) **cool** (-0.77 to Dec)	↓ **warm** (0.57 Jan-Jul) **cool** (-0.34 to Dec)
SST (Coast BC)	↓ **warm**	↓ **near/above avg** (Jan-Jun) **below avg** (Jul-Dec)
Vertical Stratification	↓ **strong**	○ **average-weak** (storms)
Upwelling	↓ **weak**	↑ **strong** (in summer)
Spring transition	↓ **delayed** (June)**	○ **average** (Early-April)
Zooplankton (warm-water spp.)	↓ **high**	↓ **high**
Large cold water euphasiids	↓ **poor (peak Ap/May)**	↓ **poor (peak May)**
WCVI Coho growth rates	↓ **lowest on record**	○ **average**
Marine bird breeding success	↓ **lowest on record**	○ **average**
Juvenile sockeye size (SOG)	↓ **below average**	↑ **largest in past 10 yrs**

In the upcoming 2008 sockeye return year (2006 smolt outmigration year), 2006 indicators are mixed indicating that there should be an improvement in sockeye ocean survival conditions relative to 2005. Fisheries managers could use these qualitative indicators to focus on return forecasts associated with more or less conservative probability levels (greater or less than the 50% probability forecasts), as opposed to the 50% probability level historically emphasized for pre-season management purposes.

Table 2. Pre-season 2008 sockeye forecast (ocean-entry year for most smolts: 2006) (DFO, 2007)

Sockeye stock/timing group	Forecast model[b]	Mean Run Size[c]		Probability of Achieving Specified Run Sizes[a]				
		all cycles	2008 cycle	0.1	0.25	0.5	0.75	0.9
Early Stuart	fry	**335,000**	**182,000**	**73,000**	**49,000**	**35,000**	**24,000**	**17,000**
Early Summer		-	-	**932,000**	**563,000**	**349,000**	**216,000**	**136,000**
(total exlcuding miscellaneous)		***(499,000)***	***(538,000)***	***(702,000)***	***(444,000)***	***(288,000)***	***(185,000)***	***(120,000)***
Bowron	Ricker-pi	23,000	26,000	8,000	6,000	5,000	3,000	2,000
Fennell	power	28,000	41,000	37,000	25,000	17,000	11,000	7,000
Gates	power	65,000	149,000	148,000	97,000	63,000	38,000	25,000
Nadina	fry	80,000	129,000	288,000	168,000	103,000	59,000	35,000
Pitt	power	61,000	65,000	91,000	73,000	59,000	52,000	39,000
Raft	power	32,000	64,000	91,000	51,000	27,000	14,000	8,000
Scotch	power	63,000	16,000	19,000	10,000	5,000	3,000	1,000
Seymour	Ricker-cyc	147,000	48,000	20,000	14,000	9,000	5,000	3,000
Misc[d]	R/S	-	-	136,000	72,000	37,000	20,000	10,000
Misc[e]	R/S	-	-	50,000	26,000	14,000	7,000	4,000
Misc[f]	avg escp	-	-	44,000	21,000	10,000	4,000	2,000
Summer		**5,677,000**	**2,882,000**	**4,324,000**	**2,729,000**	**1,810,000**	**1,182,000**	**822,000**
Chilko	smolt	1,760,000	1,804,000	1,783,000	1,230,000	885,000	596,000	433,000
Late Stuart	power	834,000	323,000	1,450,000	714,000	355,000	177,000	95,000
Quesnel	power	2,556,000	90,000	255,000	163,000	93,000	48,000	27,000
Stellako	Ricker	527,000	665,000	836,000	622,000	477,000	361,000	267,000
Late		-	-	**1,728,000**	**1,139,000**	**705,000**	**432,000**	**283,000**
(total exlcuding miscellaneous)		***(3,172,000)***	***(788,000)***	***(1,435,000)***	***(938,000)***	***(610,000)***	***(400,000)***	***(268,000)***
Cultus	smolt-jack	19,000	6,000	14,000	9,000	5,000	3,000	2,000
Harrison[h]	TSA	47,000	19,000	233,000	110,000	47,000	21,000	10,000
Late Shuswap	Larkin	2,133,000	39,000	49,000	26,000	15,000	7,000	3,000
Portage	power	58,000	24,000	49,000	27,000	15,000	7,000	4,000
Weaver	fry	432,000	405,000	629,000	434,000	290,000	193,000	126,000
Birkenhead	power	483,000	295,000	461,000	332,000	238,000	169,000	123,000
Misc. Shuswap[g]	R/S	-	-	6,000	3,000	2,000	1,000	1,000
Misc. non-Shuswap[g]	R/S	-	-	287,000	198,000	93,000	31,000	14,000
TOTAL		-	-	**7,057,000**	**4,480,000**	**2,899,000**	**1,854,000**	**1,258,000**
(TOTAL excluding miscellaneous)		***(9,683,000)***	***(4,390,000)***	***(6,534,000)***	***(4,160,000)***	***(2,743,000)***	***(1,791,000)***	***(1,227,000)***

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