Fisheries and Oceans Canada
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Pacific Region **Ocean Status Report 2007/001**

STATE OF THE PACIFIC OCEAN 2006

Figure 1. Location of regions described in this report. Ocean conditions are monitored along Line P, which extends from the mouth of Juan de Fuca Strait to Ocean Station Papa at 50°N, 145°W.

Context:

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 this 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. Contributors to this report are members of the Fisheries and Oceanography Working Group of the DFO Pacific Centre for Science Advice, with additional contributions from scientists of the U.S. National Marine Fisheries Service.

June 2007

SUMMARY

This section summarises the physical and biological state of the marine ecosystems of Canada's Pacific Region in 2006 and early 2007 based on individual contributions presented in the Appendix of this report. New for this year are invited reports from American scientists, describing conditions along the west coast of Oregon and southern Washington State. This report, and the report for previous years, can be found at:
www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm.

This report is the eighth 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 ocean 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.

Top Stories of 2006

- Global warming continued and the West Coast seas remained warm in early to mid-2006
- Storms of late 2006 were the worst to hit southern BC, cooling ocean waters in autumn
- "Warm-ocean pattern" of marine life continued into summer 2006
- Juvenile coho and seabirds along Vancouver Island rebounded from very low numbers
- Where were the herring? Numbers declined all through BC waters
- Where were the hake? Few found west of Vancouver Island for first time in several years
- Returns of sockeye salmon were weak due to poor ocean conditions when they were young
- Oxygen concentration continued to decline in subsurface waters in the northeast Pacific
- Strait of Georgia stayed warm in 2006
- Fraser River was warm for returning sockeye salmon
- Biggest plankton bloom ever observed in BC waters from space was in summer 2006

ASSESSMENT

Global warming continued, and the West Coast seas remained warm in early to mid-2006

Global warming of air and water temperatures continued during 2006 (Fig. 2). This ongoing and cumulative warming trend is beginning to exceed the warm conditions that were experienced during previous El Niño events. In 2006, the annual global air temperature (including land and ocean) was 0.54°C above average, making it the 5th warmest year since the start of coordinated measurements in 1880.

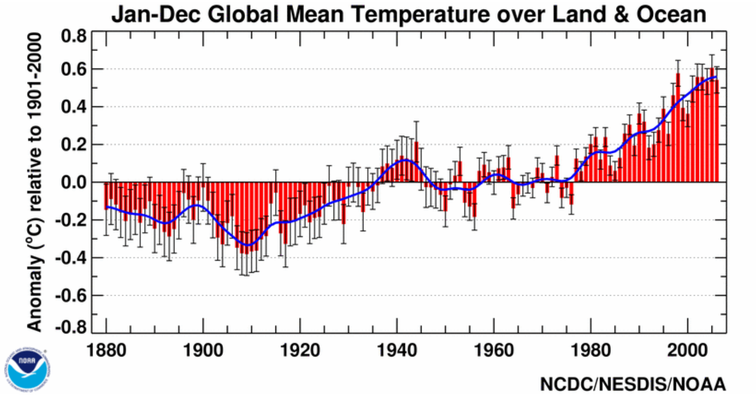

Fig. 2 Global annual average air temperatures over land and ocean from 1880 to 2006. Plot shows differences (anomalies) of annual temperatures from the average over the period 1880-2006. Plot courtesy of NOAA http://www.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html

Along the Pacific coast of Canada, average annual **air** temperatures in 2006 were 0.5°C above average, making it the 23rd warmest year since 1948, and therefore close to this period's average. Precipitation along coastal BC in 2006 was 5.6% below average, making it the 18th driest year since 1948. The summer of 2006 was especially dry.

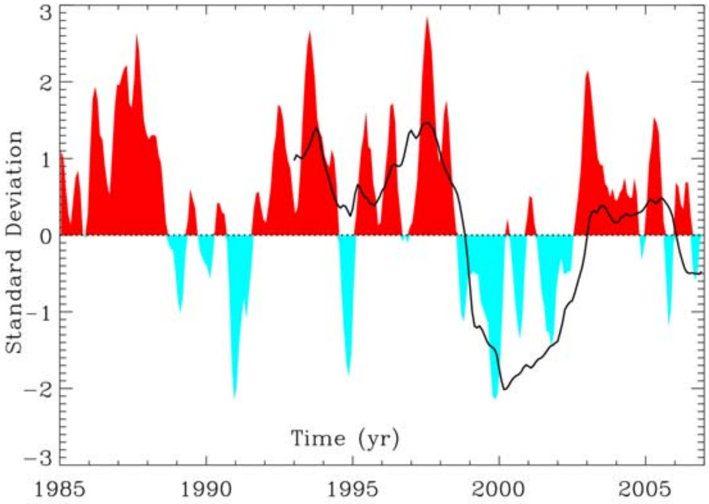

Figure 3. The solid red/blue curve gives the recent history of the Pacific Decadal Oscillation index (from http://jisao.washington.edu/pdo/PDO.latest*). The solid black line is a measure of upper ocean variability over the NE Pacific based on the first principal component of sea surface height over the region [Source for figures 3 and 4: P. Cummins. See report on "Sea surface height over the northeast Pacific in 2006" in the Appendix.]*

Within this general global warming, however, smaller regions can experience different conditions. The Pacific Decadal Oscillation (PDO) identifies oscillations in sea surface temperature across the North Pacific and has been used to define warm and cool regimes in the ocean climate of this region. From late 2002 to early 2006 the PDO was positive, bringing generally warmer waters to the Pacific Region of Canada. However, the PDO became negative in 2006, as noted in Figure 3, bringing cooler waters to the West Coast. This change in ocean conditions was also detected in sea surface heights in deep-sea waters. The black line in Figure 3 denotes the PDO pattern as detected in sea levels, which represent the amount of heat over greater depths than does the PDO and is therefore a more robust indicator of interannual changes. This signal became negative in 2006 and remained there to year-end. The extent to which this impacted British Columbia, Washington and Oregon waters is revealed in Figure 4. The two panels show sea surface height anomalies for the first and second quarters of 2006.

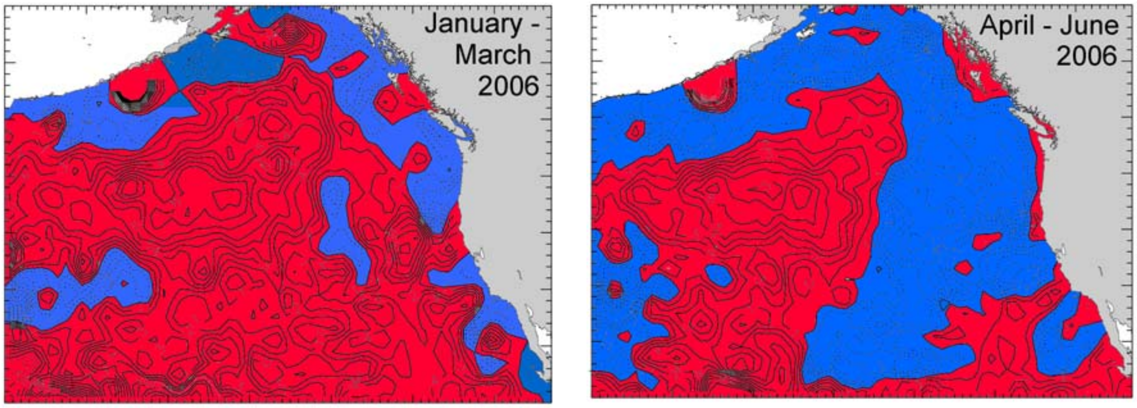

Figure 4. Differences in sea surface height from average conditions (anomalies) over the northeast Pacific Ocean (taken as 180-113°W; 25-60°N). The contour interval is 1 centimetre, with red denoting high sea level and blue denoting low sea level. Each panel presents a three-month average of monthly anomalies, based on measurements by TOPEX/POSEIDON and Jason-1 satellites. Measurements began in 1992 and monthly anomalies are determined relative to the years 1993 to 2006.

Notice how the region of high sea level in Figure 4 (red shading denoting higher-than-average values) shrank in size between the first and second quarters of 2006. This change marks the shift from positive PDO to negative PDO and from generally warm waters to cooler than normal temperatures in the eastern Gulf of Alaska. This pattern persisted to at least the end of 2006.

El Niño is a coupled atmosphere-ocean phenomenon that originates in the tropical Pacific Ocean and can affect global climate. The multivariate index used to identify El Niño conditions in the tropical Pacific indicated a weak El Niño occurred through the last half of 2006, but ended in early 2007. El Niño conditions often bring warmer winters to southern British Columbia, but the 2006 El Niño had little impact here. By April 2007, Pacific equatorial conditions were closer to those of La Niña (cool water) and were expected to remain in this state for several months.

Coastal sea levels were also average for the year 2006, but overall sea levels continue to rise by about 10 cm/century at Victoria and Prince Rupert. The southern coast of BC experienced relatively strong downwelling-favourable (blowing from the SE) winds during winter 2006, and stronger upwelling-favourable (blowing from the NW) winds during summer, compared with average conditions. The seasonal switch between these dominant winter-summer wind directions, called the Spring Transition and representing the start of the productive summer season, was near average (early April) in 2006 compared with 2005 which had the latest Spring Transition on record (June).

Temperature conditions at the surface and at depth along the outer coasts of BC during 2006 can be characterised into two states: near or above average during the first half of the year, followed by cooling from mid-summer to fall and winter 2006/2007. Figure 5 tracks this cooling at lighthouses and shore stations in British Columbia.

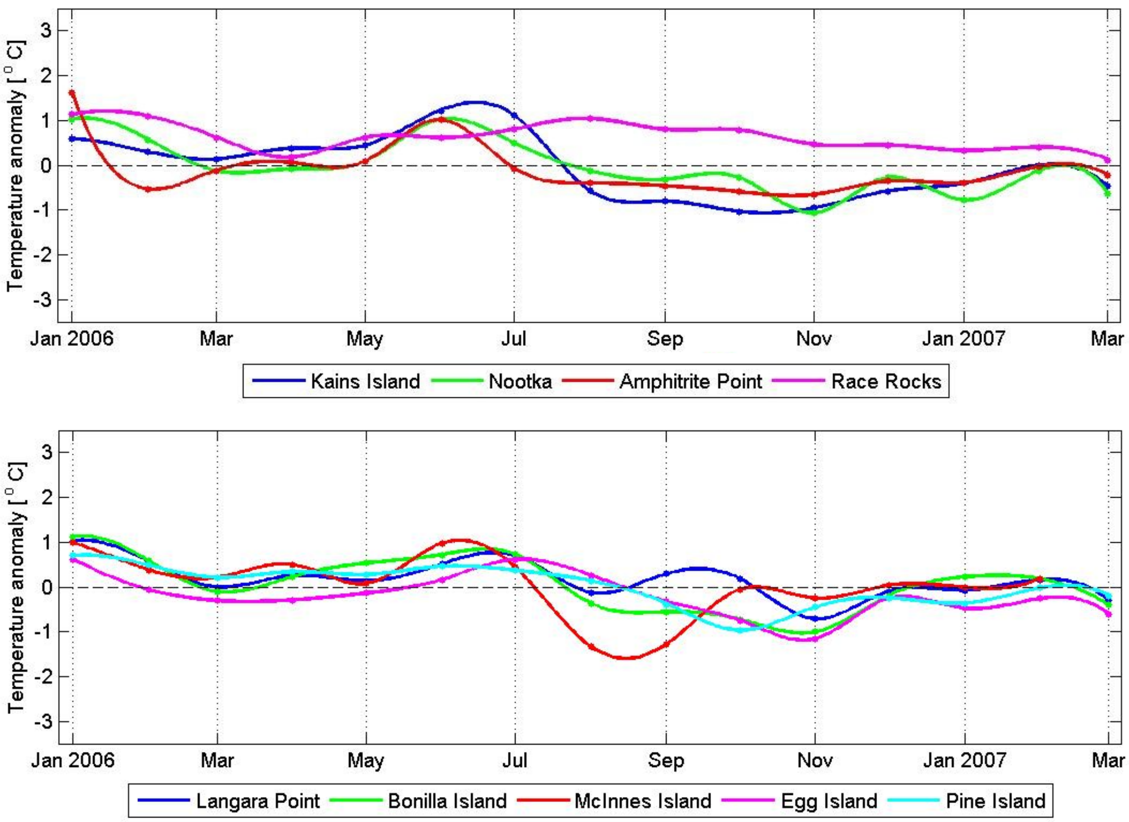

Figure 5. Sea surface temperature anomalies measured at lighthouse stations along the BC coast. Values are the differences of monthly average temperatures in 2006 and early 2007 from the long-term (generally since the 1930s) average for that month. Note that all locations had below average temperatures during fall 2006. [Source: P. Chandler, see the report on "Long-term temperature and salinity at BC Lighthouses" in the Appendix]

Storms in late 2006 were the worst to hit southern BC oceans, cooling these seas by early 2007

The significant weather story for coastal BC in 2006, however, was the series of frequent and very intense storms that occurred in late fall, mostly in November. Ten major storms hit southern Vancouver Island that month, approximately one every three days, and 149 weather warnings (for rain, snow, and/or wind) were issued, which is considerably more than in previous years. Windy conditions continued into December 2006, with monthly average wind speed records set or almost set (within 1%) at six meteorological buoys in coastal BC waters. Many residents spent nervous days and nights without power, often listening to falling trees.

These storms further cooled sea temperatures all along the outer BC coast, so that temperatures were below average by the end of 2006 and even cooler in early 2007 (Fig. 5). In addition, deep-sea temperatures plunged through late 2006 and early 2007, and by March 2007 the entire Gulf of Alaska was below normal temperature. The blue area near BC and Alaska in Figure 6 shows how unusually cold our local ocean was in March 2007.

As a result, the vertical stratification of the Gulf of Alaska (between the surface and 75 m depth) was close to average, after several years of very strong stratification that likely reduced the vertical mixing of nutrients into the surface layers. The increased vertical mixing appears to have carried more essential plant nutrients from deep to near-surface waters in the NE Pacific, with nitrate concentrations that were measured in February 2007 being typical of a cool winter with deep vertical mixing. This may lead to stronger and longer-lasting plankton growth in deep sea waters in spring 2007.

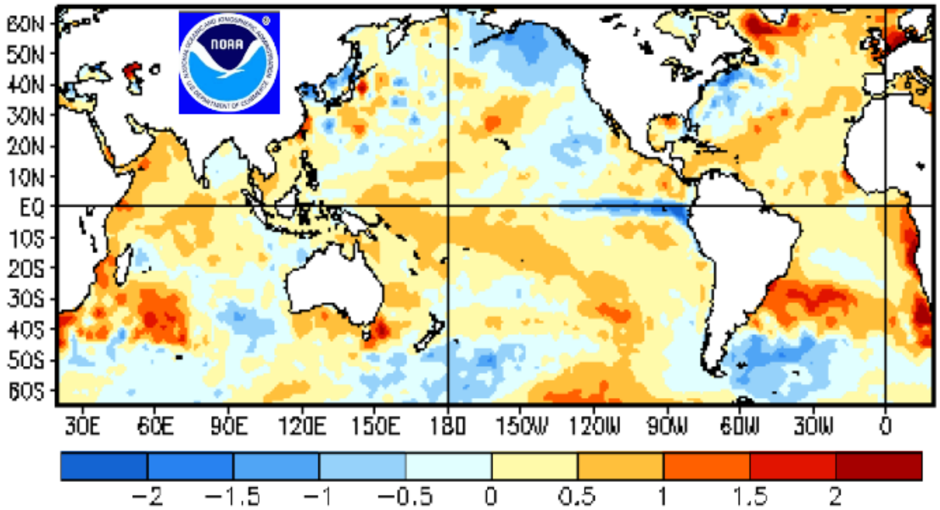

Figure 6. Sea surface temperature anomalies (Degrees Celsius) for 11 March 2007 to 7 April 2007. Although most regions were warmer, the entire Gulf of Alaska was significantly cooler than normal. [Source: B. Crawford, see report on “Cooling ocean from summer 2005 to winter 2006/2007” in Appendix. Figure source is http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf]

“Warm-ocean pattern” of marine life continued into summer 2006

Marine life in deep-sea waters in the Gulf of Alaska maintained many of the warm-water features of the preceding two years. The timing of the development of the large sub-arctic copepods, which are important food items for higher animals such as fish and whales, was early in 2006 (April-May) and similar to that in 2004 and 2005. This happens when conditions are warmer, and is in contrast to 2000-2003 when conditions were cooler and copepod development was later (June). Closer to shore, the amount of phytoplankton, which forms the base of the main food web, has been monitored along the BC coast since 1997 using satellites. Monthly data indicate a somewhat later start to the spring bloom (May) in 2006 compared with previous years (April).

Most marine animals along the outer coast of BC during 2006 continued to be affected by the very warm conditions of 2005 and the warm conditions of early 2006. A composite analysis including zooplankton, temperature, and predatory fish and seabird species suggests that 2005 was a very bad year for the productivity and survival of many BC species (comparable to conditions during the 1997/1998 El Niño), whereas 2006 was near average but with mixed signals of cooler temperatures and continued “warm ocean” effects on marine life. The species composition and seasonal development of zooplankton, which are critical components of the marine food web and important food for many fishes and seabirds, continued in a “warm ocean” pattern off Vancouver Island. There were high abundances in BC waters of zooplankton that are normally centered off California (Fig. 7) and relatively low abundances of euphausiids, another key group of zooplankton which are important as food for fish. In addition, the peak occurrences of the typical cold water species (copepods) in the surface waters of BC were among the earliest recorded (early May), which is consistent with warm ocean conditions. The amount of smooth pink shrimp off Vancouver Island continued to be low, also consistent with warm conditions.

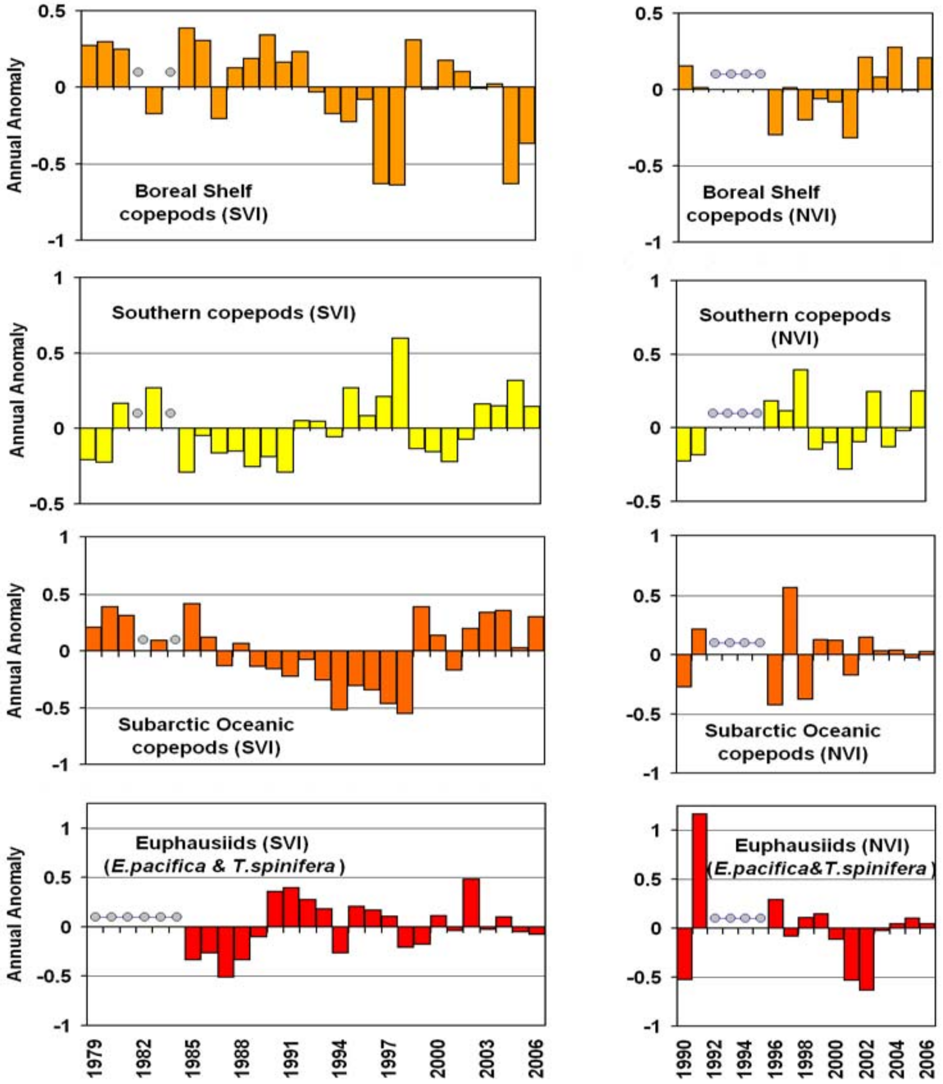

Figure 7. Time series of differences of zooplankton biomass from their average values (measured since 1979) for four groups of zooplankton off southern Vancouver Island (left) and northern Vancouver Island (right). [Source: D. Mackas; see section on "Zooplankton in a 'warm-ocean' pattern off Vancouver Island, despite cooling in 2006" in the Appendix]

The patterns that were observed during 2006 in Canadian waters are similar to those observed to the south off Oregon until July 2006. Both southern Vancouver Island and Oregon marine waters are part of the California Current large marine ecosystem, so some similarity of events is to be expected. Warmer-than-average temperatures occurred off Oregon from late 2002 until June 2006. Beginning in July 2006, sea surface temperatures became cooler than normal and remained below normal into spring 2007. Initial observations of zooplankton species composition off Oregon in late 2006 and early spring 2007 indicate the zooplankton are dominated by species which prefer colder water; this represents an important change from previous conditions which were dominated by warm water species. If this shift took place along Vancouver Island, it happened after the final plankton survey of the year in September 2006.

Juvenile coho and seabirds rebounded from very low numbers in 2005 along Vancouver Island

The growth of juvenile coho salmon off Vancouver Island and SE Alaska has been monitored during early summer and late fall surveys since 1998. Overall, marine survival of coho salmon off the west coast of Vancouver Island is expected to be high when the growth rates of juvenile coho are high. The growth of juvenile coho in 2006 off Vancouver Island increased from the lowest recorded in 2005 to near the 1998-2004 average (Fig. 8). Surveys for yearling coho and Chinook salmon off southern Washington State and Oregon in summer had higher catches of these species in 2006 compared with 2004 and 2005.

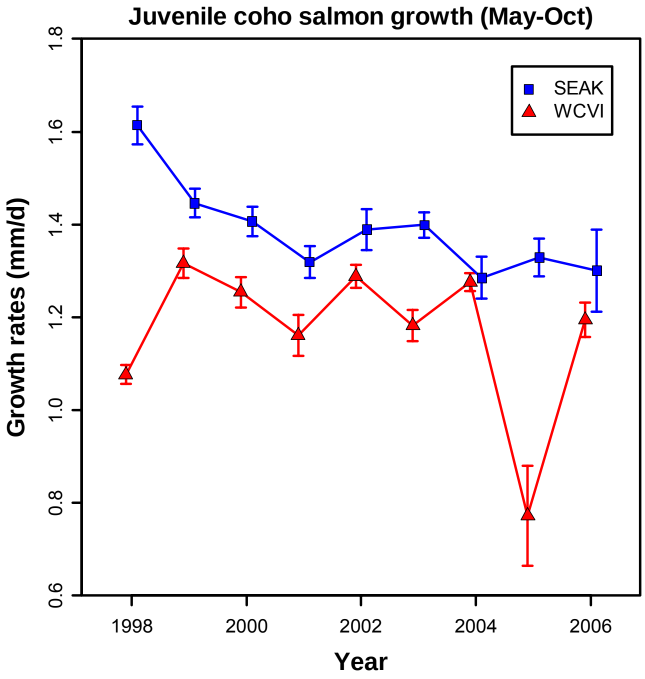

Figure 8. Growth rates (May-October) of juvenile coho salmon off the west coast of Vancouver Island (WCVI red triangles) and Southeast Alaska (SEAK blue squares). Juvenile coho generally grow faster off SE Alaska, and growth rates appear to have been relatively stable there since 2004, in comparison with the west coast of Vancouver Island. [Source: M. Trudel; see report on "Average growth conditions for coho salmon in southern BC" in the Appendix]

Marine birds are good indicators of the state of marine ecosystems because they are readily observed and because they feed on a range of species from zooplankton to fish. Seabird breeding success is also closely tied to the availability of key prey and therefore can vary widely among years, depending on ocean conditions and prey concentrations. In spring 2006, the reproductive timing and breeding success of sea birds off northern Vancouver Island were close to their long-term (since 1975) averages. This indicates that food availability and feeding conditions during spring 2006 were about normal. Breeding success for these birds in 2006 was also close to their long-term averages, in contrast to the worst ever breeding year of 2005.

Where were the herring? Numbers declined through BC waters

Small pelagic fishes such as Pacific herring and Pacific sardine are important food for many species of larger fishes. Herring spawn in all BC waters and prefer cooler conditions; sardine spawn mostly off of California and migrate into BC waters with warm conditions. The total pre-fishery biomass of herring in all regions of BC has declined over the past few years. This declining abundance is related to successive years of poor recruitment, which continued in 2006. Herring biomass off the west coast of Vancouver Island in 2006 was very low, having declined further from the low biomass recorded in 2005 (Fig. 9). This low biomass is related to successive years of poor recruitment, possibly caused by warm ocean conditions, low zooplankton food, and increased predation by Pacific hake. Despite declines in pre-fishery biomass in the past two years, the Strait of Georgia herring fishery is reasonably healthy.

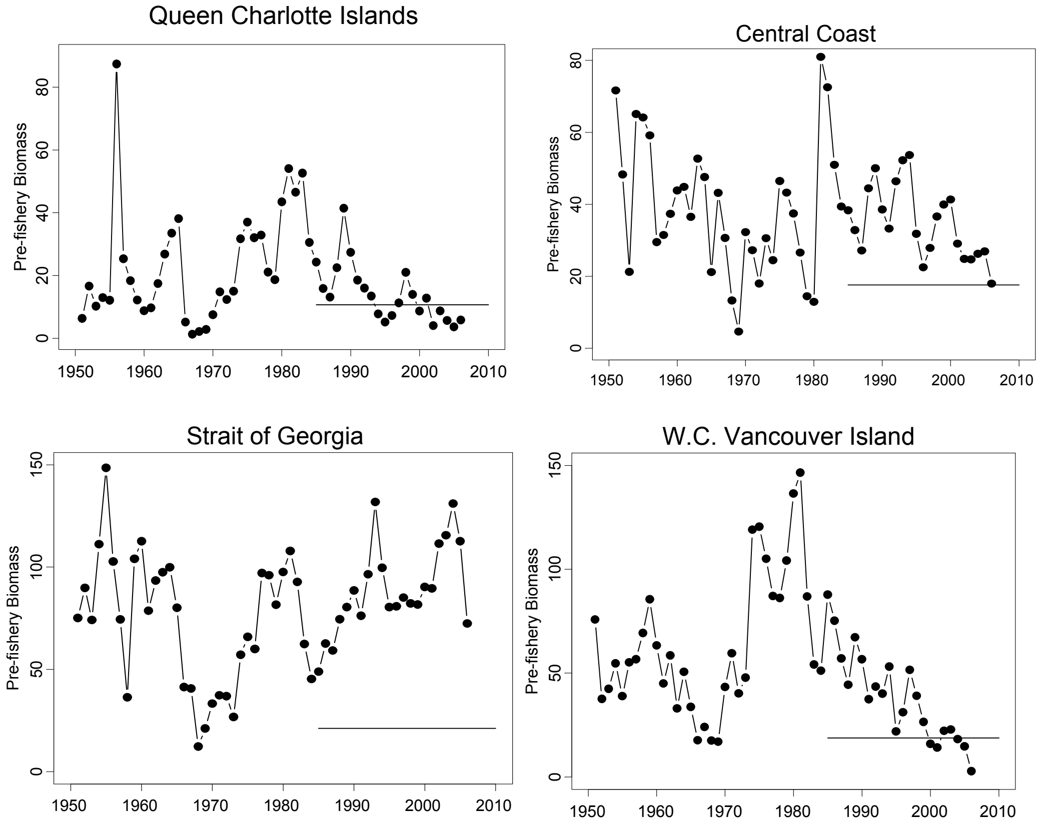

Figure 9. Pre-fishery biomass (1000 tonnes) of Pacific herring in four of the five management areas of British Columbia. [Source: J. Schweigert; see report on "Small pelagic fishes" in the Appendix]

Where were the hake? Few were found west of Vancouver Island for first time in several years.

Pacific hake is an important predatory and commercial fish that spawns off California and migrates into BC waters each summer; more hake migrate further north when conditions are warmer. Although the overall biomass of Pacific hake appears to be increasing because of strong recruitment in 1999, their distribution in BC in 2006 was unusual. They arrived in Canadian waters in May and supported the usual fishery off southern Vancouver Island, but by mid-June these fish had moved north and were being fished in Queen Charlotte Sound. Their distribution reversed the usual state of more hake off Vancouver Island than in northern BC. This behaviour may be related to the reduced abundances of their preferred euphausiid prey, and perhaps the cooling conditions that started during summer 2006.

Returns of sockeye salmon were weak because of poor ocean conditions when they were young

Returns of sockeye salmon in 2006 to the Central and South Coasts of BC were below average, but near to above-average for North BC coast and Alaska Trans-boundary stocks, respectively (Figure 10). This reflected the ocean conditions of southern BC waters and cooler conditions in the north at the time they went to sea as smolts in 2003 and 2004. Barkley Sound sockeye salmon returns were well below their long-term averages in both 2005 and 2006, as anticipated by high sea temperatures and El Niño-like conditions. Sockeye salmon returns in 2006 to Rivers and Smith Inlets on the Central BC coast were also below average.

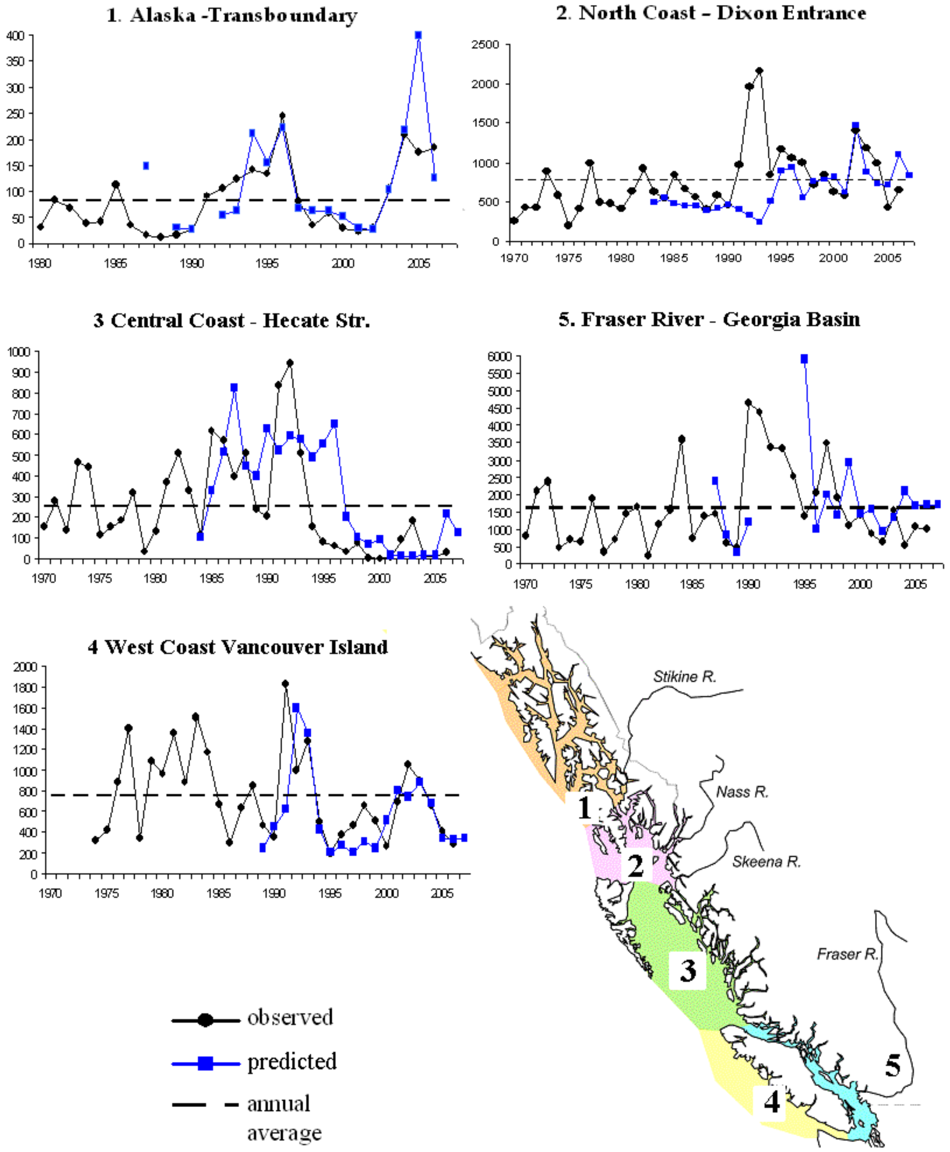

Figure 10. Trends in total returns and forecasts for British Columbia sockeye index stocks, 1970 - 2006, including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Barkley Sound and 5. Chilko Lake sockeye salmon. Y-axis represents returns in thousands of fish. [Source: Kim Hyatt. See report "Sockeye salmon index stocks" in Appendix]

Oxygen declined in summer coastal waters

Oxygen levels have declined by 22% in subsurface waters (100 to 600 m) at Ocean Station P (P26) in the past 50 years. This decline is accompanied by a temperature increase that is somewhat greater than that observed in the global atmosphere. Coastal waters from California to southern Alaska are seeing similar or higher rates of oxygen decline in waters found between 100 and 400 m below the ocean surface (e.g. Fig. 11). At station P4 (also on Line P, Fig. 1) on the continental slope of southern BC, oxygen is declining at about 1% per year at depths of ~250 m, faster than is being observed at P26. The northward flowing California Undercurrent waters are losing oxygen at a rate similar to P4 and strongly influence the southern coast of BC.

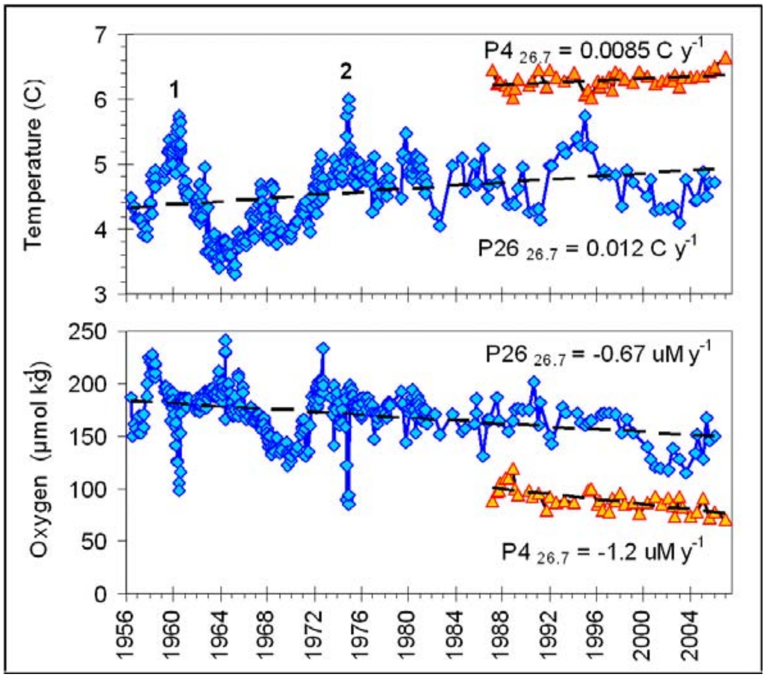

Figure 11. Oxygen and temperature on the 26.7 isopycnal surface at stations P4 and P26 on Line P. Note the steady decline in oxygen at P4 since monitoring began in 1988. Two mesoscale eddies (1 & 2) at P26 are identified in the upper panel. (Source: F. Whitney and M. Robert; see report on "Open ocean observations from Line P and Skaugran surveys" in Appendix)

Deadly low oxygen levels were observed on the Oregon continental shelf in 2006 and in the previous four years, but new in 2006 was a likely dead zone on the continental shelf west of the Olympic Peninsula and much closer to Canadian waters (http://www.piscoweb.org/files/archive-august-11-2006.pdf). This event was the closest occurrence of hypoxia to the continental slope waters of BC ever observed, although marine biota have been killed by low oxygen in coastal inlets like Howe Sound when annual flushing of basin waters does not occur. Because we have an incomplete understanding of processes that cause declines of oxygen concentrations off Oregon and Washington to lethal levels, we cannot rule out such events reaching Canadian waters in future years. Low oxygen levels kill bottom life such as crabs and clams. Fish usually escape by rising to shallower depths, although fish kills were recorded in Washington when low oxygen levels were transported to the surface in summer 2006, and about 33% of the ling cod stock in the lower reaches of Hood Canal in Washington State were killed when they lost their shallow water refuge during wind induced upwelling in 2006.

Strait of Georgia stayed warm in 2006

The Strait of Georgia and Georgia Basin are the major exception to the pattern of warm conditions during early 2006 followed by cool conditions in late 2006. The warm conditions that began in the Strait of Georgia in 2003 continued during 2006, with the heat penetrating to deeper depths. Temperatures, however, were slightly cooler than the excessive warm conditions of 2005 (Fig. 12). Past observations suggest that conditions in the Strait of Georgia lag those offshore by about 1 year, therefore the warm conditions in the Strait of Georgia in 2006 are expected to cool further during 2007.

Sampling of zooplankton in spring in the Strait of Georgia suggests that abundances of the major large copepod *Neocalanus plumchrus* in 2006 and 2007 were the third and second lowest, respectively, observed since 2001. The lowest abundance was observed in 2005. Pacific herring had been doing well in the Strait of Georgia until 2004, but the population biomass declined in 2005 and again in 2006 (Fig. 9), which appears to be due to the declining recruitment of young herring of the past few years. Some salmon populations in the Georgia Basin did well in 2006, whereas others did poorly, depending on when during 2005 and 2006 they entered the marine environment and the growth conditions that they experienced. The size of juvenile coho and their catches in surveys in the Strait of Georgia during 2006 were among the highest observed in the past 10 years, suggesting they should experience improved survival. In addition, there continues to be a decline in the percentage of hatchery-reared coho and an increase of wild coho in these surveys. This may reflect improved survival of wild coho which enter the Strait of Georgia earlier (and therefore into a more productive feeding environment), than hatchery-reared coho which are released into the ocean later in each year.

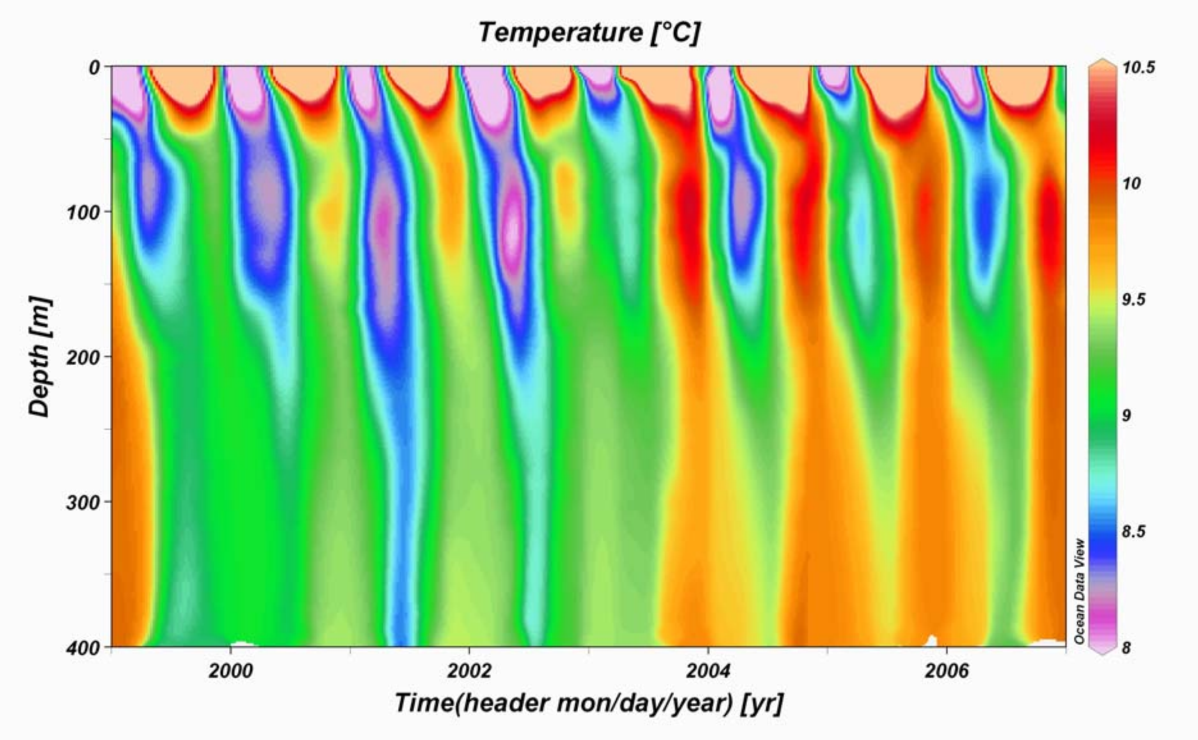

Figure 12. Strait of Georgia temperature by time (bottom axis) and depth (left axis). Colours display temperature, which has been warm during summers over the past few years. [Source: D. Masson; see report on "Strait of Georgia" in the Appendix]

Fraser River was warm for returning sockeye salmon

In the Fraser River, high flows and warm water can be detrimental to the spawning success of sockeye salmon during up-river migrations to their spawning grounds. 2006 was an exceptional year in the Fraser River, with temperatures well-above average throughout the entire salmon migration season. In addition, flows peaked early (28 May) but fell rapidly to record or near-record lows which lasted until early November. These adverse conditions caused elevated mortalities to summer and late-run sockeye salmon which were above the long-term average but lower than the highest values observed over the past 10 years.

Plankton bloom in summer 2006 was largest ever observed in BC waters from space

BC coastal waters were in the world media spotlight after NASA posted an image collected by their MODIS satellite on June 25, 2006, showing an extensive bloom west of Vancouver Island and Washington State (Fig. 13). Samples collected from the Canadian Coast Guard Ship *John P. Tully* confirm that this was due to a coccolithophore species of phytoplankton. Visual observations described the patterns in the water as very dramatic. This was the largest such bloom ever observed in these waters. These phytoplankton are not the harmful type that produce toxic conditions along the coast.

Figure 13 A "true colour" image of the ocean surface taken by the NASA satellite MODIS on 25 June 2006. (Source: J. Gower; see report on "Bright plankton blooms off the BC coast" in the Appendix)

Outlook for 2007

The cooling sea temperatures at the end of 2006 and which have continued into early 2007 suggest an end to the very warm conditions of 2004 and 2005. In addition, the U.S. Climate Prediction Center's El Niño bulletin (issued 10 May 2007; see footnote[1]) indicates that a transition from neutral El Niño to La Niña conditions is possible within the next 2 to 3 months. The Pacific Decadal Oscillation is also expected to be below average for the next several months[2]. This is all consistent with an outlook for cool sea temperatures to persist well into 2007. In addition, the cool temperatures, strong vertical mixing and higher nutrient concentrations in the Gulf of Alaska in winter 2006-2007 should permit increased primary production during spring 2007, if the weather is relatively clear and calm. If these cool conditions remain throughout 2007, and the primary productivity is high in spring, they imply a decline in southern zooplankton and improved growth conditions off BC for large subarctic copepods, Pacific herring, seabirds, and most salmon species that spend time in the waters of the BC continental shelf. However, the results of these improved growth conditions will not be observed until those species return to spawn in 2008-2010.

The outlook for cool water fish in 2007 and 2008 remains dominated by the poor growth conditions these animals experienced during 2005. Off the west coast of Vancouver Island, herring is at an historically low level. Recent conditions have been unfavourable for herring survival, and continued weak recruitment to the stock over the next couple of years is expected, although their growth may improve if cooler conditions bring more cold-water zooplankton. On the Central and North coasts of BC, the increased abundances of Pacific hake in 2005 and 2006 may have negatively affected herring recruitment and stock biomass, suggesting that herring declines in northern BC waters may persist into 2008.

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[1] http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.pdf

[2] SST Anomalies Forecast data provided by the CIRES/Climate Diagnostics Center and Physical Science Division/ESRL/NOAA, Boulder, Colorado (Alexander, M.A., Matrosova, L., Penland, C., Scott, J.D., and Chang, P. (2006) Forecasting Pacific SSTs: Linear Inverse Model Predictions of the PDO) from their Web site at http://www.esrl.noaa.gov/psd/.

Pacific salmon abundance forecasts have been made for populations returning to many major rivers and fisheries throughout Pacific Region by DFO for decades. Uncertainties in forecasts occur because of real variations in fish survival and environmental conditions, and uncertainties in data and models used for forecasting. Index salmon stocks entering continental shelf waters with strong ocean influences (such as the Central Coast and west coast of Vancouver Island) appear to be affected more strongly by La Niña (cool conditions leading to better survival) and El Niño (warm conditions leading to poor survival) than stocks entering protected inside and Strait of Georgia waters. As a result of the persistent El Niño-like (warm) conditions during 2003 to 2005, salmon returns are expected to remain below average in 2007 for Central Coast and west coast Vancouver Island sockeye, Carnation Creek coho, and Robertson Creek coho and Chinook. Returns of sockeye salmon to the west coast of Vancouver Island may improve in 2008 if cool conditions continue through 2007.

The Strait of Georgia experienced warm conditions through 2006, although the Strait was cooler than during 2005. The Strait of Georgia tends to lag conditions on the continental shelf of BC by about one year, therefore cooling of the Strait of Georgia is expected to continue through 2007. The declining trend in herring recruitment during the past four years will result in reduced abundances of herring over the next few years.

There are large variations in estimates of salmon survival among sockeye populations from the Fraser River system. This suggests that environmental factors within the Fraser River system and perhaps the different times that these fish enter the Strait of Georgia as juveniles may cause much of this variability in survival. For example, fisheries research cruises in 2005 found the juvenile Fraser River sockeye to be larger than normal in size, so returns could be higher than normal based only on this factor. This sampling does not take into account variations among individual Fraser River sockeye stocks, because the stock to which these juveniles belonged could not be determined. Therefore, we cannot predict which of the many sockeye stocks of the Fraser River may have large returns.

A different approach uses sea temperatures in the Gulf of Alaska and long time series of data from the Chilko Lake stock of sockeye salmon in the Fraser River system. A study of the impact of ocean temperatures on the survival of this stock suggests they fare better when outgoing juveniles encounter cooler-than-normal water in the Gulf of Alaska, and when the returning adults swim through a warmer-than-normal ocean. Based only on this factor, it is expected that numbers of returning Chilko Lake sockeye in 2007 will be lower than normal, since the ocean was very warm in 2005, and is expected to remain cool in 2007.

Juvenile coho in the Strait of Georgia return from the ocean one year before juvenile Chilko Lake sockeye, so the number of returning coho can be used to predict the impact of marine conditions on this sockeye run. This factor also predicts low returns of Chilko Lake sockeye in 2007, since the number of coho returning in 2006 was very low.

However, it is difficult to extrapolate this 2007 prediction of Chilko Lake sockeye numbers to other Fraser river sockeye. A detailed study compared the number of Fraser River sockeye spawning in each stream with the number of their progeny returning from the ocean to spawn as adults, and found large variations from stream to stream over the past 50 years. Climate change impacts on salmon will increase uncertainties in pre-season abundance forecasts. A significant challenge is to understand how environmental and ecosystem processes affect the productivity of salmon under these changing conditions.

Contributors to this Report

Sonia Batten	SAHFOS[1]	Roy Hourston	DFO	Angelica Peña	DFO
Richard Beamish	DFO[2]	Karen Hunter	DFO	Ian Perry (Editor)	DFO
Jim Boutillier	DFO	Kim Hyatt	DFO	Bill Peterson	NMFS
Edmundo Casillas	NMFS[3]	Jackie King	DFO	Paul Rankin	DFO
Al Cass	DFO	Dave Mackas	DFO	Marie Robert	DFO
Peter Chandler	DFO	Diane Masson	DFO	Jake Schweigert	DFO
Bill Crawford (Editor)	DFO	Gordon McFarlane	DFO	Margot Stockwell	DFO
Patrick Cummins	DFO	Skip McKinnell	PICES[6]	Rusty Sweeting	DFO
John Dower	U.Vic[4]	Cheryl Morgan	NMFS	Ron Tanasichuk	DFO
Howard Freeland	DFO	John Morrison	DFO	Richard Thomson	DFO
Jim Gower	DFO	Chrys Neville	DFO	Marc Trudel	DFO
Mark Hipfner	EC[5]	Ian Okabe	EC	Frank Whitney	DFO

[1] Sir Alister Hardy Foundation for Ocean Science, Plymouth, UK
[2] Fisheries and Oceans Canada
[3] United States National Marine Fisheries Service
[4] University of Victoria
[5] Environment Canada
[6] PICES is North Pacific Marine Sciences Organization

SOURCES OF INFORMATION

On-Line access to this full report with appendices:
http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm

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

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

FOR MORE INFORMATION

Contact: Bill Crawford
Institute of Ocean Sciences
Fisheries and Oceans Canada
P.O. Box 6000
Sidney, B.C. V8L 4B2
Tel: 250-363-6369
Fax: 250-363-6746
E-Mail: CrawfordB@pac.dfo-mpo.gc.ca

or

Ian Perry
Pacific Biological Station
Fisheries and Oceans Canada
3190 Hammond Bay Road
Nanaimo, B.C. V9T 6N7
Tel: 250-756-7137
Fax: 250-756-7053
E-Mail: PerryI@pac.dfo-mpo.gc.ca

This report is available from the:

Centre for Science Advice (CSA)
Pacific Region
Fisheries and Oceans Canada
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, British Columbia
Telephone: (250) 756-7208
Fax: (250) 756-7209
E-Mail: psarc@pac.dfo-mpo.gc.ca
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Continuing Global Warming in 2006

Compiled by Jackie King, Fisheries & Oceans Canada

The global annual temperature for combined land and ocean surfaces in 2006 was 0.54°C above average, ranking as the fifth warmest since the beginning of recorded global temperature in 1880 (Figure A1). During the past century, global surface temperatures have increased at a rate near 0.6°C/century, but this trend accelerated to a rate of 1.8°C/century after 1975. This increased rate is comparable to the rates of warming projected to occur during the next century with continued increases of anthropogenic greenhouse gases. Air temperature over land increased at a faster rate than temperatures above the ocean. In 2006, the largest temperature anomalies (land and ocean combined) were observed in high latitude regions of the Northern Hemisphere (Figure A2).

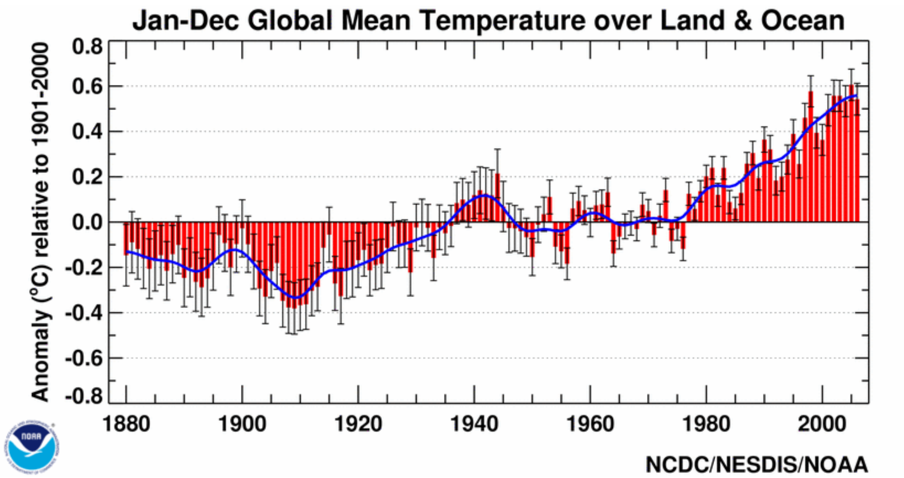


Figure A1. Anomalies of global temperature from 1880 to 2006 based on Smith and Reynolds (2005) that incorporates new algorithms that better account for changes in spatial coverage and observation methods.

Source: http://www.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html

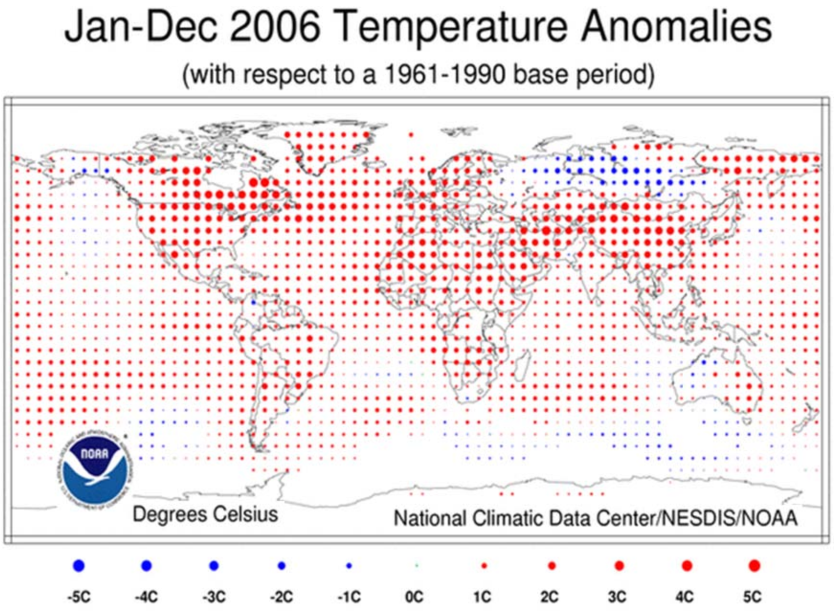


Figure A2. Global distribution of 2006 temperature anomalies. High latitude regions in the Northern Hemisphere such as North America, Europe, and China experienced the largest anomalies in 2006.

Source: http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/global.html#Gtemp

Reference

Smith, T. M., and R. W. Reynolds. 2005. A global merged land air and sea surface temperature reconstruction based on historical observations (1880-1997), J. Climate 18, 2021-2036.

High-Resolution Map of Global Warming

Jim Gower, Fisheries & Oceans Canada

The Reynolds data of global high-resolution sea surface temperature data now cover a period of 25 years. These temperatures show a clear warming trend (0.0115°C per year) over this period, with significant modulation by ENSO events, and possibly volcanic eruptions. (Fig. A3)

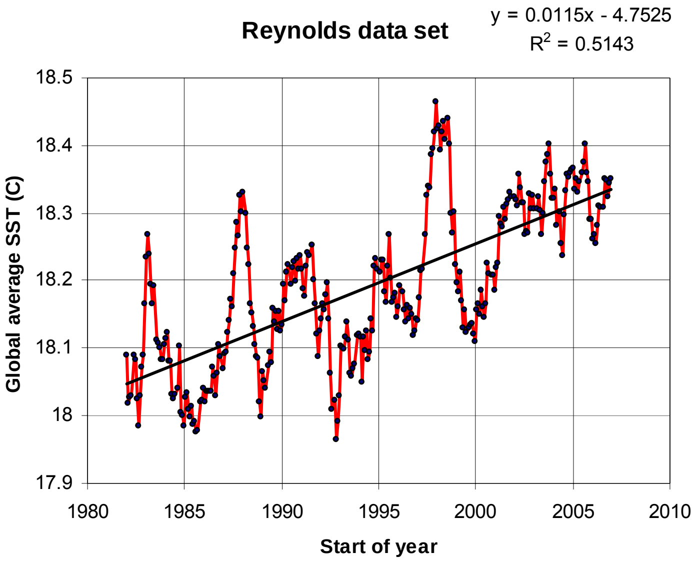
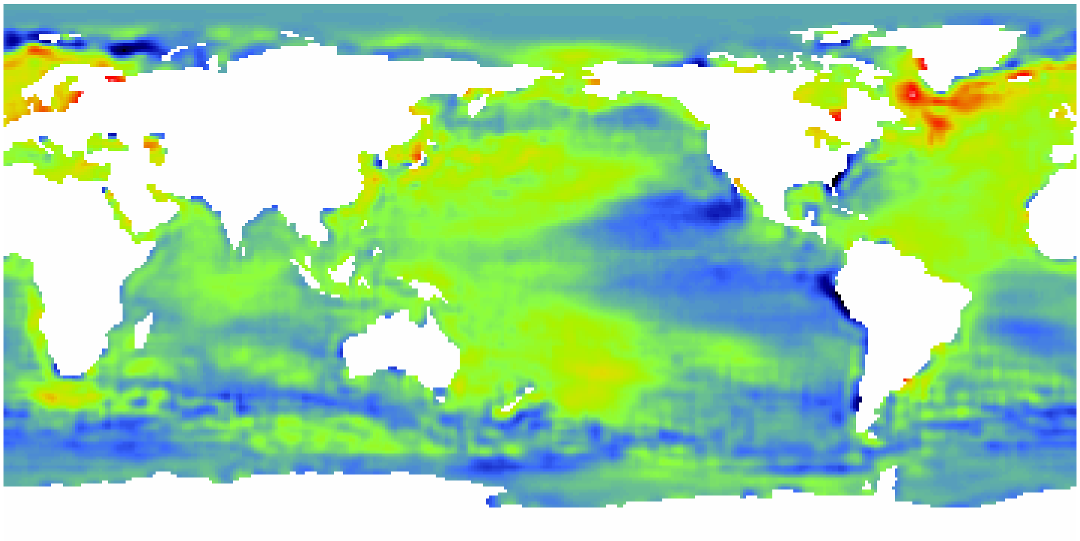


Figure A3. (left) Monthly average temperatures are computed over 1-degree latitude by 1-degree longitude squares of the ocean. Time series at left represents the monthly global averages.

Figure A4. (below) The spatial pattern of global warming and cooling in the past 25 years. Red represents greatest warming; black denotes greatest cooling. The colour sequence red to yellow, green, blue, then darker blue and black represents positive (warming) to negative (cooling) over the range 0.1 to -0.05 C per year.



The Figure A4 shows an image of all the best-fit linear temperature trends for every 1-degree square in the Reynolds data set over the 25 years, indicating where the ocean surface is warming faster (red), or cooling (black). Zero change is indicated by the blue of the most northern latitudes, where the SST data are set to show unchanging -1.8°C under sea ice. Except for a coastal strip 2-300 km wide, waters off BC show very little warming over the 25 years. Fastest warming is in the North Atlantic and west Pacific. Large areas of the eastern Pacific show no trend in temperature and some relatively small areas show cooling. The most rapid warming south of Greenland is at a rate of up to 0.1 C per year, roughly ten times the global average rate.

Pacific Decadal Oscillation and Aleutian Low Pressure Index

Jackie King, Fisheries & Oceans Canada

The Pacific Decadal Oscillation (PDO) is a term used to describe decadal-scale pattern of variability in the North Pacific Ocean (Figure A5). The classic PDO spatial pattern has generally been associated with only two states; a 'positive phase' that is associated with warming of surface waters in the eastern North Pacific and cooling in the central and western North Pacific; and a 'negative phase' with opposite thermal patterns. Data are available at: ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest

Recently, climatologists have recognized that the second mode of this analysis, referred to as the **Victoria Mode**, has dominated since 1990. (Figure A6, Bond et al., 2003; King, 2005), Both indices are used with other climate indices to detect regime shifts in the North Pacific.

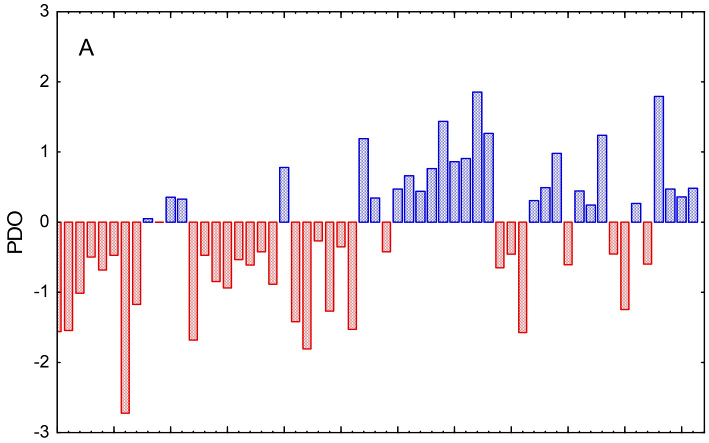


Figure A5 The first component from a principal component analysis of North Pacific winter (November-March) sea surface temperature fields north of 20° from 1950-2006, averaged into 5 degree grids, which represents the Pacific Decadal Oscillation (PDO) index. The change from many years of negative values to positive values in the late 1970s is the main indicator of the regime shift then. Positive anomalies lead to warmer waters in British Columbia.

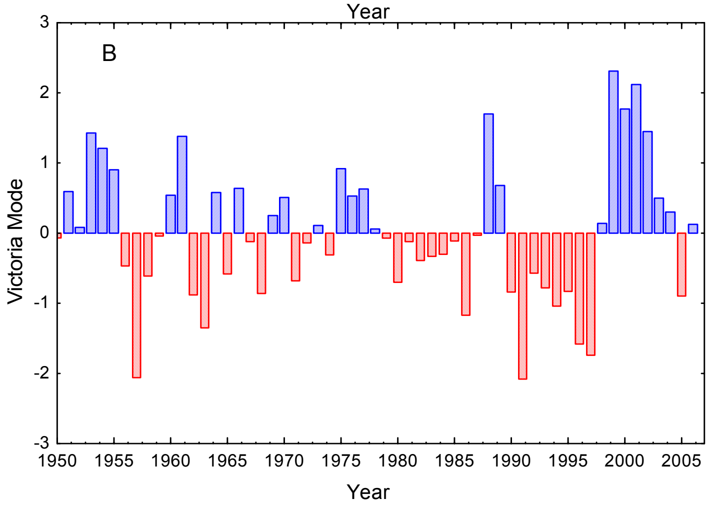


Figure A6 The second component (1950-2006) is an alternate pattern of sea surface temperature variability (the Victoria Mode) and shows a shift to large amplitude since the early 1990s. The Victoria Mode remained negative throughout the 1990s and shifted to a positive phase in 1998. It remained in a positive north-south phase through 2004, with generally decreasing absolute values since then. Positive anomalies lead to cooler waters in British Columbia. (Updated from Bond et al., 2003.)

References

Bond, N.A., J.E. Overland, M. Spillane and P. Stabeno. 2003. Recent shifts in the state of the North Pacific. Geo. Res. Lett. 30: 2183-2186.

King, J.R. (ed.). 2005. Report of the Study Group on Fisheries and Ecosystem Responses to Recent Regime Shifts. PICES Sci. Rep. No. 28. 163 pp.

Mantua, N.J., 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: 1069-1079.

The Aleutian Low atmospheric pressure system is a semi-permanent feature of the North Pacific winters whose relative intensity has been linked to patterns in marine productivity (McFarlane and Beamish, 1992; Beamish *et al.*, 1997). Typically, intense Aleutian Lows result in intense winter storms, which through horizontal and vertical ocean flows, improves mid-ocean and coastal productivity. Following the 1998 regime shift, the Aleutian Low exhibited a moderate intensity as measured by the Aleutian Low Pressure Index (ALPI, Figure A7).

The ALPI is calculated as a standardized value (from the 1950-1997 mean) of the mean December through March area (km^2) in the North Pacific that is encompassed by the Aleutian Low pressure system (less than 100.5 kPa). In 1998, the Aleutian Low was extremely intense and ALPI values remained positive through 2002. In 2002, the ALPI value was extremely high, indicating a strong Aleutian Low. While the ALPI values in 2003 and 2004 are not as high as in 2002, they still reflect strong Aleutian Lows (Figure A7). The Aleutian Low Pressure Index value in 2005 was near neutral indicating a moderate pressure system (Figure A7). This continued in 2006, with another near neutral value. The shift of the Aleutian Low to stronger winter values since 1950 is one of the major climate shifts associated with global climate change (Raible et al. 2005).

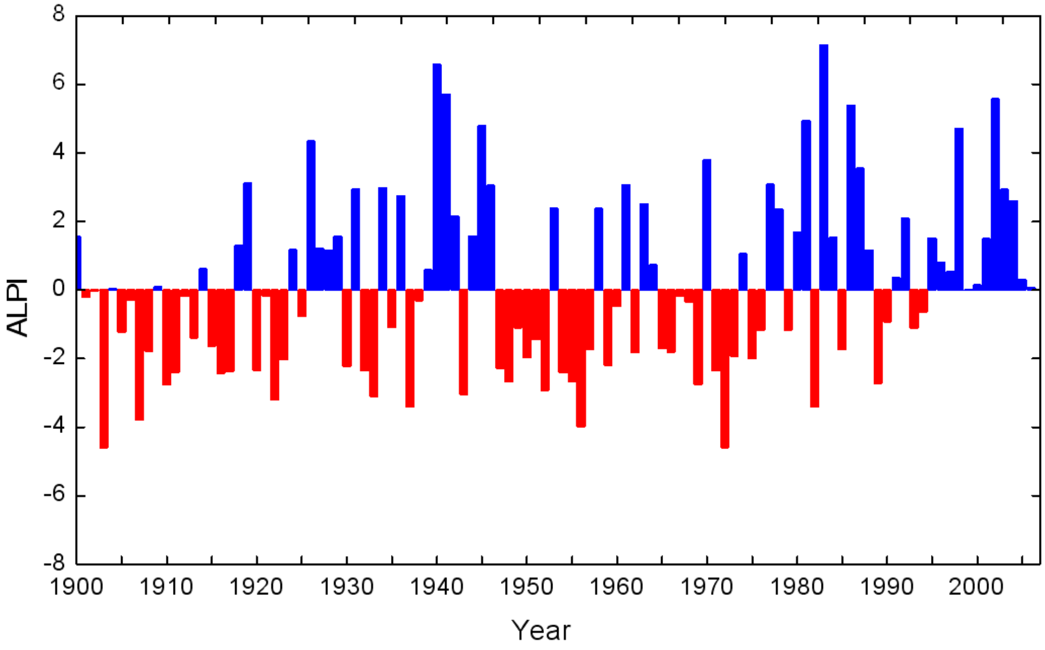


Figure A7. The Aleutian Low Pressure Index (ALPI) from 1900 to 2006. Since the 1998 regime shift, the Aleutian Low Pressure system has been relatively strong as indicated by the continuance of mainly large positive values; however, as with 2005, the value in 2006 was near neutral. Data available from http://www.pac.dfompo.gc.ca/sci/sa-mfpd/climate/clm_indx_alpi.htm.

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

Raible, C.C., T.F. Stocker, M. Yoshimori, M. Renold and U. Beyerle. 2005. Northern Hemisphere trends of pressure indices and atmospheric circulation patterns in observations, reconstructions and coupled GCM simulations. J. Climate 18: 3968-3982.

Sea Surface Height over the Northeast Pacific in 2006

Patrick Cummins, Fisheries & Oceans Canada

Anomalies of sea surface height (SSH) over the northeast Pacific were examined to detect changes in upper ocean conditions over the region in 2006. On interannual and longer time scales, SSH variability is related to changes in internal ocean conditions. As an integrator of upper ocean conditions, SSH has greater 'inertia' and fluctuates less rapidly than sea surface temperature. SSH anomalies were constructed by removing monthly means computed from 14 years of satellite altimeter data (1993-2006), gridded at a resolution of 1 degree.

In 2006 SSH anomalies over the northeast Pacific were dominated by the development of a large-scale pattern of negative anomalies that is usually associated with cooler near-surface waters. This pattern, which is coupled to the cold phase of the Pacific Decadal Oscillation (PDO), persisted through the fourth quarter of 2006 and likely into 2007. Consistent with this interpretation, the PDO index and an index based on the first principal component of SSH over the NE Pacific (Cummins et al., 2005) show a transition to negative values in 2006 (Figure A8), similar to, but not as strong as the one that occurred in 1999.

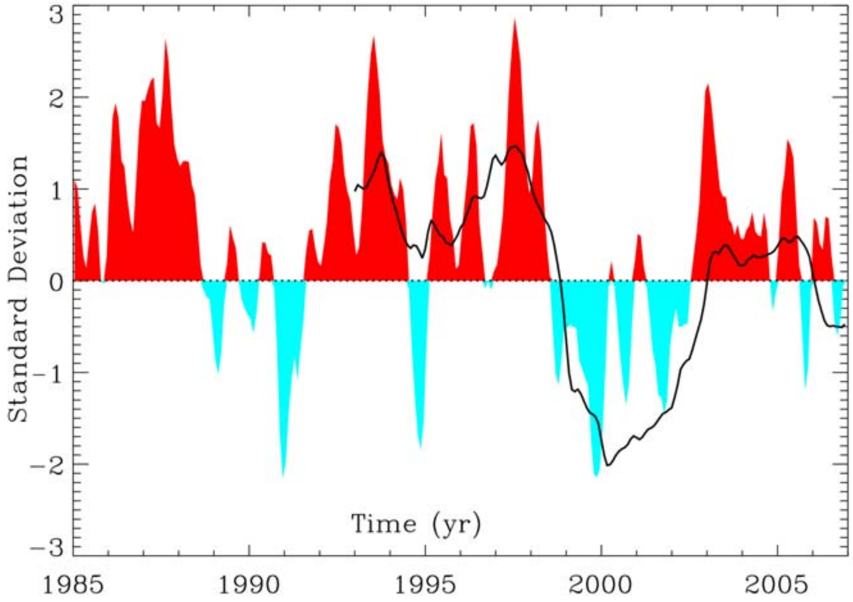


Figure A8. The solid red/blue curve gives the recent history of the PDO index (obtained from http://jisao.washington.edu/pdo/PDO.latest). The solid black line is an index of upper ocean variability over the NE Pacific based on the first principal component of SSH over the region

The regions influenced by this shift in PDO are presented in Figure A9 on the next page. Three-month-long averages of the anomalies were constructed to produce a field for each quarter of 2006. For comparison, an average for the last quarter of 2005 is also included. The figure shows generally positive anomalies over much of the NE Pacific in late 2005 and early 2006. Positive SSH anomalies are associated with positive anomalies in integrated upper ocean heat content, and depressed internal density surfaces. There are negative anomalies of limited extent immediately adjacent to the coast, north of 45°N. Between the 1st and 2nd quarter of 2006, a remarkable change occurred with the development of large-scale negative anomalies in a broad horseshoe-shaped pattern around the perimeter of the Gulf of Alaska, and extending into the central Pacific out to 205°E (155°W). This pattern is similar to the extended, 4-year long, La Niña pattern of anomalies that occurred in 1999-2002.

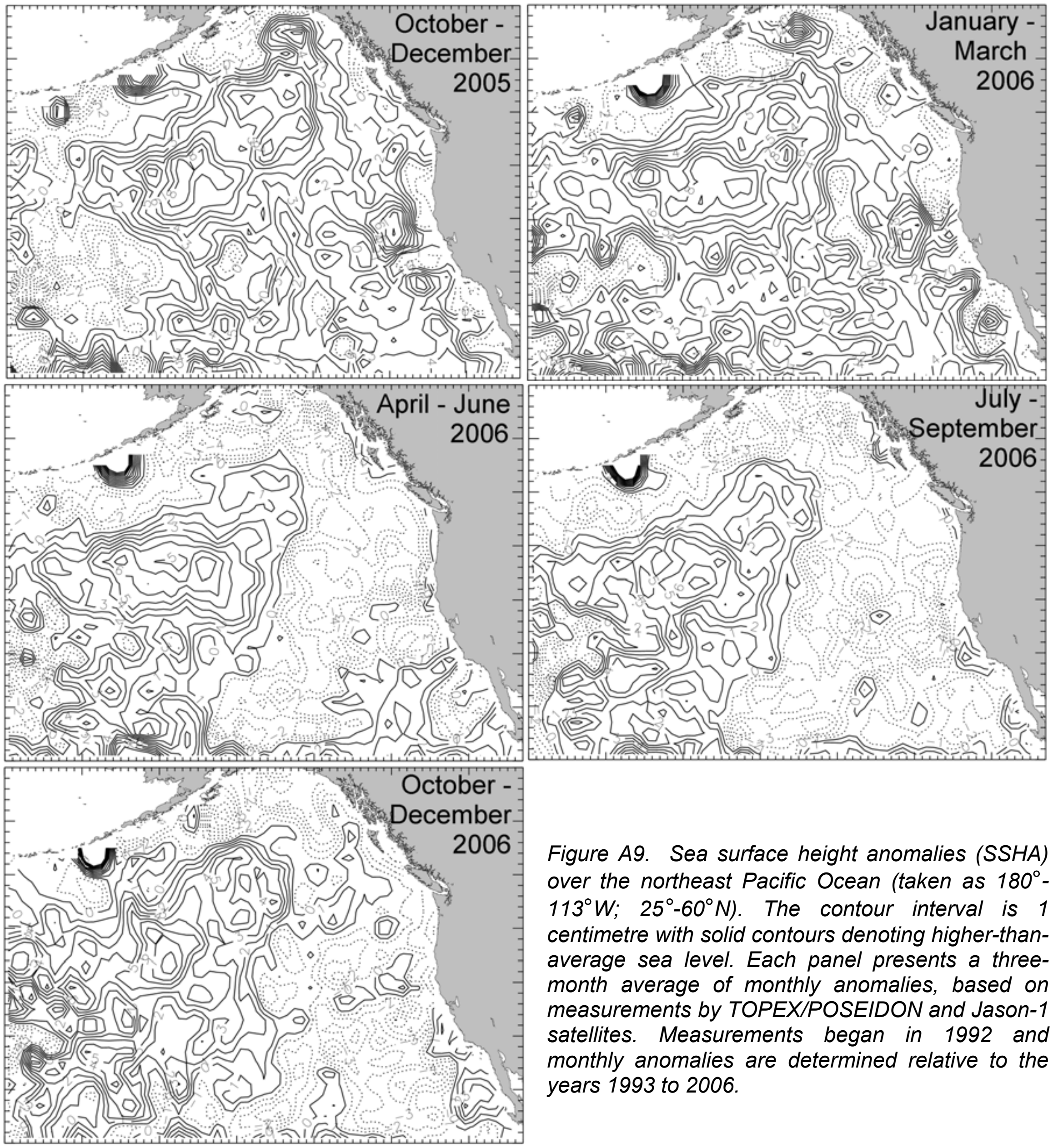


Figure A9. Sea surface height anomalies (SSHA) over the northeast Pacific Ocean (taken as 180°-113°W; 25°-60°N). The contour interval is 1 centimetre with solid contours denoting higher-than-average sea level. Each panel presents a three-month average of monthly anomalies, based on measurements by TOPEX/POSEIDON and Jason-1 satellites. Measurements began in 1992 and monthly anomalies are determined relative to the years 1993 to 2006.

Reference

Cummins, P.F., G.S.E. Lagerloef and G. Mitchum, (2005): A regional index of northeast Pacific variability based on satellite altimeter data. Geophysical Research Letters 32: L17607 doi:10.1029/2005GL023642

Cooling Ocean from Summer 2005 to Winter 2007

Bill Crawford, Fisheries & Oceans Canada

From summer 2005 to winter 2007, surface water temperatures declined relative to historical conditions; this is shown in Figure A10. Most of the decline in deep-sea waters took place between summer 2005 and winter 2006. Anomalies of global surface temperatures in early 2007 show cool waters in the Gulf of Alaska surrounded by a generally warmer ocean (Figure A11).

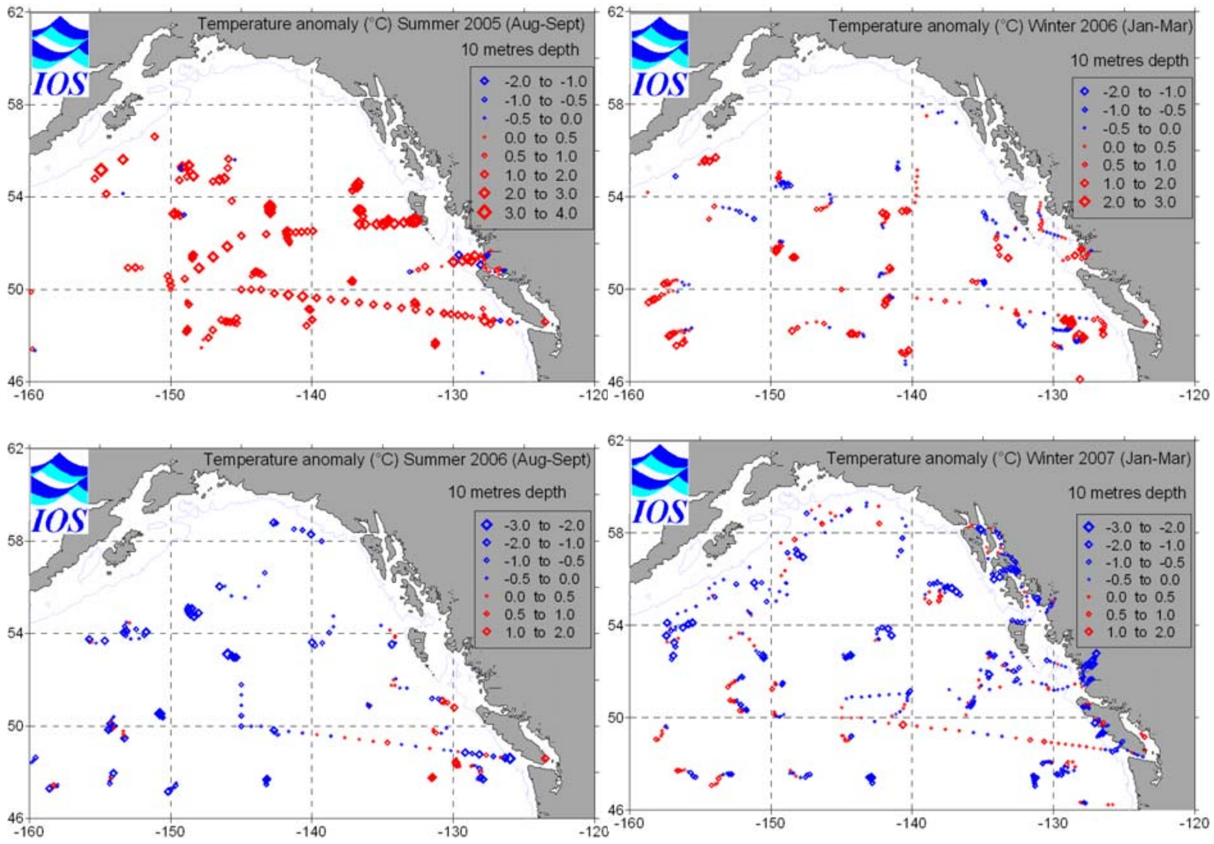


Figure A10. Temperature anomalies (relative to average conditions in historical data from 1931 to 2005) as measured by surveys in the Gulf of Alaska and coastal waters of British Columbia. Each symbol represents a measurement at 10 metres depth by ship-based sampling, or by an Argo autonomous profiler.

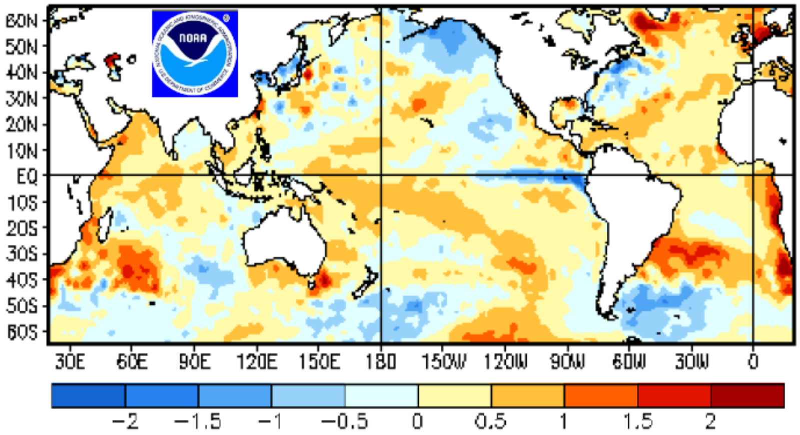


Figure A11. Anomaly of ocean temperature between 11 March 2007 and 4 April 2007. Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf

Waters of the NE Pacific – Normal in 2006 and an Anæmic Response to the 2006/07 El Niño Event

Howard Freeland, Fisheries & Oceans Canada

Figure A12 shows the spatial density of Argo floats in the NE Pacific. If the number of floats per unit area was at the target value then the density would be 1.0 and the area coloured red. What this shows is that a large area of the NE Pacific Ocean and Gulf of Alaska has achieved the target density of floats. Every 10 days these report the climate status of the ocean at each of the yellow dots.

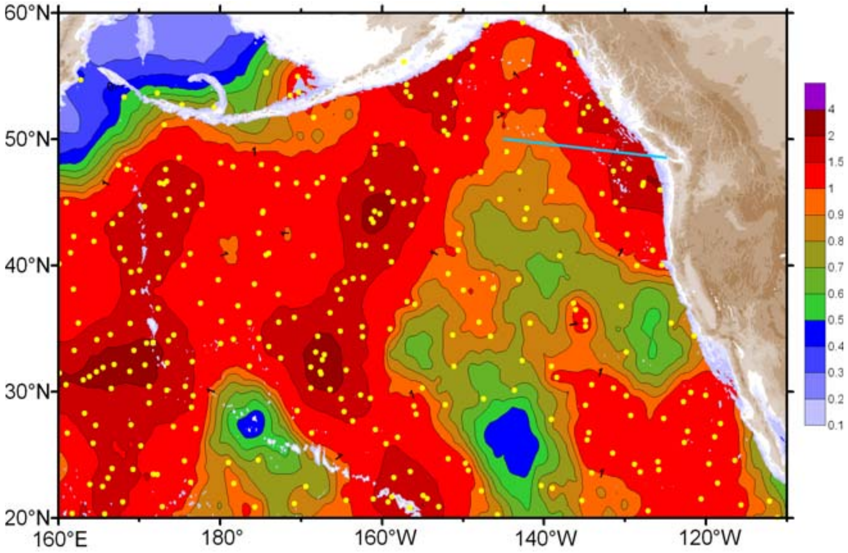


Fig A12. The number of Argo floats per unit area divided by the number there would be with an even nearest-neighbour distance of 300 km. Argo floats are autonomous ocean instruments that measure ocean temperature and salinity every ten days from 2000 m depth to ocean surface, and transmit these observations via satellite to public data servers. Line P extends from the West Coast of Canada out to 145°W in the Pacific Ocean along the blue line in this figure.

Argo observations can be obtained from these two Internet sites:
http://www.usgodae.org/cgi-bin/argo_select.pl
http://www.coriolis.eu.org/cdc/DataSelection/cdcDataSelections.asp

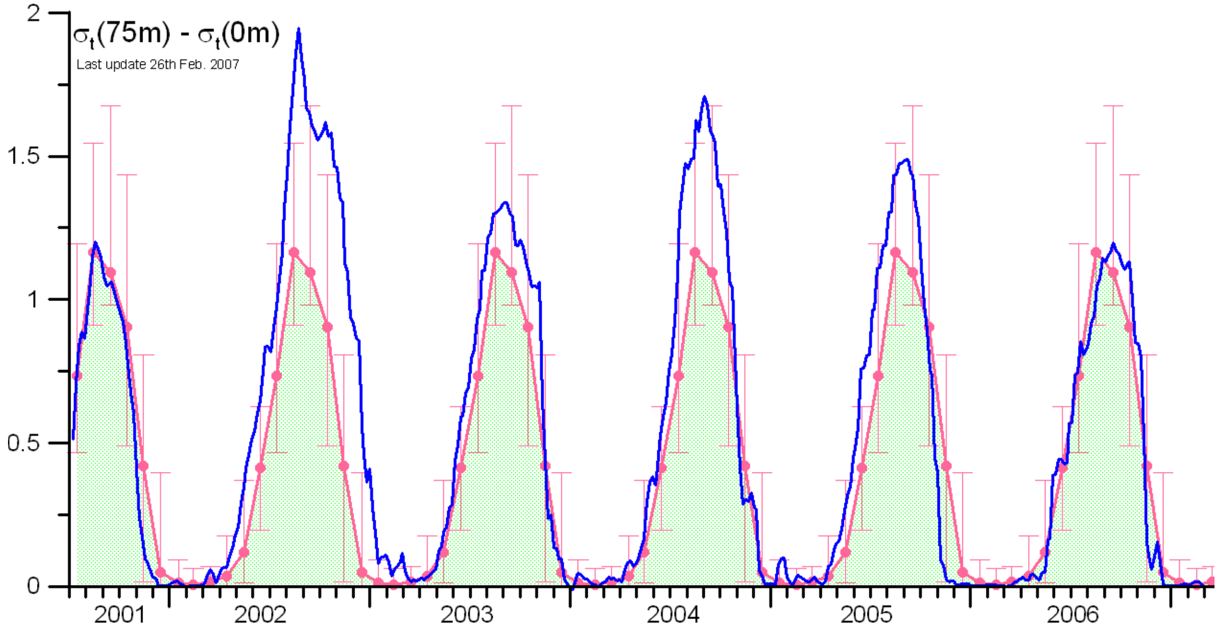


Fig A13. A simple measure of the strength of the stratification of the upper ocean at Ocean Station Papa, 2001 to present. The red line plots typical monthly values from historical data. The blue line reveals stratification for individual months

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; suffice it to say that there were no large anomalies during 2006. This is slightly surprising as there was a 2006/07 El Niño. However, on the equator this was a minor event and other observations suggest a thoroughly anæmic response in the Gulf of Alaska to this El Niño.

Of considerable interest was the strength of the vertical stratification. This is shown in Figure A13. In this diagram the “stratification” is simply estimated as the difference in sigma-t (a parameter measuring water density) between the surface of the ocean and at a depth of 75 metres. In the winter this always goes to zero as the ocean is mixed to depths greater than 75 metres. The red line and error bars show the climatologically averaged variation and the blue line the stratification observed from Argo floats. This shows that following a long period of anomalously strong stratification, conditions have finally returned to normal during 2006. Environment Canada reported a high number of weather warnings in southwest British Columbia in November 2006, and on Figure A13 one can clearly see the rapid destruction of upper-ocean stratification during that month. J. Gower has computed the rate of working by winds at the offshore weather buoys. These show records in November and December 2006 consistent with the picture we are seeing in the ocean itself. This is presenting us with evidence of a winter with greatly enhanced vertical mixing.

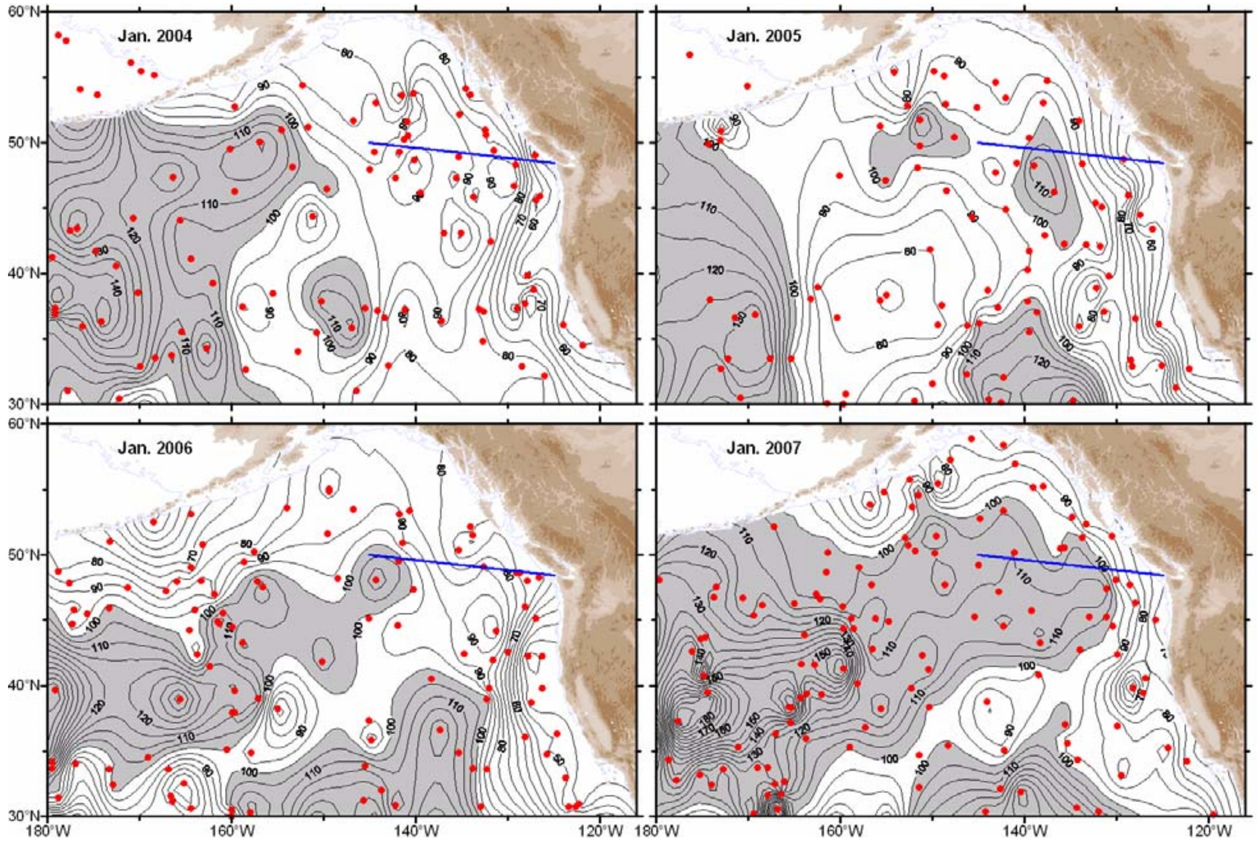


Figure A14. Mixed-layer depth in the NE Pacific in January 2004/5/6 and 7. Depth contours are plotted in metres. Blue line is location of Line P.

The effect of these storms is clearly visible in Figure A14 that shows the distribution of mixed-layer depths for the last 4 Januaries. The shaded regions show areas where mixed-layer depth exceeds 100 metres. It is clear that the region of deep mixed layers is much greater in January

2007 than in any of the previous three winters. It is interesting that the axis of the line of deepest mixed layers in 2007 runs north-eastward from the dateline at about 37°N towards Vancouver Island near 48°N at longitude 130°W. This also corresponds quite well to the storm tracks seen through November and December 2006.

A third view of the unusualness of the winter mixing is shown in Figure A15 showing the time history of ocean density versus depth at Ocean Station Papa (50°N, 145°W). The yellow patches at 12 month intervals are very low-density water occurring each summer. Each winter we see deep mixing occurring, but different extents each winter. Mixing was sufficient to raise the deep density surface 25.8 (the red contour) to the surface during the winter of 2001/02 but there was insufficient mixing in the following 4 winters. Finally, late in the winter of 2006/07, this density contour has been brought to the surface again following an intense mid-March storm. Another severe storm could bring the surface 25.9 (green contour) to the surface, but we must note that the deeper surface 26.0 was last observed at the ocean surface at Station Papa in the winter of 1971/72, a very rare event.

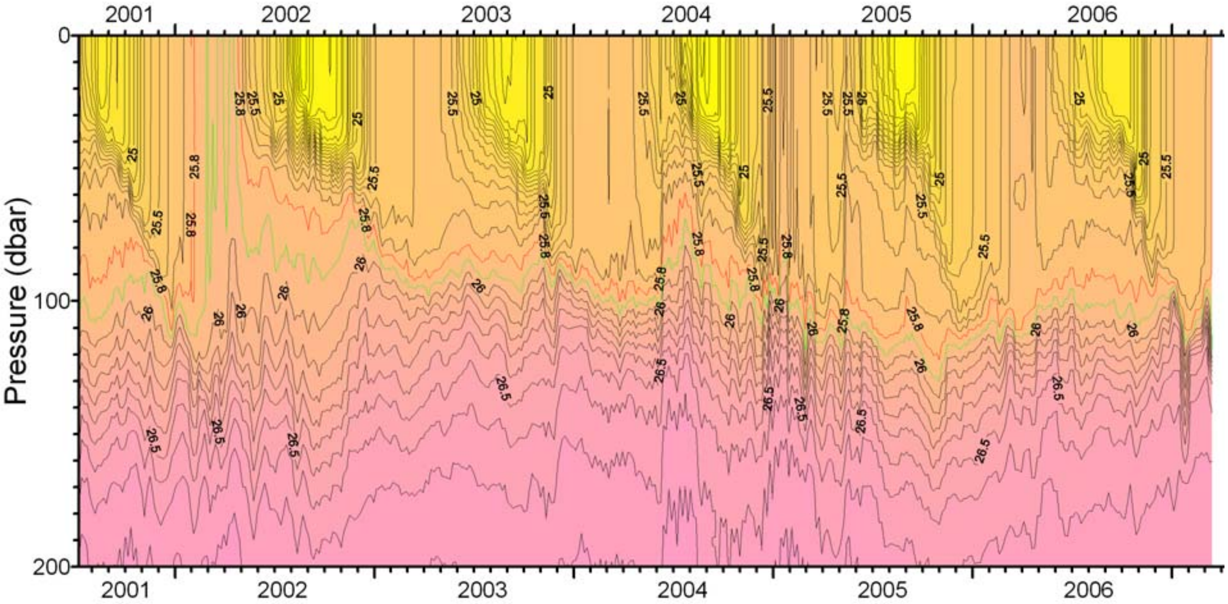


Figure A15. A plot of sigma-t versus depth and time interpolated from Argo observations to Ocean Station Papa.

This storm activity and resultant mixing should result in a good supply of macro and micro nutrients at the end of the winter 2006/07.

Argo can also be used to monitor the changing circulation of the NE Pacific and we have seen some substantial changes to the circulation during 2006, from the very narrow and intense North Pacific Current in January 2006 to the broad and slow flow seen during January 2007 (See Figure A16). Observations of the strength of the various current systems show a systematic increase in the flow of water into the North Pacific Current through 2006, with the largest value seen since the start of project Argo appearing in January 2007. Most of this water appears to have been systematically routed in the Alaska Gyre with the flow in that feature also showing a steady increase through the year. The amount of water flowing south into the California Current remained close to average through the year.

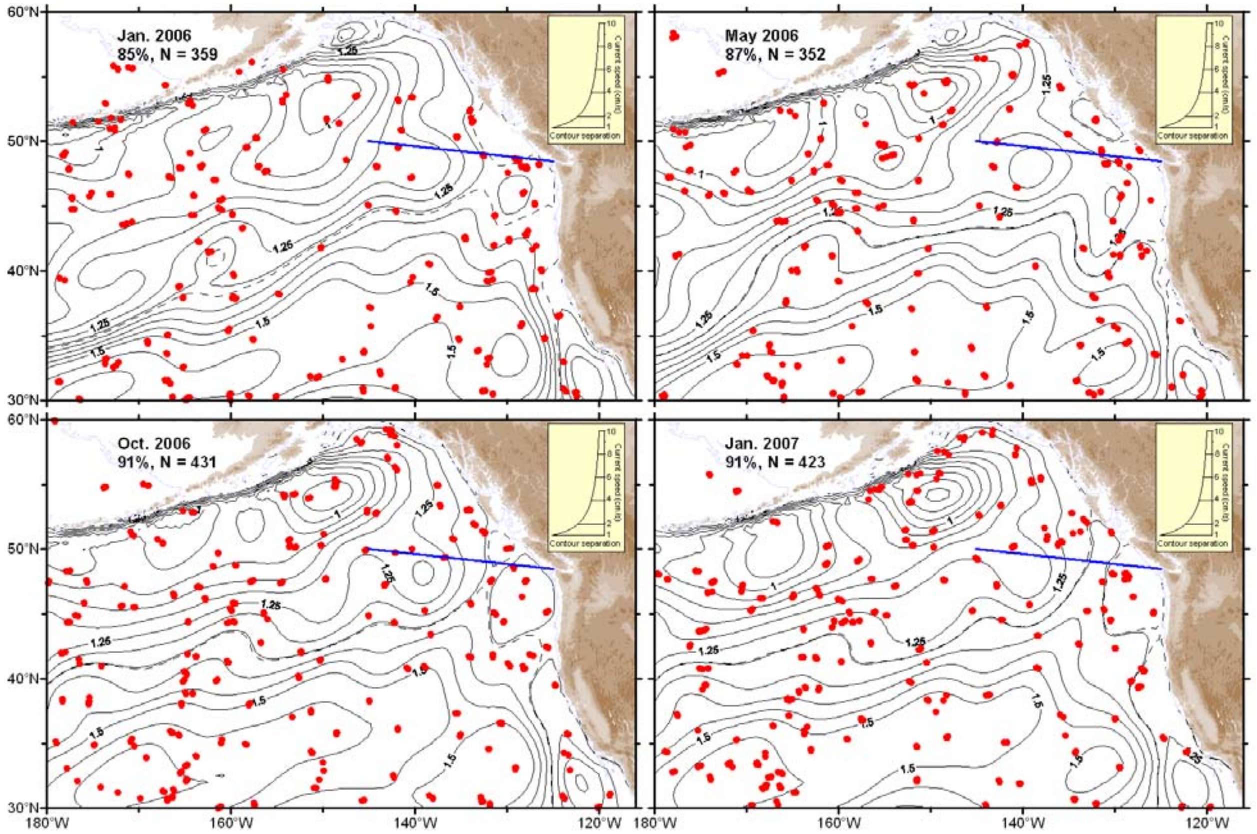


Figure A16. The time-varying circulation of the NE Pacific, January 2006 through January 2007. The black lines are paths of flow; as contours bunch together flow-speed increases. Flow direction is to the northwest along the dashed line. The observations are at the red dots; the blue line shows Line-P, for reference; the dashed line is the dividing streamline.

Ocean Observations from Line P and *Skaugran* Surveys

Frank Whitney and Marie Robert, Fisheries & Oceans Canada

Fisheries & Oceans Canada samples waters of the NE Pacific on Line P cruises (3 per year to full ocean depth) and the *Skaugran* ship of opportunity (10-12 per year, surface only). Both programs (Fig. A17) have been operating long enough for us to compare individual years against more than a decade of sampling. Using these series, anomalies in nutrient drawdown are assessed in the high nutrient-low chlorophyll portions (open ocean region) of both surveys. Due to summer upwelling in coastal waters, this assessment cannot be done near shore.

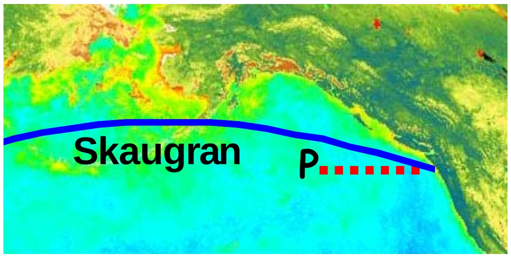


Fig A17. Cruise tracks of the Skaugran and Line P programs. Line P ends at Ocean Station P (P).

Nitrate removal from surface waters was less than average (7-8 μM) in 2006 in both data sets, as plotted in Figure A18, suggesting there may have been lower primary productivity by as much as 30%. However, because these data are only from the sea surface, it is not possible to know what changes there might have been in the thickness of the surface ocean layer. With a relatively deep mixed layer, less nitrate drawdown per volume of seawater would not reflect reduced phytoplankton growth.

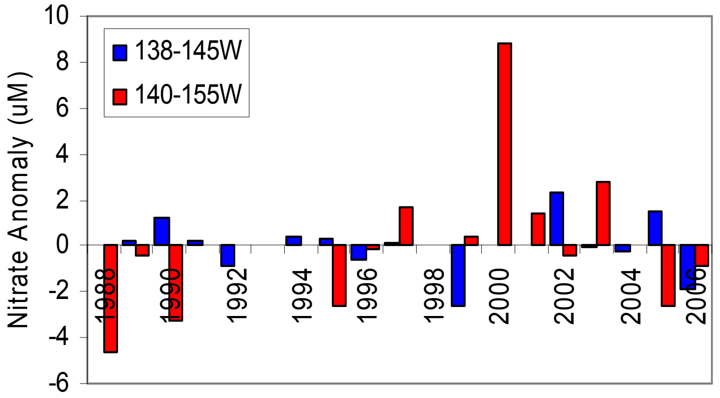


Fig. A18. Surface nitrate drawdown (winter to late summer) anomaly from 1988 to 2006 (red bars for Skaugran, blue for Line P).

Long term climate trends are evident in the 50 years of data from Ocean Station P (OSP). The annual warming and cooling cycle masks temperature trends near surface, although waters between 150 and 300 m are warming at ~0.01° C y^{-1}. However, surface waters are persistently freshening (Fig. A19), resulting in a more stratified upper ocean. This trend is consistent with observations from the Alaska coast and Bering Sea, suggesting it is occurring broadly throughout the subarctic northeast Pacific. A more stratified ocean will lead to reduced nutrient supply to the photic zone and to reduced ventilation of interior waters.

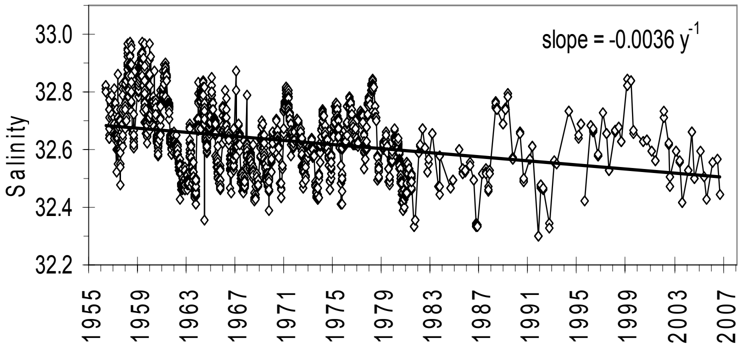


Fig. A19. Surface salinity at Ocean Station P (50°N, 145°W) from 1956 to present. A linear regression through the data shows a freshening of these waters by 0.0036 y^{-1}.

At OSP, oxygen is declining between ~125-400 metres depth at rates of 0.5-1.0 μM y^{-1}. Over the past 50 years, oxygen levels have decreased by 22%. At station P4 on the continental slope of southern BC (water depth 1300 m), oxygen is declining more rapidly than at OSP (Fig. A20 comparisons are for the 26.7 isopycnal surface found at ~170 metres depth at OSP and 285 metres depth at P4). This is the result of the strong influence of the northward flowing California Undercurrent whose waters are losing oxygen at a rate similar to P4 (S. Bograd, pers. comm.).

Warming of the interior ocean is common in all subarctic data sets, and is occurring at a rate similar to that of the global atmosphere.

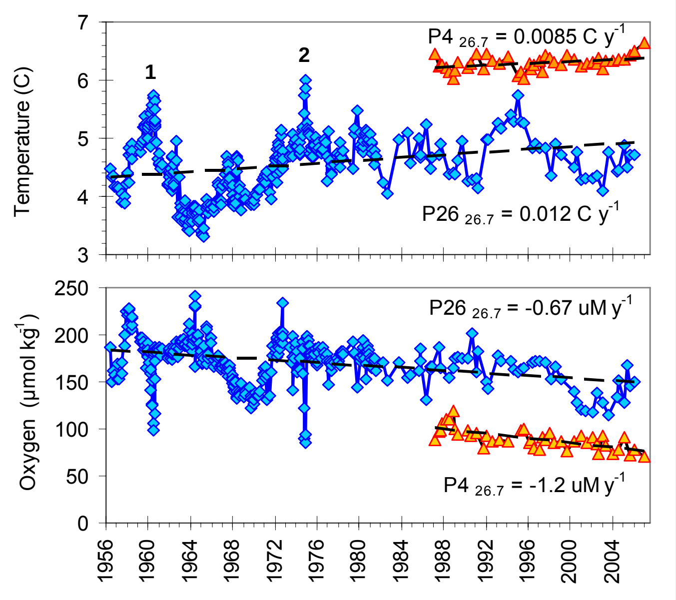


Figure A20. Oxygen and temperature on the 26.7 isopycnal at stations P4 and OSP. Two mesoscale eddies (1 & 2) are identified in the upper panel.

Along Line P in February 2007, (Fig. A21) temperature was near normal except for a warm column of water that may be associated with a mesoscale eddy about 200 km offshore. More saline waters underlie the mixed layer in stations furthest from the coast, whereas fresher waters are found at ~125 m throughout the central portion of Line P (in waters that are "Transitional" between open ocean and coastal domains). In surface waters, nitrate supply is above average, typical of a cool year with deeper mixing. Depending on spring stratification, this could result in a more productive growing season in 2007. However, if the spring remains windy and cloudy (as happened the La Niña year 1999), limited solar radiation could restrict phytoplankton growth.

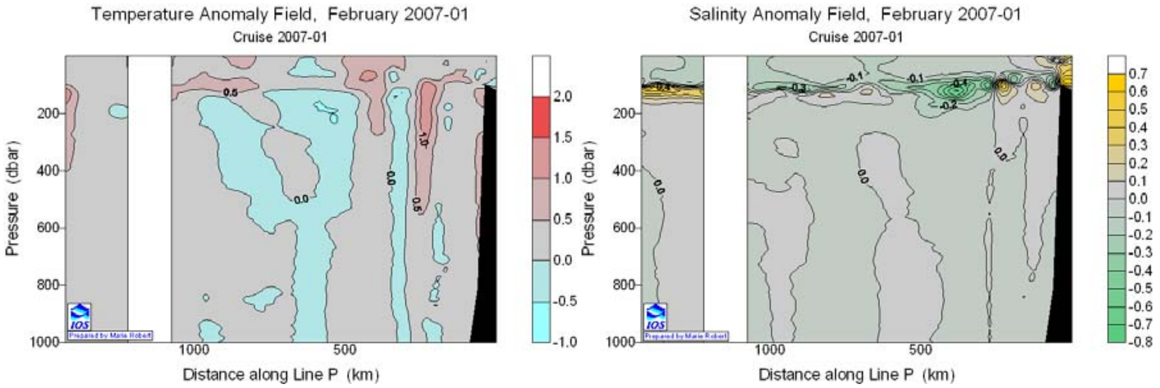


Figure A21. Temperature and salinity anomalies, computed against monthly averages for the period 1956-1991, are shown for Line P in February 2007. Line P starts at the southern end of Vancouver Island and heads almost westward to Ocean Station P (Fig. A17).

Our data sets do not distinguish 2006 as a peculiar year. What is most evident in our time series measurements are the persistent symptoms of global warming (increased ocean stratification, reduced nutrient supply to the upper ocean, decreased ventilation of the ocean interior). These trends will likely continue, causing ecosystem changes over time due to loss of habitat by organisms that cannot tolerate warm or low-oxygen waters.

Mesozooplankton in the Gulf of Alaska in 2006: Biomass is High, and Still Early

Sonia Batten, Sir Alister Hardy Foundation for Ocean Science (SAHFOS)

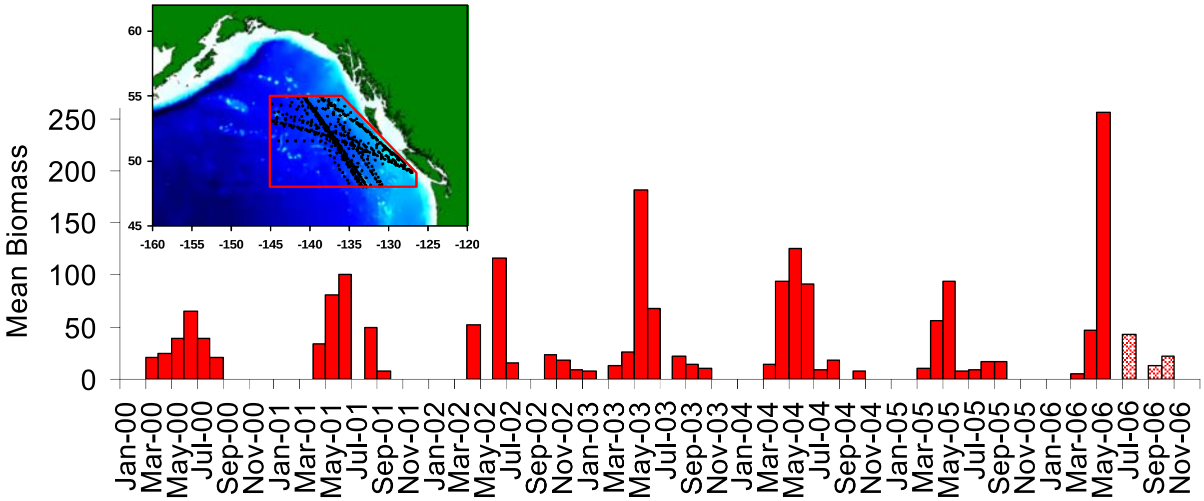


Figure A22. Time series of mesozooplankton biomass as mean monthly biomass in mg dry weight per sample (~$3m^3$) from Continuous Plankton Recorder sampling (which occurs approximately monthly6 times p.a. between March and October) in the Gulf of Alaska area shown by the box. Lightly shaded bars to the right show where sample analysis has not been completed yet and so data are preliminary.

The spring peak in mesozooplankton biomass has been early in recent years, coincident with warmer sea surface temperatures. The value for May 2006 in Figure A22 is also early and looks to be high, and higher than any other May value in the time series. At this time of the year the contribution of the copepod *Neocalanus plumchrus/flemingeri* to overall biomass is very large. 2006 saw a larger mean number per sample in May than previous years (Fig A23) and we also know from stage composition analyses that development was early, similar to 2004/2005. The narrower, more focussed peak in recent warmer years is evident, whereas 2000/01 had a broader seasonal cycle.

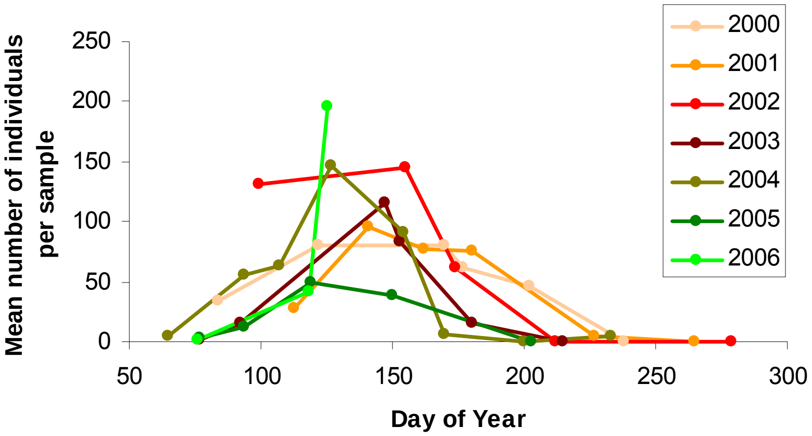


Figure A23. Annual cycle of Neocalanus plumchrus/flemingeri abundance. Data beyond May 2006 are not yet available.

www.sahfos.org for background information,
http://192.171.163.165/pacific_project.htm for further data

The Storms of November 2006

Ian Okabe, Meteorological Service of Canada

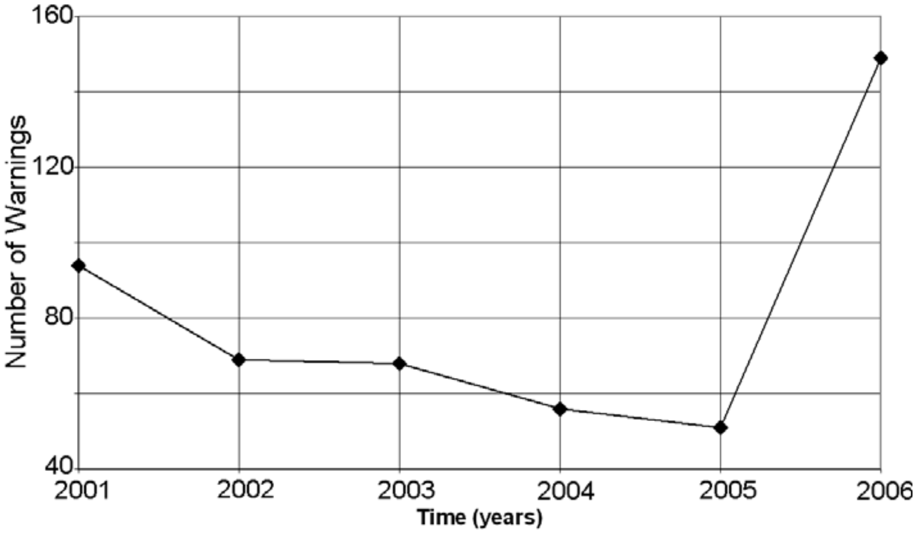


Figure A24. Weather warnings in November, 2001 to 2006.

There were 149 weather warnings (rain, snow, and wind) issued for Coastal British Columbia in November of 2006. This was considerably higher than in previous years (Figure A24).

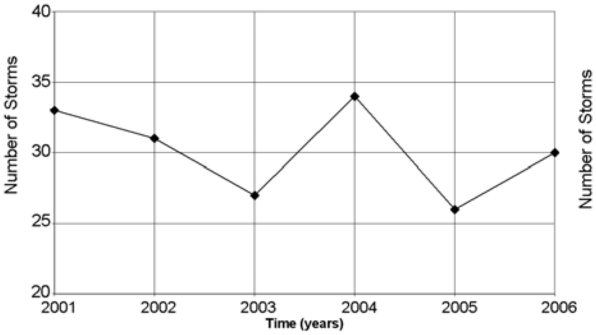


Figure A25. Western Pacific tropical storms

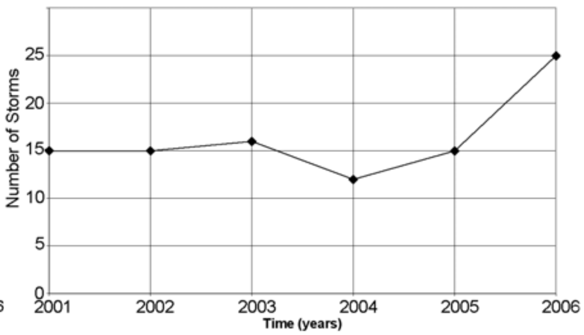


Figure A26. Eastern Pacific tropical storms.

An examination of the gridded zonal wind at 250 mb showed that 2006 had stronger westerlies, but not considerably stronger, and zonal winds were much stronger in the early 1990's (figure not shown).

Many of the strong storms we have in British Columbia are linked to tropical moisture from the remnants of western Pacific tropical storms. However, tropical activity in the western Pacific was not high in 2006 (Figure A25). On the other hand, tropical activity in the eastern Pacific was considerably stronger in 2006 than in previous years (Figure A26). Hence, the same atmospheric forcing that produced British Columbia November storms may also be responsible for increasing the tropical activity in the eastern Pacific. Conversely, the tropical moisture from eastern Pacific tropical storms may be 'feeding' into our storms and intensifying them. Both hypotheses are untested, and require further work.

Strongest Ocean Winds Recorded were in November 2006

Jim Gower, Fisheries & Oceans Canada

Other sections of this report note that November 2006 was an extremely windy month for coastal regions of BC, setting several records. The ocean buoy data (Locations are shown in Figure A27.) confirm that the average wind speed for the 13 exposed buoys for the month was above 10 m/s for the first time since records began, as noted in Figure A28. The figure omits data from the two buoys in Hecate Strait and one in Queen Charlotte Sound

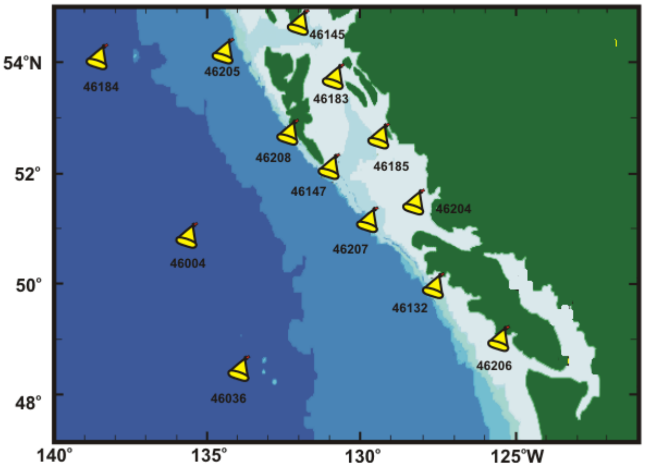


Figure A27. Locations of offshore weatherbuoys.

Monthly average wind speeds at these weather buoys set records at 3 locations, including one in Hecate Strait, and came within 1% of setting records at 3 other locations. Data for December were missing at two buoys in Hecate Strait and Queen Charlotte Sound that would have been expected to show high winds. Such gaps are usually associated with wind damage to anemometers. Had these data been available, the average might have been even higher.

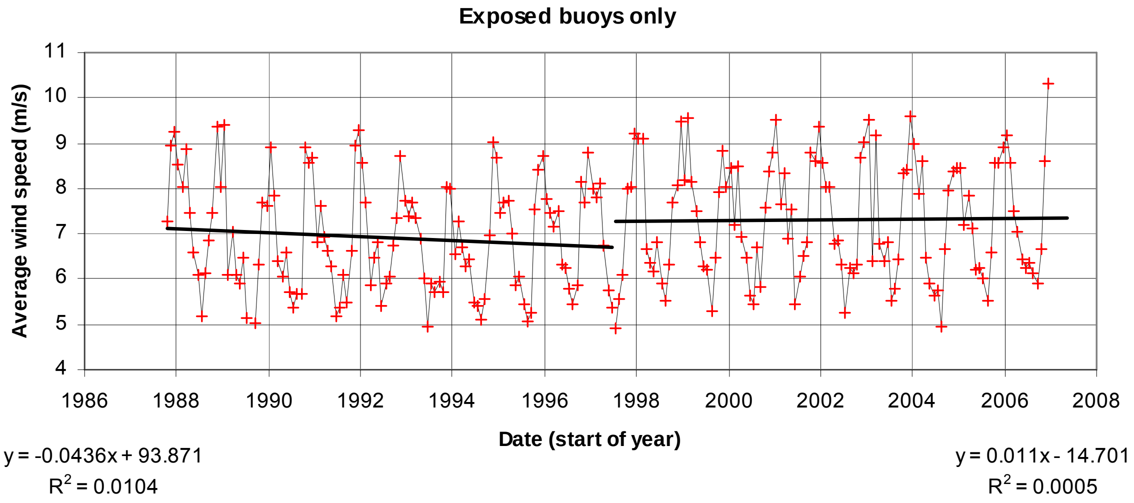


Figure A28. Monthly averaged wind speeds at offshore weather buoys west of British Columbia.

The best-fit lines in Fig. A28 show the effect of the switch from vector to scalar wind speed averaging in 1997. The switch was made by altering the averages computed on the buoys, so that consistent data, required for measuring long-term trends from 1988 to 2006, cannot be recovered. Despite record high wind speeds in November 2006, no trend is observed in wind speeds after 1998.

Long-Term Temperature and Salinity at BC Lighthouses

Peter Chandler, Fisheries & Oceans Canada

Temperature and salinity are measured daily at daylight high tide by light keepers at shore stations through BC waters as part of a program that began early in the 1900s. These time series form the longest continuous ocean temperature and salinity record on the Pacific Coast north of San Diego. The 13 shore stations presently in the network are shown in the figure below.

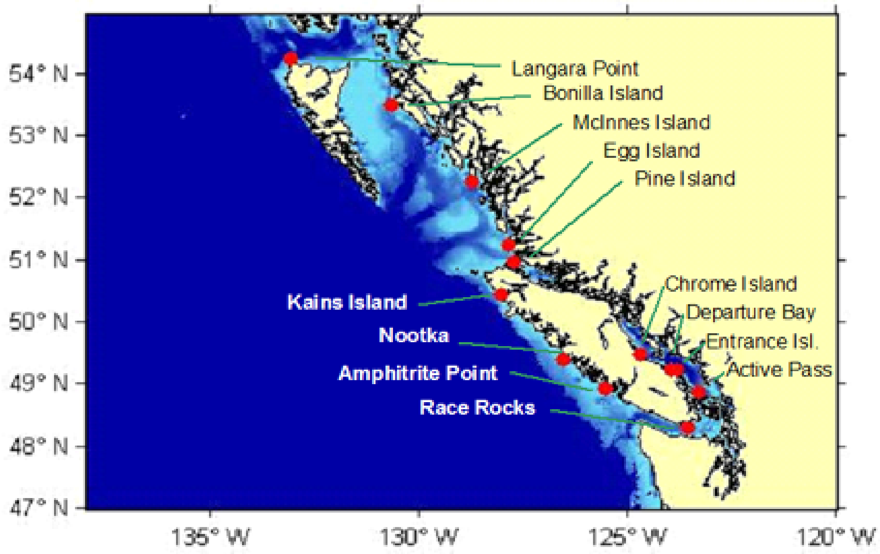


Figure A29. The 13 stations presently in the network

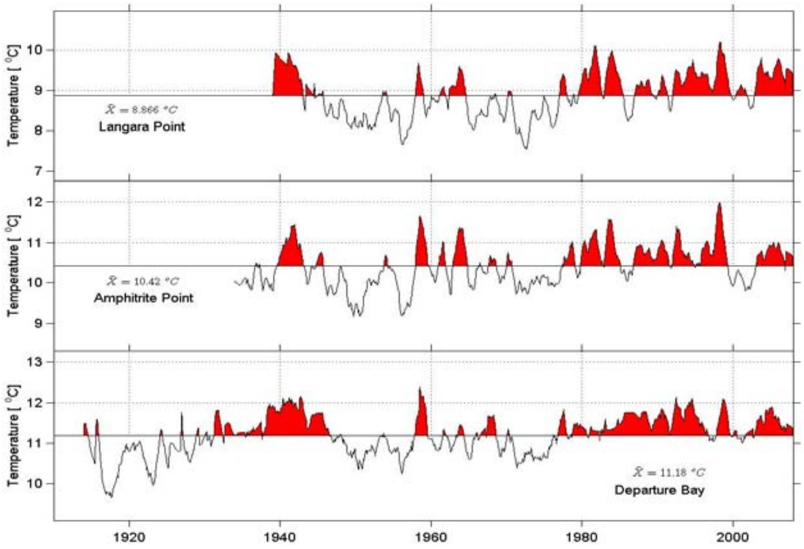


Figure A30. Long-term time series of annual-average temperature at representative stations in BC. Observations continue to show temperatures above the long term average, although conditions in 2006 were cooler than in previous years, and closer to the long term average.

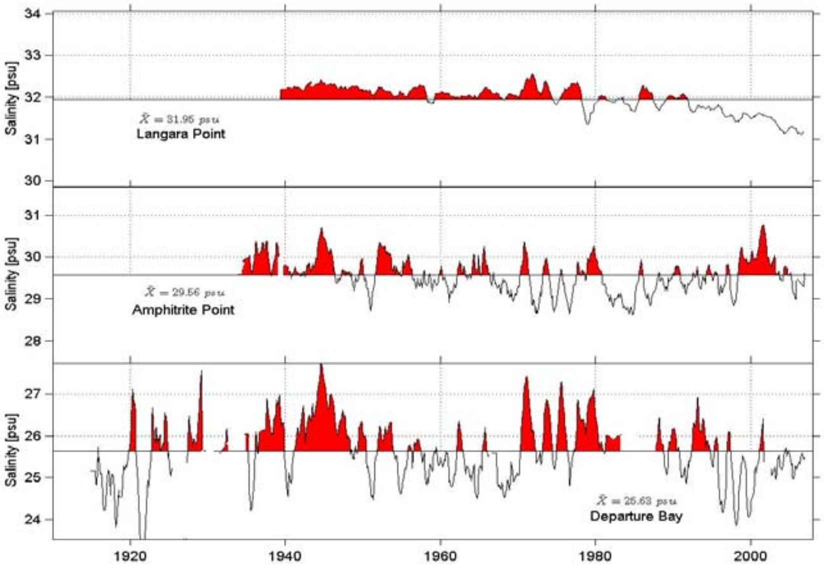


Figure A31. Long-term salinity time series at representative stations. Surface waters show a freshening trend, especially at Langara Point.

Strait of Georgia Shore Stations - 2006

As reported last year the waters in the Strait continue to show above average temperatures over all seasons; the salinity signal reveals the typical pattern of an increase in saltiness through the summer although two stations showed an episodic freshening in June, most likely due to the Fraser River freshet.

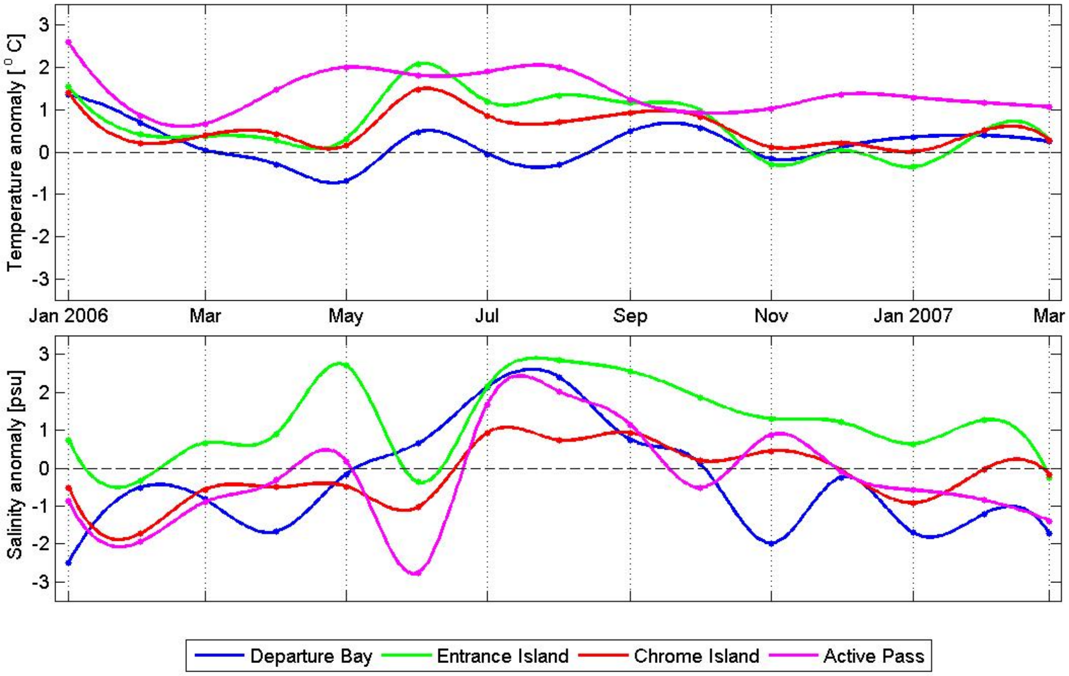


Figure A32. Time series of monthly average temperature and salinity in 2006 in Strait of Georgia

West Coast of Vancouver Island Stations - 2006

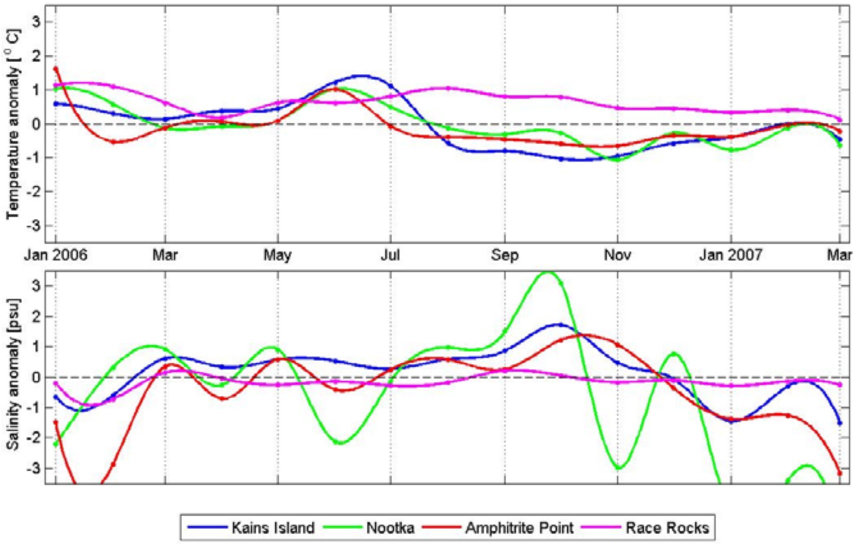


Figure A33. Time series of monthly average temperature and salinity along West Coast of Vancouver Island

Ocean temperatures along the west coast of Vancouver Island declined to below-average conditions in the latter half of 2006. The waters near Race Rocks, at the eastern end of the Juan de Fuca Strait, did not follow this pattern, and remained above average all year. All stations showed temperatures near the long term average from March to May. The salinity signal, with the exception of the typically variable salinity in the Nootka region, was close to the long-term average.

Northern British Columbia Shore Stations - 2006

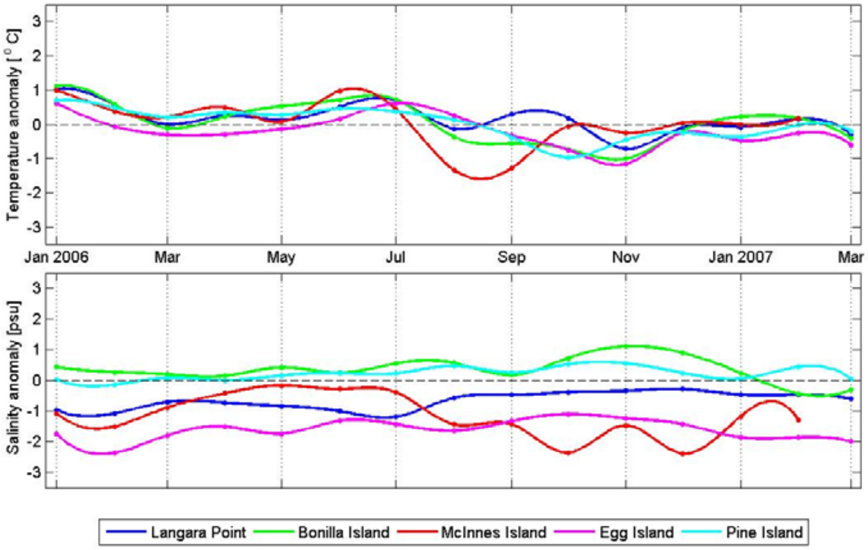
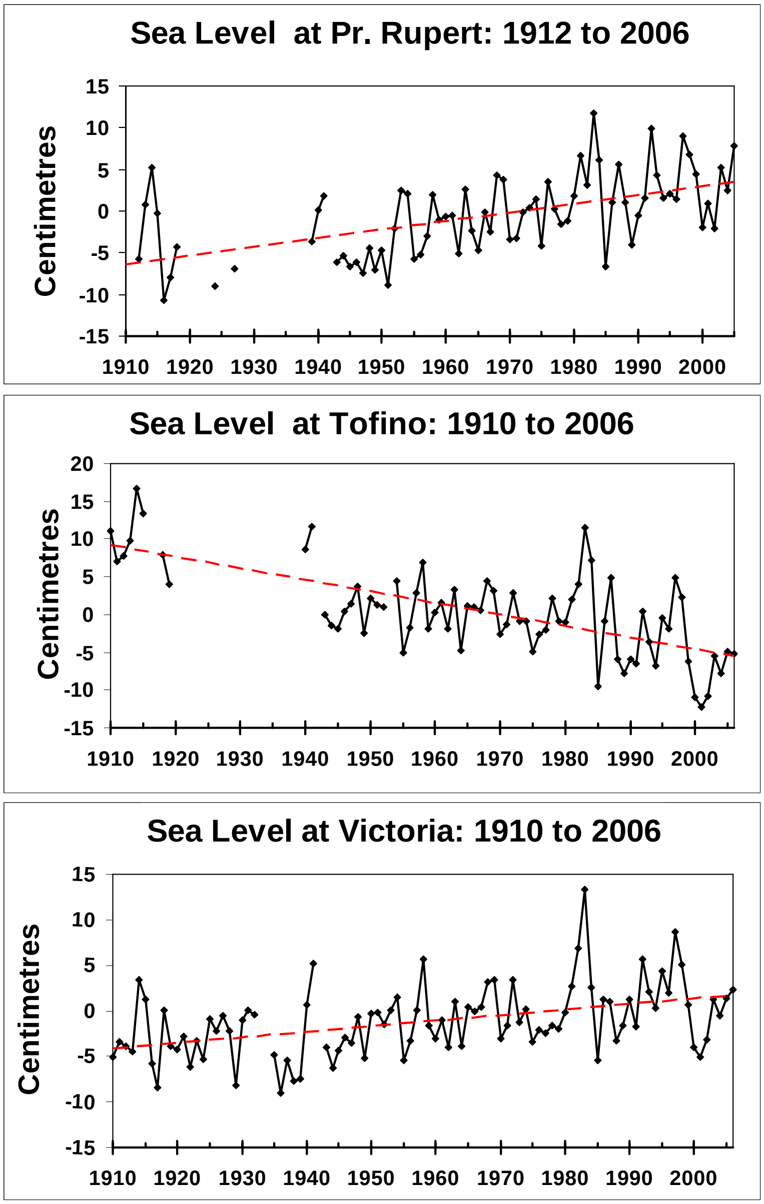


Figure A34. Time series of monthly average temperature and salinity in northern BC.

Near normal water temperatures were observed during the early part of the year, and after a slight midsummer increase all stations showed declining temperatures in the latter part of 2006. The salinity signal from each station remained relatively constant, with the exception of McInnes Island which experienced saltier water in May, June and July than at other times in the year. Three of the stations (Langara, McInnes, and Egg Island) showed a freshening of the surface water compared to the long term average.

Coastal Sea Levels: Long Term Rise Continues

Bill Crawford, Fisheries & Oceans Canada



The Canadian Hydrographic Service monitors levels along the coast. The records at left show deviations from long-term average levels at three BC ports. 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	-15

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 15 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 a metre or so, and send a major tsunami toward the BC coast.

Figure A35. Graphs of annually averaged sea levels at three British Columbia Ports. Long-term linear trends are plotted as red dashed lines.

Global sea levels rose about 10 to 20 cm over the 20th century (=0.1 to 0.2 cm/year). 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 (=0.2 to 0.6 cm/year) and to continue rising for many centuries.

Links: Canadian Hydrographic Service (http://www-sci.pac.dfo-mpo.gc.ca/charts/home_e.htm)
Contact: Bill Crawford (CrawfordB@pac.dfo-mpo.gc.ca)

West Coast Vancouver Island Physical Oceanographic Conditions

Richard Thomson and Roy Hourston, Fisheries & Oceans Canada

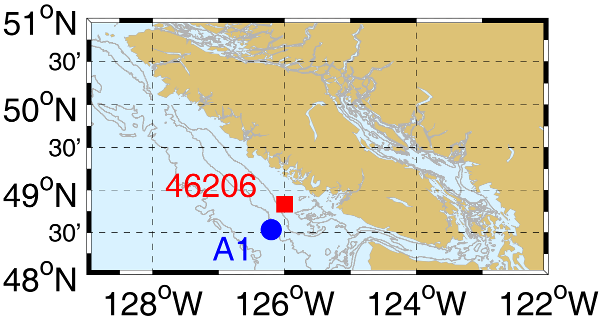


Figure A36. Locations of current meter mooring A1 and meteorological buoy 46206.

Ocean current velocity, along with water temperature and salinity, have been measured at mooring A1 continuously since 1985. A1 is located at 48° 32'N, 126° 12'W in 500 m of water on the continental slope seaward of La Pérouse Bank (Figure A36).

Sea surface temperature, wind velocity, and other meteorological properties have been measured at nearby buoy 46206 (48° 50'N, 126° 00'W) since 1988. These records enable us to characterize interannual variability of surface and subsurface meteorological and physical oceanographic conditions off the West Coast of Vancouver Island.

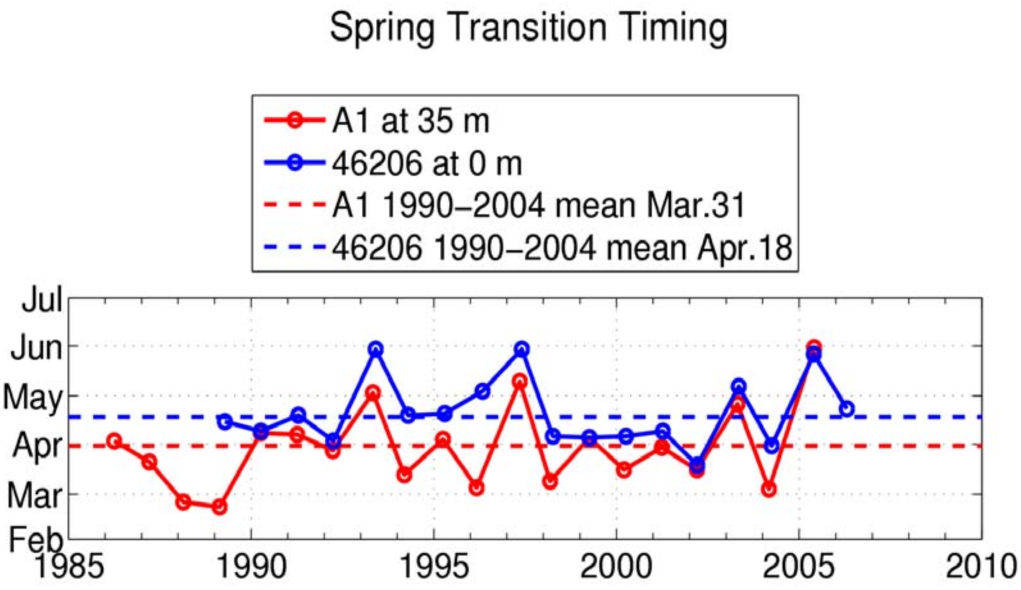


Figure A37. Spring transition timing of longshore current velocity at A1 at 35 m and longshore wind stress at 46206. Timing was derived from when the monthly mean time series crossed the zero line (poleward to equatorward) in the spring. In the case of multiple crosses in one year, the times were averaged to obtain one value per year.

Figure A37 shows the timing of the spring transition based on alongshore current velocities at A1 at 35 m depth and the alongshore wind stress at the meteorological buoy 46206. This time marks the transition from poleward to equatorward flow and the beginning of the biologically productive spring and summer upwelling seasons. The wind and current transitions are closely linked, with the ocean current leading the wind by roughly two and a half weeks on average. Years of late transition such as 2005 have been characterized by poor or greatly changed productivity in plankton, fish, and birds documented in earlier State of the Ocean reports. Based on these data, it appears that the spring transition timing for the coastal ocean current was near average in 2006, a remarkable change from 2005 when the transition was the latest it has ever been in our records.

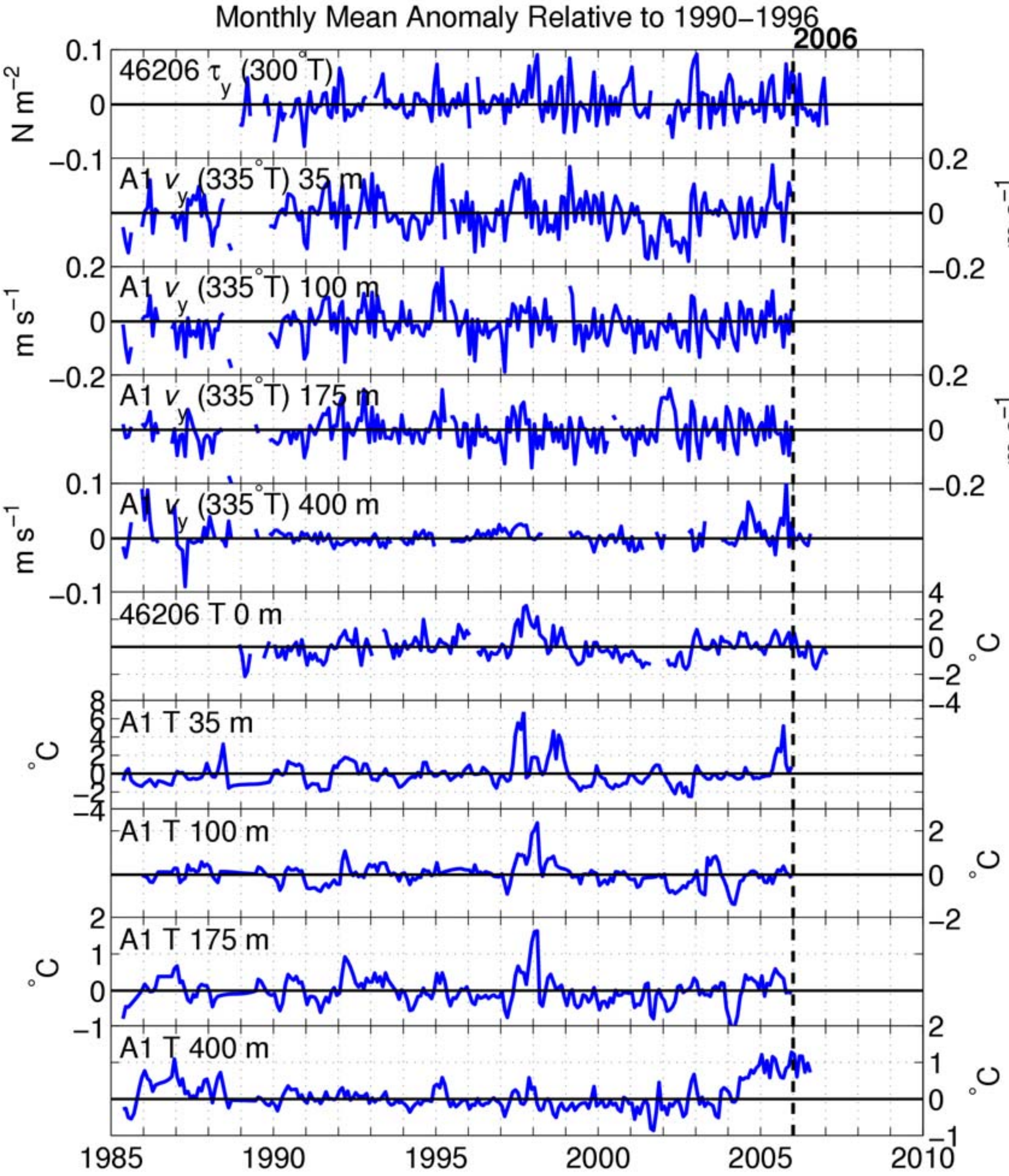


Figure A38. Monthly mean anomalies for longshore wind stress (τ_y) at 46206, longshore velocities (A1 v_y) at A1, and ocean temperatures (T) at 46206 and A1.

Figure A38 shows monthly anomalies of the longshore component of wind stress along with the longshore component of current velocity and associated water temperatures from the surface to 400 m depth for the period 1985–2006. Winds in 2006 were characterized by relatively strong downwelling in winter and strengthening upwelling winds in summer. In January 2006, most of mooring A1 was destroyed by a fishing vessel. Data were recovered for the deepest instruments only. 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, while at 175 and 400 m depth, velocity anomalies were positive (stronger poleward and/or weaker equatorward). Temperatures at all depths warmed through 2004/05, probably due to El Niño effects, but began cooling substantially at the end of 2006. The weak El Niño of 2006/07 appears to be giving way to La Niña conditions.

Bright Plankton Blooms off the BC coast

Jim Gower, Fisheries & Oceans Canada

BC coastal waters were in the world media spotlight after NASA posted an image collected by their MODIS satellite on 25 June 2006 showing an extensive bright bloom off Vancouver Island. Samples collected from the Canadian Coast Guard Ship *John P. Tully* confirm that this was due to a coccolithophore species of phytoplankton. Visual observations described the patterns in the water as very dramatic. This was the largest such bloom ever observed in these waters.

Figure A39. MODIS image "true colour" for 25 June 2006

An older satellite named SeaWiFS has been collecting ocean colour images since 1997, providing a valuable time series of ocean phytoplankton concentrations at ocean surface.

The monthly average global data set (next page) shows this bright water off Vancouver Island for the month of June (centre of bottom row in Fig. A40a), and also reminds us that similar blooms have happened in previous years. This figure shows monthly average water brightness (normalized water-leaving radiance at 555 nm) for each month of each year since 1997 (top row) to 2006 (bottom row) with a spatial resolution of about 9 km. The blooms in June were followed by similar events further north in July. Bright water events in winter months are associated with suspended material from land run-off.

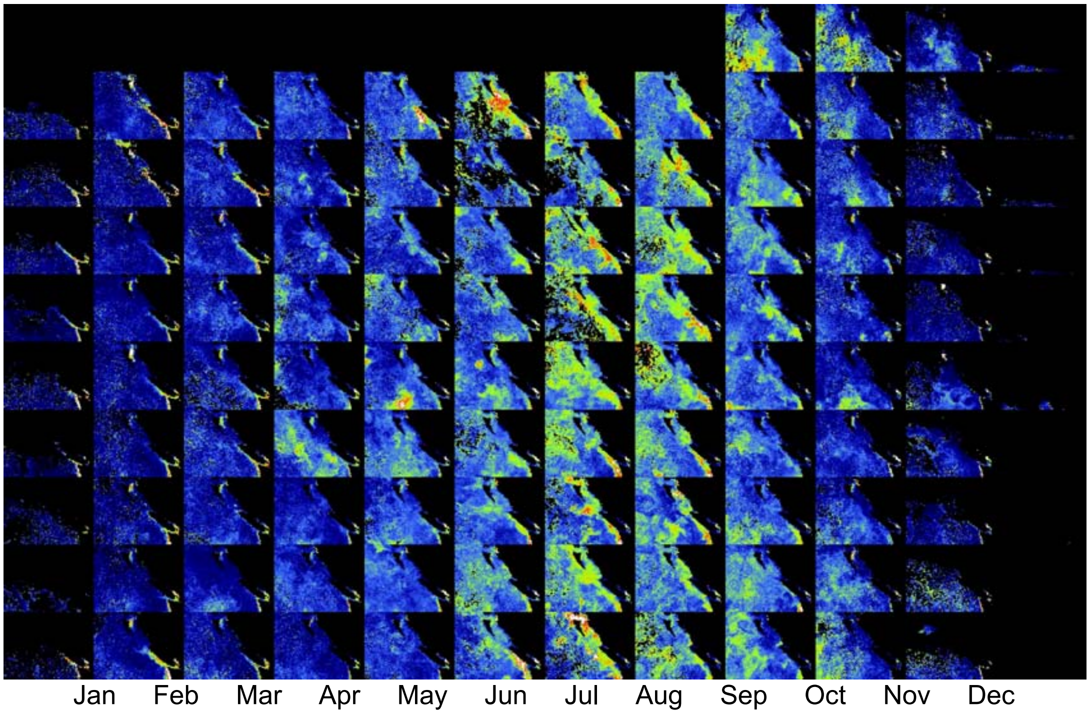


Figure A40a. SeaWiFS monthly composite water brightness data comparing 2006 (bottom row) with data from previous years, back to 1997 (top row).

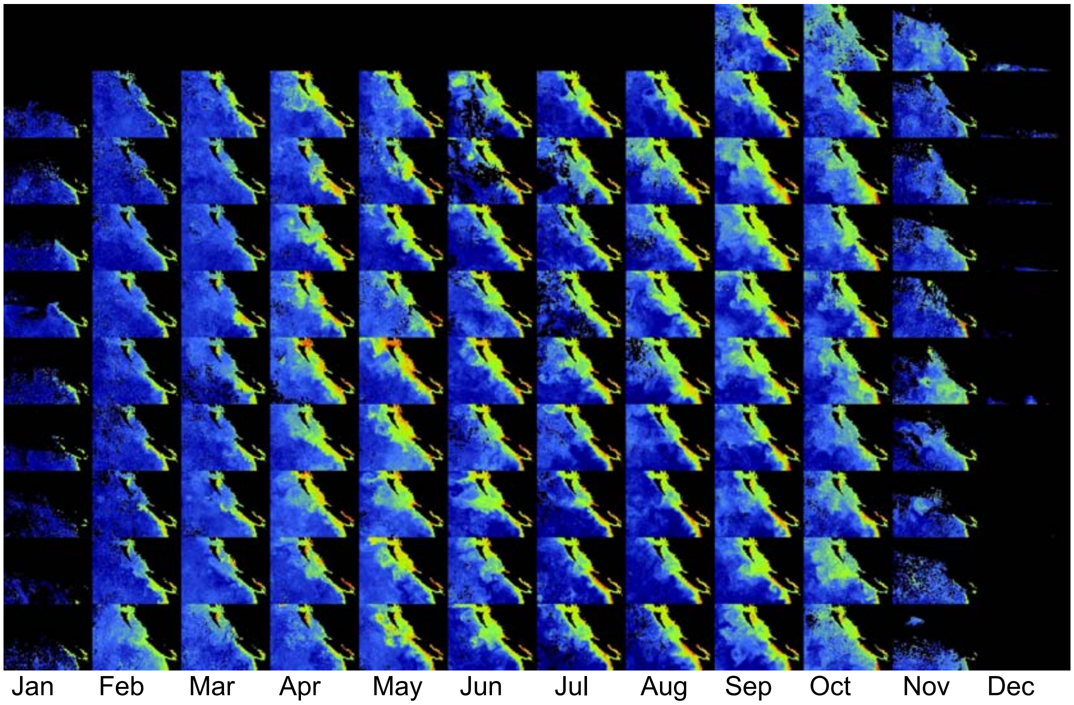


Figure A40b. SeaWiFS monthly composite surface chlorophyll comparing 2006 (bottom row) with data from previous years, back to 1997 (top row).

The images in Figure A40b reveal phytoplankton concentrations. They suggest a later start to the spring bloom in 2006 (lower values in April) compared to previous years.

Zooplankton in a ‘Warm-Ocean’ Pattern off Vancouver Island, Despite Cooling in 2006

David Mackas, Moira Galbraith, Steven Romaine, Fisheries & Oceans Canada

Ocean environmental conditions such as water temperature, stratification, nutrient availability, and zooplankton productivity and community composition all vary strongly at several time scales: seasonal, 1-2 year (e.g. El Niño), 4-20 year (decadal “regimes”), and much longer-term trend and fluctuations (anthropogenic global warming or natural glacial-interglacial cycles). Although most ocean biota are well-adapted to the ‘expected’ variability associated with the seasonal cycle, the interannual deviations from normal conditions are less predictable, and can have severe impacts on life cycles, growth, survival, and reproductive success. Anomalously warm upper-ocean temperatures (compared to historical norms) have been frequent in the NE Pacific during the past decade, due to superposition of El Niño and warm-phase ‘regime’ fluctuations onto a sustained and global-scale warming trend. Warm temperatures have direct effects on biota, plus are correlated with other ecologically important environmental factors: 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 the above tend to be accompanied by reduced growth and survival of resident species and increased abundance of their ‘warm-water’ competitors and predators, leading to shifts in community composition and food web pathways. Monitoring of recent ocean conditions can provide a ‘leading indicator’ for subsequent fish recruitment because much of the year-to-year variability of marine survival rate appears to be concentrated at early life stages (for salmon, in their first year after ocean entry).

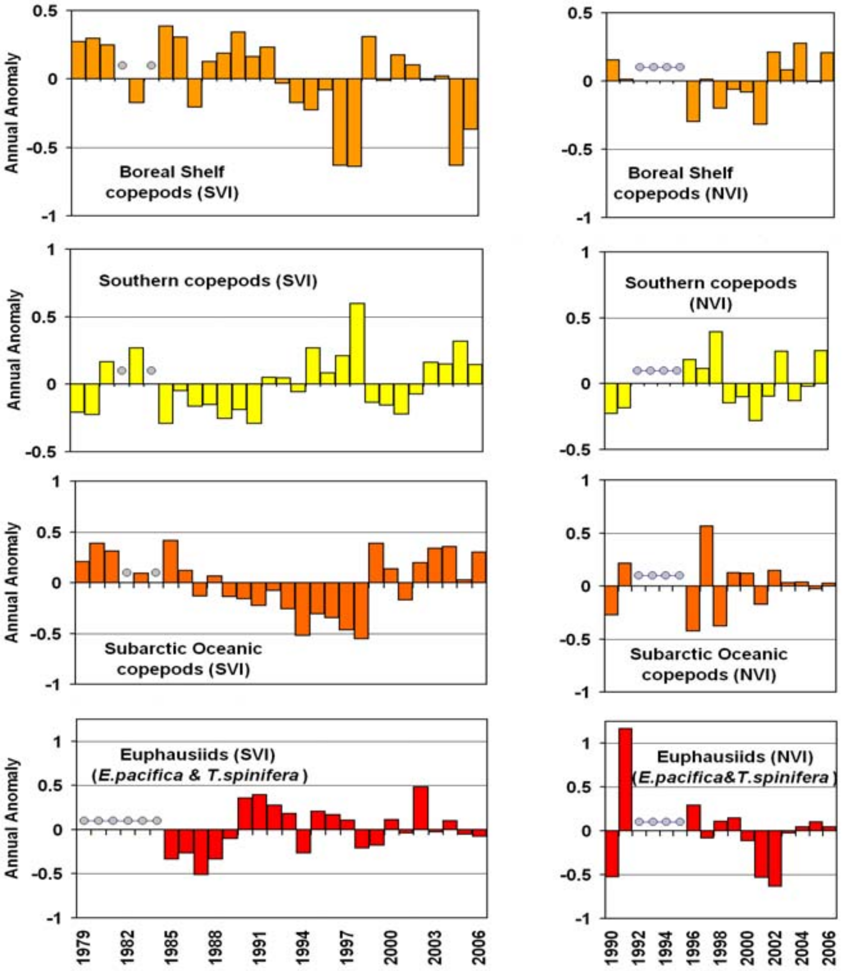


Fig. A41. Anomaly time series for four important crustacean zooplankton species groups.

Left panels are southern Vancouver Island, (referenced to 1979-1991 average seasonal cycle, then centered to zero mean for 1979-present).

Right panels are data from northern Vancouver Island (1990-2001 seasonal cycle). Circles indicate years with no or too few data.

Time series sampling of zooplankton on the continental-shelf and the adjoining deep ocean off Vancouver Island is carried out 3-6 times per year. The southern Vancouver Island region (SVI, 48°-49°N) has been sampled since 1979 (standardized methods and locations since 1985), and the northern Vancouver Island region (NVI, 50º-51.5ºN) since the early 1990s (standardized methods and locations since 1996). These long time series allow us to estimate annual anomalies of most of the major zooplankton species, relative to their long term baseline average annual seasonal cycle. Mackas, Thomson and Galbraith (2001), provide detailed descriptions of sampling and data analysis methods

Figure A41 shows cross-shore and annually averaged biomass anomalies for four important crustacean species groups (left panels are from SVI, right panels the briefer time series from NVI). 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; –1 means they were one tenth as common. West coast zooplankton biomass and composition anomalies are positively correlated throughout much of the California Current system (Mackas et al. 2006). Through most of the 1990s, there was a strong and cumulative shift to a more 'southerly' copepod fauna, and a reduction of abundance for the normal resident copepods (boreal-subarctic off Vancouver Island). This trend reversed sharply in 1999, following the 1997-1999 El Niño-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 were similar to the 1979-1991 baseline period. However, warm conditions resumed 2003-2005, and zooplankton anomalies off SVI 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*. In 2006, despite a return to cooler ocean conditions, the SVI zooplankton have retained a strong southerly bias in community composition.

Reduction in biomass and abundance of the ‘subarctic oceanic’ copepods (*Neocalanus* spp.) has been less extreme than during the late 1990s. However, the recent warming has been accompanied by large changes in the time of year when they are most abundant (Fig A42). 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.

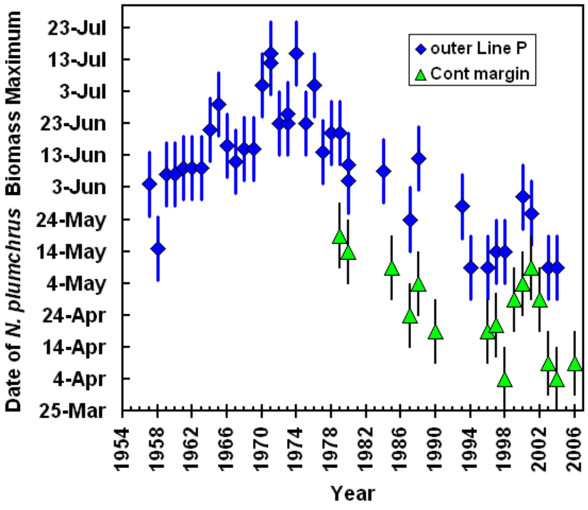


Fig. A42. Changing seasonal timing of the dominant subarctic oceanic copepod Neocalanus plumchrus (updated from Mackas et al. 1998)

Early timing is strongly associated with warm upper ocean temperature during the spring growing season.

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, and in the Alaska Gyre (the North Pacific Continuous Plankton Recorder surveys had similar results)

A recent analysis (Mackas, Batten and Trudel, 2007; summary in the 2006 State of the Ocean Report) used multivariate ordination to study covariance among zooplankton composition and timing anomalies, local and large-scale indices of upper ocean temperature, and 'success' of predator species (growth and marine survival of outer coast coho; sablefish recruitment; seabird reproductive success). Variability of all of these time series projected strongly onto a single component axis (loosely interpretable as a 'cool-and-productive' to 'warm-and-unproductive' gradient). Fig. A43 shows the updated time series of scores for this principal component.

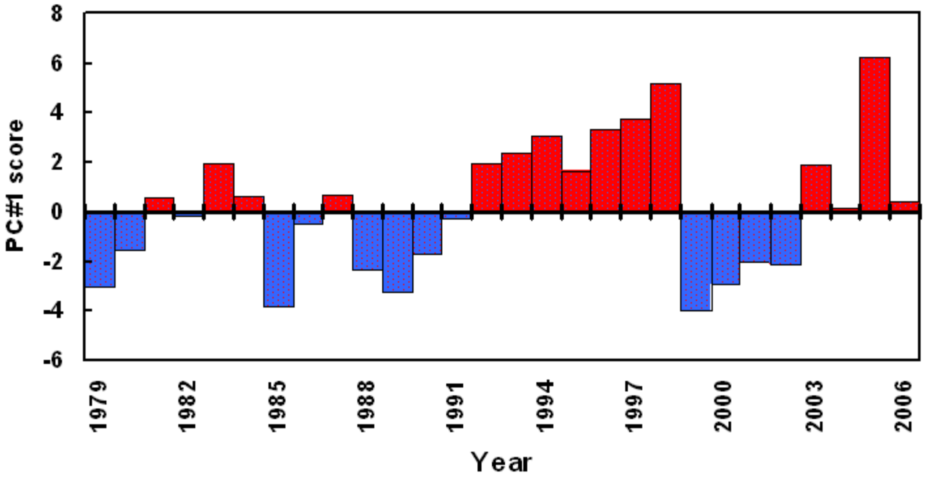


Fig. A43. Annual scores for zooplankton-temperature-predator PC#1. Blue indicates cool temperature and favourable conditions for most of the endemic zooplankton and predators, red indicates warm and favourable for the southern zooplankton but unfavourable for endemic zooplankton and predators.

The PC scores of Fig. A43 suggest that 2005 was a very difficult year for productivity and survival of many endemic species (comparable to the 1998 El Niño). The composite score for 2006 was near the long term average, but includes a mixed message of cool physical environment but a continuing 'warm' pattern for zooplankton.

Sources and contacts for additional information:
D. Mackas, M. Galbraith, and S. Romaine, Institute of Ocean Sciences

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Euphausiids and Hake on the West Coast of Vancouver Island: Less Food for Chum and Sockeye, and More Hake Predation/Competition

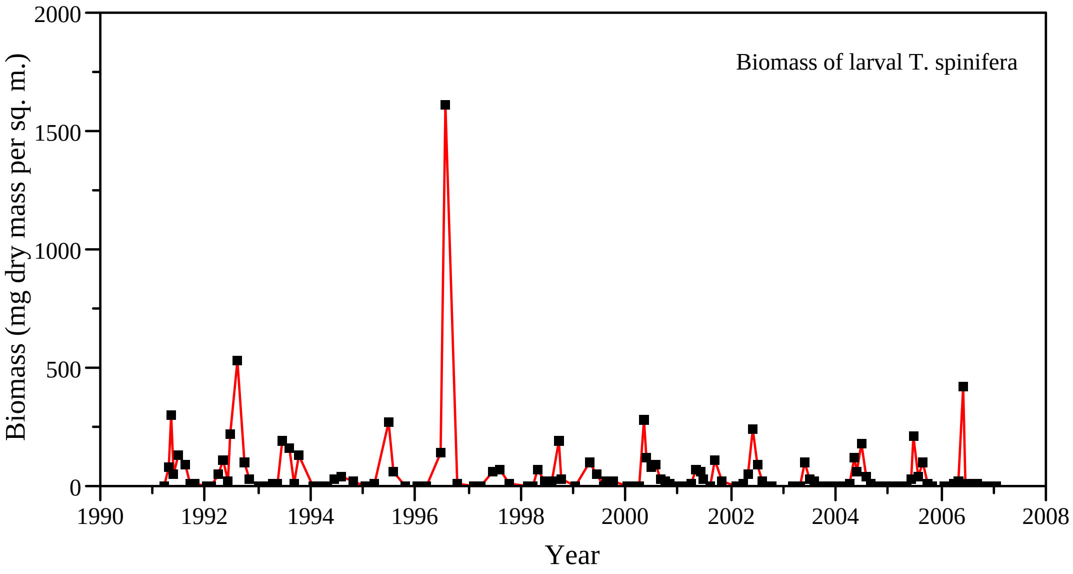
Ron Tanasichuk, Fisheries & Oceans Canada

One of our research activities focuses on evaluating simultaneously the influences of stock, food, and predation on the productivity of Pacific herring (*Clupea pallasi*), and coho (*Oncorhynchus kisutch*), sockeye (*O. nerka*), and chum (*O. keta*) salmon along the southwest coast of Vancouver Island (WCVI). Diet analysis indicates that herring and coho prefer the euphausiid (also called Krill) ***Thysanoessa spinifera*** and that these fish select prey longer than about 17 and 19 mm respectively. Sockeye prefer 3-5 mm long *T. spinifera* and chum salmon prefer 3-4 mm individuals. The 1991-2006 time series of *T. spinifera* biomass is presented in Fig. A44).
T. spinifera biomass remained low in 2006. Pacific hake (*Merluccius productus*) dominates the pelagic biomass in summer and is considered to be the most important predator. This species can also be a competitor because *T. spinifera* is a key prey item. Hake recruitment, as indexed by the estimate of age 2+ fish, for the 1999 yearclass was lower than only 10% of the recruitments in the 1972-2005 time series. In 2004, hake from this yearclass became large enough to start consuming fish. Results from the 2005 hydro-acoustic survey suggested that hake piscivorous (fish-eating) biomass remained relatively high and total hake biomass was increasing.

Herring recruitment (production of new spawners) varies as a result of stock, *T. spinifera* biomass and/or hake biomass effects. Recruitment variation for northern (Queen Charlotte Islands, North Coast, Central Coast) herring is a result of the effects of stock size and competition with hake during herring's second year of life. For Strait of Georgia herring, recruitment varies in response to stock size 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 explains changes in growth of WCVI herring, and variation in adult natural mortality rates for WCVI and Strait of Georgia herring. WCVI wild coho return variability is affected by smolt production and *T. spinifera* biomass variability. Barkley Sound (Sproat and Great Central lakes) and Central Coast (Oweekeno and Long lakes) sockeye return variability can be explained by variations in *T. spinifera* biomass early in marine life. Chum productivity, as indexed by returns of ages 4 and 5 Nitinat River Hatchery fish, is affected mostly by variations in hake biomass, but *T. spinifera* biomass affects the return of age 3 chum. Euphausiid population dynamics is complex enough that predator-specific prey biomass must be estimated. In 2006, prey biomasses were near average for coho and herring, and the third lowest in the time series for sockeye and chum.

The following are the anticipated consequences of 2006 prey and predator biomass levels.

- Herring: recruitment to all major BC stocks should continue declining in 2008 because of the hake predation/competition effect, growth of WCVI herring should improve and WCVI and Strait of Georgia adult natural mortality rates should decline;
- WCVI wild coho: marine survival is forecast to be about 3% for the 2007 return year because of reduced smolt production, even though food availability increased in the 2006 smolt year;
- Barkley Sound/Central Coast sockeye: returns in 2007 and 2008 should be poor because low euphausiid biomass in the 2005 and 2006 smolt years;
- Nitinat River Hatchery chum: returns should decline markedly as of 2007 because of hake predation.



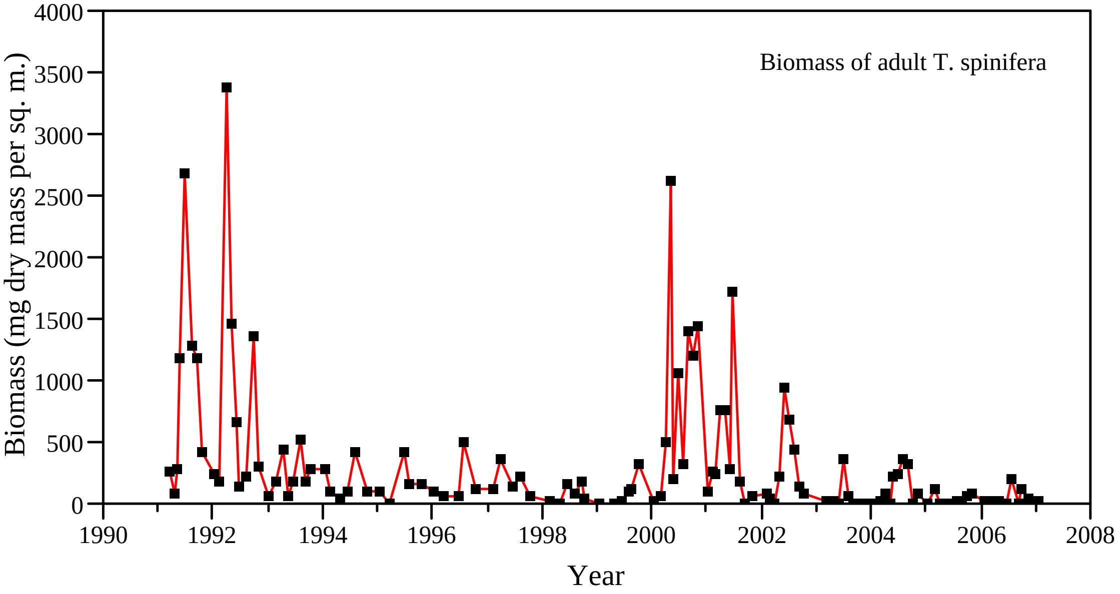


*Fig. A44. The 1991-2006 time series of **larval** (top panel, <10 mm long) and **adult** (bottom panel > 9 mm long) T. spinifera biomass. Median larval and adult biomasses in 2006 were the third and second lowest respectively in the time series; larval biomass increased by 25% and adult biomass decreased by 37% from 2005.*

Small-Mesh Bottom-Trawl Surveys: Continued Low Shrimp Biomass, and Declines of other Key Indicator Species in 2006

Ian Perry and Jim Boutillier, Fisheries & 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 2006 found that the biomass of *Pandalus jordani* shrimp off central Vancouver Island was low and similar to that in 2004 and 2005. Pink shrimp responses to warm ocean conditions since 2003 have been similar to their responses during the warm 1990s. The survey found that warm water species (Pacific hake) and cool water species (such as walleye pollock), and English sole, Arrowtooth flounder, Pacific halibut and spiny dogfish, declined from near-record maximal biomass (for some species) that had been observed in 2005. **These results suggest a continuation of the effects of warm water conditions that occurred in 2005 in contrast to cooler conditions from 1999 to 2002.** In addition, diversity indices (not shown) indicate that the biomass among 31 vertebrate and invertebrate taxa was concentrated into fewer taxa in 2005 and 2006 compared with 1997-2004.

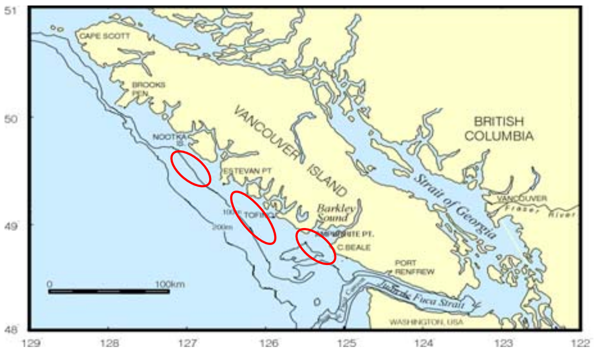
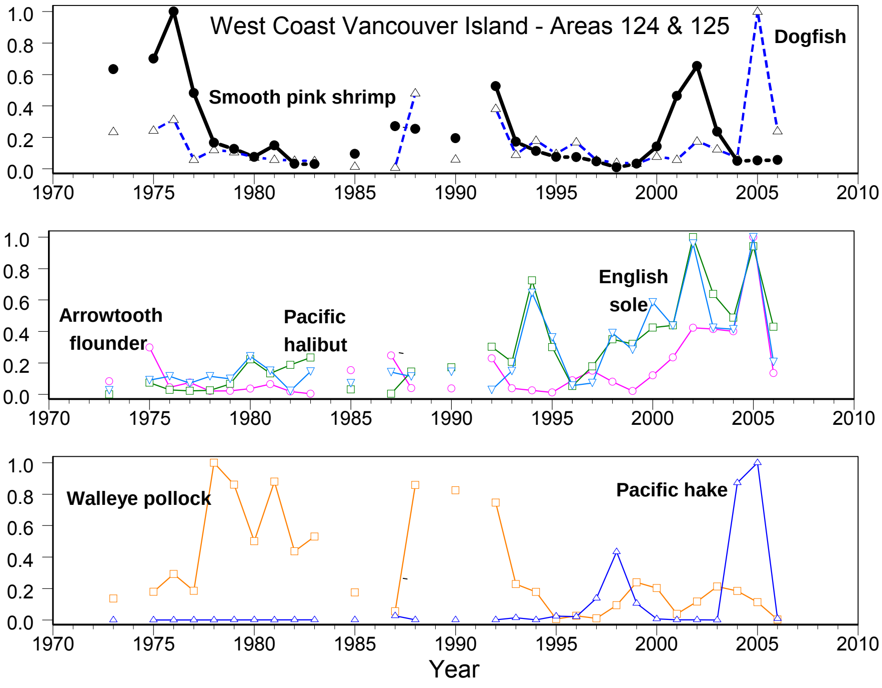


Figure A45 (left) Map showing the three main shrimp (Pandalus jordani) survey grounds off Vancouver Island (red ovals). The Nootka (Area 125) and Tofino (Area 124) Grounds are the northern and middle ovals, respectively.

Figure A46 (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.



Seabird Reproductive Performance on Triangle Island in 2006: Timing and Success Close to Long-Term Averages

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 the 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 2006, and places 2006 results within the context of the 1994-2005 time series.

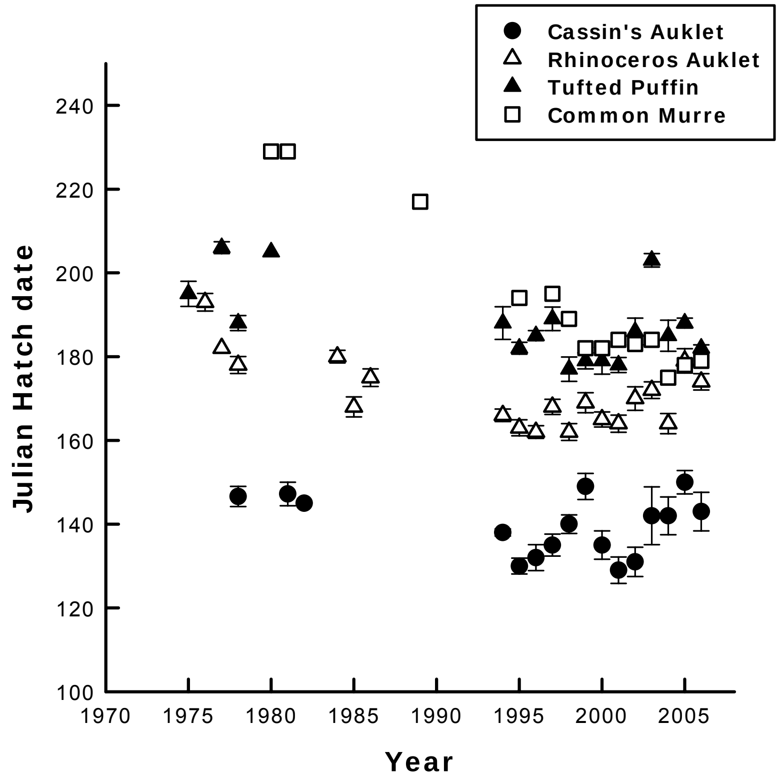


Fig. A47. Timing of breeding for seabirds on Triangle Island, British Columbia, 1975-2006. Reported are mean hatching dates, with 95% confidence intervals, for Cassin's Auklets, Rhinoceros Auklets and Tufted Puffins, and dates when nestlings were first seen for Common Murres. Timing of breeding was close to long-term averages for all but Common Murres, which continue to breed early.

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 was close to the long-term average, compared to previous years (Fig. A47). The lone exception was the Common Murre, a species that continues to lay early. Feeding conditions were apparently normal early in the 2006 season.

Breeding success

For all species, breeding success was close to long-term average values at Triangle Island in 2006. In our two focal species, success in 2006 also was close to values predicted from March 2006 (Cassin’s Auklet) or April 2006 (Rhinoceros Auklet) sea-surface temperatures recorded at Pine Island (Fig. A48). However, diets fed to nestlings were low in putatively preferred species: the copepod *Neocalanus cristatus* for Cassin’s Auklets (euphausiids were more prevalent than normal in diets in 2006), and Pacific sandlance for Rhinoceros Auklets (in the latter, continuing a seven-year decline). On the whole, 2006 was a very average year for the seabirds on Triangle Island.

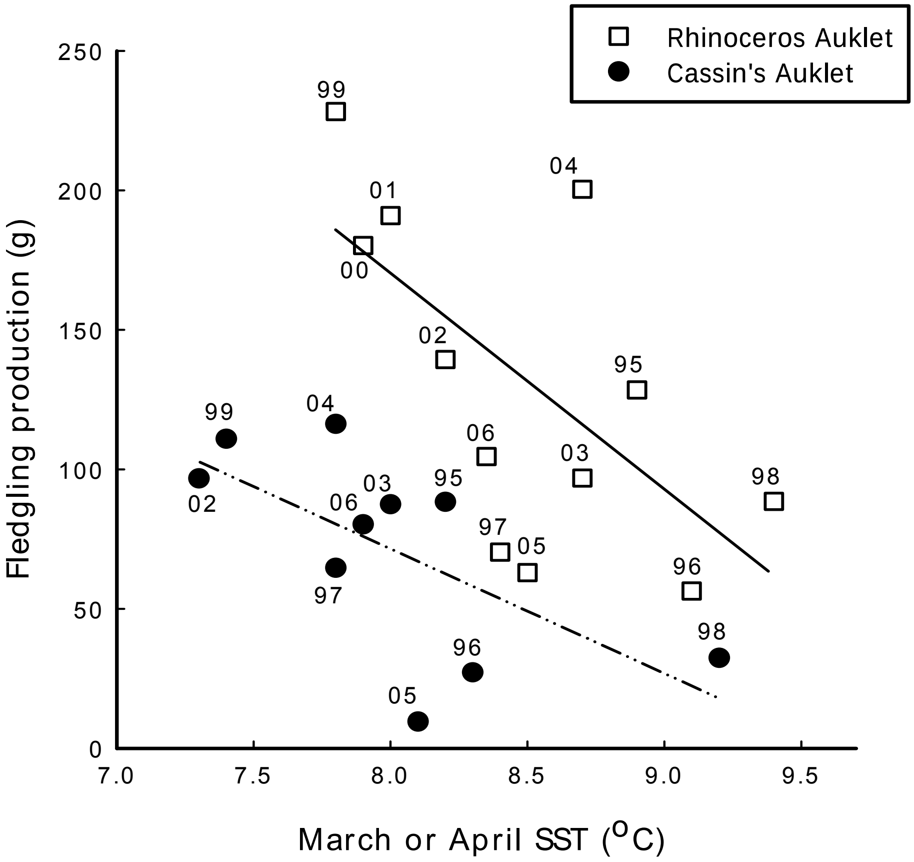


*Fig. A48. Consequences of April sea surface temperatures, measured at the Pine Island Lightstation (50°35'N 127°26'), for Cassin’s and Rhinoceros auklets breeding on Triangle Island, British Columbia, 1994-2006. Fledgling production is calculated as: hatching success * % fledging success * mean fledging mass; or in other words, the mean mass of fledged chick produced per egg laid.*

Links Scott Islands Marine Wildlife Area (http://www.cpawsbc.org/pdfs/scott_islands_mwa.pdf)
Canadian Wildlife Service bird monitoring in BC(http://www.ecoinfo.ec.gc.ca/env_ind/region/seabird/seabird_data_e.cfm#Map)
Seabirds in Ocean Status Report 2005 (Page 48)
Environment Canada Contact: Mark Hipfner (mark.hipfner@ec.gc.ca)

Small Pelagic Fishes

Jake Schweigert, Fisheries & 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 2006 declined substantially from the previous year, continuing the decreasing trend. 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 resulting in poor herring survival that may result in continued reduced recruitment to the stock in 2007 and 2008.

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 2006 sardines appeared in Canadian waters in late June. The distribution was more offshore than in 2005 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 years, 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. Indications are that a poor 2003 year-class occurred in all three areas following the average 2002 year-class and resulted in decline in abundance from the previous year.

Strait of Georgia

Herring survival conditions and recruitment have been unusually good in the Strait of Georgia for the last decade. Abundance of herring reached an historical high in 2003 in excess of 150 000 mt, exceeding the previous high in 1955. However, the 2003 year-class appears to be the weakest during the past decade resulting in a substantial decline in abundance in 2006. Nevertheless, the recent strong recruitments should maintain the stock at a healthy level in the short term.

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 (Figure A49). As a result, the productivity of the west coast of Vancouver Island herring stock has been declining since the early 1980s (Figure A49). 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. Ocean conditions have warmed in the last few years impacting herring survival in 2004 and 2005 and could result in continuing reduced recruitment to the stock in 2007 and 2008.

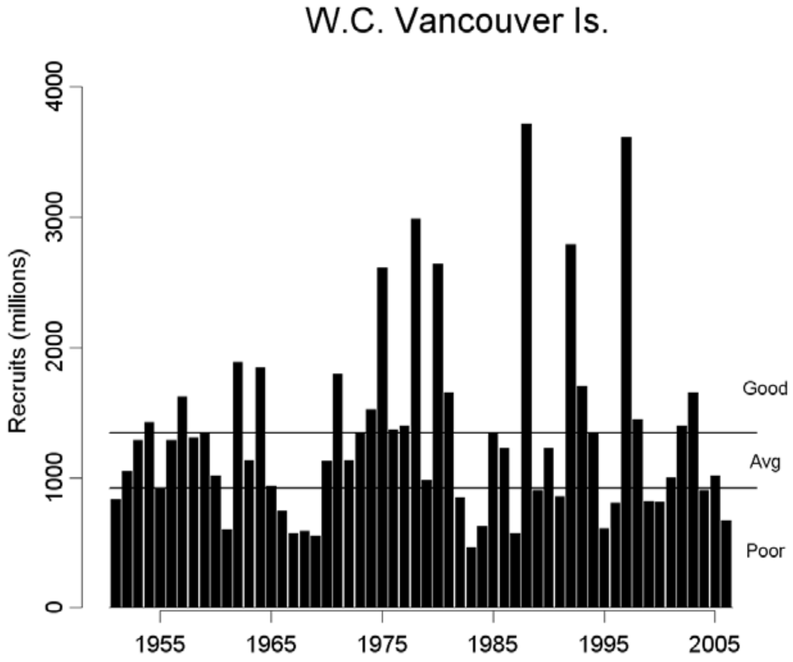


Figure A49. Interannual variability and decadal trends in recruitment to the west coast of Vancouver Island herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 6 of the last 10 recruitments have been 'poor'.

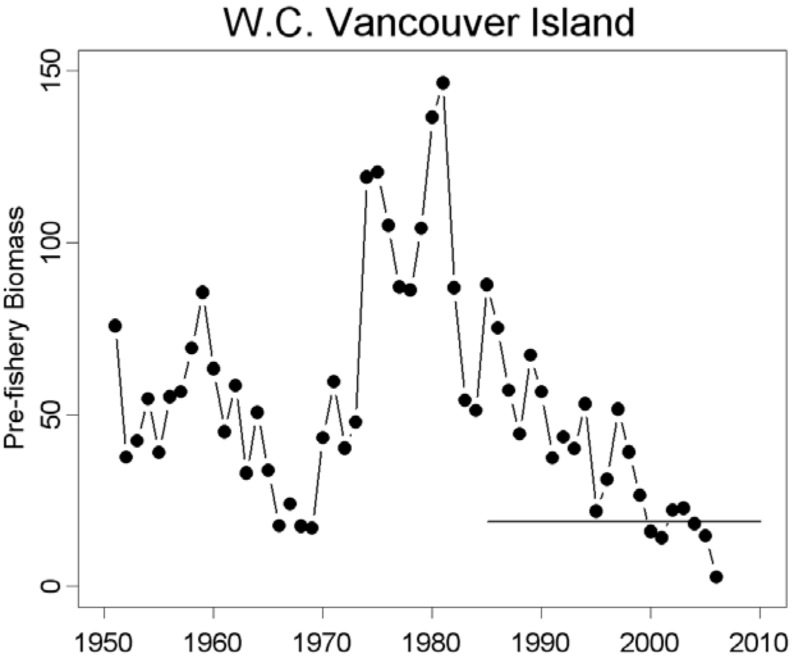


Figure A50. West Coast Vancouver Island herring biomass (1000 tonnes).

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 following the La Niña, sardine distribution again contracted southward. During 2006, 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. The most recent U.S. assessment suggests that coastwide abundance has been stable since the mid-1990s at just over 1 million tonnes (Fig. A51).

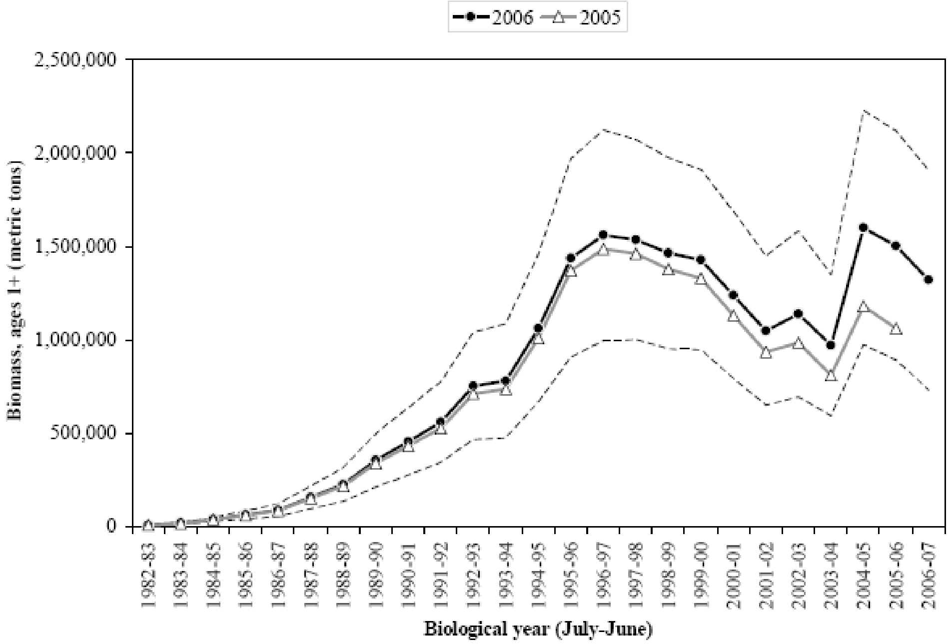


Figure A51. Time series of Pacific sardine stock biomass of age 1 and older fish, estimated from an age-structured stock assessment model (data from Hill et al. 2005).

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 (Fig. A51). Levels of recruitment to the Queen Charlotte Islands have been depressed (Fig. A52) with only 3 of the past 10 year-classes being above average, whereas the Prince Rupert stock has experienced a good recruitment at least every 4 years since 1980. Recruitment to the Central Coast stock has been less regular, but the 'good' year-classes that have occurred were very strong. Indications are that the most recent recruitment of the 2003 year-class is poor and resulted in declines in the Prince Rupert and Central Coast stocks while the Queen Charlotte Islands remained stable.

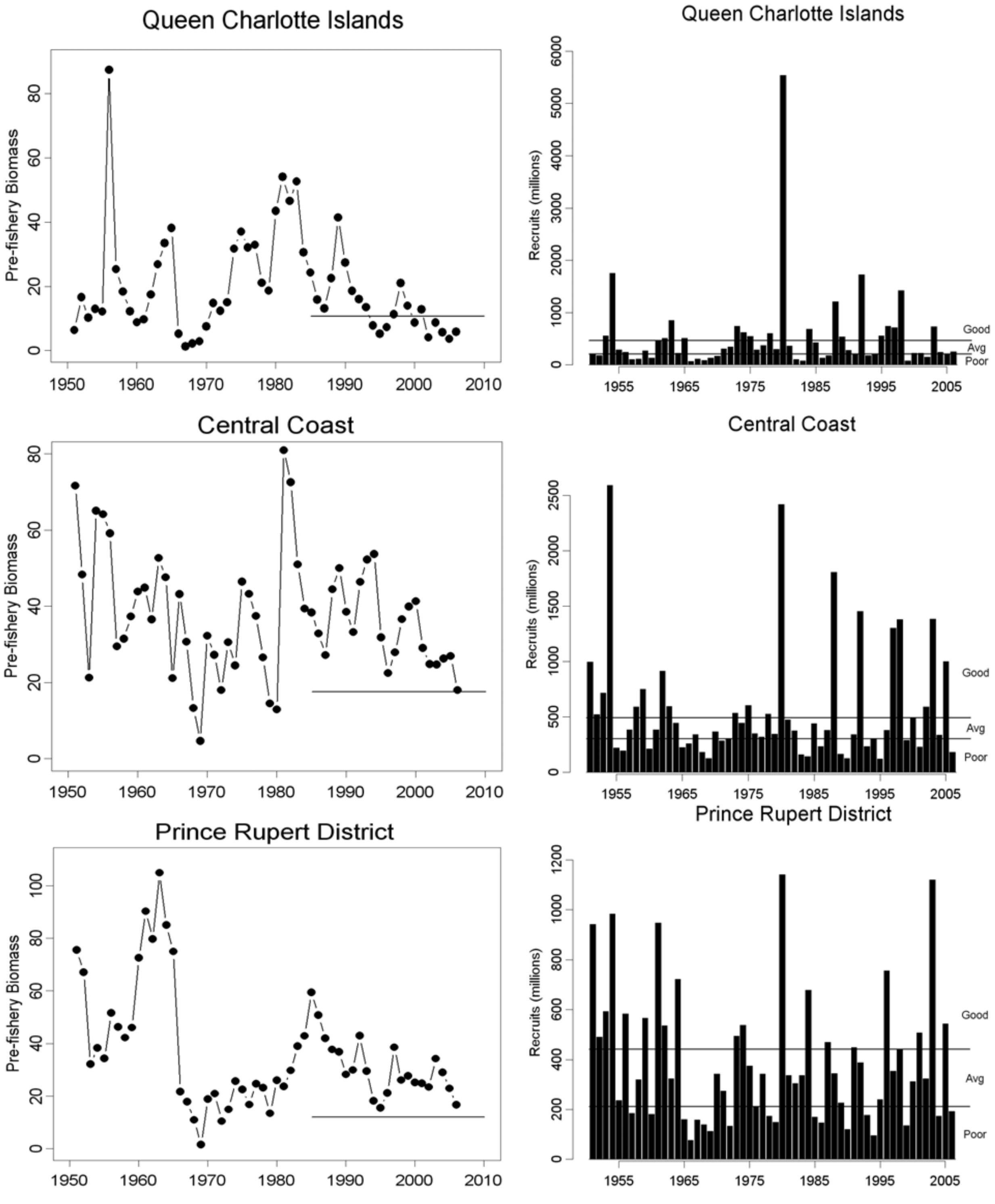


Figure A52. (Left) Herring biomass (1000 tonnes) in three Hecate Strait stocks: Queen Charlotte Islands, Central Coast and Prince Rupert District. (Right) Interannual variability and decadal trends in recruitment to the Hecate Strait herring stocks. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that many of the recent recruitments have been 'poor' in the Queen Charlotte Islands stock, whereas 'good' recruitments have occurred almost every four years since 1980 in the Prince Rupert stock.

Herring in the Strait of Georgia

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 a recent high level in 2003 at just over 150,000 tonnes (Fig. A53) exceeding the historical high of 1955. Recruitment to this stock has been very strong with 8 of the last 10 year-classes being average or better (Fig. A54). The strongest recruitment occurred in 2000, and subsequent year-classes have been progressively smaller. The most recent recruitment in 2006 was poor. 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 lead to further declines in overall abundance.

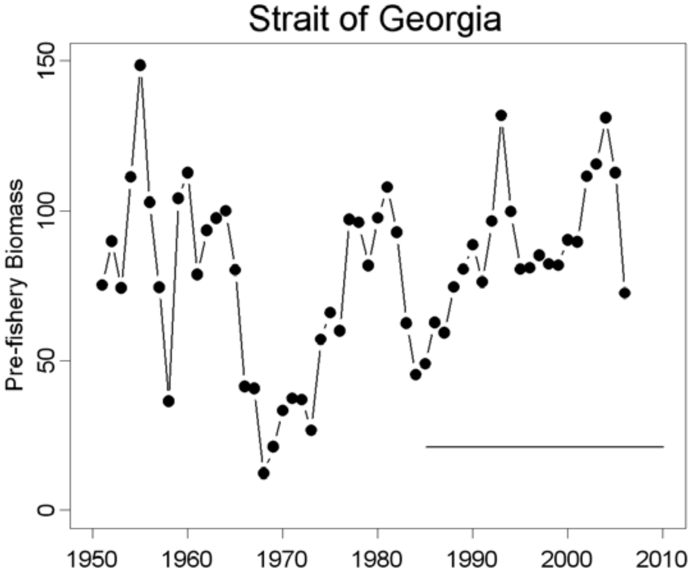


Figure A53. Strait of Georgia herring biomass (1000 tonnes).

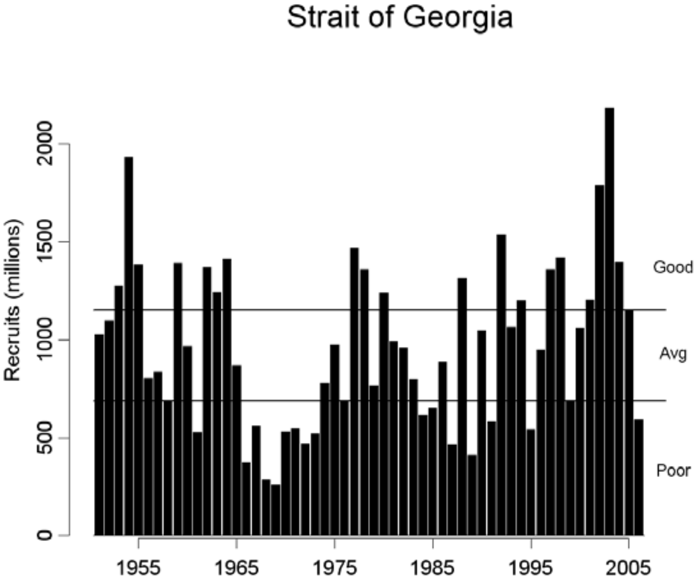


Figure A54. Interannual variability and decadal trends in recruitment to the Strait of Georgia stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

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 again reduced and limited to the inlets of Vancouver Island and offshore areas in the south. Recent warm conditions and a very strong 2003 year-class resulted in widespread distribution of sardines throughout southern Hecate Strait and Queen Charlotte Sound.

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 year-class in 2006 was poor following an average 2002 year-class, resulting in moderate declines in Prince Rupert and the Central Coast. The abundance of hake in this area during the last few years may be expected to negatively impact herring recruitment and stock abundance over the short term.

Strait of Georgia

Herring: The abundance of herring in 2006 declined substantially from the historical high of more than 150,000 tonnes in 2003. 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 over the next few years.

Reference

Hill, K. T., N. C. H. Lo, B. J. Macewicz, and R. Felix-Uraga. 2005. Assessment of the Pacific sardine (Sardinops sagax caerulea) population for U.S. management in 2006. Pacific Fishery Management Council, Agenda Item D.1.a, Supplemental Attachment 1. 141 p.

Average Growth Conditions for Coho Salmon of the West Coast of Vancouver Island

Marc Trudel, Fisheries & 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. A55). This could potentially explain the higher marine survival of southeast Alaska coho salmon compared to southern British Columbia stocks. In 2006, juvenile coho salmon growth increased from the lowest on record observed in 2005 to a rate near the 1998-2005 average off the west coast of Vancouver Island, while it remained relatively stable off southeast Alaska (Fig. A55). Hence, the marine survival and adult returns of coho salmon are expected to be average for west coast Vancouver Island stocks in 2007 (Fig. A56).

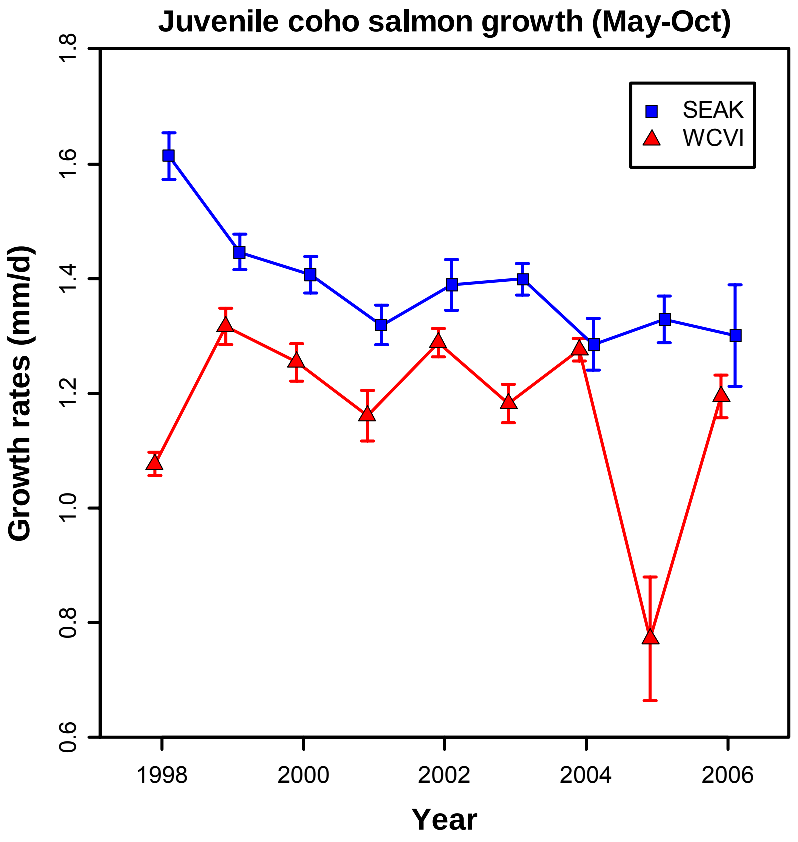


Figure A55. Growth rates (May-October) of juvenile coho salmon off the west coast of Vancouver Island (red triangles) and Southeast Alaska (blue squares). The error bars are 2 x SE.

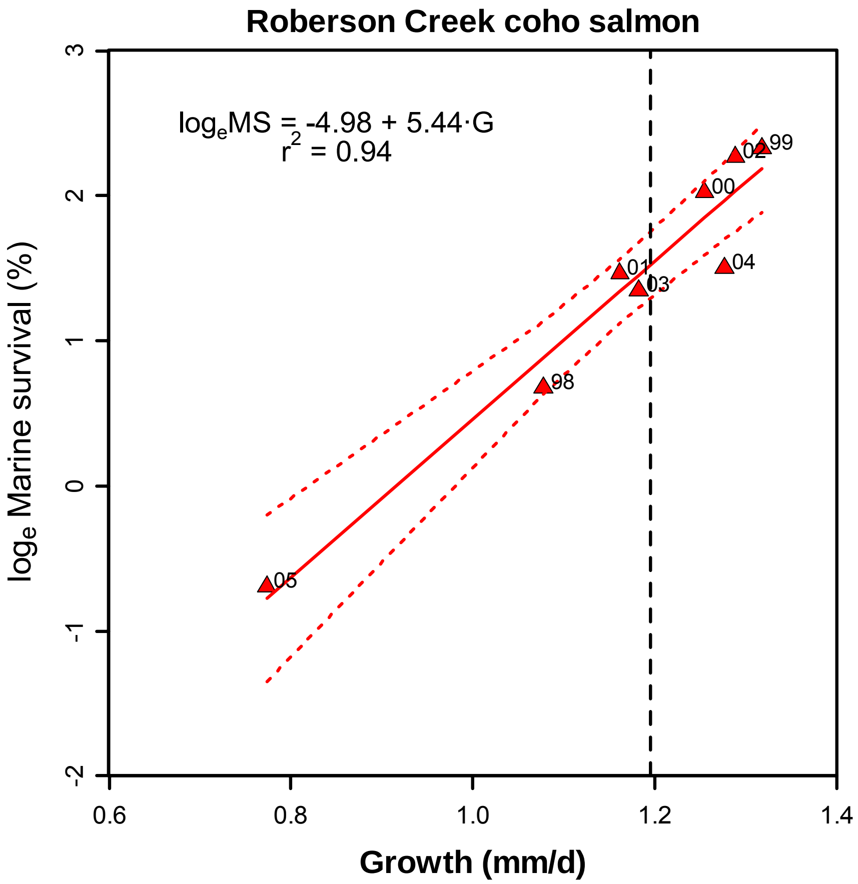


Figure A56. Relationship between the marine survival (MS) of Robertson Creek coho salmon and the May-October growth rates (G) of juvenile coho salmon off the west coast of Vancouver Island. The numbers beside the symbols represent ocean entry year (add one year to obtain the return year). The dashed black line represents the observed growth rate for the 2006 ocean entry year. Note that the marine survival data were transformed using the natural log transformation prior to fitting the linear regression model.

Sockeye Salmon Index Stocks –Regional Overview of Trends and 2006 Returns

Kim Hyatt, Karen Hunter, Paul Rankin and Margot Stockwell,
Fisheries & 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 is 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 returns of sockeye salmon returning to major rivers and fisheries throughout coastal British Columbia have been completed annually by DFO stock assessment personnel for decades (Figure A57). 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, West Coast Vancouver Island (WCVI) and Fraser index stocks all declined from early-1990s highs to sub-average returns of the mid-1990s persisting in most years to present (Figure A57).
- 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 (Figure A57) 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 Figure A57*) appear more responsive to alternations in La Nina-like (*anomalously cool, survival favourable*) and El Nino-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 Figure A57*).
- Sockeye returns in 2006 were sub-average for index stocks originating from Central and South Coast areas of BC and near average to above average for North Coast and Alaska Transboundary stocks respectively.
- Returns in 2006 likely reflect environmental conditions influencing survival of salmon smolts from several weeks before to several weeks after sea entry in 2003 and 2004.
- Persistence of strong El Nino-like conditions through most of 2005 (DFO 2006) suggests the likely continuation of below average survival and returns for Central Coast (Rivers and Smith Inlet), WCVI (Barkley Sound) and Fraser (Chilko Lake) sockeye index stocks during 2007.

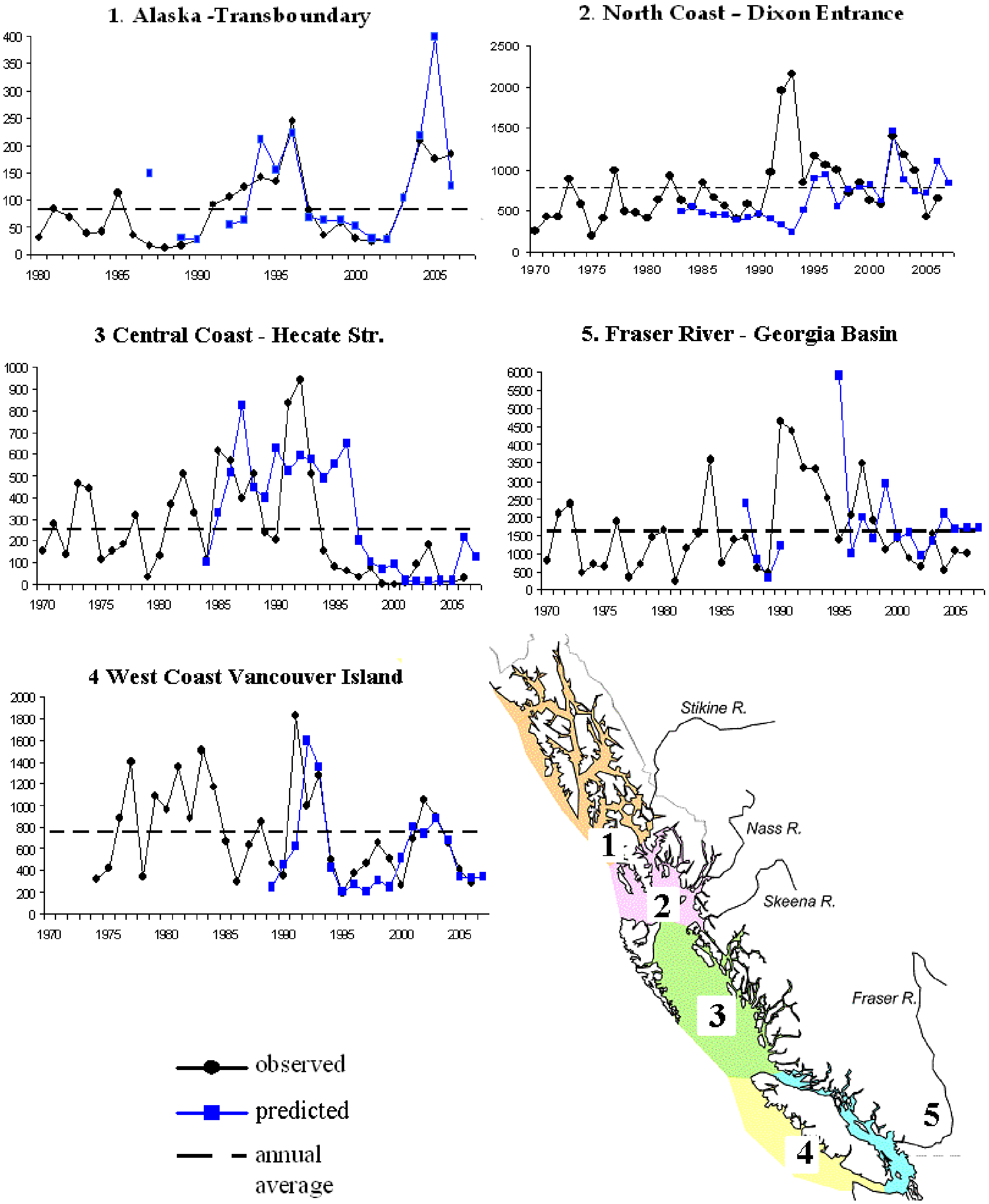


Figure A57. Trends in the total returns and forecasts for British Columbia sockeye index stocks including: 1. Tahltan, 2. Nass, 3. Smith's Inlet, 4. Barkley Sound and 5. Chilko Lake sockeye salmon (which are not necessarily representative of all sockeye salmon from the Fraser River system). Y-axis represents returns in thousands of fish. Each graph is for one or more "index" streams in the region noted, not for all streams in that region.

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 (Figure A58). 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, 2004-2006) 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 Nina-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 Nino-like" conditions (*SST > 30 yr average, elevated sea level, high northward transport*) with lower marine survival (2.5 %).

2006 Observations:

Barkley Sound sockeye salmon returns remained well below the long term average in both 2005 and 2006 as predicted by the SStM model (Figure A58). Lower marine survivals experienced by WCVI juvenile salmon during their 2003 and 2004 ocean entry years (adult returns in 2005, 2006 and 2007) were anticipated by positive SST and ENSO indices respectively (DFO, 2005).

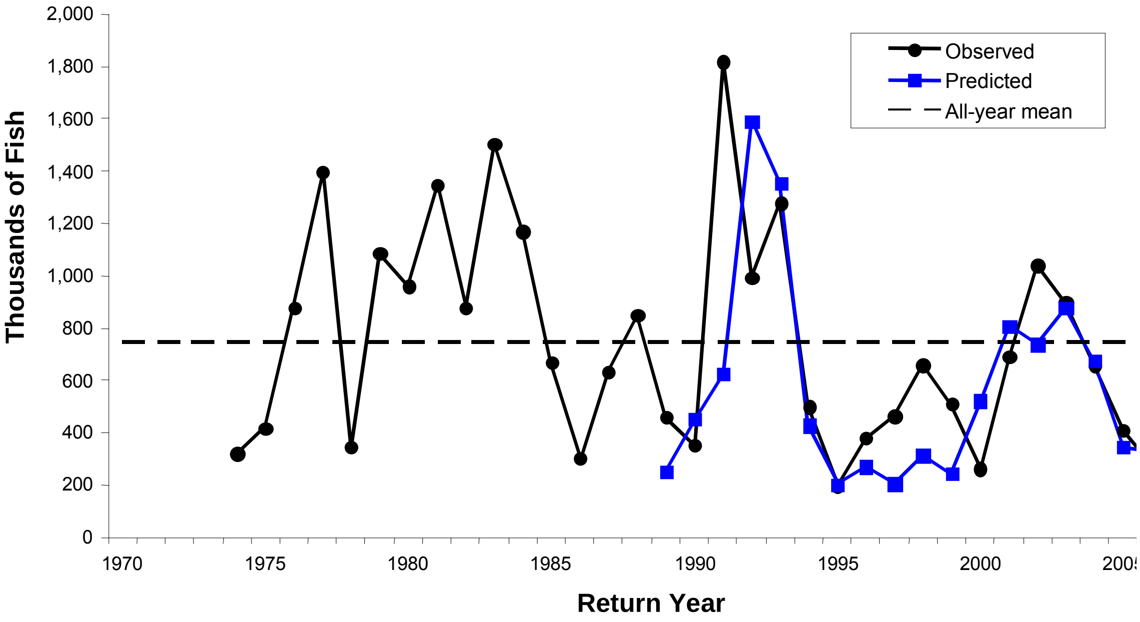


Figure A58. Returns and forecasts of Barkley Sound sockeye salmon 1974-2007.

Outlook for 2007 and beyond

In spring 2005, sea surface temperature anomalies at Amphitrite Point and the NOAA multivariate ENSO index were mainly positive (i.e. El Niño-like, DFO 2006). Consequently, 2007 returns of adult sockeye to Barkley Sound (Figure A58) and for several other salmon stocks (all WCVI origin sockeye stocks, Carnation Creek coho, Robertson Creek coho and Chinook) are expected to remain below average. By contrast, the shift to a weak La Nina state in winter of 2005 and the persistence of near average conditions throughout 2006 anticipate some improvement in survival for WCVI coho and sockeye migrating seaward in 2006 and returning as adults in either 2007 (coho) or 2008 (sockeye).

Central Coast – Queen Charlotte Sound

Rivers and Smith Inlet Sockeye Salmon: Returns may be lower than the current "stationary" forecast.

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 (Figure A59) forced their closure. Time series assessments permitting partitioning of freshwater versus marine production stages (Hyatt et al. 2000) and analyses by McKinnell et al. (2001) support the view that the mechanisms controlling Rivers and Smith Inlet sockeye declines were principally marine rather than freshwater in origin. Returns to Smith Inlet in 2006 were strongly sub-average and much lower than the pre-season forecast.

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 (Figure A57) appear to reflect signature effects of alternating El Nino and La Nina-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, 05-06 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 Figure A56). Given the low forecast of Barkley Sound sockeye returns in 2007 expected under a variable-state, survival model, it is likely that predictions of Smith Inlet returns in 2007, under a stationary model, are currently biased high.

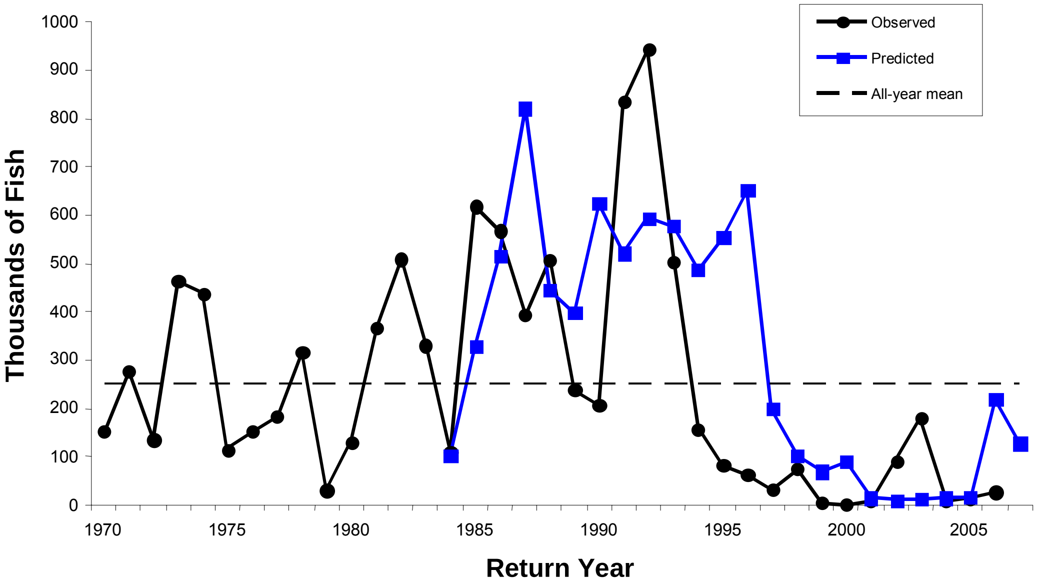


Figure A59. Returns and forecasts of Smith Inlet sockeye salmon, 1970-2007.

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Pacific Hake – Unusual Distributions in BC in 2006

Sandy McFarlane, Fisheries & Oceans Canada

Pacific hake are an important component of the west coast Vancouver Island ecosystem. They range throughout the California Current System from Baja California to the Gulf of Alaska. Their distribution and abundance are closely linked to oceanographic conditions in the NE Pacific. The biomass (typically over 1 million metric tonnes) is the largest of any species on the continental shelf and supports large domestic fisheries in both Canada and the U.S. An integrated acoustic and trawl survey has been conducted every three years or so since 1977 to assess their distribution, abundance and biology. No acoustic survey was done in 2006; instead we rely on catch statistics for information

On average between 250,000 and 500,000 tonnes of hake migrate into Canadian waters off the west coast of Vancouver Island in May/June and feed in the area until October. This large biomass can have dramatic impacts on resident species. For example, their predatory control of Pacific herring stocks in the area has been well documented (Ware and McFarlane 1995; McFarlane et al 2001).

Unusual juvenile and adult distribution patterns have been seen since 1994 along the US and Canadian coast. Juveniles spread northward through Canadian waters during the 1994-99 years of warmer waters. Evidence for this was found in the numerous age-1 fish (1997 year class) seen in the 1998 acoustic survey off Queen Charlotte Islands, far to the north of their traditional domain. Equally dramatic was the reduced occurrence of hake off Canada in 2000 and 2001. This southward shift correlated with cooler ocean conditions in 1999-2001.

In 2006, the distribution of hake again changed dramatically, even though oceanographic conditions appeared moderate. The biomass of hake entered the Canadian zone west of Vancouver Island in May and supported an early fishery. However, by early-mid June the majority of fish had moved to northern BC waters and the fishery in the traditional La Perouse area declined dramatically (Table 1; Fig A60, a b). Virtually no hake were found off the west coast of Vancouver Island from mid-June to mid-September and the fishery was prosecuted entirely in Queen Charlotte Sound. Hake reappeared off the Vancouver Island west coast in late September and supported a fishery until late October. It is at present unclear what conditions caused the dramatic change in distribution of hake during 2006; however it is likely related to changes in ocean conditions and food availability.

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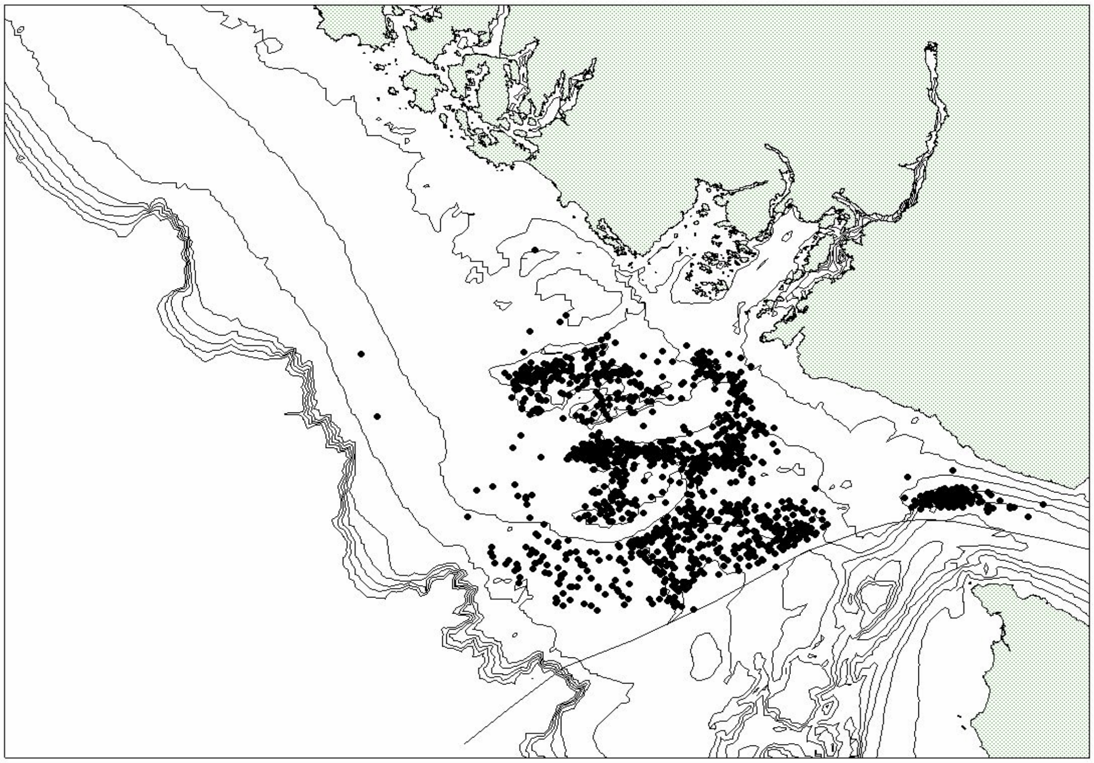
Table 1: Offshore hake catches (t) by month (May-Oct) in Area 3C (SWCVI) from 2002 – 2006.

Year	May	June	July	August	September	October
2002	328.1	10865.6	15589.3	9741.6	4286.7	1376.2
2003	212.0	12773.9	20493.1	13918.8	9783.0	1368.2
2004	4806.7	7793.1	7481.6	10575.1	10264.3	6227.1
2005	10045.0	13445.7	11506.9	16898.4	12012.8	5378.0
2006	2817.7	2494.4	846.5	0.8	1874.9	12857.6

a)



b)

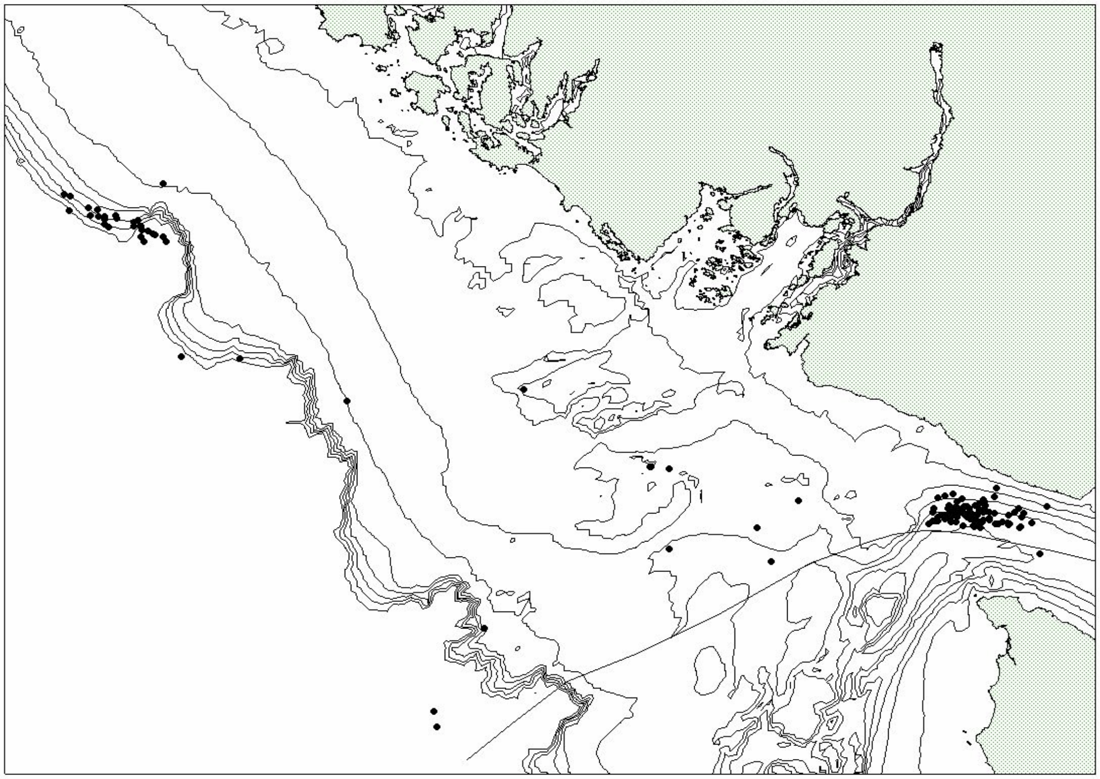


Fig A60: Hake catch location (June-Sept) a) 2005, b) 2006

Cool Ocean Conditions Return to Central Oregon in July 2006

Bill Peterson, United States National Marine Fisheries Service

Monthly averaged sea surface temperatures (SST) at the NOAA Buoy 46050 off central Oregon closely track the Pacific Decadal Oscillation (PDO), a good example of how the PDO is relevant to local conditions. There is a 4-6 month time lag between persistent changes in sign of the PDO and the pattern of SST off central Oregon (mid-1998, late 2002). After the PDO changed sign in November 2002, warmer than average temperatures persisted off central Oregon until June 2006. Beginning in July 2006, SSTs became cooler than normal. The "cool" pattern continues to persist into spring 2007.

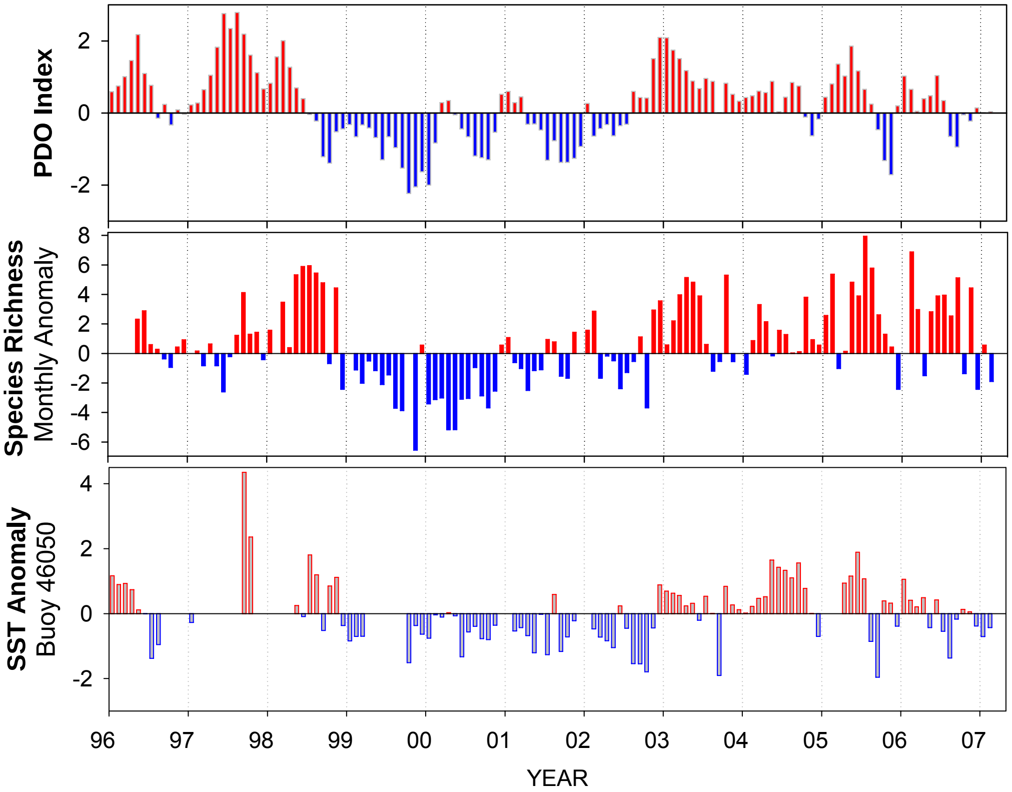


Figure A61. Time series of three related properties of Oregon waters and the North Pacific Ocean. The PDO (Top graph) is a measure of a dominant pattern of sea surface temperature (SST) variability over the entire North Pacific Ocean. Species richness anomaly (Middle) is determined from zooplankton sampling along the Oregon coast. SST anomaly (Bottom) is based on temperatures observed at NOAA weather buoy 46050.

The number of copepod species in zooplankton samples collected off Newport Oregon also tracks the SST and PDO. Higher-than-average numbers of species (known as "species richness") are found in samples collected off Newport when the PDO is positive and waters are warm, and vice versa. Positive PDO values are associated with weak coastal upwelling resulting in onshore transport of warm waters that normally reside off Oregon; negative PDO values may indicate a transport of cold species-poor sub-arctic water into the Oregon upwelling zone.

Preliminary indications from samples collected in winter/early spring of 2007 are that the copepod community is dominated by cool water species; *Pseudocalanus mimus* and *Calanus marshallae*. *Neocalanus plumchrus/flemingerii* appear to be unusually abundant.

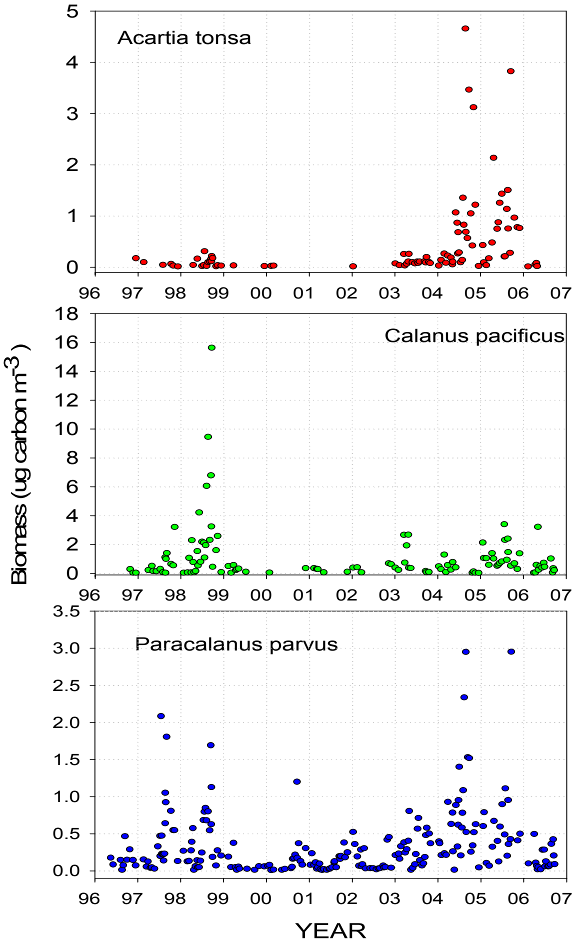


Figure A62. Biomass of three warmer-water zooplankton species in samples from waters of the Oregon continental shelf in summer.

A dozen or more warm water copepod species are found off Oregon during the winter months when the Davidson Current flows poleward. Two of these "warm water/winter-time" species, *Acartia tonsa* and *Paracalanus parvus*, appeared in Oregon's shelf waters in summer 2003, and seemed to establish year-round residence. Such a behavior has been seen in the past but only during the 1997-98 El Niño event. These two species became very abundant during the warm summers of 2004 and 2005, even more abundant than during the 1997-98 El Niño event. Their abundances dropped greatly during summer of 2006, signaling a return to cold water conditions.

One other prominent species that also occurs in most winters (and during El Niño events), *Calanus pacificus,* was also commonly found during the summers of 2003-2005. Unlike *A. tonsa* and *P. parvus*, *C. pacificus* persisted into the early summer of 2006. No individuals were found after mid-July, commensurate with the return of cold ocean conditions – SST anomalies became negative at the NOAA Buoy 46050 in mid-July 2006.

Long-Term Changes in Copepod Species Richness

Bill Peterson, United States National Marine Fisheries Service

One possible effect of global warming on plankton communities off Central Oregon may be an increase in biodiversity. Analysis of historical zooplankton samples collected off Newport shows that species richness averaged ~ 7 species during summer months and ~ 10 species during winter months, whereas since at least 1996, species richness has increased to an average of 9 species in summer and 13 species in winter. On many sampling dates in recent winters, species richness has been double that observed in the 1970s. The direct cause of the increase in biodiversity is not known, but the change is consistent with changes in bottom water temperatures at the mid-shelf off Newport: the average temperature has increased by 0.25°C since the 1960s. We hypothesize that the increased species richness in recent years is due to an increase in the transport of warm waters from offshore into the upwelling zone off central Oregon. An alternate hypothesis, that warmer waters favour warm water species, seems insufficient to explain differences since the waters have warmed by only a few tenths of a degree.

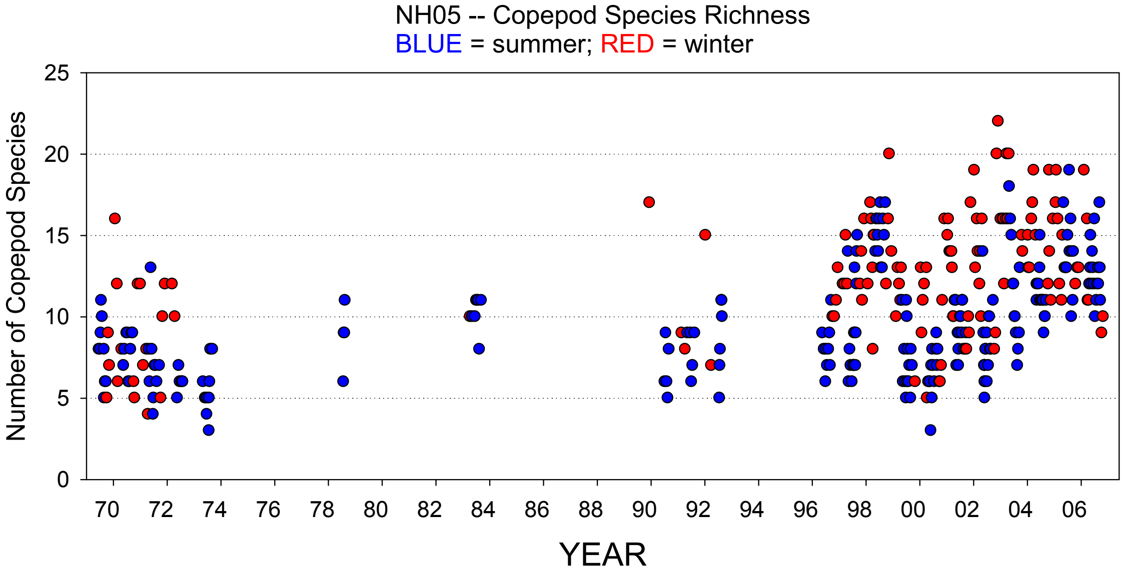


Figure A63. Plot of the number of copepod species collected in both summer and winter in samples at Sampling Station NH05 off central Oregon.

Coho Salmon in Shelf Waters off Washington and Oregon

Bill Peterson, Cheryl Morgan and Edmundo Casillas,
United States National Marine Fisheries Service

Juvenile salmonids are surveyed in June and September along eight cross-shelf transects extending from La Push Washington south to Newport Oregon. Transect spacing is ~ 30 nautical miles. The trawl is a NET Systems Nordic 264 rope trawl: mouth is 30 m wide by 20 m deep when fishing. Trawl mesh sizes range from 163 cm in the throat of the trawl near the jib lines to 8.9 cm in the cod end. To retain catches of small fish and squid, a 6.1 m long, 0.8 cm knotless liner is sewn into the cod end.

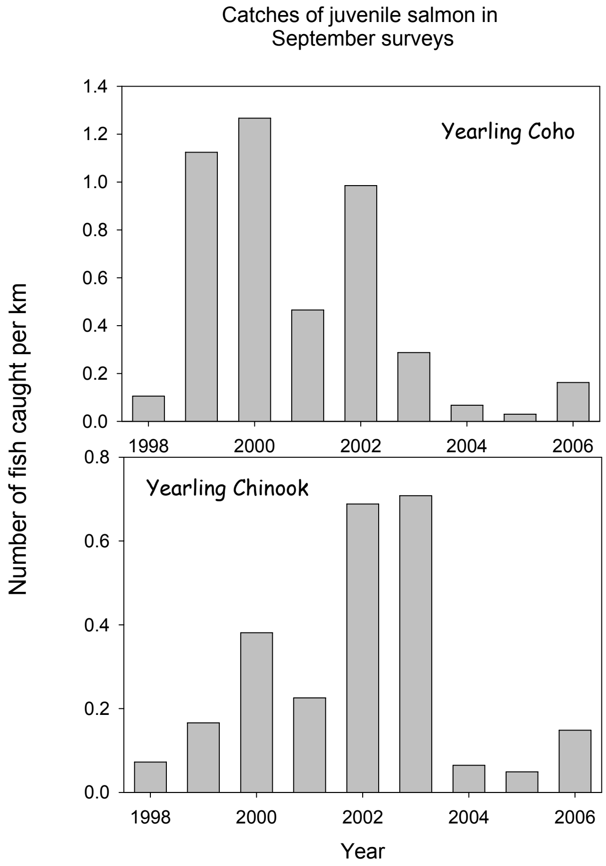


Figure A64. Catches of yearling coho (upper) and yearling chinook (lower) salmon during September surveys.

Note that the number of yearling coho salmon caught has been declining since 2003, and that yearling Chinook catches have been in decline since 2004. Catches in 2005 for both species were lower than catches during the monster El Niño event of 1998. A slight recovery was observed during summer of 2006.

We have also found that catches of coho in the September survey are positively correlated with the survival of hatchery coho salmon (Fig. A65). This result is similar to that reported in "State of the Ocean 2005", Figure 77, page 69. Such a result gives us the ability to forecast return of coho salmon to coastal rivers and the lower Columbia system one year in advance.

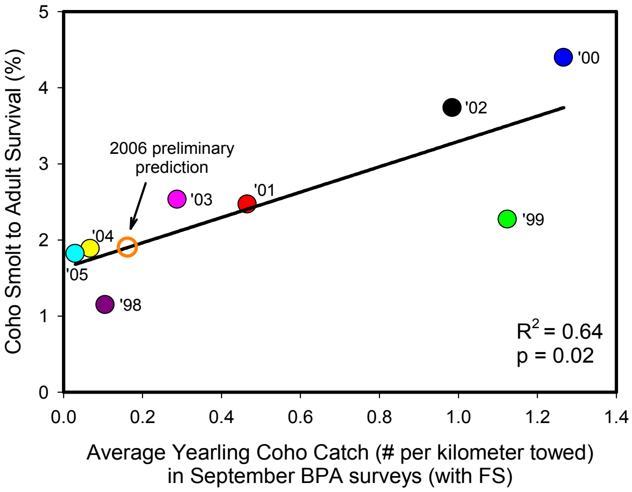


Figure A65. Comparison of the number of yearling coho caught per kilometre of net tow with the percentage survival of coho to adults.

Strait of Georgia: Continuing Warm in 2006

Diane Masson, Fisheries & Oceans Canada

The relatively warm conditions prevailing in the Strait of Georgia since mid 2003 continued into 2006. Figure A66 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 of 2006, colder intrusions brought down the temperature throughout the water column. However, relatively warm water subsequently entered the strait in late summer.

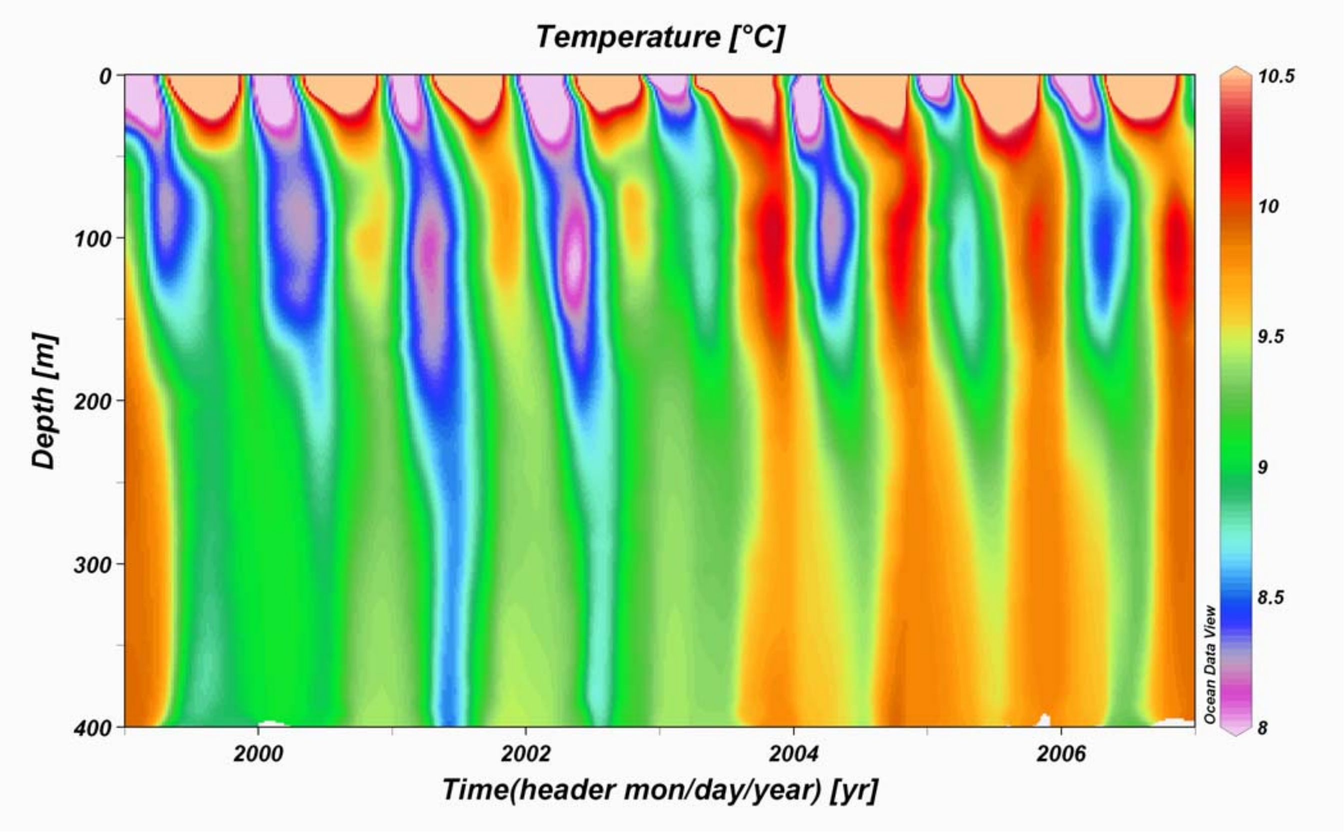


Figure A66. Contours of temperature (°C) at Nanoose station (central Strait of Georgia) since 1999.

Figure A67 on the next page gives the temperature of the deep basin (below 300 m depth) measured at the Nanoose station since 1999. Despite slightly lower summer temperatures following the cold spring intrusions, the deep basin has remained relatively warm in the past few years, with temperatures rising to 9.8°C in the fall. This deep-water annual maximum has been about the same since 2003, and is similar to the maximum values observed following the strong 1998 El Nino.

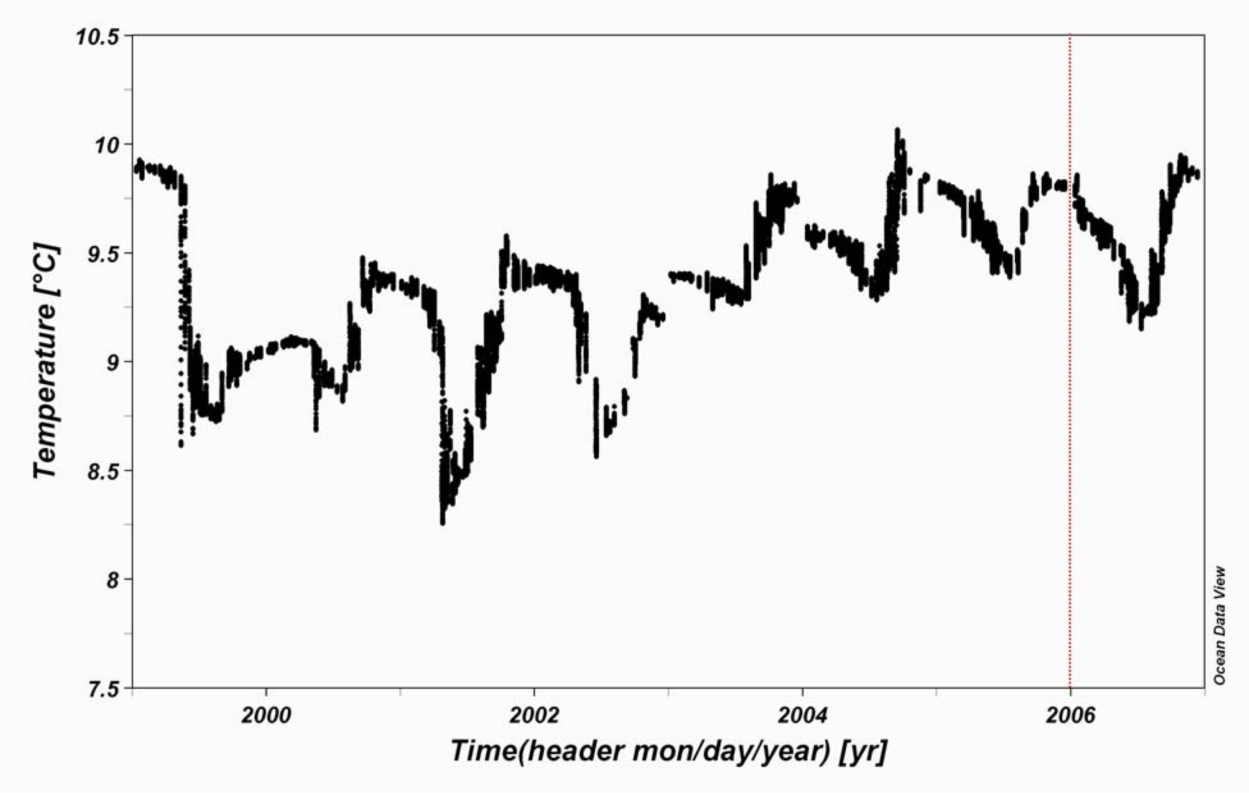


Figure A67. Temperature measured below 300 m depth at the Nanoose station.

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Fraser River Conditions: Record High Temperature, Record Low Flow on Many Days in Summer

John Morrison, Fisheries & Oceans Canada

In the Fraser River, high flows and warm water can be detrimental to the spawning success of sockeye salmon during up-river migrations to their spawning grounds. 2006 was an exceptional year in the Fraser River, with temperatures well-above average throughout the entire salmon migration season, with record daily high temperatures on nine occasions. In addition, flows peaked early (28 May) then fell rapidly to record or near-record lows which lasted until early November. Preliminary estimates of up-river mortality during 2006 suggest that summer and late-run sockeye were most severely affected, with mortalities above the long-term average but lower than the highest mortalities observed over the past 10 years.

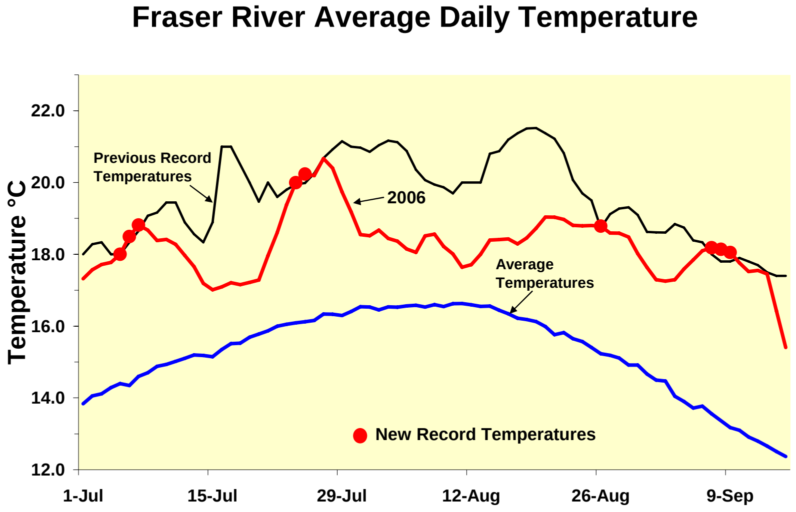

Figure A68. Fraser River temperature at Qualark, July 1 to September 15 2006

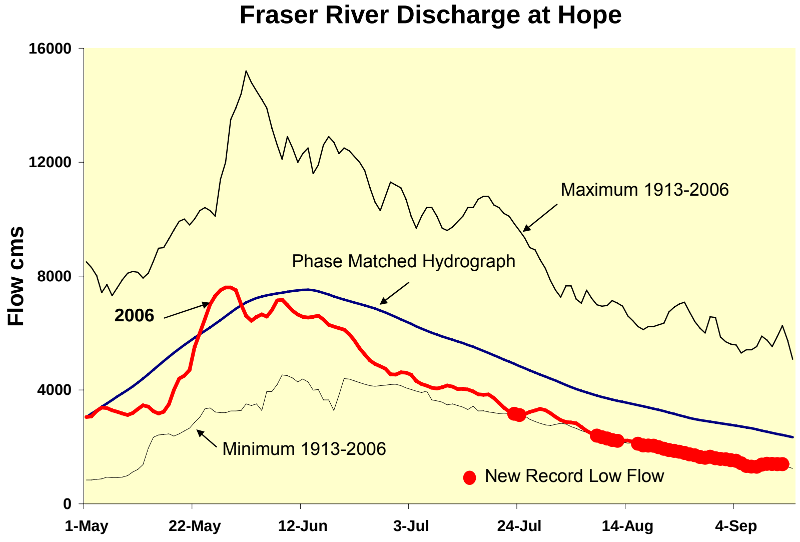

Figure A69. Fraser River discharge at Hope from May 1 to September 15 2006

Phytoplankton in the Strait of Georgia

Angelica Peña, Fisheries & Oceans Canada

Phytoplankton and nitrate are measured four times a year (April, June, September and November) along a 20-station transect in the Juan de Fuca / Strait of Georgia Basin (Fig. A70). The distribution of phytoplankton and nitrate concentration during 2006 were similar to those observed in previous years.

Figure A70. 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 A71, 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, an indicator of phytoplankton biomass, is higher and more variable in the Strait of Georgia sector than elsewhere in this region (Fig. A71). Seasonally, chlorophyll concentrations are highest during the spring bloom season (March-April), low during the summer, increasing again at the end of the summer/early fall, and lowest during winter.

Relative to previous years, surface chlorophyll concentrations in April and November of 2006 were lower at most stations (Figure A71). Otherwise, the distribution and concentration of chlorophyll was within the range of values observed in previous years. In comparison, surface nitrate concentrations in the Strait of Georgia during April of 2006 were higher than those measured in 2002-2004 but similar to those observed in 2005. At the mouth of Juan de Fuca Strait, nitrate concentrations in November were higher than those observed in the four previous years. At other locations, nitrate concentrations were similar to those observed in previous years.

The higher nitrate and lower chlorophyll concentrations observed in the Strait of Georgia in April of 2006 suggest a late start of the spring bloom during this year. However, because phytoplankton grow rapidly (exponential growth rates order 0.3-1 d^{-1}), its biomass can respond quickly to seasonal changes in solar radiation and water-column stratification. Therefore, frequent sampling is necessary to monitor changes in the time of the spring bloom, and our sampling frequency (four times per year) is not adequate to detect these changes. Numerous studies have shown that the timing of the spring phytoplankton bloom can significantly impact food web production and in particular the growth and survival of copepods and fish larvae.

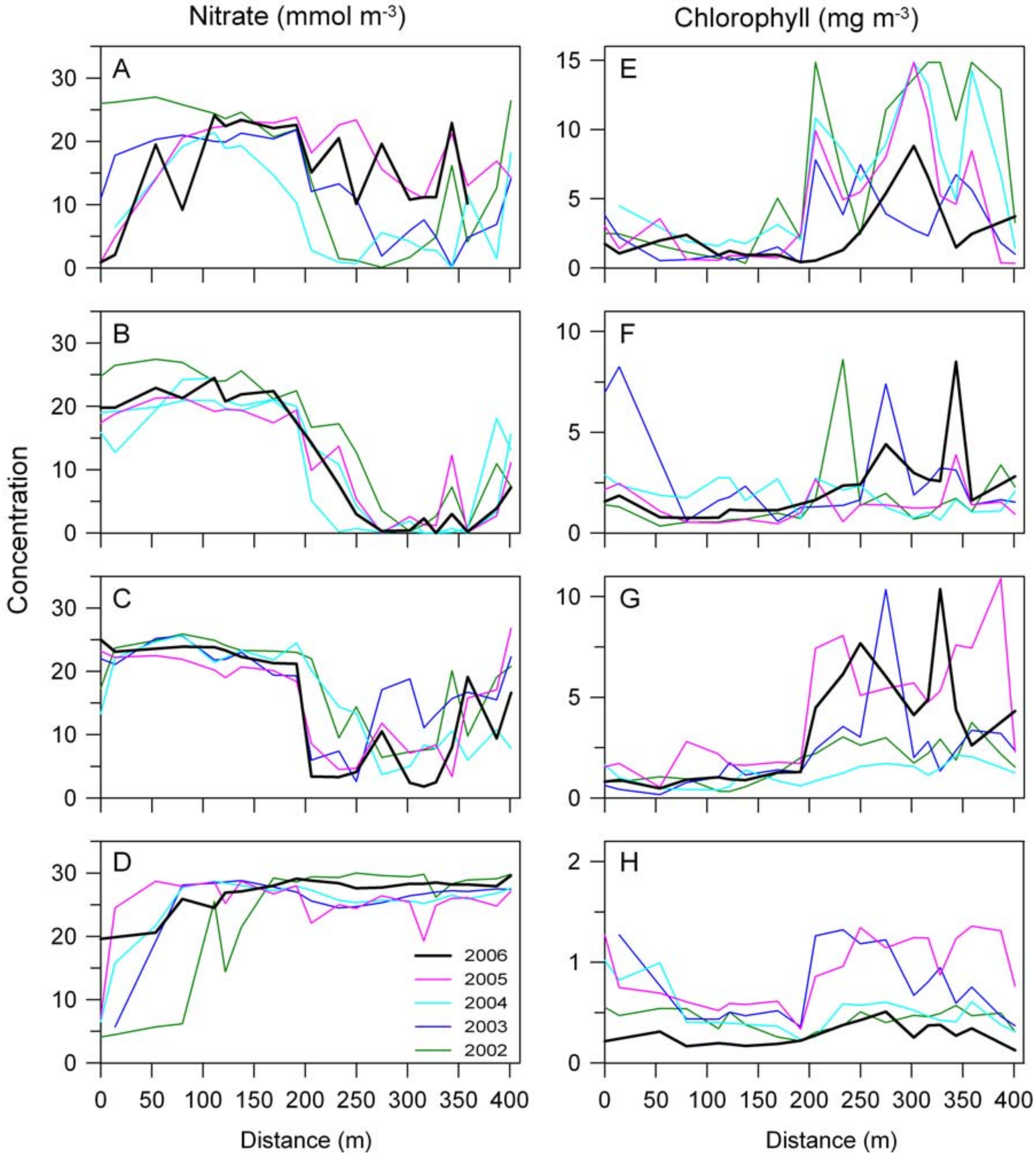

Figure A71. Surface concentration of nitrate (left panel) and chlorophyll (right panel) along a transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring (A and E), summer (B and F), fall (C and G), and winter (D and H) of 2002 to 2006.

Georgia Basin Salmon Forecasts for 2007

Richard Beamish, Ruston Sweeting and Chrys Neville,
Fisheries & Oceans Canada

In 2005 there was a very early discharge of fresh water from the Fraser River that resulted in a very early production of plankton, as observed in the satellite fluorescence imagery. We believe that this resulted in significantly reduced prey abundance for coho and chinook salmon that entered the Strait of Georgia later in the year, but which resulted in exceptional chum salmon survival because they enter the marine environment earlier in the year.

Juvenile coho catch per unit effort was the lowest in the 10 years in our 2005 survey, and we forecasted very poor returns in 2006. As most people now know, coho salmon returns to the Strait of Georgia in 2006 were extremely poor. Our catches of juvenile coho in our 2006 surveys were among the highest observed during our study, as was the overall size of the fish. Both of these point to a much improved survival for Strait of Georgia coho and we are forecasting a 2.0% survival in 2007 (See Figures A72 and A73).

The early prey production in the Strait of Georgia in 2005 should also affect chinook salmon returns in 2007 for stocks such as the Cowichan River that spend two winters in the ocean. Thus we forecast very poor returns of chinook salmon around the Strait of Georgia in 2007, in the order of 0.3-0.4%.

However, size of juvenile sockeye salmon in the 2005 July survey were the largest in 10 years, suggesting that they benefited from favourable ocean conditions. Our forecast is for an above average sockeye return year in 2007 for those stocks which transit the Strait of Georgia.

Because Strait of Georgia chum salmon early marine survival in 2005 was also very good, their return in 2008 should also be above average. There is no pink salmon forecast, as 2007 is an off year.

In the 2006 Strait of Georgia survey of juvenile coho, we continued to see a decline in the percentage of hatchery coho salmon and an increase in wild coho salmon (see Figure A74). The change in percentage occurred after the 1998 regime shift, probably because hatchery coho salmon are released at a constant date and wild coho salmon were entering the ocean earlier. Note that odd-year percentages are consistently higher than even-year percentages, indicating a density-dependent impact of juvenile pink salmon that is abundant in the Strait of Georgia in even-numbered years.

We also estimate abundance of juvenile wild coho salmon from our ship-based surveys. The estimated abundance in 2006 was equivalent to the high levels for the late 1970s. Thus, we forecast that wild coho salmon returns in the Strait of Georgia in 2007 may be the best in a decade, but overall marine survival will continue to be low.

In summary, in 2007 in the Strait of Georgia coho salmon returns should be the best in a decade with strong wild coho salmon returns. Chinook salmon returns should be poor. Sockeye salmon returns may have been affected by good early marine survival in 2005 but poor winter feeding conditions in 2005/2006. We suggest that marine survival will be above average, but that adult sizes may be small. Chum salmon returns in 2007 should continue to be strong.

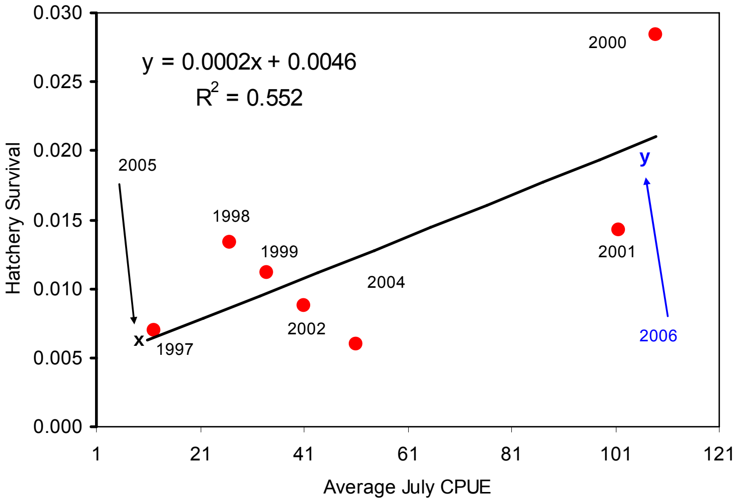

Figure A72. Forecast of Strait of Georgia coho marine survival for 2006-2007 ocean year, based on CPUE in July surveys.

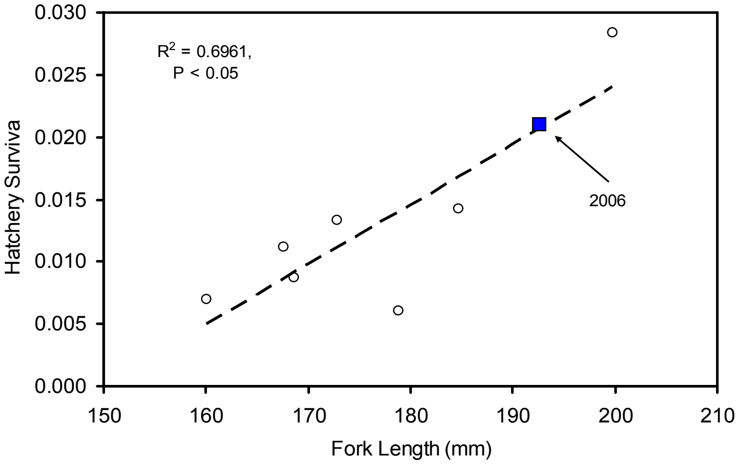

Figure A73. Forecast of Strait of Georgia coho marine survival for 2006-2007 ocean year, based on average fork length in July surveys.

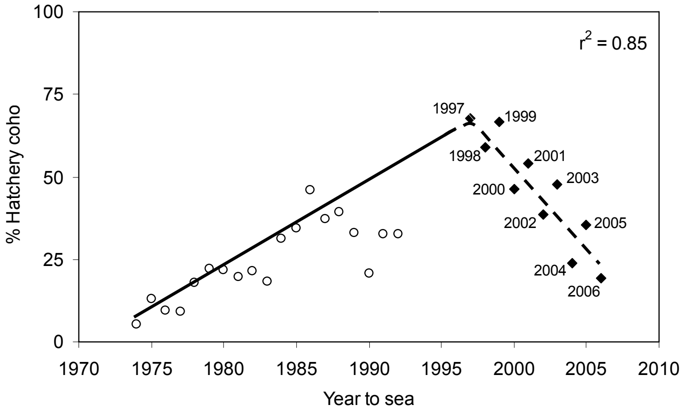

Figure A74. Percentage of Strait of Georgia coho salmon from Canadian hatcheries, September 1974-2006. Open circles are from Sweeting et al. (2003) and Kadowaki et al. (1995). The solid diamonds are from our study.

An experimental forecast of a possible regime shift in 2007 or 2008

Regimes and regime shifts are generally accepted phenomena by most scientists studying the dynamics of fish populations in the North Pacific and North Atlantic. The best known regime shift was in 1977 and it profoundly changed the dynamics of a number of key species in the major fisheries off the west coast of North America. The last regime shift was in 1998 and as they recently have occurred on almost-decadal frequencies, another change should occur soon. The Aleutian Low Pressure System dominates the winter and spring atmospheric circulation in the North Pacific. Changes in the trend of the Aleutian Low affect recruitment of a number of species including Pacific salmon. There are several indices of the trends in the Aleutian Low. All indices record impacts and all show regimes and regime shifts. One index is based on the area of intense winds, but an index could also be based on energy as stronger winter winds require energy to strengthen these winds. We use seasonal and annual trends in energy flow among the rotating shells of the planet (atmosphere, hydrosphere, solid earth and liquid core) to forecast when a regime shift might occur. The energy to intensify the Aleutian Low must come from one of these rotating shells and because energy is not lost or gained, a change in the velocity of one shell can be detected in the rotation of another shell. We use the rotation of the solid earth or length of day (LOD) as the index of energy transfer. Both the 1989 and 1998 regime shifts were associated with a shift in the pattern of the seasonal LOD and a preceding change in the average annual LOD of about two years. There was a change in the annual LOD in 2005 resulting in a slowing down of the solid earth. We are watching the seasonal pattern and if the patterns are similar to the previous two regime shifts, we expect to see a change in the seasonal LOD about two years after the annual trend changed or this fall or next fall. Predicting regime shifts is vital to fisheries management as the major cause of overfishing is excessive fishing mortality after a major decline in the ocean productivity supporting the recruitment of a particular species. We are confident that it is possible to predict regime shifts and this information will greatly improve managers' ability to work with fishermen to be precautionary.

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The Reliability of Fraser River Sockeye Forecasts

Alan Cass, Pacific Science Advice Review Committee

Pre-season forecasts of the abundance of Fraser River sockeye salmon are used to set harvest expectations for fishers and are used by management for planning and conducting fisheries. Fraser sockeye forecasts are also an international obligation of Canada under the Canada-US Pacific Salmon Treaty. The pattern of returns varies among stocks and many of the large nursery lakes in the Fraser watershed show persistent 4 year cycles in abundance (Figure A75). Forecast models have two key inputs: 1) estimates of abundance of one or more life stage (i.e. spawners, juveniles and returning adults), and 2) assumptions or indices of survival of the fishable population. A fundamental assumption is that uncertainty in future survival is captured in the historical data and in an underlying model that relates the abundance of one life stage to another. Estimates of spawning escapement are the core biological predictor of annual returns for most stocks. Stock-recruitment models (i.e. Ricker model) that predict returns from escapement have been the primary forecast tool. Juvenile data exist for a small number of populations, most notably for Chilko Lake sockeye. Pre-season forecasts can be highly uncertain. Sea surface temperature (SST) and Pacific Decadal Oscillation (PDO) data have been included as proxies for environmental impacts on Fraser sockeye survival but with limited success.

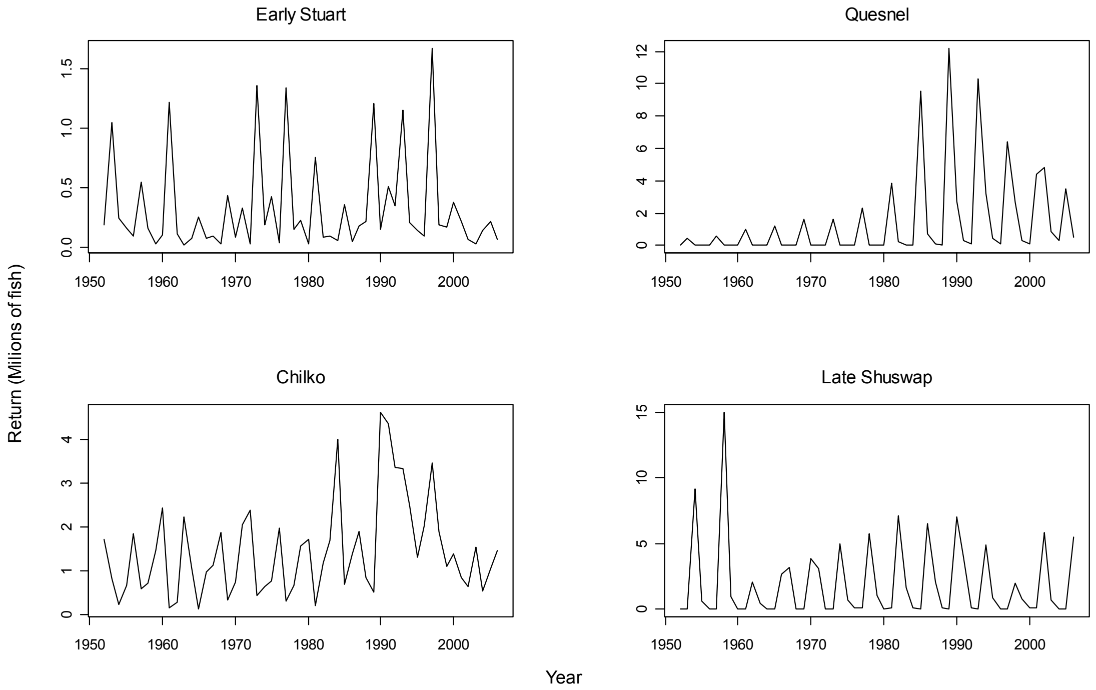

Figure A75. Estimated returns (1950-2006) for four Fraser River sockeye stocks. Note the persistent 4-year cyclic pattern for Quesnel and Shuswap Lake populations that is characteristic of many of the large lake rearing systems in the Fraser River. Returns in 2006 are preliminary.

Trends and correlations in density-independent survival indices among stocks

Twelve key Fraser sockeye populations, each with time series of spawner abundance and adult recruitment data back to the early 1950s, were used to assess density-independent survival and determine the correlation in survival among populations. The purpose of the assessment is to evaluate the degree to which wide-scale environmental factors could affect sockeye productivity and therefore the reliability of forecasts. The populations used in the analysis are two run-timing populations that spawn and rear in the Stuart basin in the upper Fraser watershed (Early and Late Stuart), Bowron Lake, Stellako Lake, Quesnel Lake, Chilko Lake (including smolts), Late Shuswap Lake, Pitt Lake, Seymour River, Raft River, Birkenhead and Harrison River sockeye.

A Larkin model with log-normal error was used to estimate a density-independent survival series for brood years 1952-2002 after accounting for spawning density effects in the brood year and also for delay-density effects in the preceding three brood years (Walters and Staley 1987). A time series of density-independent survival indices is then represented by the residuals in log space. These are plotted in Figure A76. The smolt-to-adult series for Chilko sockeye are also included for comparison. The Chilko smolt data exclude spawner-to-smolt survival effects present in the other data sets.

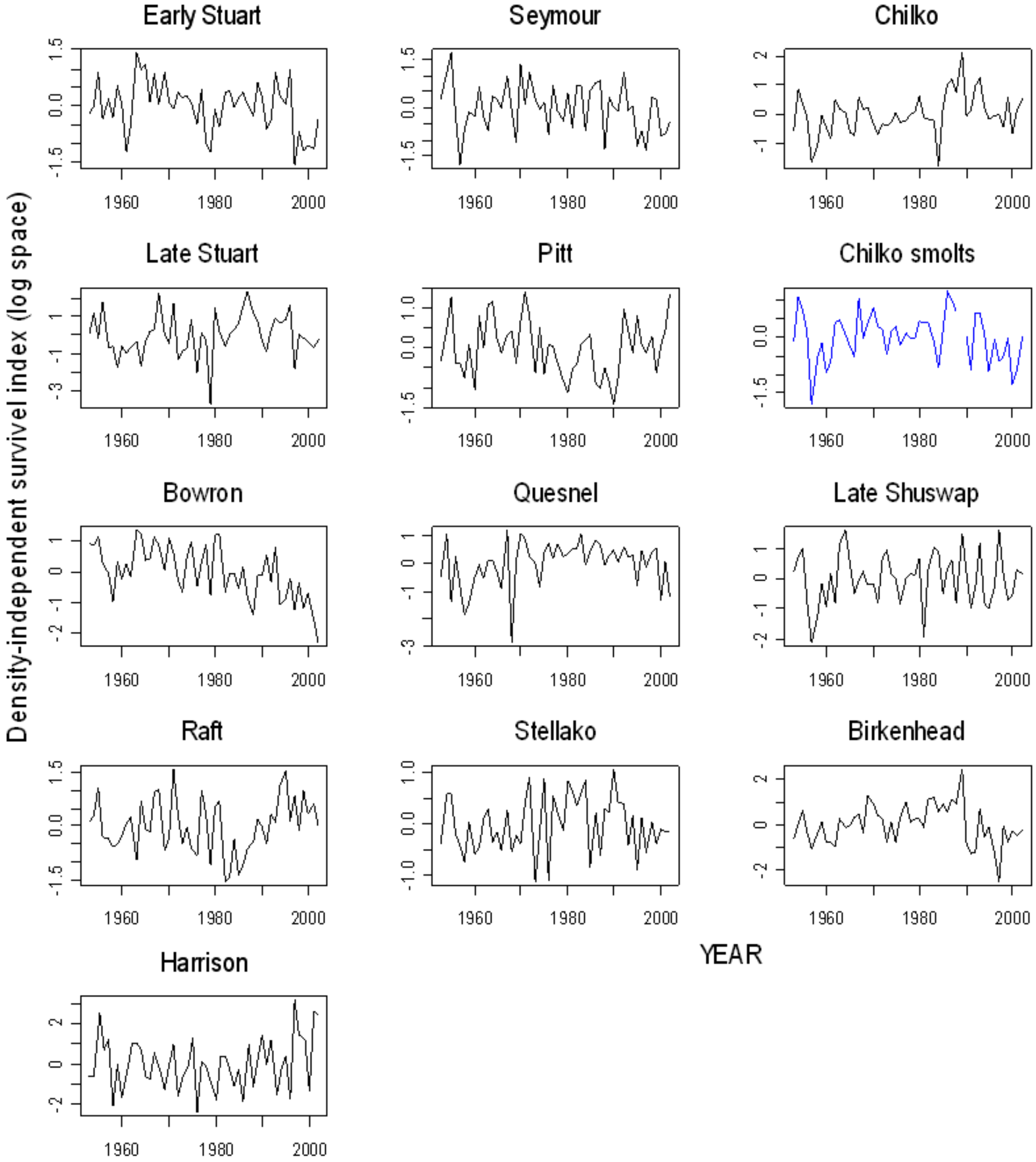

Figure A76. Time series of spawner-to-adult survival indices for key populations of Fraser sockeye by brood year (1953-2002) based on residuals from a Larkin spawner-recruitment model. The plot titled "Chilko smolts" is the smolt-to-adult survival anomaly for Chilkio sockeye smolts.

Figure A76 shows that density-independent survival has been highly variable since the early 1950s but with some coherence among most populations. For example, low survival early in the series is evident for most populations. A recent decline in survival since the late 1990s is also evident for some but not all populations. This coherence among populations is further illustrated in pair-wise scatter plots in Figure A77. The correlation is weak, with an average comparison of 0.15, and positive for 23 of 28 among-stock comparisons (82%). A weak and statistically positive correlation in survival is also consistent with the conclusions of Peterman et al. (1998).

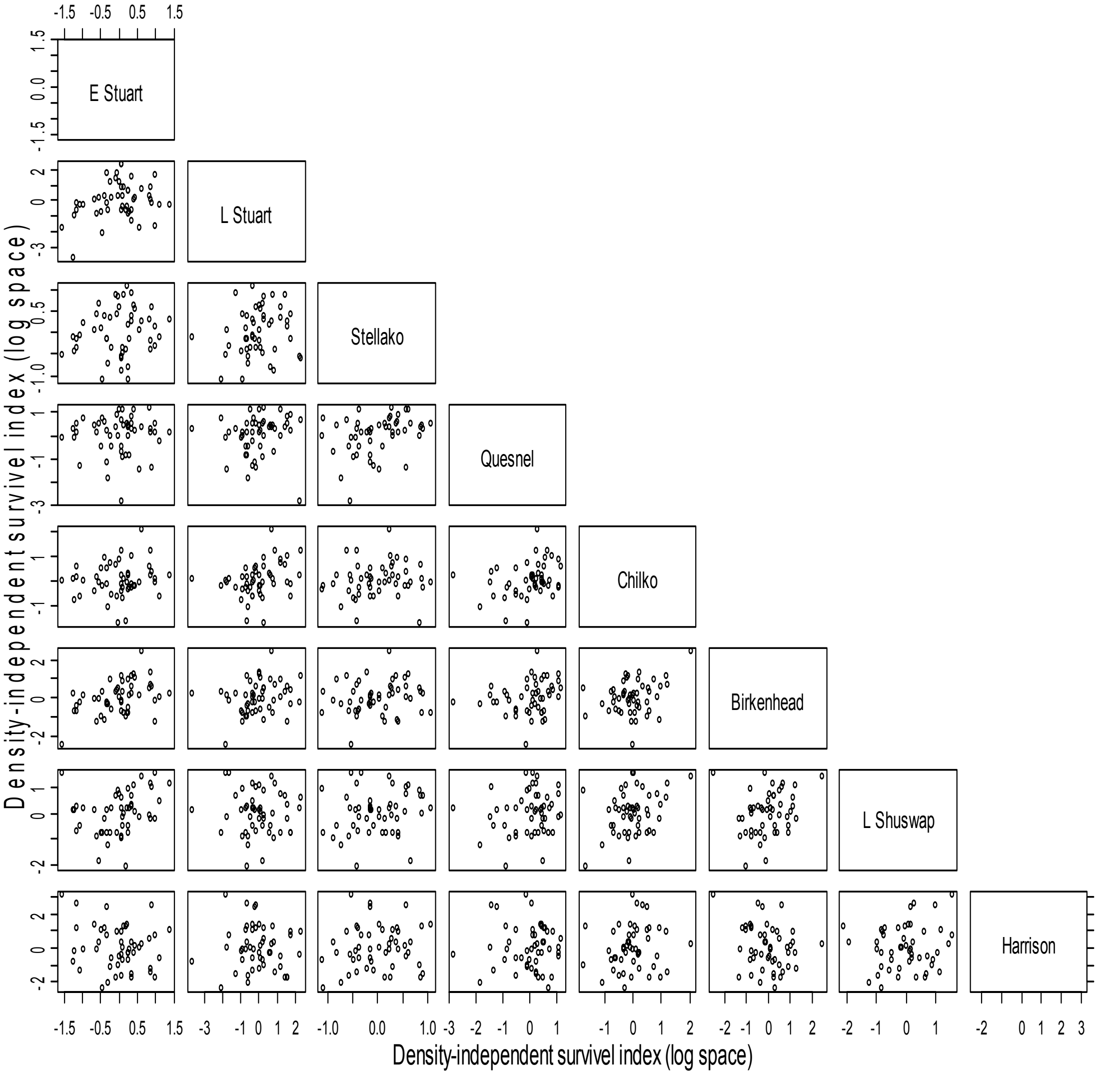

Figure A77. The correlation in survival among key Fraser River sockeye populations. Note the high degree of scatter and weak positive correlation among populations

Conclusions

The weak but positive correlation in survival among populations indicates that a small amount of the variation potentially could be explained by broad-scale environmental factors. The biological response to basin-wide environmental forcing could also be non-linear in its effect on different populations via other biological factors (i.e. smolt size/growth; migratory timing and distribution). Attempts to improve the reliability of Fraser sockeye forecasts using hierarchical models to model common among-population patterns in survival have not proven fruitful for Fraser sockeye (Cass et al.2006) or pink salmon (Haeseker et al. 2005) largely because of the high and unexplained within-stock variation in survival.

References

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Haeseker, S.L., R.M. Peterman, Z.Su and C.C. Wood. 2005. Retrospective evaluation of pre-season forecasting models for pink salmon. North Am. J. Fish Manag. 25: 897-918.

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Expectations for Marine Survival of Chilko Lake Sockeye Returning in 2007

Skip McKinnell[3], North Pacific Marine Science Organization

> "...it is evident that if we had some accurate method of determining from year to year the number of fish on the spawning grounds, this would afford data for prophecy..."
> Charles H. Gilbert, 1922, Professor of Zoology, Stanford University on contract to Govt. of B.C.
>
> *"The futility of predictions from year to year is evident."*
> W.A. Clemens, 1927, Director of the Pacific Biological Station

An oft-cited but rarely tested hypothesis says that the state of the ocean during the first year at sea has a greater influence on the survival of a cohort of salmon in the sea than other periods. The logic is reasonable because the total abundance of a cohort at sea is greatest during ocean entry year, and if even minor fractions of that mortality could be deferred until adulthood, greater returns to the fishery would materialize. For the most part, all that is known about the mortality of Fraser River sockeye salmon at sea is the final outcome for one stock, Chilko Lake, after 26 months at sea (Figure A78). For most of the stocks, only the total mortality (freshwater and marine) has been estimated.

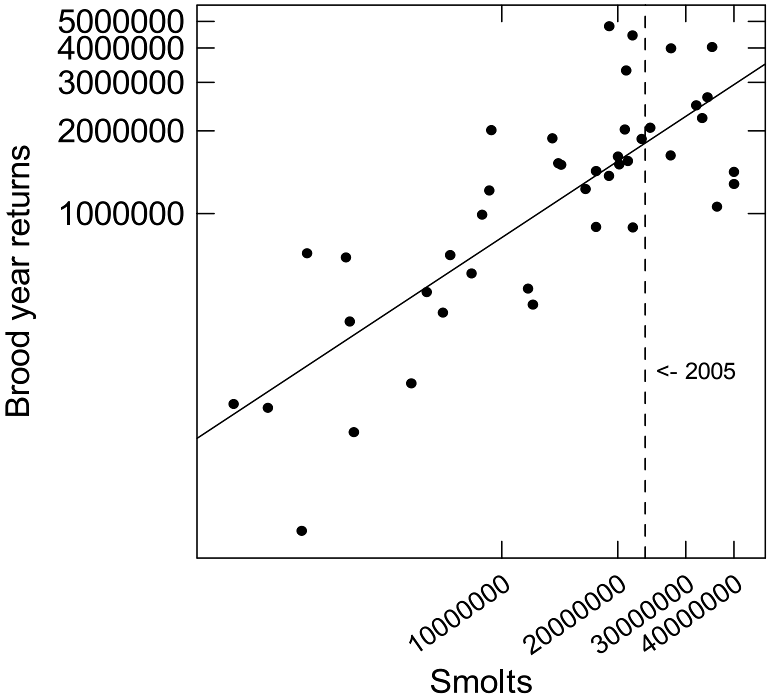

Figure A78. Brood year returns versus smolt abundance of Chilko Lake sockeye salmon on logarithmic scales. The vertical dashed line is the estimated number of smolts leaving Chilko Lake in 2005. Assuming average marine survival, the returns in 2007 will be about 1.7 million (approximately the DFO forecast) but evidence against average returns is good.

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[3] The views expressed in this document are the author's, not his employer's.

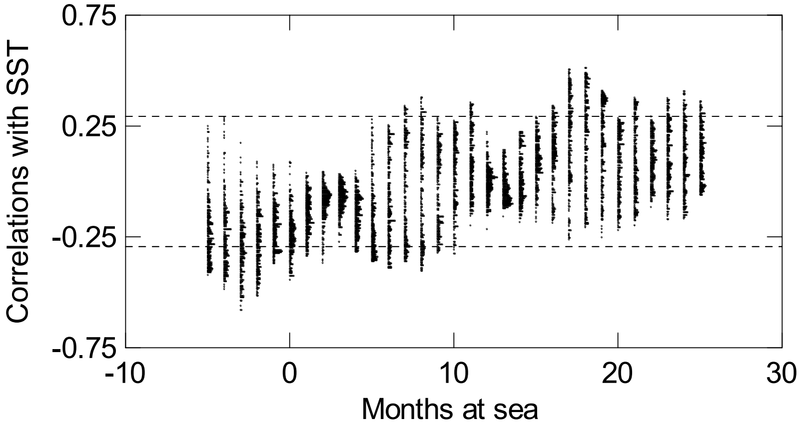

Figure A79. By month, correlations between average monthly SST at each point on a 2°x2° lat/long grid in the Gulf of Alaska with annual marine survival (√ transformed) for Chilko Lake sockeye salmon (1952-2002 brood years). The period of interest corresponds approximately with the ocean life of an age 1.2 sockeye. Negative months at sea are SSTs in months before ocean entry. The horizontal dashed lines indicate a magnitude required to reach statistical significance (α= 0.05) with 43 years of observations. Not all years were observed between 1952-2002 so the sample size is smaller than 51.

Sea surface temperature (SST) is often used as a simple index of the outcome of many interacting variables that are responsible for changing the characteristics of the upper ocean from month to month and year to year. If the monthly average SST anomalies at each grid point on a 2° latitude by 2° longitude grid for the entire Gulf of Alaska (north of 40°N, and 170°W to the coast) from the NOAA Extended Reconstructed SST data are correlated with the annual estimates of marine survival for Chilko Lake sockeye salmon at lags from 5 months prior to ocean entry until age at maturity 2 years later, statistically significant correlations (α=0.05) are evident. The correlations are largely negative (max. -0.58) during the smolt year and positive (max. 0.51) during return year (Figure) with largest positive median values appearing during the winter of the return year and greatest negative correlations appearing in the early spring of ocean entry. Of the 7719 correlations calculated, 1270 are individually statistically significant (16.5%). While the correlations tend, on average to be low, their evolution through time is certainly not random. If this pattern is based on a real connection between physics and biology, it suggests that increased survivals are 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.

The greatest negative correlations of SST with marine survival of Chilko Lake sockeye salmon appear in the spring before ocean entry in the central Gulf of Alaska (A80). This region is centred to the northwest of Station Papa (50°N 215°E). There is no strong connection between coastal SSTs (where the sockeye are found during early marine life) and survival to adult when measured over the entire record of observations. The challenge is to determine if there is a physical connection between the state of the Gulf of Alaska 3 months before the fish enter the sea and survival to adult. The region of greatest positive correlation of SST with marine survival of Chilko Lake sockeye salmon appears in early winter (November/December) and is distributed broadly across the Gulf of Alaska at latitudes just southward of where most Fraser River sockeye salmon are located in the spring prior to their spawning migration (McKinnell 1995). Survival tends to be better in years when the return year is warmer in the Gulf of Alaska (Figure A81).

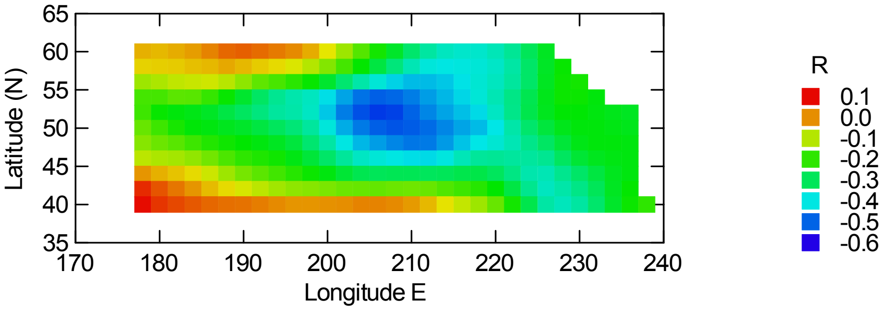

Figure A80. Correlations between surface ocean temperature in the Gulf of Alaska in March of ocean entry year with marine survival of Chilko Lake sockeye salmon. The legend indicates the correspondence between colour and correlation. Correlations < -0.3 are statistically significant.

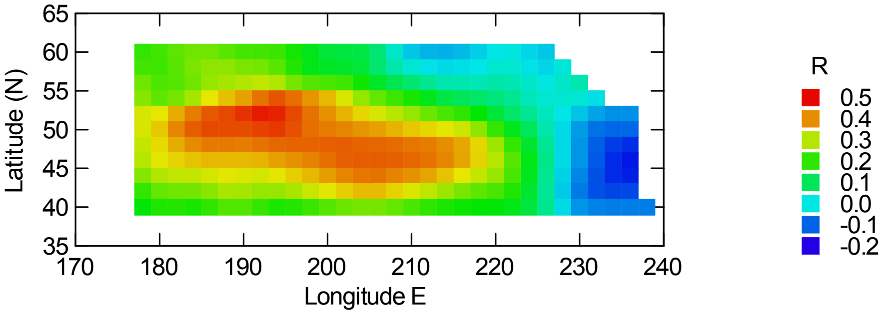

Figure A81. Correlations between surface ocean temperature in the Gulf of Alaska in the November before returning to spawn with marine survival of Chilko Lake sockeye salmon. The legend indicates the correspondence between colour and correlation. Correlations > 0.3 are statistically significant.

Expectations for 2007

If there is more than a coincidental association of Chilko Lake sockeye salmon with Gulf of Alaska surface ocean temperatures over the last 50 years, it appears that the 2003 brood year has faced the opposite of temperatures that are associated with better survival. Chilko Lake sockeye salmon that will return in 2007 went to sea in 2005, one of the warmest winters in the Gulf of Alaska in the last 25 years (Figure A82) and “Warm Out” years are negatively correlated with survival.

Furthermore, the average SST anomaly for the entire Gulf of Alaska for December 2006 – March 2007 has been the third coldest since 1983 (Figure A82). “Cold Home” years are associated with poorer marine survival. This pattern suggest that the marine survival of Chilko Lake sockeye salmon returning in 2007 will be less than average because the Gulf of Alaska is cool and perhaps will stay that way.

The large scale SST patterns in the North Pacific, as indicated by the first and second empirical orthogonal functions do not tend to oscillate rapidly between months and they are currently in a pattern that is associated with cooler temperatures in the Gulf of Alaska (Figure A83).

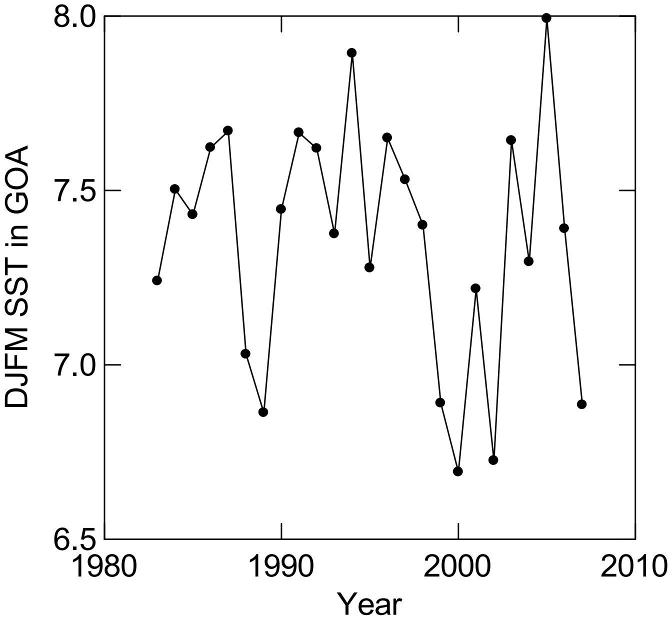

Figure A82. Average December-March sea surface temperature in the Gulf of Alaska, 1983-2007

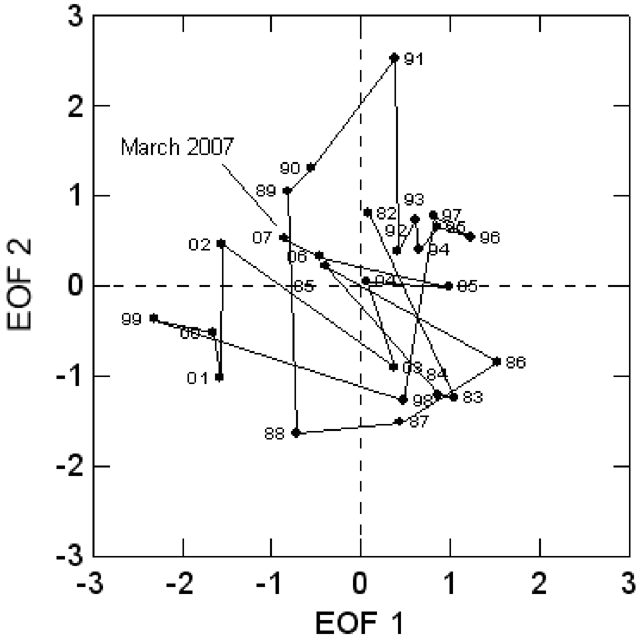

Figure A83. EOF phase plot from an analysis of March SST data only (1982-2007). EOF1 in March is associated with the PDO and EOF2 with the Victoria Pattern. Changes in the last 2 years are largely on the PDO mode.

Georgia Strait coho indicator

The annual survival of Strait of Georgia coho salmon indicator stocks are weakly but significantly correlated with the survival of Chilko Lake sockeye salmon that went to sea during the same year (Figure A84). As of the 2003 ocean entry year, both were in the lower left quadrant of the survival domain of Figure A84. The value of this relationship is that the coho return one year earlier than Chilko Lake sockeye so it can be used as a leading indicator if there is a significant relationship, which there is ($P < 0.01$). Perhaps the most significant point of this plot is that the preliminary (not all hatcheries reporting yet) average Strait of Georgia coho survivals were the lowest on record for coho salmon that went to sea in 2005.

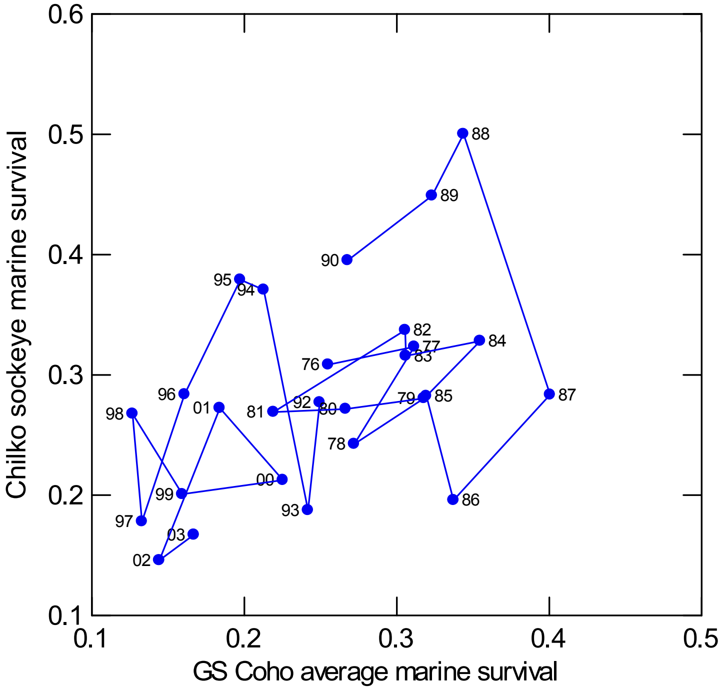

Figure A84. Chilko Lake sockeye salmon post-smolt survival versus average Strait of Georgia coho survival. Survivals are √ transformed, Ocean entry year is indicated on the plot point labels. R-squared = 25%, P<0.01) assuming there is no uncertainty in the survival estimates. The preliminary estimate of average survival of GS coho that went to sea in 2005 is 0.4% (=0.064 on the abscissa which is off the scale of this figure).

A forward-stepping multiple linear regression of Chilko Lake sockeye salmon marine survival on average coho salmon survival of the equivalent smolt year and all lagged monthly SSTs generated the following model fit to the data:

Survival= 0.056 – 0.077 × GOASST(6) + 0.124*GOASST(20) + 0.423 × Coho_survival (y-1).

GOASST is the average SST in the Gulf of Alaska after (n) months at sea. In this case the selection was SST in December of ocean entry year and February of the return year. R-squared was 51.4% (P<0.01). All survivals were square-root transformed. Plugging the 2005 ocean entry data into this equation, back-transforming to get marine survival as a percentage, and multiplying by the Chilko Lake smolt count in 2003 produced an estimate of 560,000 sockeye (95% chance in the range 30,000 – 1.8 million, 50% chance in the range 200,000 to 1.1 million). While the 95% interval estimate includes the DFO pre-season forecast of 1.7 million returns, the expectation from this model is much lower. Projecting from the abundance of smolts that went to sea in 2005, it seems more likely that the returns to Chilko Lake will be less than 1,000,000 rather than more and perhaps significantly less (Figure A84). As the correlations with SST are rather weak, and this forecast is untested, it is difficult to offer this with a lot of conviction. Neverthless, there were new predators in BC and Alaskan waters in 2004/05, such as the large Humboldt squid, along with all of the other unusual physics and biology that occurred; most of which would not be good for salmon survival. The coho salmon returns last year may be a harbinger of how bad.