



## STATE OF THE PACIFIC OCEAN 2008



### 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 U.S. fisheries and climate scientists.

## SUMMARY

- This report summarizes highlights from the tenth in an annual report series updating the state of physical, biological, and selected fishery resources of Canadian Pacific marine ecosystems. Canadian Pacific marine waters lie in a transition zone between coastal upwelling (California Current) and downwelling (Alaskan Coastal Current) regions, and experience strong seasonality and considerable freshwater influence. Variability is closely coupled with events and conditions throughout the tropical and North Pacific Ocean, experiencing frequent El Niño and La Niña events particularly over the past decade. The region supports important resident and migratory populations of invertebrates, groundfish and pelagic fishes, marine mammals and seabirds. Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by a number of government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. Support for these programs is provided by Fisheries and Oceans Canada, Environment Canada, and various other agencies.
- Despite continuing increases in overall global water temperatures, the waters off the Pacific coast of Canada were the coldest in 50 years, and the cooling extended far into the Pacific Ocean and south along the American coast. Near-shore temperatures dropped as well, as did temperature in deep waters of the Strait of Georgia. Only the surface temperatures in the Strait of Georgia remained at or above normal. This cooling is associated with weather patterns typical of La Niña and of the local cold phase of the Pacific Decadal Oscillation (PDO).
- Surface phytoplankton and zooplankton concentrations were the highest in a decade of observations across the Gulf of Alaska in August and September 2008. The cause is as-yet uncertain, but injection of iron by winds or currents is suspected (Iron is a limiting nutrient in this region), along with higher levels of nitrate and silicate in spring. Ship-based sampling for phytoplankton in Juan de Fuca Strait revealed high near-surface concentrations in early September. Deep-sea and coastal zooplankton populations continued their recent shift to cold-water species and delayed spring blooms.
- In the Gulf of Alaska, the ocean mixed-layer depth was relatively deep in early 2008, and surface oxygen concentrations were relatively high in early 2009. However, oxygen concentrations have generally declined in deep waters along the continental slope over the past several decades. A sudden decline in bottom-water oxygen concentration in 2008 on the continental shelf was likely due to denser water with naturally low oxygen levels moving up onto the shelf in this year due to anomalous winds and currents. This oxygen drop may have been a factor in the movement of some groundfish species to shallower depths in 2008.
- Cool marine conditions generally improve marine survival for salmon. However, despite relatively cool ocean conditions in 2007 and 2008, many BC populations remain depressed due to low numbers of brood-year spawners, partially attributed to warm oceans in 2003 to 2005. Sockeye returns remain generally low coast-wide, with one notable exception being Okanagan sockeye that returned in record numbers in 2008. High pre-spawn mortality was observed for many Fraser River watershed sockeye populations in 2008, and river entry of returning adults was generally early. Coho populations in southern BC remain extremely depressed, while northern coho populations have improved. For chinook, the situation is somewhat reversed – northern populations continue to decline while the status of southern chinook is highly variable.
- Classification of salmon marine survival expectations based on a “weight of indicators” approach continues to show promise. In general, survivals of coho and sockeye that

went to sea in 2008 are predicted to be at average to above-average levels, meaning improved coho returns in 2009, and sockeye in 2010, relative to brood year strengths. One possible exception is Strait of Georgia coho.

- Herring biomass has declined recently for all five major BC stocks. In the Georgia Basin where herring biomass was at record high levels earlier this century, the biomass declined almost to the fishery-closure limit in 2008. Three other Canadian herring stocks were at or below the fishing limit. Eulachon populations remain depressed. Although there was no wide-scale hake survey in 2008, their numbers on the BC continental shelf, particularly on the traditional fishing grounds around La Pérouse bank, appear to have been very low, continuing a trend that began developing around 2003-04. Smooth pink shrimp and English sole along the west coast of Vancouver Island increased in numbers in 2008.
- For many of our fish species including salmon, Pacific Ocean conditions have been improving since the extremely poor year of 2005. Cool water generated bottom-up changes to the food web that have contributed to improving marine survival for many juvenile fish. Linkages between ocean conditions and fish survival are not completely understood and additional exploration of existing data is warranted.

## INTRODUCTION / BACKGROUND

This year marked the 10<sup>th</sup> year that the Fisheries Oceanography Working Group (FOWG) met to review the state of the ocean and its marine life. About 50 scientists met at the Institute of Ocean Sciences (IOS) in Sidney, BC on 17-18 February 2009 for presentations on the state of the ocean and its marine life in 2008 and early 2009. The meeting was chaired by Jim Irvine and Bill Crawford, both of Fisheries and Oceans Canada. They subsequently produced this report based on contributions by participants. A new contribution this year is a summary of a counterpart report by American scientists on ocean and marine life in Alaskan waters.

This summary report describes the 10 top stories from the 2008 review of resources of Pacific Canadian marine ecosystems:

- [Cooler ocean in 50 years in northeast Pacific](#)
- [Record high plankton numbers in the Gulf of Alaska](#)
- [Stronger flow in North Pacific Current](#)
- [Spreading hypoxia in deep waters along the west coast](#)
- [High survival for juvenile salmon, seabirds and sablefish off Vancouver Island](#)
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- [Indicators for 2009 salmon returns in the Georgia Basin](#)

## ASSESSMENT AND CONCLUSION

### Coollest ocean in 50 years in the northeast Pacific

Waters off the Pacific coast of Canada were the coldest in 50 years of observations, and the cooling extended far into the Pacific Ocean and south along the American coast. The blue and green regions of relatively cold waters in Figure 1 dominated the central and northeast Pacific Ocean. Global warming prevailed almost everywhere else. Warmer temperatures covered almost the entire globe, with highest warming in the Arctic and northern Europe and Asia.

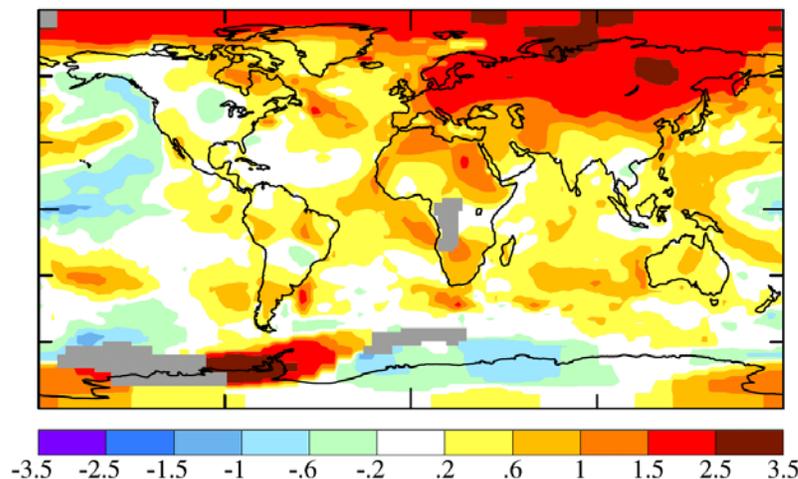


Figure 1. Annual surface temperature anomaly for 2008 ( $^{\circ}\text{C}$ ) relative to 1961 to 1991. Image provided by Goddard Institute for Space Studies <http://data.giss.nasa.gov/gistemp/2008>

We attribute this cool northeast Pacific Ocean to La Niña and to a cool phase of the Pacific Decadal Oscillation (PDO) that dominated through 2008. La Niña events are defined by ocean temperatures in the white-bordered box of Figure 2, top panel. Relatively cool oceans on the Equator normally bring cool winds and waters to the northeast Pacific in winter. This is just what happened through the winter of 2007 to 2008, when the Aleutian Low Pressure system strengthened and moved eastward into the northern Gulf of Alaska, bringing cool westerly winds across the Gulf of Alaska, rather than warmer “Hawaiian” air masses of typical winters that blow from the southeast. This pattern repeated in late 2008 although with weaker winds, and the cool waters persisted off the west coast well into spring 2009.

The images of Figure 2 reveal only sea surface temperatures; for a look at temperature below the surface we rely on ship-based measurements and autonomous floats. Ship-based observations are provided by scientists of Fisheries and Oceans Canada who have measured ocean temperature for more than 50 years in the northeast Pacific Ocean along Line P, a set of stations extending almost 1500 km west from Vancouver Island as shown in Figure 3a. Figure 3b reveals the extent of cooling in the top 500 metres in June 2008 along this set of ocean climate stations. Surface temperatures reached almost 4 degrees Celsius below normal and the cooling extended 100s of metres down into these waters. Only ocean surface cooling and horizontal transport of cool water into this region in winter could have dropped temperatures so far. Figure 3c compares the cool waters of 2008 to all previous years along Line P. Only in 1969 was the temperature close to the record cooling in 2008.

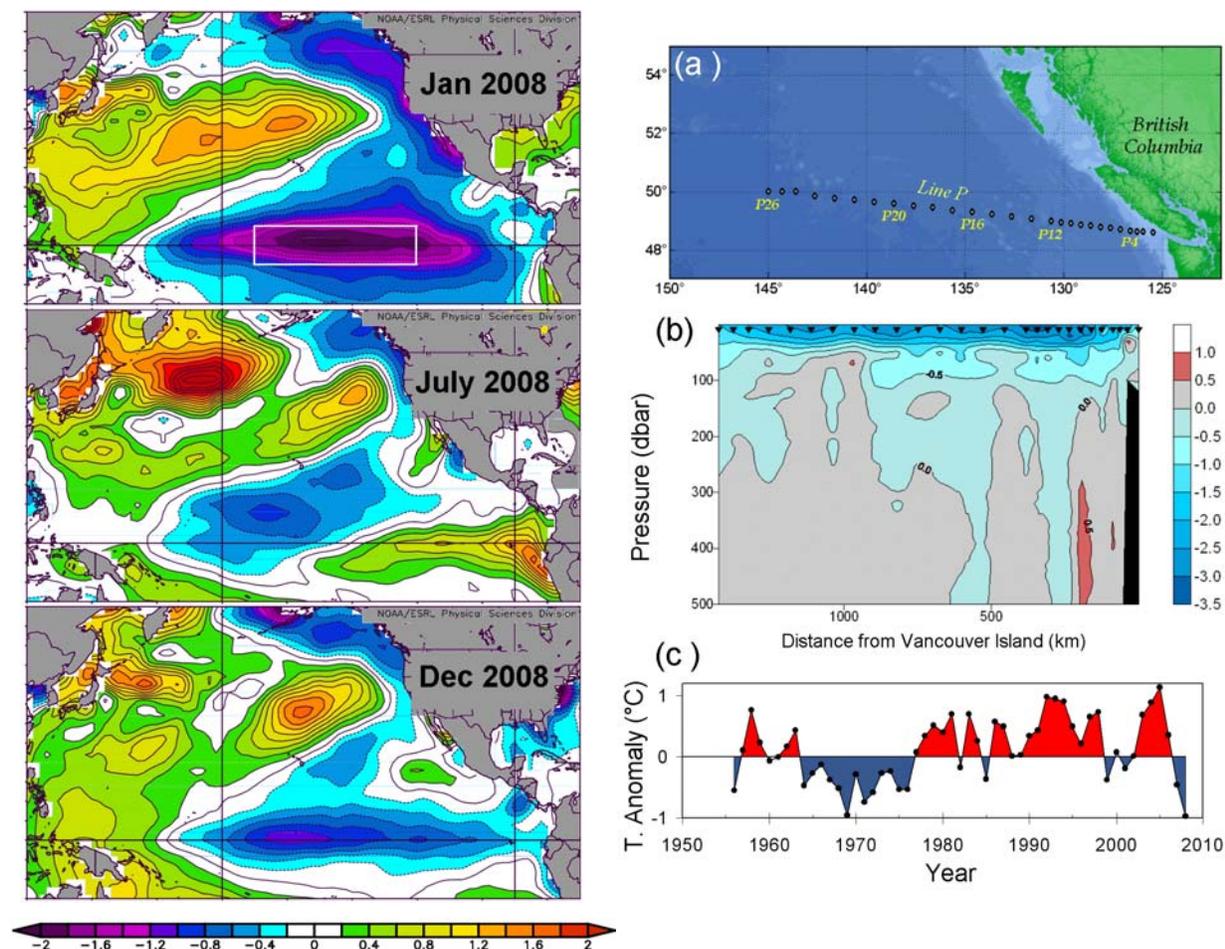


Figure 2 (left). Ocean surface temperature anomalies ( $^{\circ}\text{C}$ ) in tropical and North Pacific in January, July and December 2008. Reference years are 1968 to 1998. Temperature scale is at bottom of the figure. The white-bordered box outlines the Niño 3.4 region whose temperatures determine the official strength of El Niño and La Niña events. Note the very negative anomalies there in January 2008, indicating a strong La Niña. Source: NOAA Environmental Studies Research Lab., Physical Sciences Division.

Figure 3 (right).

(a) Map of ocean-climate stations along Line P. DFO scientists lead multi-disciplinary research cruises along these stations three times per year, accompanied by academics from all over North America. Intensive sampling of water properties takes place at the five labelled stations in this figure.

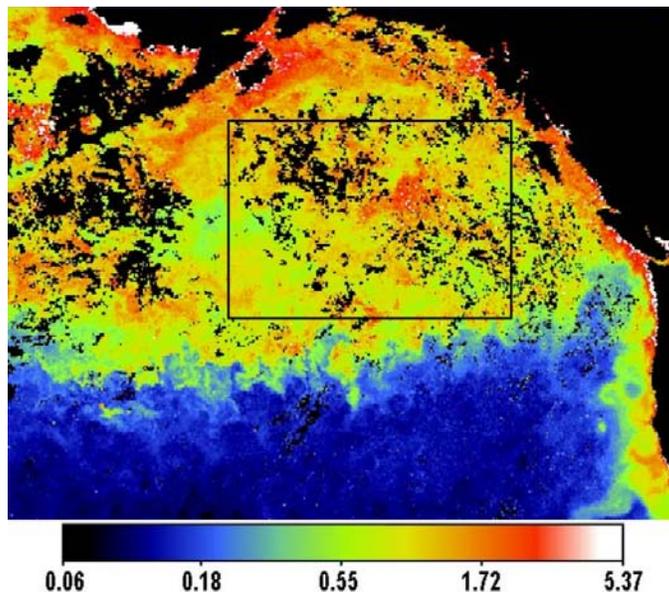
(b) Plots of temperature anomaly along Line P in June 2008. The pressure level determines the depth below surface (1 dbar = 1 metre of depth). Black region at right is the Vancouver Island continental shelf.

(c) Graph of annual-average temperature anomalies along Line P at 10 to 50 metres below ocean surface. The last point on the right shows 2008 to have the coldest-ever temperature of the entire series, although only  $0.02^{\circ}\text{C}$  cooler than in 1969. Warmest-ever temperature was in 2005, only three years earlier. This decline of 2 degrees Celsius in only 3 years is by far the greatest decline observed, and is attributed to a major shift in winds and currents in the Gulf of Alaska.

## Record high plankton numbers in the Gulf of Alaska

Phytoplankton and zooplankton concentrations in deep-sea waters in August 2008 were by far the highest observed in any summer in the past 10 years, and might have enriched the food supply for salmon in these waters. Some of these salmon will return to west coast rivers in 2009.

Two American satellites, SeaWiFS and MODIS, determine the concentration of chlorophyll at the ocean surface based on their observations of ocean colour. Chlorophyll is an indicator of phytoplankton biomass, so from these measurements we can estimate the concentration of phytoplankton in the ocean. Although clouds obscure the view over the Gulf of Alaska on most days, a monthly composite of the best observations provides distribution maps of this microscopic plant life at the ocean surface. Figure 4 below presents an image for August 2008, revealing that the entire ocean surface of the Gulf of Alaska was filled with phytoplankton.



*Figure 4. Chlorophyll concentration in the Gulf of Alaska in August 2008, based on observations by NASA MODIS satellite. Colour bar below the figure presents chlorophyll scale in  $\text{mg m}^{-3}$ . White regions near the coast hold highest concentrations, due to local nutrient enrichment. Red and yellow colours reveal waters with abnormally high levels for August in mid-ocean. The black box outlines the regions over which a time series of chlorophyll concentrations is plotted in the next figure.*

The time series of Figure 5 below shows month-by-month anomalies of chlorophyll at the ocean surface, based on the type of data plotted above over the Gulf of Alaska. The concentrations of August and September 2008 rose well above the levels found in any previous month. Growth of phytoplankton in this gulf in summer is normally limited by lack of iron. Although we suspect enhanced iron supply as a likely cause of the phytoplankton bloom, its source is uncertain. Several volcanoes erupted in summer 2008 in the Aleutian Islands, so volcanic dust is a possible source of iron, but it is not easily spread over the entire gulf by winds alone. Unusual currents in the summer of 2008, which could have transported either volcanic or oceanic iron from the Alaskan Peninsula into mid-gulf, are described in the report on flow in the North Pacific Current.

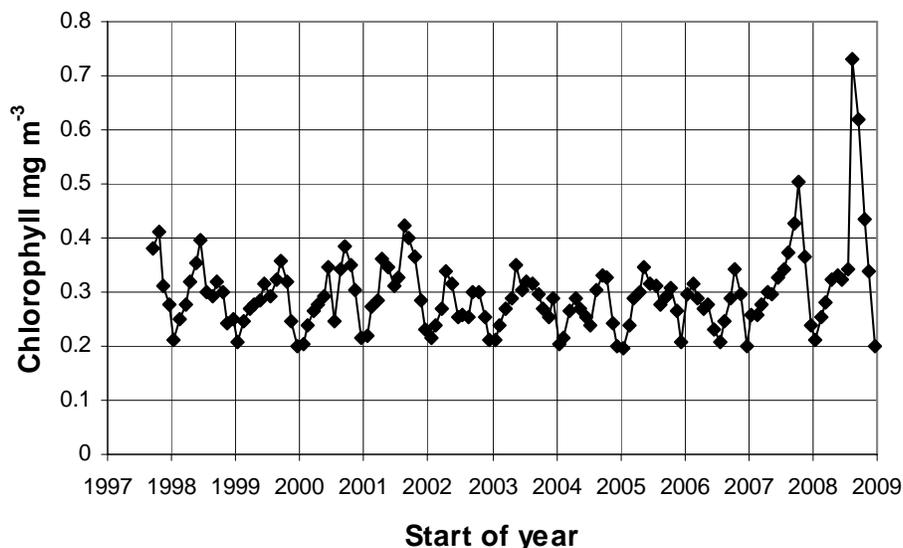
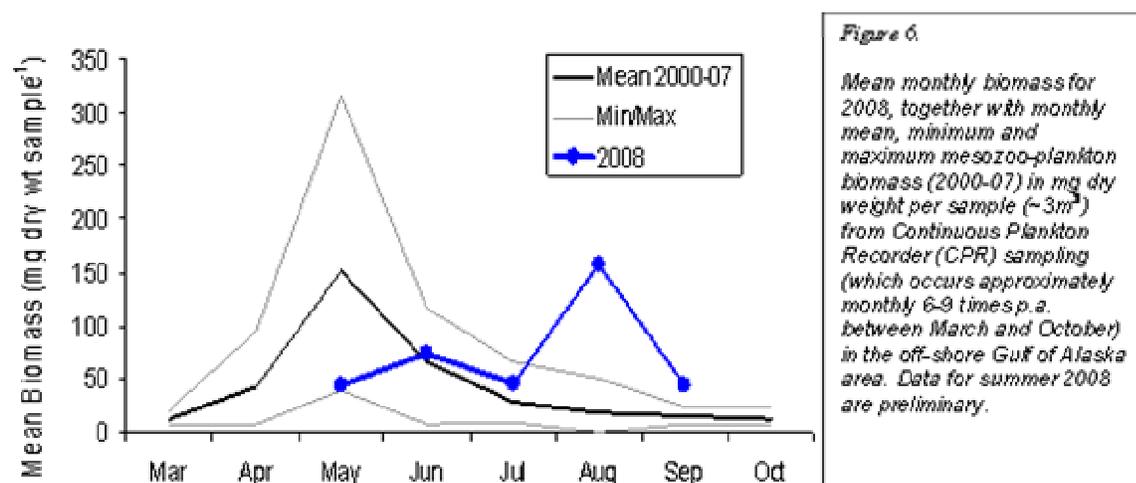


Figure 5. Time series of monthly chlorophyll in the Gulf of Alaska averaged over the black-bordered box shown in Figure 4. Data are provided by NASA satellites SeaWiFS and MODIS. Observations in 2008 are by MODIS sensor on Aqua satellite. Data provided by: <http://oceancolor.gsfc.nasa.gov/>

Zooplankton concentrations rose to the highest levels recorded in ten years of observations, as revealed in Figure 6. Zooplankton are the smallest animals in the ocean and many feed on phytoplankton, so it is not surprising to see the highest recorded concentrations of zooplankton in the Gulf of Alaska in August 2008 during the phytoplankton bloom. Zooplankton samples plotted in Figure 6 below were collected from continuous plankton recorders (CPR) towed behind commercial vessels, as part of a program now ten years old. The blue trace for 2008 in Figure 6 reveals the clear maximum in zooplankton concentrations for August, coinciding with the phytoplankton maximum. *Neocalanus cristatus* (an exceptionally large calanoid copepod type of zooplankton) had highest summer abundances recorded in the CPR time series in 2008, and this was augmented by later occurrences of *N. plumchrus* as well as *Calanus pacificus* being present in reasonable numbers.



## Stronger flow in North Pacific Current

Stronger winter westerly winds in the winter of 2006-07 and 2007-08, combined with a more intense Aleutian Low Pressure System in the northern Gulf of Alaska, are the likely causes of a very strong North Pacific Current all through 2008, peaking in summer 2008. Figure 7 below shows the classical view of ocean surface currents of the Gulf of Alaska and Figure 8 presents the time series of the strength of these currents since 2001, based on observations by Argo autonomous floats in the gulf.

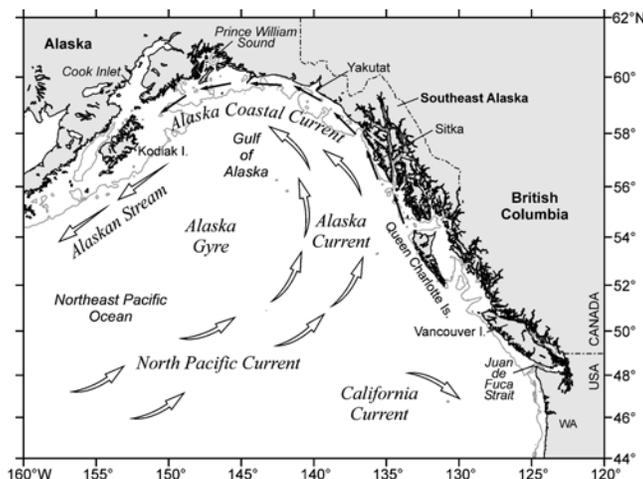


Figure 7. The North Pacific Current flows across the middle of the Gulf of Alaska, splitting near North America into the northward-flowing Alaska Current and the southward-flowing California Current. Stronger eddies off Kodiak Island combined with a more easterly and stronger North Pacific Current might be factor in providing sufficient iron into the middle of the gulf for the plankton bloom of 2008 summer.

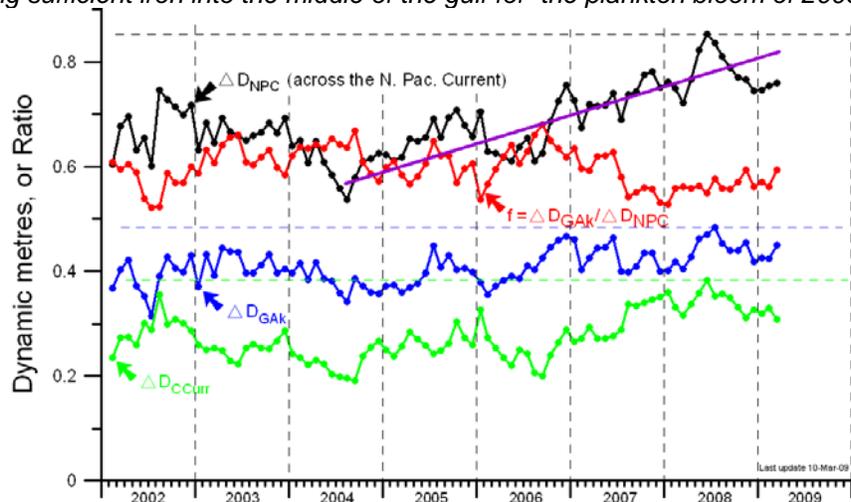


Figure 8. Time series of ocean current strength in the Gulf of Alaska, based on dynamic height calculated from temperature and salinity measured by Argo floats.

The North Pacific Current reached maximum strength in May to August of 2008. The red line presents the fraction of eastward flowing North Pacific Current waters that continue into the Alaskan Stream. Remaining water flows into the California Current.

## Spreading hypoxia in deep waters along the west coast

Oxygen levels are declining in waters found 100 to 500 metres below the ocean surface (Figure 9), based on time-series measurements of at least 25 years collected in the mid gulf of Alaska at Ocean Station P, and along the Pacific coast of southern California (S CA), southern BC (WCVI), and the west coast of Queen Charlotte Islands in northern BC (WCQCI). Rates of decline exceed 1% per year in the 200 to 300 metre range in coastal waters that presently contain 50 to 130  $\mu\text{M}$  oxygen.

Many other studies have remarked on the loss of oxygen in sub-surface waters of the subarctic Pacific, identifying the cause as weakening winter ventilation off the Asian coast due to a freshening and perhaps warming of the mixed layer. The warming trend is not as assured as freshening because of the large annual cycle. As oxygen diminishes in coastal waters, there must be impacts on biological communities since all animals require oxygen. Along the Oregon coast, low oxygen events have caused fish and crab kills at the ocean bottom within the last several years, events not observed in the previous century.

Oxygen concentrations in bottom waters of the BC continental shelf dropped markedly in 2008, compared to 2006. This finding was determined from instruments attached to trawl nets during research cruises in these two years. (No sampling took place in 2007. Oxygen sensors were not available prior to 2006). Figure 10 presents these observations along the west coast of Vancouver Island in May and June of 2006 and 2008. The red symbols, representing 2008 samples, clearly show lower oxygen concentrations than found in 2006. However, a study of the water density of these samples reveals that the difference is mainly due to denser water with lower oxygen content moving to shallower depths in 2008, due to anomalous winds and ocean currents.

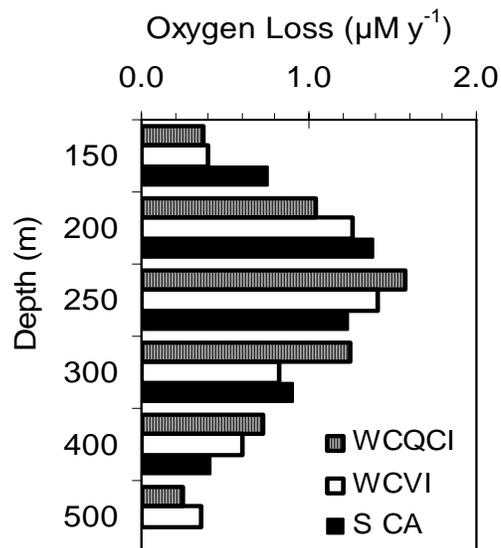


Figure 9. Rates of oxygen loss at three stations along the Pacific coast of North America.

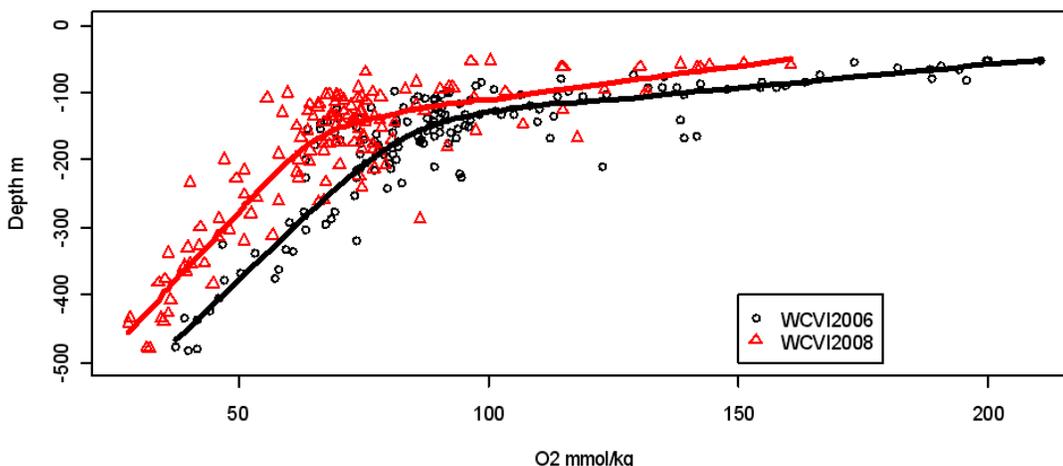


Figure 10. Oxygen measured in bottom water during trawl surveys, May - June 2006, 2008.

## High survival for juvenile salmon, seabirds and sablefish off Vancouver Island

Almost 30 years of regular sampling of zooplankton off Vancouver Island shows that we can predict juvenile survival rates of key marine species based on these data. Measurements in 2008 show these survival rates were high and provide good news for fisheries several years from now. These species include juvenile salmon and sablefish in southern BC, and seabirds on Triangle Island.

Although there are more than 50 species of zooplankton that are counted in samples every year, those that thrive best in coastal waters fall mainly into “warm” and “cool” groups, named for the relative temperature of water they prefer. It is suspected that ‘cool water’ zooplankton are better fish food (larger individual body size and much higher energy content).

Because much of the year-to-year variability of marine survival rate of harvested fish species and seabirds occurs at early life stages (for salmon, in their first year after ocean entry), observations of zooplankton anomalies provide a useful index of health and survival of juvenile coho salmon along the outer coast, sablefish recruitment, and seabird reproductive success on Triangle Island off northern Vancouver Island. Interannual variability of all of these time series can be described as ‘cool-and-productive’ or ‘warm-and-unproductive’.

Figure 11 presents this index, updated for 2008. Note that 2008 was among the four most “cool and productive” years. Survival of seabird chicks was the highest ever in 2008 on Triangle Island. We must wait a few years to see if coho and sablefish juveniles thrived as successfully as seabirds. However, other observations noted below also suggest high survival of juvenile salmon.

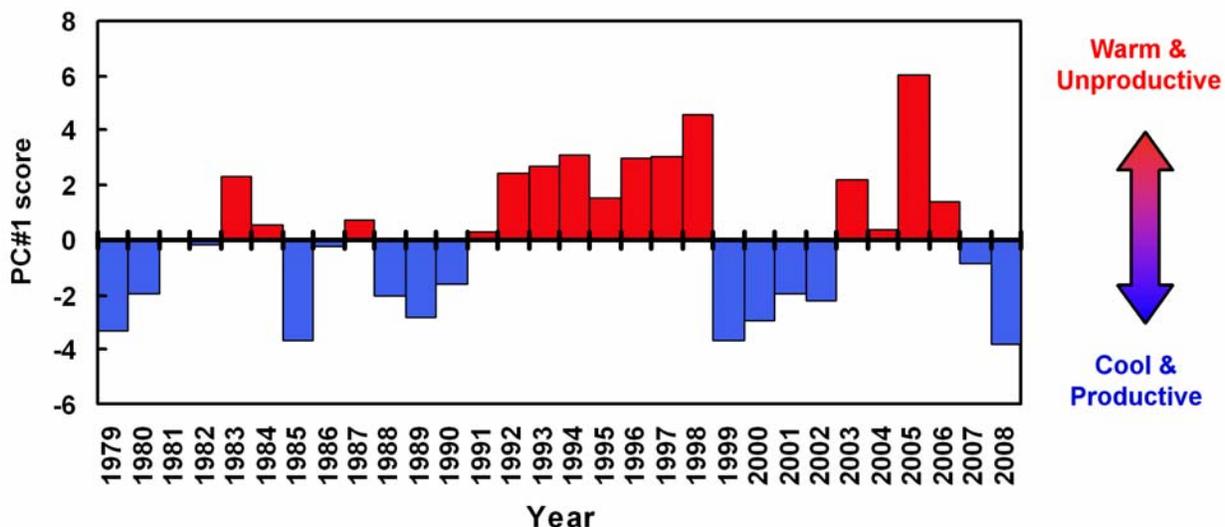


Figure 11. Time series of scores of the marine survival index in coastal waters off Vancouver Island.

Scientists of Fisheries and Ocean Canada also rely on direct observations of juvenile salmon numbers and size to determine future returns. The June-July 2008 catches-per-unit-effort of juvenile Chinook, sockeye and chum salmon off the west coast of Vancouver Island were the highest on record since 1998 by nearly a factor of ten, and the third highest for juvenile coho salmon. This suggests that early marine survival was consistently high for all the species of salmon in 2008 in this area. Thus, adult returns are expected to be high in 2009 for coho salmon, in 2010-2011 for Chinook and sockeye salmon, and in 2011 for chum salmon.

However, the predictions for Chinook salmon are only applicable to Columbia River spring Chinook, as these are the stocks normally caught during the June-July surveys off the west coast of Vancouver Island.

In contrast to 2008, catch-per-unit effort of juvenile salmon in 2005 off the west coast of Vancouver Island were generally the lowest on record for most species, suggesting poor marine survival for the smolts that migrated to sea that year. This may explain the poor returns of several stocks of salmon in recent years.

## **Sardine, herring and eulachon are down; shrimp are in slow recovery**

### Herring:

Herring abundance on the west coast of Vancouver Island is at an historically low level following a decade long series of poor recruitments. However, recruitment may improve over the next few years as a result of reduced predator levels. 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 average to good. Recruitment of the 2003 and 2005 year-classes was weak in all three areas resulting in slight declines over the past four years. Cooling ocean conditions since 2005,, combined with a decrease in abundance of hake population, may result in an improvement in herring recruitment and stock abundance over the short term.

The abundance of Strait of Georgia herring in 2008 continued the decline that began in 2002 from the near-historic high levels of more than 100,000 tonnes. The declining trend in recruitment over the past five years will translate into reduced mature abundance levels over the next few years. Reduced hake abundance may result in improving recruitment and fall surveys of juvenile herring suggest an average recruitment in 2009 followed by a weaker year-class in 2010.

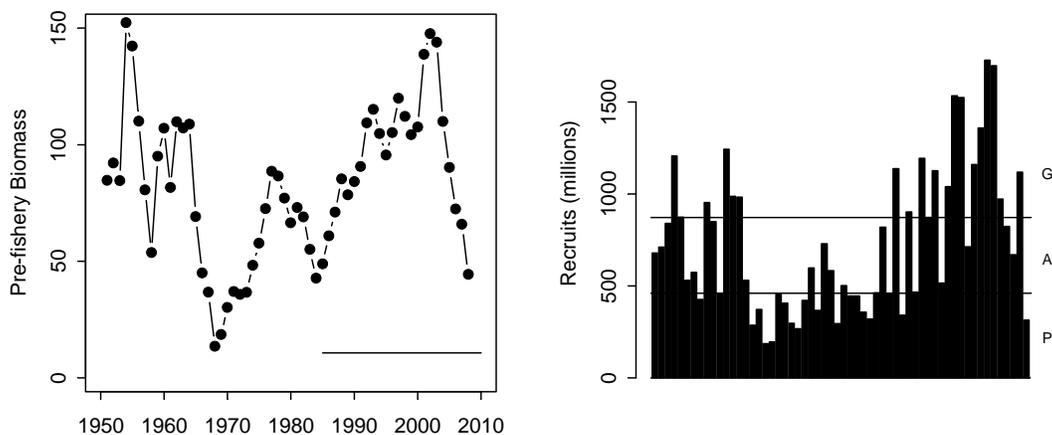


Figure 12. Pre-recruitment biomass and number of recruits of herring in Strait of Georgia stocks, one of five stocks monitored by Fisheries and Oceans Canada.

### Sardine:

Sardines reappeared off the west coast of Vancouver Island in 1992. During the 1990s their distribution expanded northward from southern Vancouver Island through Hecate Strait to Dixon Entrance. In 2003 and 2004 the distribution of sardines in B.C. was limited to the inlets of

Vancouver Island and offshore areas in the south. Warm conditions in 2004 to 2005 and a very strong 2003 year-class has resulted in widespread distribution of sardines throughout southern Hecate Strait and Queen Charlotte Sound since then.

### Eulachon:

Eulachon abundances as evidenced from incidental capture in the shrimp research survey off the WCVI and egg and larval surveys in the Fraser River both indicate substantial decline in population size since the mid-1990s. Anecdotal information suggests the decline in eulachon has been coast-wide throughout British Columbia and Washington, implying a large scale oceanographic process impacting their survival. Recent data suggests that eulachon are at an historical low level of abundance in the Fraser River.

### Smooth Pink Shrimp:

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 2008 found the biomass of *Pandalus jordani* shrimp off central Vancouver Island had increased from very low levels during 2004-2007, possibly as a result of colder ocean conditions when they were hatched in 2006; this population may be beginning to recover after warm conditions during mid-decade. Biomass of flatfish species also increased in 2008 after declines in 2006 and 2007. Some biomass changes, such as for spiny dogfish, English sole and Pacific hake in recent years, may be due to increased catches of adult fish rather than sub-adults during these research fisheries.

## **Marine species of Pacific Rim National Park Reserve**

Pacific Rim National Park Reserve of Canada, located on the west coast of Vancouver Island between the towns of Tofino and Port Renfrew, has the mandate to monitor and report on the state of its ecological integrity of marine and terrestrial ecosystems within the Park bounds. Information is provided here for marine biota with more than 10 years of observations.

The overall abundance of Littleneck and Manila Clams changed little, but Butter Clams seem to show a general decline in the past 7 years. Some other species, however, displayed statistically significant trends. The overall density of the exotic Varnish Clam has increased 8-fold from mid 1990s, whereas no Varnish Clams were recorded in the Park in 1978. On the other hand the density of the Olympia Oyster has declined sharply over the past 10 years.

Regression analyses suggested that out of the six common species of seabirds for which Pacific Rim National Park has long-term data, four – Marbled Murrelet (*Brachyramphus marmoratus*), Surf Scoter (*Melanitta perspicillata*), Pelagic Cormorant (*Phalacrocorax pelagicus*) and Rhinoceros Auklet (*Cerorhinca monocerata*) – have declined or continue to decline as compared to mid 1990s. In at least three of the species that feed on pelagic forage fish and zooplankton (Marbled Murrelet, Pelagic Cormorant and Rhinoceros Auklet), the recorded numbers mirror biomass estimates for Pacific herring. Much of the decline seems to be associated with the collapse of local Pacific herring stocks.

Two larger Glaucous-winged Gull (*Larus glaucescens*) colonies in the Park – Florencia Island and Seabird Rocks – experienced steep population declines in late 1960s – early 1970 (although large data gaps make this assessment qualitative). It appears the Seabird Rock colony collapsed first, with many birds moving to Florencia Island, with the latter colony succumbing to the agent of decline by 1975. The timing of the declines coincided with the coast-wide collapse of Pacific herring stocks in the 60s and 70s, due to overfishing.

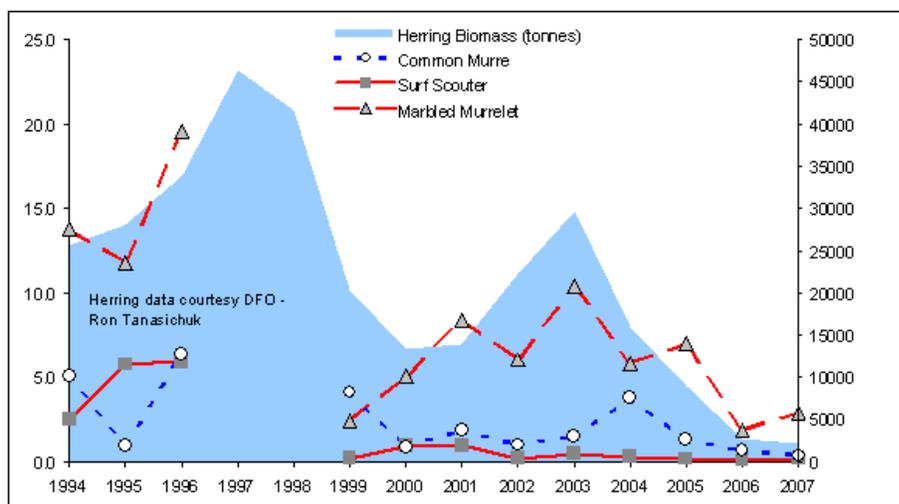


Figure 13. Trends in seabird numbers expressed as density per 1 km linear route contrasted against local Herring stocks (blue background). Red trends indicated species with statistically significant population declines. Blue trends refer to relatively stable populations within Park waters.

Grey whales (*Eschrichtius robustus*) are photographed and then individually identified using patterns of scratches, scars, and growths of barnacles and whale lice. Numbers fluctuate widely: 30 or more grey whales were observed in each of 1998, 2005 and 2006, whereas only 2 and 3 individuals were recorded in 2001 and 2007. In 2008, 46 individuals were recorded, which is the record count for the Park.

### **Variable sockeye returns, despite improving ocean survival**

In each of five regions of BC and southeast Alaska, one or more sockeye runs are assessed with accurate and precise enumeration methods for adult returns and juvenile outmigrants, and are used as indicators of freshwater and marine survival and productivity for nearby stocks. Sockeye indicator stocks for four regions are described below. The return strength for stocks depends on both the brood year escapement (number of spawners) and survival conditions in both the freshwater and marine environment. If brood year escapements are below average returns generally will also be below average despite overall good survival conditions.

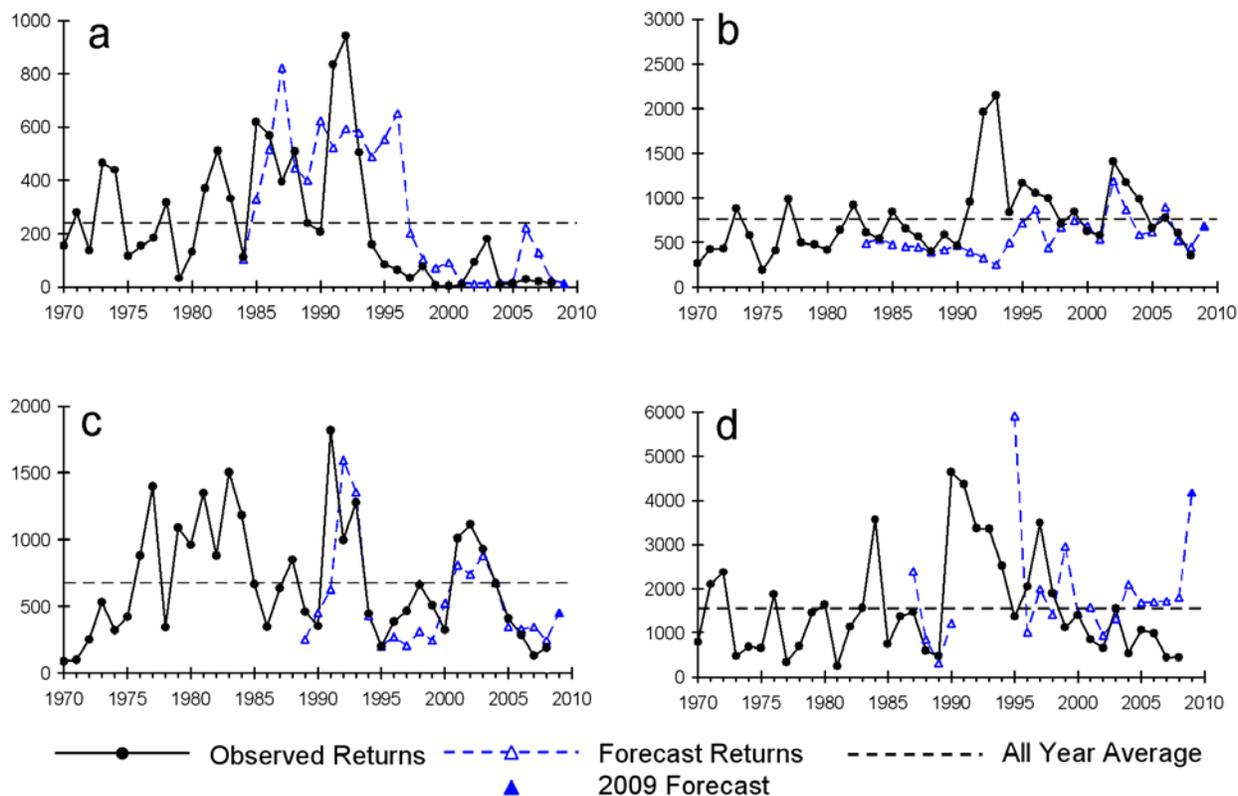


Figure 14. Trends in the total returns and forecasts for British Columbia sockeye index stocks: (a) Nass, (b) Rivers and Smith's Inlet, (c) Barkley Sound sockeye salmon, (d) Fraser River sockeye salmon. Y-axes represent returns in thousands of fish.

Barkley Sound 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 14c). Studies of these variations have supported the use of a simple two-state, "survival-stanza", model since 1988, whereby "La Niña-like" conditions (SST < 30 yr average during smolt migration, low northward transport, average to below-average sea level) are associated with relatively high marine survival (5 %) and "El Niño-like" conditions (SST > 30 yr average, elevated sea level, high northward transport) with lower marine survival (2.5 %) of fish in their first year in the ocean. With the cool conditions of 2007-2008, and some observations of increased numbers of juvenile sockeye along the Vancouver Island West Coast, we anticipate increased marine survival that will permit a period of stock rebuilding for west coast Vancouver Island coho returning in 2008-2009 and sockeye returning in 2009-2010, but total returns are likely to remain sub-average until depressed escapements are rebuilt.

Rivers and Smith's Inlet sockeye (Figure 14b) supported one of the most valuable fisheries on the central coast of BC until severe stock declines in the early to mid-1990s forced their closure. Studies suggest that the steep decline and low returns of sockeye this region since the 1990s are due to persistently low marine survival. By contrast, a strong compensatory response of increased egg-to-fall-fry survival in freshwater (Smokehouse River, Canoe Creek, and Long Lake), accompanied major reductions in spawner abundance for the 1997-2001 and 2005-2006 brood years and buffered Smith's Inlet sockeye from even more severe declines. The depressed state of sockeye escapements in 2004-2005 and reduced smolt output in sea-entry years 2006 and 2007 suggest sub-average total returns to Smith's Inlet and Long Lake in 2009.

Nass River indicator stocks (Fig. 14a) declined from early-1990s highs, exhibited by all sockeye indicator stocks, but relative to more southerly stocks, have remained closer to their all-year average return values since the late 1990s.

For the Fraser River indicator stock (Chilko River sockeye), marine survival was low in recent years (1995 to 2009 return years) attributed to poorer ocean survival conditions in the corresponding smolt outmigration years (1993 to 2006). Ocean survival was particularly low for the 2007 return year (2005 smolt outmigration year). Ocean survival subsequently increased in the 2008 return year (2006 smolt outmigration year) and is also expected to further increase in subsequent return years due to improving ocean conditions. For Chilko in particular, well above average freshwater survival produced an unprecedented number of smolts in 2007. Figure 14d reveals a prediction of more than 4 million returns for this stock, but actual returns might be lower because the percentage of smolts that survive in the ocean is usually low when they outmigrate in very large numbers. Other Fraser stocks have generally exhibited average to above average brood year escapements for 2009 returns (with some exceptions) and, therefore, given ocean positive ocean conditions during their ocean entry year (2006), returns are expected to generally be average to above average.

### **Below average coho returns despite improving ocean survival**

Coho salmon are similar to sockeye in that northern populations tend to be doing better than populations to the south (Fig. 15). Coho from Alaska and northern BC exhibited similarly variable survivals with no significant trend. Alaska coho survived at consistently higher rates than those from northern BC. Coho from the west coast of Vancouver Island, Strait of Georgia (SOG), and Puget Sound experienced significant declines over the time series; Puget Sound coho survived at higher rates than SOG coho. The return strength for stocks depends on both the survival conditions and brood year escapements (number of spawners). If brood year escapements are below average returns generally will also be below average despite overall good survival conditions.

Various physical and biological environmental variables were significantly associated with coho survival. Relatively good survivals are forecast for BC coho returning in 2009 – one possible exception is the Strait of Georgia that experienced mixed signals. However, it is important to realize that good survivals do not necessarily mean good returns. Coho returning in 2009 are the progeny of coho that went to sea in the spring of 2005, many of which experienced extremely low survivals.

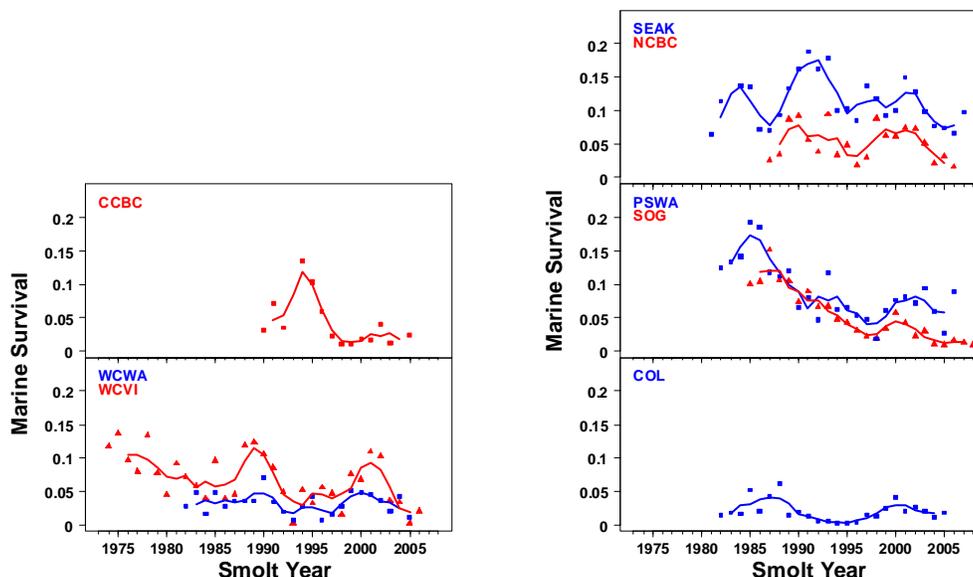


Fig. 15. Mean annual marine survivals (3-year moving averages) for representative coho salmon populations from southeast Alaska (SEAK), the north coast of BC (NCBC), central coast of BC (CCBC), Strait of Georgia (SOG), Puget Sound Washington (PSWA), west coast of Vancouver Island (WCVI), west coast of Washington State (WCWA), and Columbia River watershed (COL).

## **Indicators for 2009 salmon returns in the Georgia Basin**

Salmon have the most complex and vulnerable life cycle of any marine species on our coast. From eggs hatching far up the Fraser or other rivers, to their passage as juveniles all along the Inside Passage and out to the Aleutians, into the deep-sea waters of the Gulf of Alaska and finally back to their native stream bed to spawn, they pass millions of humans and other predators. Several approaches are used in the Pacific Region to forecast salmon returns and these include stock-recruitment approaches, the use of indicators (biological or physical oceanographic indicators) of salmon ocean survival conditions, and juvenile abundances observed in the Strait of Georgia and Pacific Ocean.

## **Fraser River Sockeye Forecasts (Stock-Recruitment Data)**

Sockeye returns are particularly difficult to forecast due to their long migrations routes through the river and ocean, and our lack of specific information on their success at each point of their journey. Predictions for numbers of each Fraser sockeye stock returning to the river are typically based on the empirical relationship between stock size (adult spawners or juveniles) and consequent recruitment. In most cases, including ocean environmental variables as covariates in stock-recruit models has not improved forecast performance. Therefore, forecasts of return abundances generally assume average marine survival conditions. If ocean conditions are below or above average, or if juvenile size at ocean entry deviates from average, then this will result in the over- or under-estimation of actual returns.

Fraser sockeye return forecasts are presented in tables as slices through a cumulative probability distribution at five probability levels: 10%, 25%, 50%, 75%, and 90% (see Table 1 for 2009 forecast for example). Probability distributions are used to capture uncertainty in forecasts

using Bayesian statistics. They are presented as the probability of exceeding the specific return forecast; therefore, the smallest percentage presented (10%) has the largest associated return forecast and as the probability percentage increases, the return forecast decreases.

Sockeye run timing group	10%	25%	50%	75%	90%
<b>Early Stuart</b>	645,000	426,000	255,000	165,000	107,000
<b>Early Summer</b>	2,284,000	1,338,000	739,000	443,000	264,000
<b>Summer</b>	31,813,000	16,071,000	8,677,000	4,914,000	2,858,000
<b>Late</b>	2,875,000	1,616,000	907,000	517,000	327,000
<b>Total</b>	37,617,000	19,451,000	10,578,001	6,039,001	3,556,001

Table 1. Pre-season sockeye forecasts for 2009 by run timing group and probability.

In recent years, the forecast process has included recommendations to use more (>50%) or less conservative (<50%) probability levels depending on indications of, respectively, poorer- or better-than-average ocean conditions. To provide some indication of marine survival conditions for Fraser River sockeye salmon, a compilation of ocean survival indicators for salmon are used to qualitatively compare relative ocean survival conditions from 1998 to 2007 (Table 2). The methodology for ranking individual indicators is based on W.T. Peterson's approach (U.S. Northwest Fisheries Sciences Centre, National Ocean and Atmospheric Agency). For the 2009 forecast (Table 1), ocean conditions using the indicator approach have improved relative to the two previous years with both biological and oceanographic conditions above average for salmon survival (Table 2). Therefore for 2009, the 50% probability forecast is recommended for pre-season planning purposes (with the exception of Early Stuart at the 75% probability level due to this stock's overall lower productivity in recent years).

Currently, the suite of ocean indicators explored only partially tracks Chilko marine survival (marine survival indicator system for Fraser sockeye stocks) (Table 2). This suggests that more ocean indicators need to be explored and/or developed to improve forecasting methodology. The prediction in Figure 14c indicates that over 4 million adults are expected to return, based on the record high number of smolts that entered the ocean in 2007.

The suite of indicators in Table 2 provided a strong indication of the very poor ocean survival conditions experienced by Fraser sockeye in 2005 (poor returns in 2007). Therefore, it may be most useful currently in providing an indication of very low marine survival rather than high survival. We will continue to explore the utility of this approach.

(BROOD YEAR)	(1996)	(1997)	(1998)	(1999)	(2000)	(2001)	(2002)	(2003)	(2004)	(2005)
OCEAN ENTRY YEAR	(1998)	(1999)	(2000)	(2001)	(2002)	(2003)	(2004)	(2005)	(2006)	(2007)
(RETURN YEAR)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
<b>Chilko Marine Survival</b>	G	Y	G	G	R	Y	G	R	Y	NA
<b>Ocean Indices</b>										
1 PDO (Jan-March average)	R	G	G	R	G	R	R	R	Y	Y
2 ALPI	R	G	Y	R	R	R	R	Y	G	G
<b>Physical Conditions</b>										
3 SST (Entrance Island)	R	G	G	G	G	R	R	R	Y	Y
4 SST (Pine Island)	R	G	G	G	Y	R	R	R	Y	G
5 Upwelling index (48°N)	G	G	R	Y	G	R	Y	R	Y	G
6 Spring transition timing (48°N)	G	G	Y	Y	G	Y	Y	R	Y	Y
<b>Biological Conditions</b>										
7 Southern Copepods (SVI)	R	G	Y	G	G	R	Y	R	R	G
8 Boreal Shelf Copepods (SVI)	R	G	G	Y	G	Y	R	R	R	G
9 Southern Copepods (NVI)	R	G	G	G	Y	R	Y	R	R	G
10 Boreal Shelf Copepods (NVI)	Y	G	G	R	G	R	R	R	Y	G

Table 2. Indicators of ocean conditions from 1998 to 2007. For each indicator, annual estimates were ranked across all years from 1 to 10 from best to worst salmon ocean survival conditions. Green (G): ranks 1 to 4; yellow (Y): ranks 5 to 7; red (R): ranks 7 to 10.

The presence of many Green boxes in 2009 in Table 2 is an encouraging sign for Fraser River sockeye fishing after several years of low returns.

## Salmon Forecasts (Juvenile Data in the Strait of Georgia)

Research fisheries in the Strait of Georgia capture small numbers of juvenile salmon at several times each year, using standard trawl methods and locations. From year-to-year changes in these catches scientists are able to provide insight into future returns of these species. In recent years adult returns are forecasted using CPUE of juvenile salmon in July midwater trawl surveys and use the red/amber/green system. The ability to forecast returns for individual stocks has improved in recent years with the development of DNA methods that can be used to identify the stock of juvenile salmon caught in the marine environment.

### Sockeye:

Juvenile sockeye catches are generally quite low in Strait of Georgia and coastal surveys, therefore, no quantitative forecasts based on juvenile abundances in the ocean have been possible. Some preliminary DNA samples have been analyzed for juvenile sockeye collected in July, September and November trawl surveys in 2008. In July, catches of juvenile sockeye were generally confined to Howe Sound, with small catches in the northern Strait of Georgia and in the Gulf Islands. By September, catches were primarily along the mainland coast up to Malaspina Strait. By November, no sockeye were found in Howe Sound, but large numbers were still present in the Gulf Islands region. DNA analysis of these fish showed that an overwhelming percentage (97%) of the sockeye in both the Strait of Georgia and in the Gulf Islands were of Harrison River origin. Harrison River sockeye are unusual along the west coast in that they migrate to sea as fry rather than spending a winter in freshwater (akin to ocean-type chinook). It appears that this stock of Fraser River sockeye may be exhibiting behavioural and migration patterns different than expected from the literature, and we propose that this may be reflected in the higher survival rate exhibited by this stock. If this interpretation is correct, then

Harrison River sockeye are behaving more like pink salmon, and the mechanisms that relate to their improved survival are keys to understanding how the Strait of Georgia is changing.

### Coho:

Marine survival of Puget Sound coho salmon continues to be superior to that of Strait of Georgia stocks, having recovered to a greater degree from the extremely low levels of both regions in the late 1990s. An examination of midwater trawl data shows a steady decline in the summer (May-September) survival rate of juvenile coho in the Strait of Georgia. This, in turn, is highly correlated to the total marine survival of coho from 1977-2006 ( $R^2=0.68$ ; Figure 17).

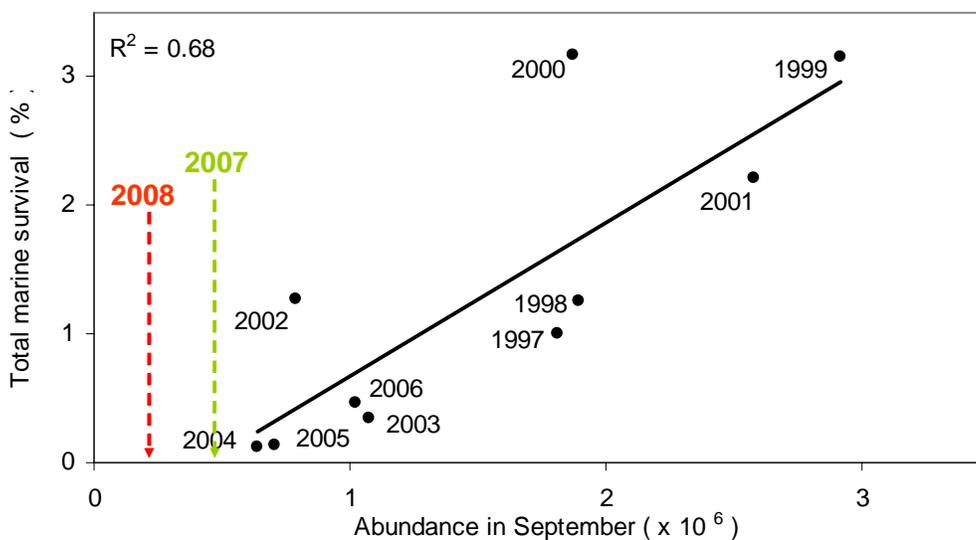


Figure 17. Relationship between September abundance of juvenile coho and marine survival in the Strait of Georgia. Final survival values for 2007 and 2008 not yet available.

One possible explanation for the lower early marine survival in the Strait of Georgia is the higher surface water temperatures, some 1-2°C greater than observed in Puget Sound, which translates into greater thermal stress as the summer proceeds. This temperature difference may be driven by differences in oceanographic conditions between these two regions. For coho salmon, the CPUE in 2008 was the lowest observed since 1997, therefore a very poor return is projected in 2009. In general, observed early marine survival for coho salmon is reduced. Figure 17 also reveals a discouraging crash in the September catch of juvenile Coho in the Strait of Georgia in 2007 and 2008, which implies very low returns in future years if the relationship of abundance to marine survival of Figure 17 holds in the future.

### Chinook:

Chinook salmon marine survival, on the other hand, does not show the same degree of disparity between Puget Sound and Strait of Georgia stocks. Although the Puget Sound marine survival rates are generally higher, both long-term and short-term trends are similar. In 2008, a large program was conducted to investigate the survival of Cowichan River Chinook. As part of this program, a large number of DNA samples taken from midwater trawls in both the Gulf Islands and in the Strait of Georgia were analyzed. Interestingly, juvenile Chinook salmon captured in the Gulf Islands in July, September and November show an increasing percentage of Puget Sound Chinook (2%, 6%, and 15%, respectively), demonstrating that this region may be utilized as over-winter rearing grounds by some stocks. A large number of Fraser River stocks of Chinook were also observed, but declining over the summer and fall (62% in June, 43% in September, and 19% in November). This has been interpreted as general movement out to the

WCVI feeding grounds. Cowichan River Chinook and east Vancouver Island stocks (mainly Puntledge) made up the rest of the population structure, increasing in percentage over time and comprising nearly 70% of the juvenile Chinook population by November. Our preliminary interpretation is that some key populations such as the Cowichan Chinook remain in local habitats for the early marine period that determines brood year strength. Thus it is the productivity of these local areas such as the Gulf Islands that are critical to the success of these populations.

Analysis of Chinook captured on the same surveys in the Strait of Georgia presented a much different picture. Puget Sound stocks were generally not found in any great percentage until November, a survey which focussed on the southern portion of the Strait of Georgia. Cowichan River Chinook were also not observed in any great numbers in the Strait of Georgia, confirming Coded Wire Tag data that these fish do not generally utilize these waters. While the July survey showed a wide variety of stocks in the Strait of Georgia, by September the ecosystem was dominated by South Thompson Chinook (79%).

Chinook salmon results are preliminary and indicate very poor total marine survival (about 0.1%). Cowichan Chinook from the hatchery may experience about 95% mortality by September of the first marine year. It is necessary to determine the reasons for the increasing trend of early marine mortality. We suspect that reduced growth results in an increased susceptibility to disease, but this remains speculative.

## SOURCES OF INFORMATION

Crawford, W.R. and J.R. Irvine. 2009. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. DFO Can. Sci. Advis. Sec. Res. Doc. Ser. 2009/022.

Irvine, J.R. and W.R. Crawford. 2008. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems. DFO Can. Sci. Advis. Sec. Res. Doc. Ser. 2008/013. [http://www.dfo-mpo.gc.ca/csas/Csas/Publications/ResDocs-DocRech/2008/2008\\_013\\_e.htm](http://www.dfo-mpo.gc.ca/csas/Csas/Publications/ResDocs-DocRech/2008/2008_013_e.htm)

As well, reports dating back to 1999 can be found at:

English: [www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean\\_SSR\\_e.htm](http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_e.htm)

French: [www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean\\_SSR\\_f.htm](http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean_SSR_f.htm)

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