Fisheries and Oceans Canada / Pêches et Océans Canada

Science / Sciences

Pacific Region

Ocean Status Report 2006/001

State of the Pacific Ocean 2005

Location of most regions described in this report. Conditions have been monitored for 50 years 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 all members of the Fisheries and Oceanography Working Group of the Pacific Scientific Advice Review Committee (PSARC).

Canada

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Key Points

On an annual basis, the Pacific coast of Canada was warmer and drier than normal in 2005.

Sea temperatures maintained warm conditions into 2005 in all B.C. marine ecosystems including the oceanic northeast Pacific.

Warm sea temperatures reduced vertical mixing in near-surface, deep-sea regions, reducing the supply of plant nutrients into the surface layers of the northeast Pacific Ocean. Consequently, production of microscopic plants (phytoplankton) was likely reduced, although few direct measurements are available.

The transition from winter to summer winds and currents occurred in mid April in 2005 compared with late February to early March in 2004. As a result, the spring outburst of plankton was delayed in 2005.

The biomass of zooplankton (food for many marine fishes) was below normal, and there were unusually high abundances of zooplankton species that normally occur off California; the typical cold-water copepods and euphausiids (krill) in B.C. were proportionally less abundant.

2005 was a very poor year for seabirds on the northern tip of Vancouver Island, with a lack of their preferred zooplankton and small fish prey, delayed breeding, and poor breeding success.

The growth of juvenile coho salmon on the west coast of Vancouver Island during spring to fall was the lowest that has been measured since these observations began in 1998. Survival can be low in years of poor ocean growth.

In contrast, warm water migratory species such as Pacific hake and Pacific sardine were abundant in B.C. waters during 2005, and there were occurrences of other warm water species not typically seen in B.C.

OUTLOOK: returning abundances of some salmon stocks and recruitment of herring to southwest Vancouver Island in 2006 and 2007 are expected to be poor because of poor (warm) conditions during their early marine periods since 2003. Warm oceanic waters appeared to be cooling to normal temperatures at the end of 2005, but it is unclear if this represents a break in the warm conditions that have persisted since 2003 or a temporary event.

Description of the Issue

This report represents the seventh in an annual series reporting on the state of physical, biological, and selected fishery resources of the Pacific Canadian marine ecosystems. This region has seen particularly dramatic changes in atmospheric and ocean conditions over the past 15 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 is intended to provide an integrated, but 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.

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Summary of conditions in 2005

This section summaries the physical and biological state of the marine ecosystems of Canada's Pacific Region in 2005 based on individual contributions presented in the main body of this report.

The year 2005 continued the recent trend of very warm conditions in the atmosphere and in the ocean (Fig. 1). Globally, 2005 had the warmest air temperatures since recordings began in the late 1800s. The decade from 1996-2005 experienced nine of the ten warmest years recorded, and there has been an overall warming trend of 0.17 °C per decade since 1975. Northern latitudes have seen even greater warming than the global average. The average annual air temperature for Canada nationally was 1.7 °C above normal, making 2005 the third warmest year since nationwide records began in 1948. The Pacific coast of Canada experienced its fifth warmest year, at 1.2 °C above normal. Nationally, it was also the wettest year on record for Canada, with precipitation 13% above normal. However, in contrast to the national picture, the Pacific coast was somewhat drier than normal with annual precipitation down by 5.5%, continuing a trend of below normal annual precipitation that has persisted since 2000 (Environment Canada, 2006).

In the ocean, sea temperatures globally in 2005 were slightly cooler than in 2004, but still ranked as the seventh warmest year recorded since 1880. The overall warming trend in the ocean of 0.13 °C per decade has been only slightly lower than that in the atmosphere.

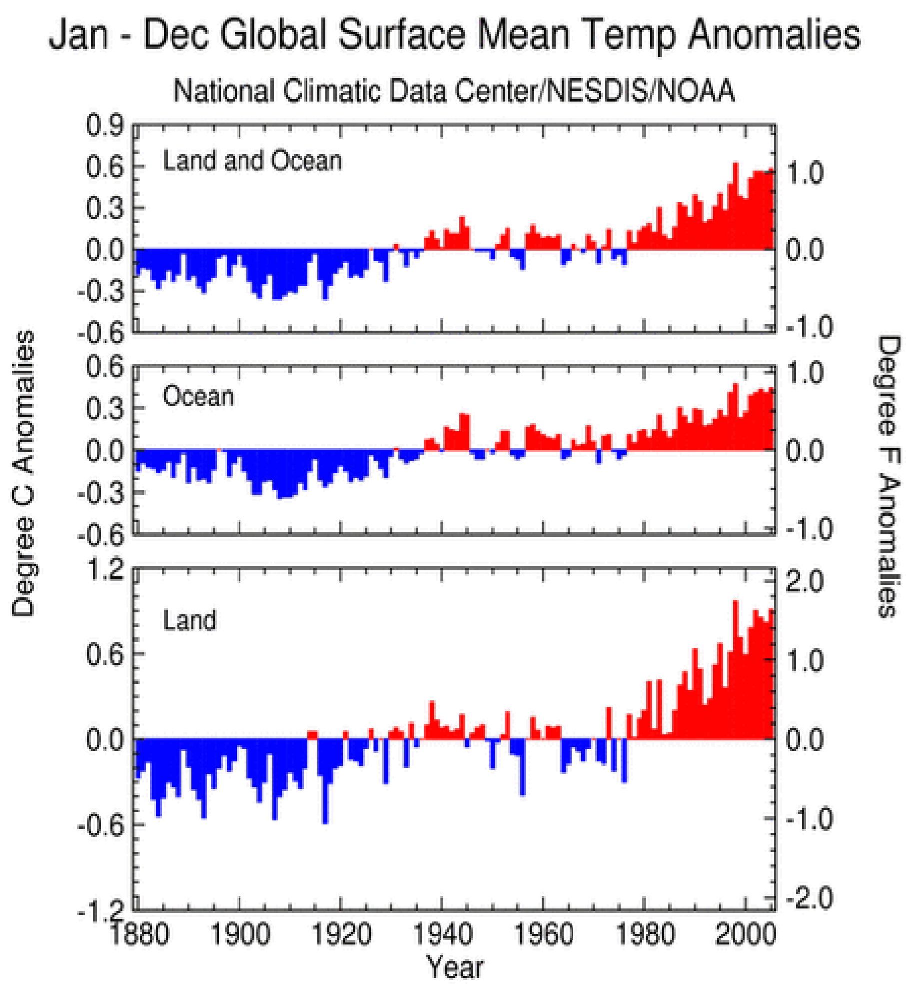

Figure 1. Anomalies of temperature from 1880 to 2005. Top panel displays global anomalies; middle panel shows anomalies over oceans only; bottom panel shows anomalies over land only. (Source: NOAA)

Several measures have been developed to describe the coupled atmosphere and ocean climate in the North Pacific (Fig. 2) The Southern Oscillation Index (SOI, top panel) identifies El Niño and La Niña conditions in the tropical Pacific Ocean; for most of 2005 it indicated warm or weakly El Niño-like conditions, but in late winter 2005 it suggested a change to cool La Niña-type conditions.

The Pacific Decadal Oscillation (PDO, bottom panel) identifies east-west variations in sea temperature across the North Pacific and has been widely used to define warm and cool regimes in the ocean climate of this region. The PDO indicated moderately warm conditions in the NE Pacific at the start of 2005, but moderately cool conditions by the end of 2005. By early 2006 its values were neutral.

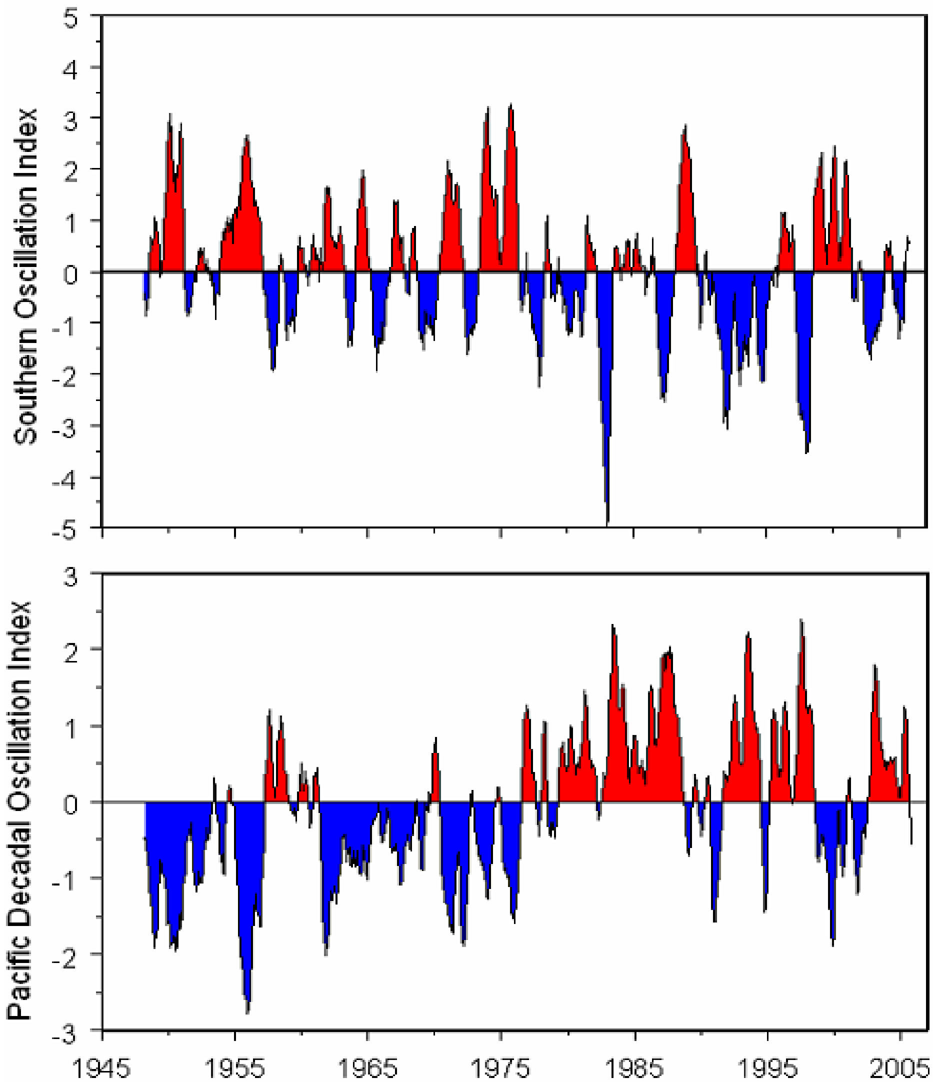

Figure 2. Top: Southern Oscillation Index, showing a weak transition to La Niña (positive SOI) conditions starting in December 2005. Bottom: Pacific Decadal Oscillation, starting warm (positive) at the beginning of 2005 but changing to moderately cool (negative) conditions at the end of 2005.

The warm surface waters that have persisted since 2003 have extended down to 175 m in deep-sea regions and also on the B.C. continental shelf. For example, the waters over parts of the shelf during spring and summer in 2005 were 0.5 to 5 °C above their 1990-1996 averages. Sea surface temperatures in May at shore stations along the west coast of Vancouver Island were much warmer than was expected based on sea temperatures in April (Fig. 3), and offshore temperatures in August were the highest on record for some locations for non-El Niño years. In addition, winds along the coast of B.C. were unusual in having more storms in April with stronger northward winds. This forced warm salty water into the Strait of Juan de Fuca and ultimately into the Strait of Georgia, producing very warm deep waters in that region.

In addition, stronger northward winds caused 2005 to have average to weaker-than-average upwelling of deep waters to the surface along the B.C. coast. Combined, the strong northward winds and greater storm activity in spring 2005 delayed the "spring transition" (the reversal of winter poleward to summer equatorward winds and currents) until mid-April, compared with late February – early March in 2004.

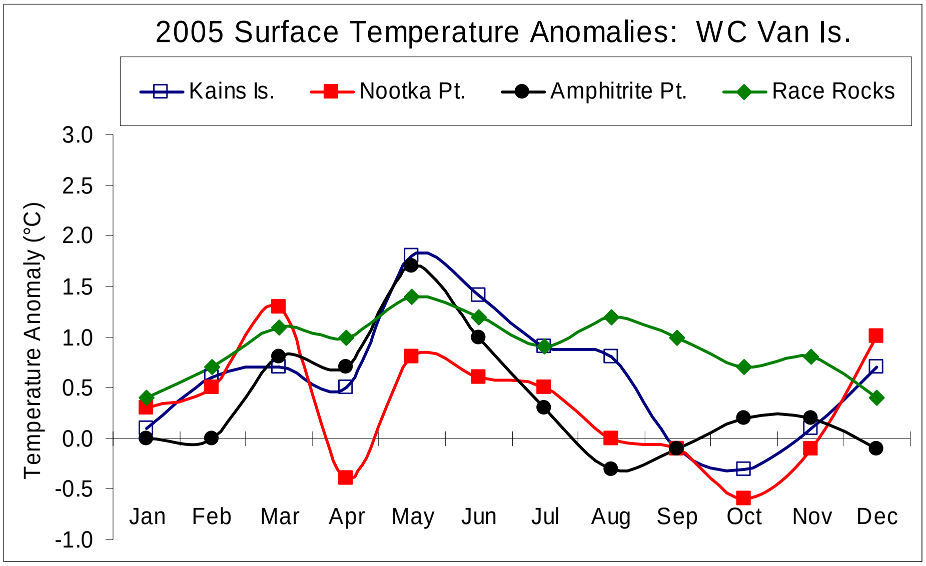

Figure 3. Warm temperature hit all along west coast Vancouver Island and Juan de Fuca Strait from late winter into early summer, in a pattern that extended into the Strait of Georgia and south to the Washington and Oregon coasts. (Source: B. Crawford, DFO. See section on Shore Stations)

These warm conditions with weak upwelling produced stronger near-surface vertical stratification (Fig. 4) which, in the oceanic NE Pacific, reduced the late winter mixing of nutrients into the upper layers where they support the growth of phytoplankton during the spring. In 2005, the amount of nitrate nutrients taken up by phytoplankton in the Gulf of Alaska during the spring-summer growing season was as much as 50% less in some areas than was used during the late 1990s, suggesting decreased phytoplankton production last year.

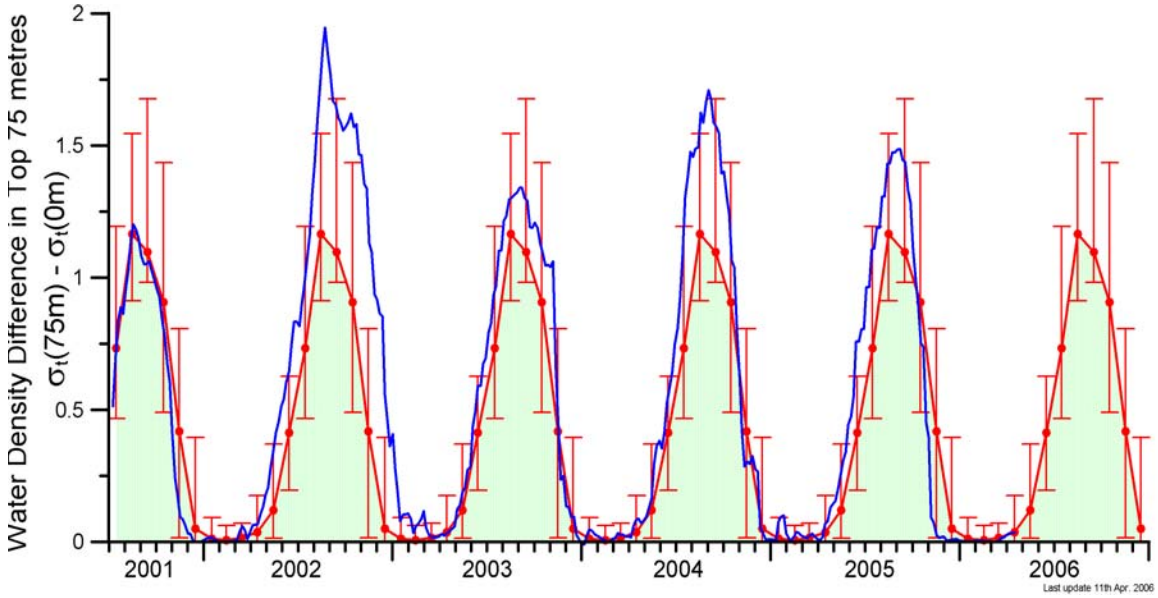

Figure 4. The blue line reveals the difference in water density between the surface and a depth of 70m at Station Papa, as computed from Argo observations. The red line and error bars show the historical average and 95% confidence bounds of this average.. See section on Waters of the Gulf of Alaska).

The production of phytoplankton, which forms the base of the marine food web, has been monitored along the B.C. coast by the SeaWiFS sensor on a satellite since 1998. The data suggest that 2005 had the earliest spring bloom recorded on the north coast of B.C. and in the Strait of Georgia (February), and was second or third earliest (after 2003 and 2004) on the west coast of Vancouver Island. These early blooms were likely a result of the warm conditions and strong vertical stratification in 2005. They are in contrast to the timing of blooms in March and later during the cool years of 1999-2002. These early blooms, however, were followed by two months of stormy weather, such that spring conditions (the spring transition in currents) did not occur until late April in 2005, which is much later than usual.

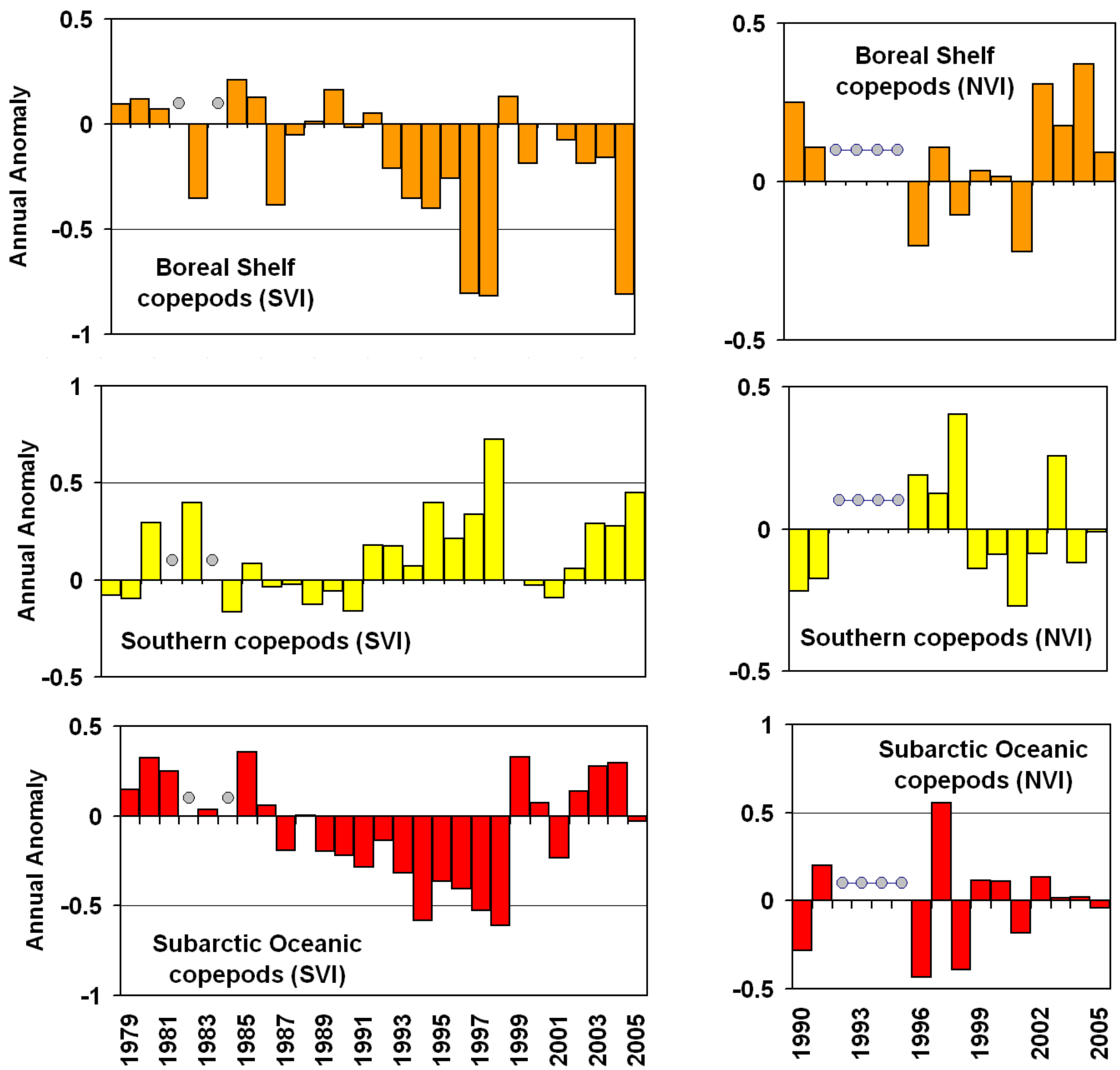

Figure 5. Anomalies of zooplankton species composition on the continental shelf of Vancouver Island. Left panels are data from southern Vancouver Is., referenced to a 1979-1991 base period. Right panels are data from northern Vancouver Is., referenced to 1990-2001. Circles indicate years with no or too few data. 2005 was a very bad year for "boreal shelf" copepods, a good year for "southern" copepods and a fair to poor year for subarctic oceanic copepods. (Source: D. Mackas. See section on Zooplankton.)

While the spring bloom may have started early in 2005, the warm water temperatures and weak upwelling resulted in low nutrient and chlorophyll (phytoplankton) concentrations, in particular on the continental shelf west of Vancouver Island (Fig. 5). Zooplankton biomass was also below normal, and a large proportion of the zooplankton species were warm-water forms more typically found off California; it was an especially poor year (particularly in the Strait of Georgia) for the large cold-water copepods and euphausiids (krill) that usually dominate B.C. and NE Pacific waters in spring (Fig. 5). In addition, warmer conditions caused the peak in biomass of these large copepods to occur earlier (April-May) in 2004 and 2005 rather than May-June as in previous years, which may have consequences for fish, seabirds and other animals that time their migrations or reproduction to match these biomass peaks. The zooplankton biomass and species composition changes were less pronounced off northern B.C., however.

Seabirds off Vancouver Island were the first and most obvious animals to show the consequences of the reduced productivity of the B.C. coast during spring in 2005. Marine birds are good indicators of ocean conditions because they gather in large aggregations to breed and because, as a group, they feed at a variety of trophic levels from zooplankton to fish. In addition, seabird breeding success is closely tied to the availability of their preferred prey. Overall, 2005 was a very poor year for seabirds at Triangle Island, the monitoring site at the northern tip of Vancouver Island. Their diets were poor in their preferred prey (large cold-water copepods for Cassin's Auklets, sand lance for Rhinoceros Auklets) consistent with the low biomass of the copepods observed in the zooplankton surveys. The warm-water southern copepod species are not adequate replacements as they have a lower energy content. The timing of breeding of these Auklets was very late (June) in 2005, suggesting that food was scarce early in the season. Breeding success in 2005 was also extremely low for all species of seabirds at Triangle Island, and lower than predicted based on a relationship with sea temperatures in early spring (Fig. 6).

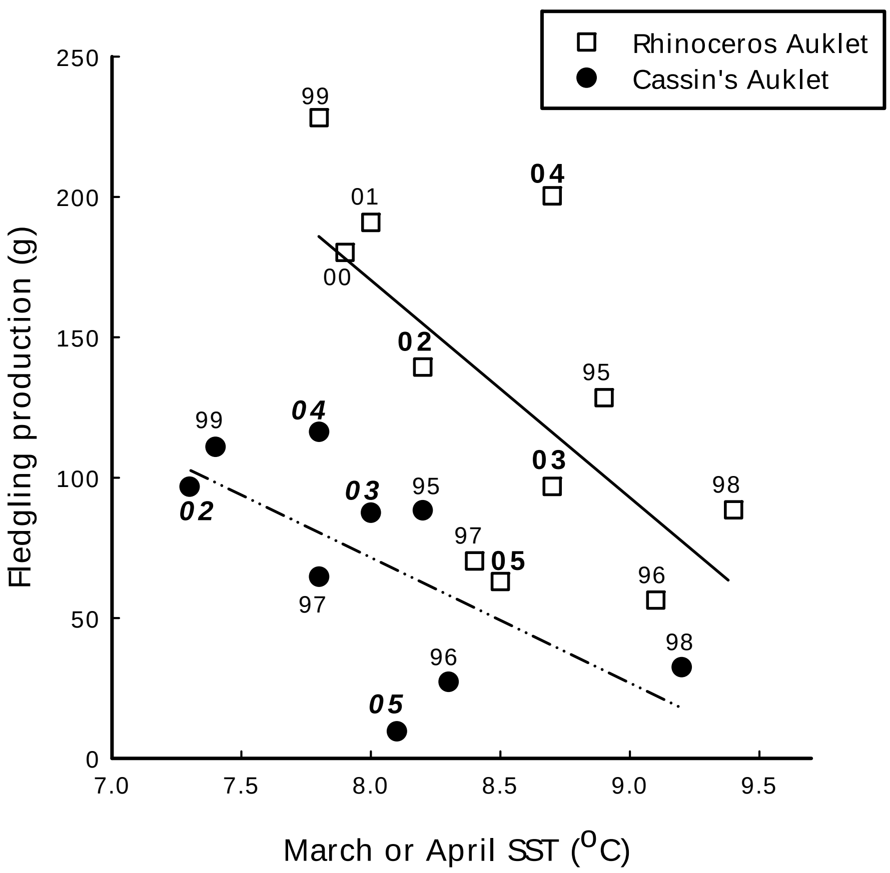

Figure 6. Consequences of April sea surface temperatures (SST), measured at the Pine Island Lightstation (50°35'N 127°26'W), for Cassin's and Rhinoceros auklets breeding on Triangle Island, British Columbia, 1994-2005. Note that success was very low in both species in 2005, and much lower than predicted from April SST. (Source: M. Hipfner, EC. See section on Seabirds)

The growth of juvenile coho salmon from spring to fall off the west coast of Vancouver Island in 2005 was the lowest that has been measured since 1998 when these observations began. Juvenile coho growth is usually greater to the north off SE Alaska; in 2005 growth rates in this region were about twice those off Vancouver Island, with no depression in rates compared with previous years (Figure 7). Test fishing for herring in February 2006 found unusually few adults older than age 3 off the west coast of Vancouver Island and in the Strait of Georgia. Although under investigation, this may represent exceptional mortalities of older herring during winter 2005 resulting from insufficient zooplankton food consumed during the summer and fall.

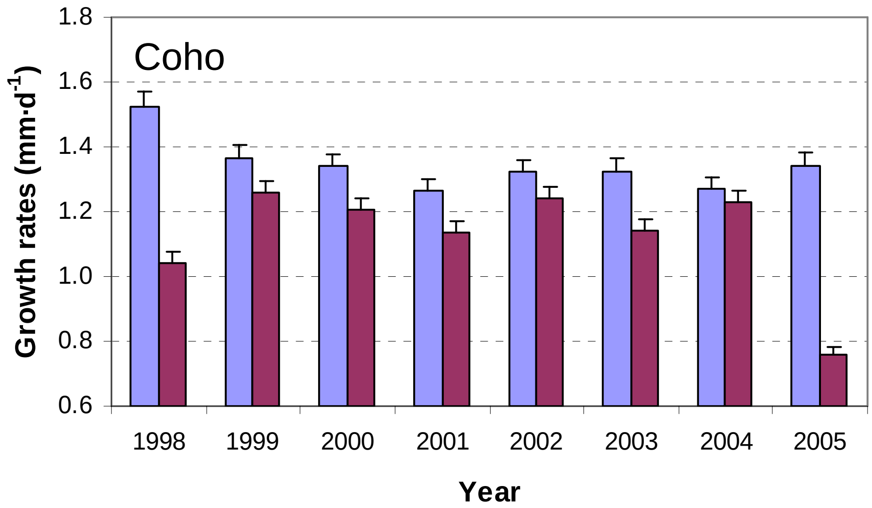

Figure 7. Growth rates (May-October) of juvenile coho salmon off the west coast of Vancouver Island (purple bars) and Southeast Alaska (blue bars). The error bars are 2 x standard errors of the mean. (Source: M. Trudel, DFO. See section on West Coast Coho)

In addition to the decreased proportion of the normal, cold-water zooplankton that are the usual prey for most fish species that reside in B.C. waters, the warm conditions and stronger northward currents facilitated the northward movements into B.C. waters of typical summer migrant species such as Pacific hake and Pacific sardine, but also of unusual species such as the ocean sunfish (*Mola mola*) and Humboldt squid (*Dosidicus gigas*). Many of these species are predatory on resident B.C. zooplankton and fish; this squid species in particular is very fast growing and a big consumer of fish such as herring, sardines, and possibly juvenile salmon. Evidence that even these species may have been affected by the unusual zooplankton conditions is provided by Pacific hake, which were very abundant through B.C. waters in 2005 (due to the warm conditions) but tended to be absent from their usual feeding grounds near the shelf edge and instead were dispersed into smaller schools closer to shore. The hake were also smaller in weight than expected, suggesting they may not have been feeding at optimal rates (note that euphausiids are their preferred prey).

Outlook for 2006

As a result of the multi-year life spans and time lags that affect higher trophic level fish and invertebrates in B.C., many of these species are still experiencing the impacts of the cool marine conditions that occurred from 1999-2002, whereas others are responding to the warm conditions that have occurred since 2003. For example, the largest year class of Pacific hake in recent memory was produced during the La Niña year of 1999. These fish were 6 years old in 2005, and dominated (58%) the migratory hake population from California to Alaska. The warm conditions since 2003, with lower zooplankton biomass and more predatory fish, are having negative consequences for several resident B.C. fish populations, in particular salmon and herring in southern B.C. Returns of Barkley Sound sockeye in 2005 were well-below average, as predicted from warm ocean conditions during their outmigrations in 2003. The persistent warm conditions throughout 2004 and 2005 suggest that salmon returns to the west coast of Vancouver Island will remain below average in 2006 and 2007. Similar forecasts have been made for wild coho and Nitinat River hatchery chum salmon in this area. Similarly with Pacific herring, which has been experiencing declining recruitment because of warm conditions with reduced food and increased predators; if these conditions continue, recruitment is likely to reduce further in 2006 and 2007. Recruitment of smooth pink shrimp (*Pandalus jordani*) populations off the west coast of Vancouver Island improved during the cool years of 1999-2002, but has declined with the return of warm conditions since 2003. It is clear that the Strait of Georgia is still producing large abundances of Pacific salmon. However, the species of salmon that benefit have changed. In 2005, there appears to have been a change in the production of plankton that resulted in good survival of juvenile chum salmon and poor survival of coho and chinook salmon. It is also clear that the Strait of Georgia ecosystem is changing and will continue to change as climate trends shift and sea surface temperatures increase.

Oceanographic conditions are more ambiguous to forecast since they depend on meteorological conditions that have yet to occur. By the end of 2005 and early 2006, surface waters in the northeast Pacific were cooler and closer to normal, associated with a weak La Niña event in the tropical Pacific. More normal temperatures would reduce the strong vertical stratification in the NE Pacific and allow more normal mixing and resupply of nutrients into the surface layers, potentially increasing phytoplankton growth. Spring sea surface temperatures on the southern B.C. coast are reasonably well (r^2 = 0.69) predicted by the atmospheric pressure at sea level in winter in the tropical western Pacific, such that high winter sea level pressures are followed by warm spring sea surface temperatures along the southern B.C. coast. The December 2005 – January 2006 sea level pressure in this tropical region suggests that spring 2006 sea surface temperatures in B.C. should be about normal. A cooling toward more normal conditions off B.C. in 2006 would improve the returns of sockeye salmon to Barkley Sound in 2008. However, an index of ocean conditions in the NE Pacific based on satellite-measured sea surface height, which is less sensitive to short-term fluctuations in the coupled atmosphere-ocean system (Figure 8), indicated little change in prevailing conditions at the end of 2005, suggesting that the 2005-2006 La Niña event may be relatively short-lived and weak, and not lead to persistent changes such as occurred from 1999-2002. If warm conditions continue for more than a few years, however, major changes to the marine ecosystems of the NE Pacific and B.C. coast can be expected.

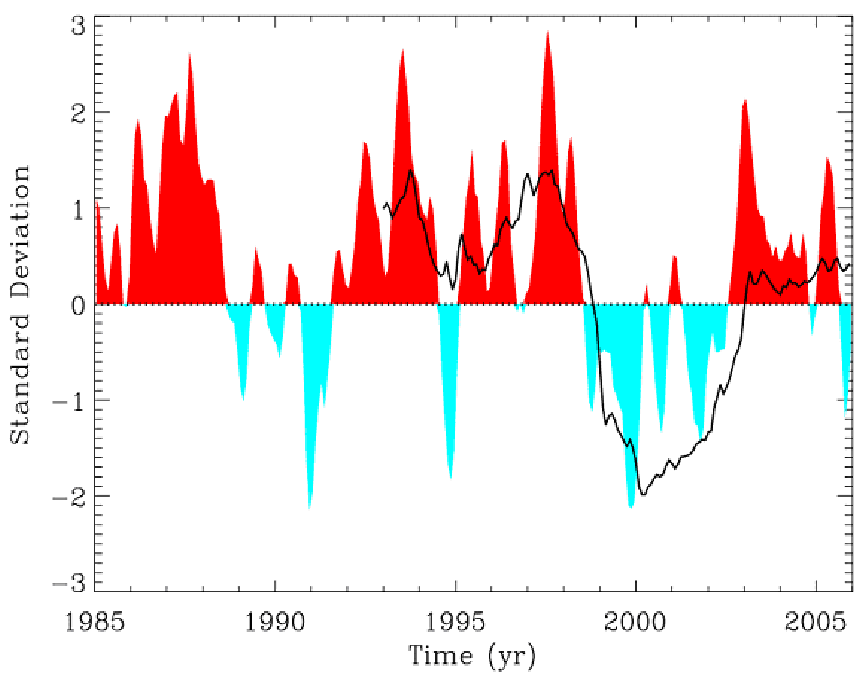

Figure 8. The Pacific Decadal Oscillation (PDO) index is shown in solid blue and red. Blue indicates the PDO cold phase and red the warm phase. The solid black curve gives the sea level index with positive values indicating elevated sea level off the west coast of North America and sea level anomalies of opposite sign in the central Pacific. (Source: P. Cummins, DFO. See section on NE Pacific sea levels).

Global Climate and North Pacific Indices

Record Global Warming in 2005

Compiled from Web pages of US National Ocean and Atmospheric Administration

The 2005 global temperature was statistically indistinguishable from the standing record set in 1998, as noted in the graph of annual temperature anomalies below. To the limits of accuracy, both 2005 and 1998 were warmest observed since the beginning of recorded global temperature in 1880. However, warming of 1998 received a boost from the strong El Niño events then, whereas 2005 was neither an El Niño nor La Niña year. During the past century, global surface temperatures have increased at a rate near 0.6°C/century, but this trend has increased to a rate of 1.8°C/century during the past 25 to 30 years.

There have been two sustained periods of warming, one beginning around 1910 and ending around 1945, and the most recent beginning about 1976. Temperatures during the latter period of warming have increased at a rate comparable to the rates of warming projected to occur during the next century with continued increases of anthropogenic greenhouse gases.

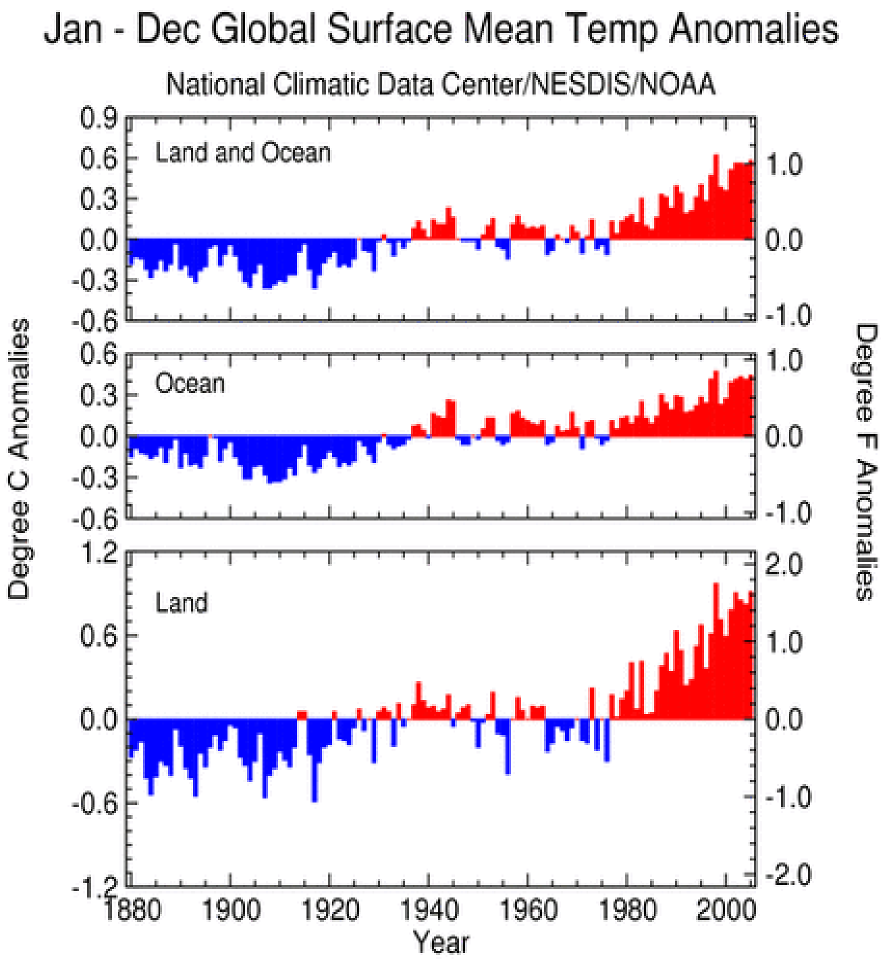

Figure 9. Anomalies of temperature from 1880 to 2005. Top panel displays global anomalies; middle panel shows anomalies over oceans only; bottom panel shows anomalies over land only. (Source: NOAA)

The graphs in the figure above show the distribution of temperature changes. Note that air temperature over land has increased at a faster rate than temperatures above the ocean. Warmest temperature anomalies in 2005 were mainly in the north of Canada, Alaska and Russia. Warning over land was generally greater than warming over oceans.

Pacific Decadal Oscillation and Aleutian Low Pressure Indices

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 basin. The PDO index (Mantua et al., 1999) is based on the results obtained from principal components analysis of mean monthly sea surface temperature anomalies over the North Pacific Ocean averaged into 5° grids since 1900 (Figure 10A).

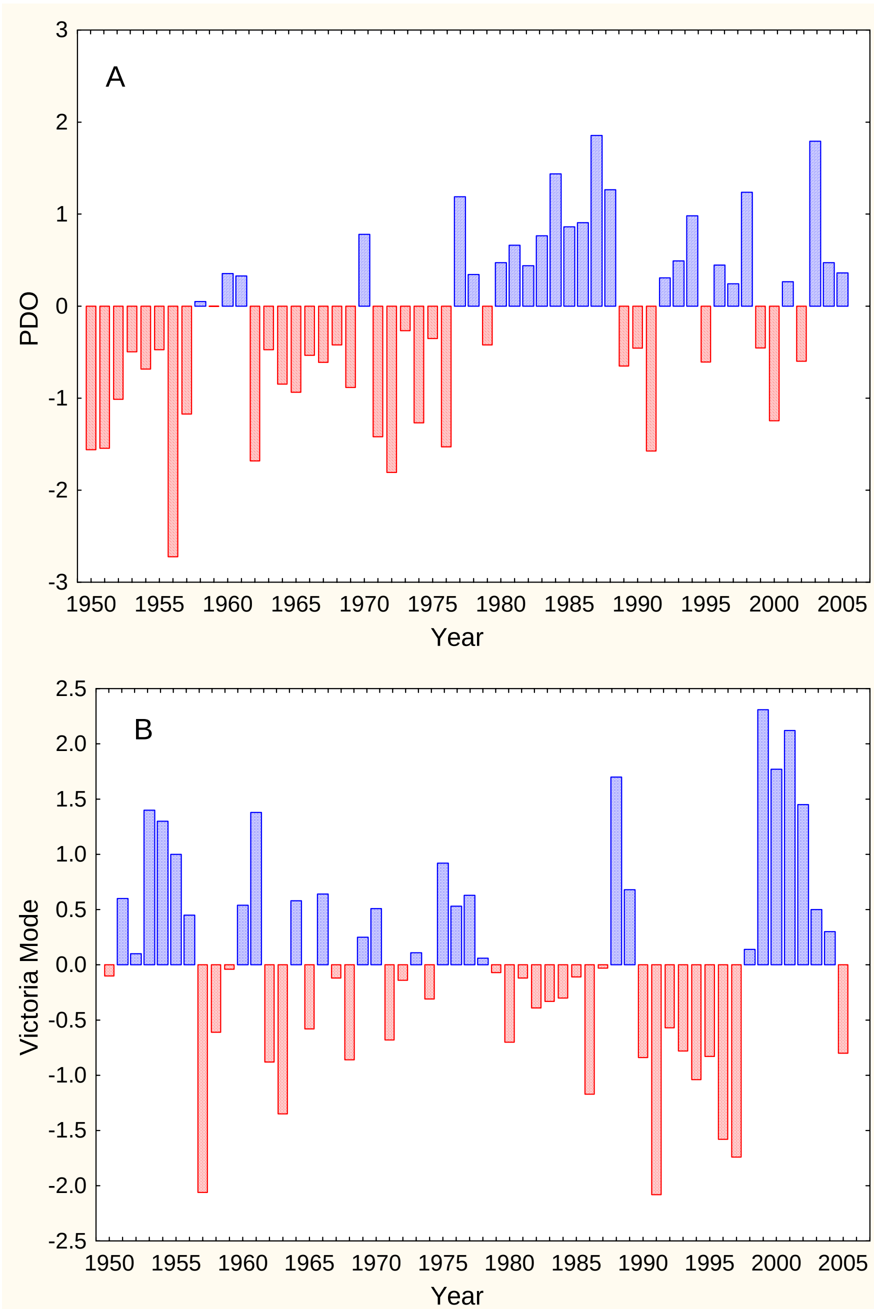

Figure 10 A) The first component from a principal component analysis of North Pacific winter (November-March) sea surface temperature fields north of 20°, which represents the Pacific Decadal Oscillation (PDO) index pattern. B) The second component is an alternate pattern of sea surface temperature variability (the Victoria Mode) and shows a shift to a large amplitude since the early 1990s, with a shift to positive values in 1998. (Updated from Bond et al., 2003.)

The analysis results in monthly loadings to the first principal component The index was introduced by Mantua et al. 1999 as an annual value based on the mean November (previous year) through March loadings. (data at ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest) 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. These two states are correlated to an east-west spatial pattern in sea surface temperature.

Recently, climatologists have recognized a second dominant spatial pattern in this sea surface temperature analysis which is a north-south spatial pattern, referred to as the Victoria Mode (Bond et al., 2003; King, 2005). This spatial pattern is represented by the mean November through March loadings for the second principal component (Figure 10B) resultant from similar analysis as that conducted for the PDO (Bond et al., 2003). The PDO index (principal component 1) captures approximately 30% of the variability in North Pacific sea surface temperatures, and the Victoria Mode captures 18% (Bond et al., 2003).

In 1977, the PDO (Figure 10A) switched from a negative east-west phase to a positive east-west phase. Since 1990, the Victoria Mode (Figure 10B) has exhibited a greater amplitude of variability and is the dominant pattern. The Victoria Mode remained negative throughout the 1990s, and shifted to a positive phase in 1998. It has remained in a positive north-south phase through 2004, though values have been moderate, or closer to zero (King, 2005). In 2005, this index value was negative (Figure 10B). Both indices are used in conjunction with other north Pacific climate indices to detect regime shifts in the North Pacific.

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 (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 11).

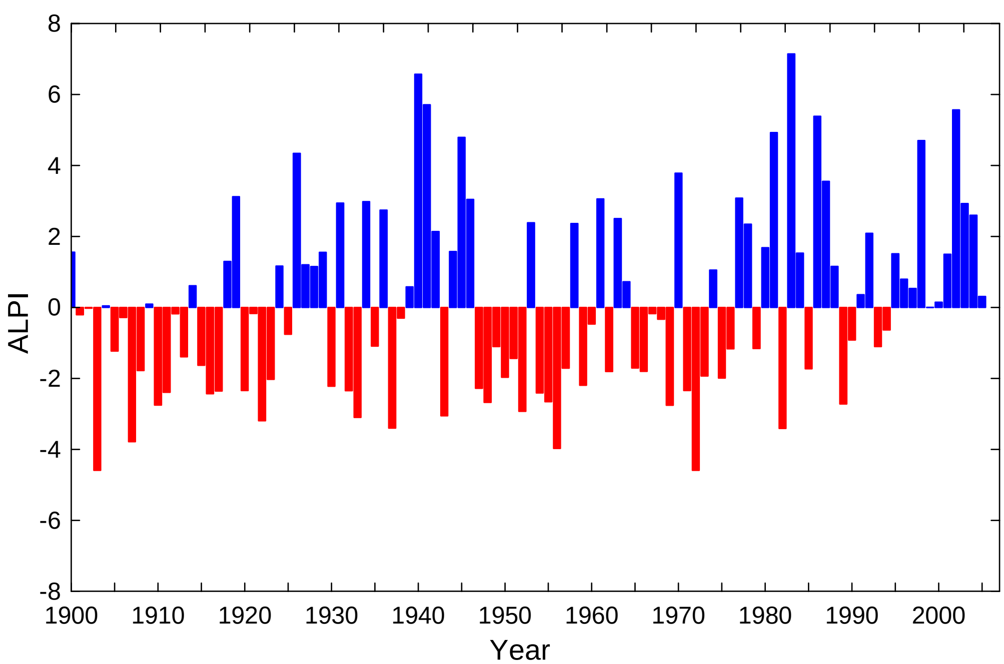

Figure 11. The Aleutian Low Pressure Index (ALPI) from 1900 to 2005. Since the 1998 regime shift, the Aleutian Low Pressure system has been relatively strong as indicated by the continuance of mainly large positive values; however the 2005 value was near neutral. Data available from http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx_alpi.htm.

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 2002, they still reflect strong Aleutian Lows (Figure 11). The Aleutian Low Pressure Index value in 2005 was near neutral indicating a moderate pressure system (Figure 11). The shift of the Aleutian Low to stronger winter values since 1950 is one of the major climate shifts associated with global climate change.

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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.

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Index of northeast Pacific sea level anomalies

Patrick Cummins, Fisheries & Oceans Canada

An index of ocean variability for the northeast Pacific Ocean may be constructed based on sea level anomalies measured by satellite altimetry. On interannual time scales, variations in sea level reflect the vertically integrated effects of temperature and salinity anomalies. An index based on sea level indicates changes occurring primarily over the top few hundred meters of the water column. It has been shown recently that for the northeast Pacific an index based on the first principal component of sea level complements the Pacific Decadal Oscillation (PDO) index, which is based on sea surface temperature. However, the sea-level-based index is less subject to short period variability than the PDO and so provides a better indication of long-term changes in the upper ocean (Cummins et al., 2005).

Figure 12 shows the recent history of the PDO and the northeast Pacific sea level index. The latter is based on altimeter data at 1 degree resolution over a region extending from the west coast of North America to the dateline and from 25 to 60°N, excluding the Bering Sea. Both the PDO and sea level indices show that persistent changes in the state of the northeast Pacific occurred in winter 1998/99 that were marked by colder SST and lower SSH over the Gulf of Alaska. These changes were characteristic of the cold phase of the PDO and occurred in response to a significant La Nina event in the tropical Pacific in the winter of 1998/99. The effects of the 1998/99 'regime shift' persisted for about 4 years, ending in 2003.

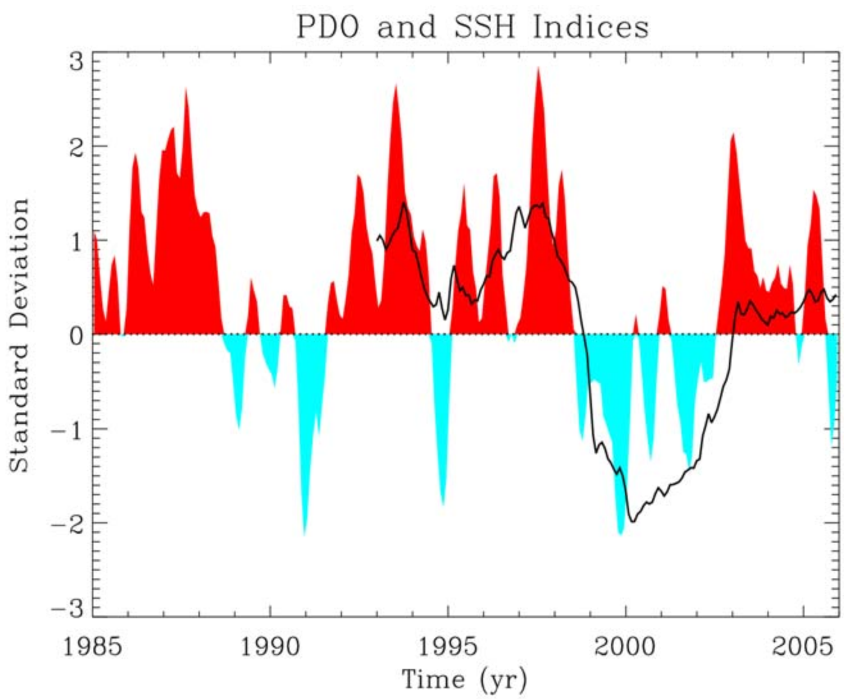


Figure 12. The PDO index is shown in solid blue and red. Blue indicates the PDO cold phase and red the warm phase. The solid black curve gives the sea level index with positive values indicating elevated sea level off the west coast of North America and sea level anomalies of opposite sign in the central Pacific.

During the last three years (2003-2005) the indices shown in Fig. 12 indicate a return to warm phase of the PDO, characterized by above-average sea surface temperatures and sea levels in the Gulf of Alaska. In late 2005, the PDO shifted to the cold phase, apparently in response to the recurrence of La Nina conditions in tropical Pacific. However, the sea level index did not change sign in 2005, suggesting that a persistent cold phase of the PDO has yet to develop. Given that the 2005/06 La Nina is relatively weak, this event may not lead to the dramatic and persistent changes seen over the northeast Pacific following the 1998/99 event.

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.

Gulf of Alaska

Ocean-surface temperature: warming all over the Gulf

Bill Crawford and Peter Chandler, Fisheries and Oceans Canada

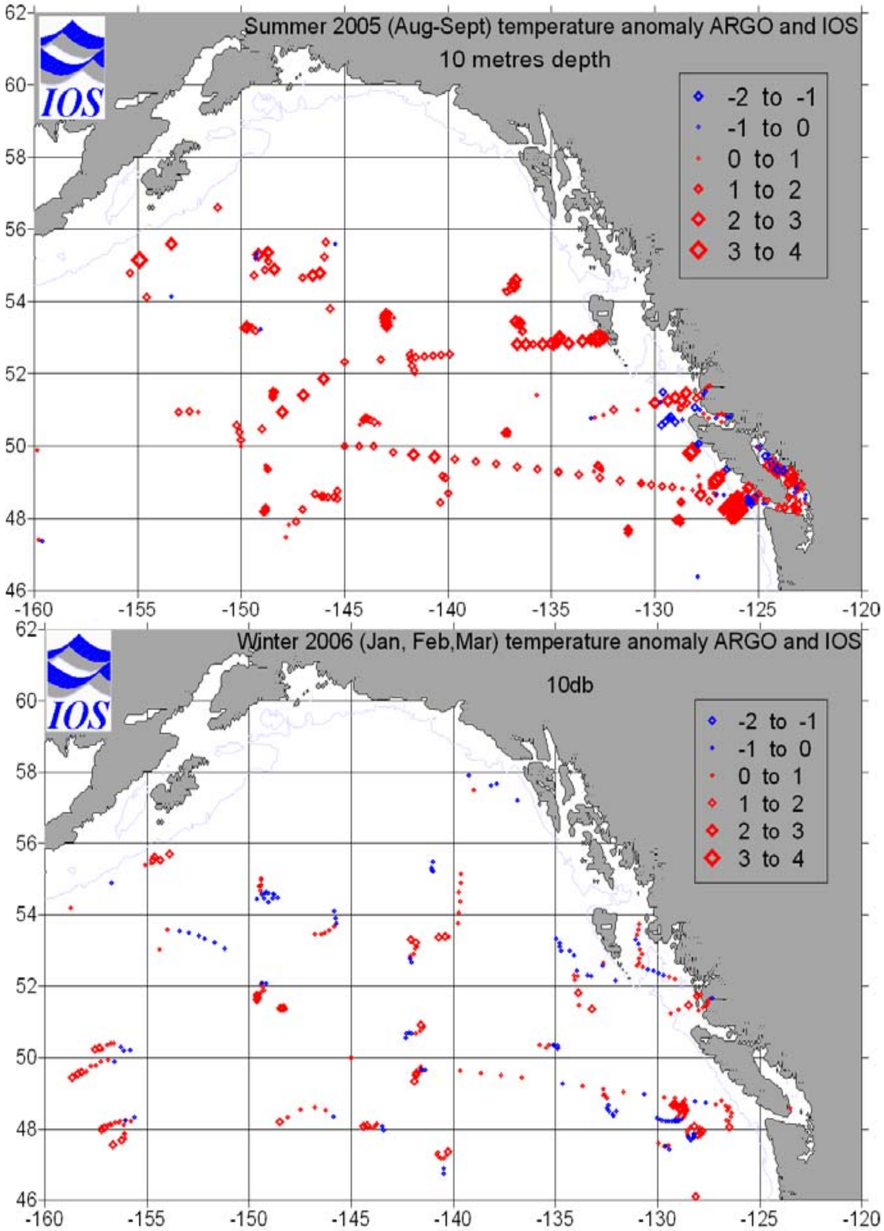


Figure 13. Temperature anomalies at 10 metres depth, measured by DFO research vessels, and by Argo profilers. Anomalies in °C are denoted by the size of symbols, according to scale in each plot. Summer 2005 is plotted in top panel, winter 2006 in bottom panel

Red denotes warm anomalies. Blue denotes cold anomalies.

All measurements are taken by profiling instruments, usually measuring temperature and salinity from ocean surface to at least 1000 metres depth. Only measurements at 10 metres depth are shown here.

Temperature measurements all through the Gulf of Alaska in August and September 2005 revealed a nearly continuous pattern of very warm water near surface in the Gulf of Alaska and coastal BC waters in the summer of 2005 that followed record warm waters in the summer of 2004, These conditions brought warm species of fish, mammals and plankton into Canadian waters, as noted elsewhere in this report. However, observations in January to March of 2006 (Lower panel of Figure 13) indicate temperature anomalies were closer to normal.

Waters of the Gulf of Alaska: Warmer through 2005

Howard Freeland, Fisheries & Oceans Canada

Figure 14 shows a ratio of the number of actual floats currently reporting data to the expected number of floats. Yellow dots show the float positions in March 2006. Red areas have achieved the target density of floats; whereas blue areas are deficient. Plans do exist to correct these deficiencies and the distribution is sufficient to map properties in the Gulf of Alaska.

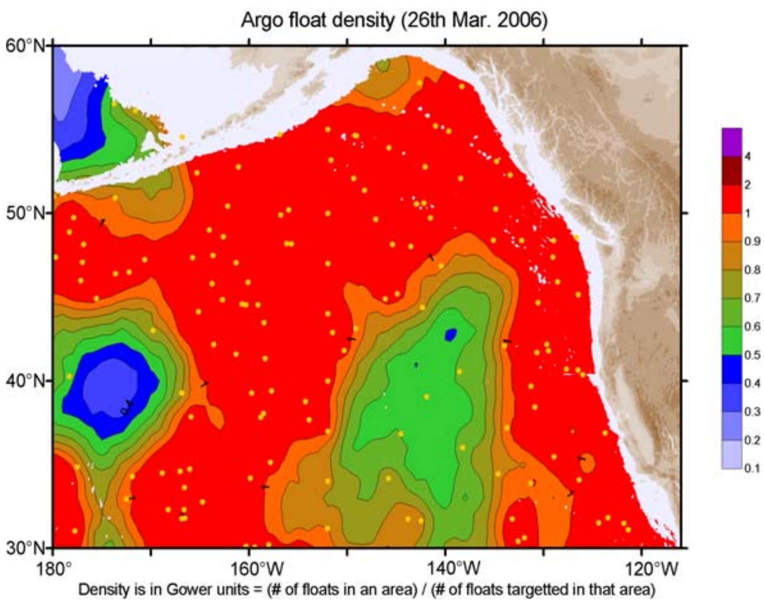


Figure 14 (Left): The density of Argo floats in the Gulf of Alaska.

Using Argo it has been possible to interpolate properties every month onto Line-P stations and thereby compute Argo descriptions of Line-P surveys every month since 2001.

When ship-based surveys are available the Argo representations of Line-P sections agree with the direct observations, though the Argo versions have much less detail. The simulated sections show waters in the Gulf of Alaska remaining significantly warmer than normal in the top 120 metres for most of the year. Salinities were close to normal throughout 2005. As 2005 was drawing to a close conditions appeared to be returning to normal. But conditions in early 2006 show some unusual anomalies.

The diagrams in Figure 15 show that though the temperature anomalies were very close to zero, a new, large salinity anomaly in 2005 appears to indicate an abrupt change in conditions in the Gulf of Alaska. More evidence of this change is presented on the next page.

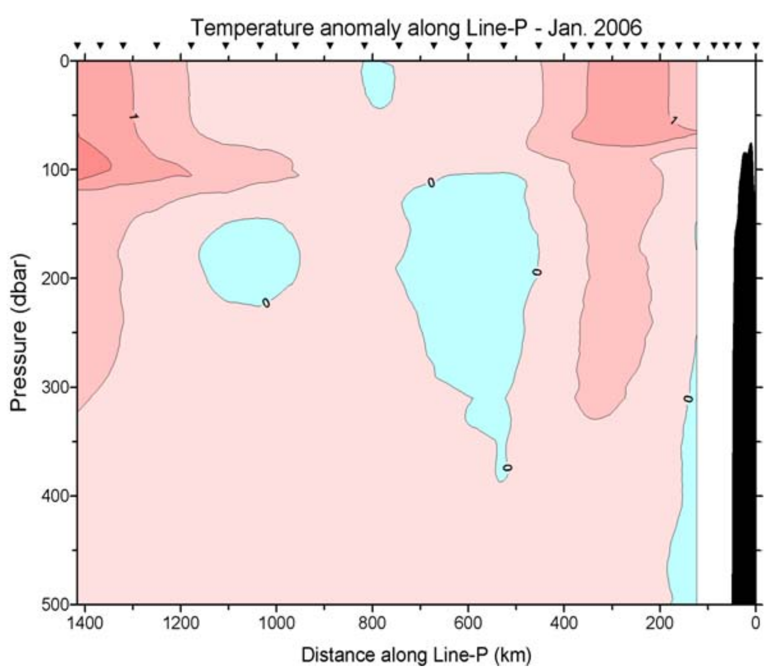


Figure 15a: Temperature anomaly along Line-P simulated using Argo floats.

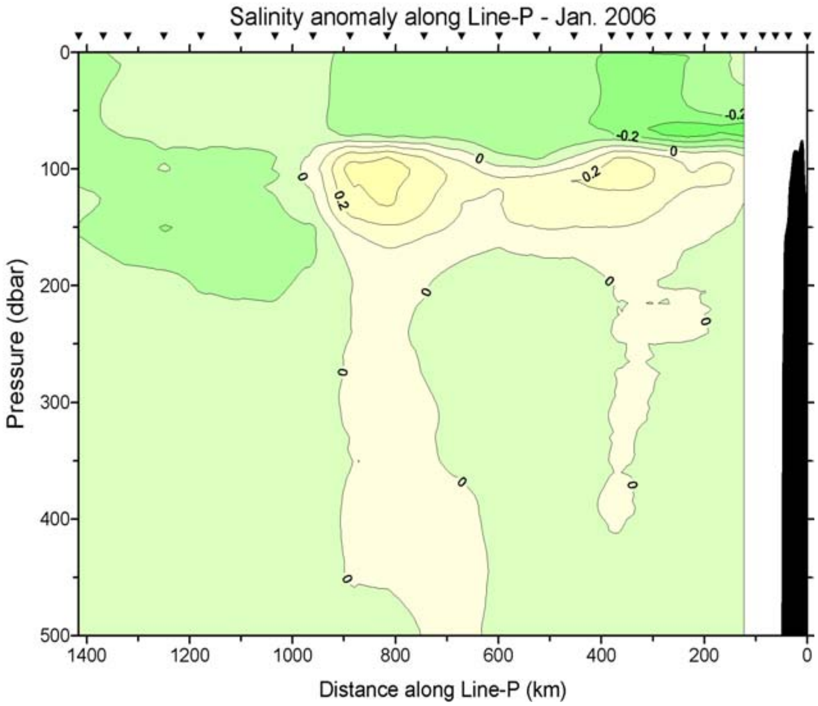


Figure 15b: Salinity anomaly along Line-P simulated using Argo floats.

Figure 16 shows that when Argo mapping at Ocean Station Papa (50°N, 145°W) became available in 2001, the near surface stratification was near the long term average. During 2002 the near-surface stratification increased dramatically and this continued into 2005. However, late in 2005 the stratification decreased to being even weaker than normal. Increased stratification in 2002 to 2005 likely impeded the supply of nutrients to the upper ocean. Weaker stratification in late 2005 may have allowed the supply of nutrients to return to normal. This nutrient input to surface waters is needed for marine plant growth in spring.

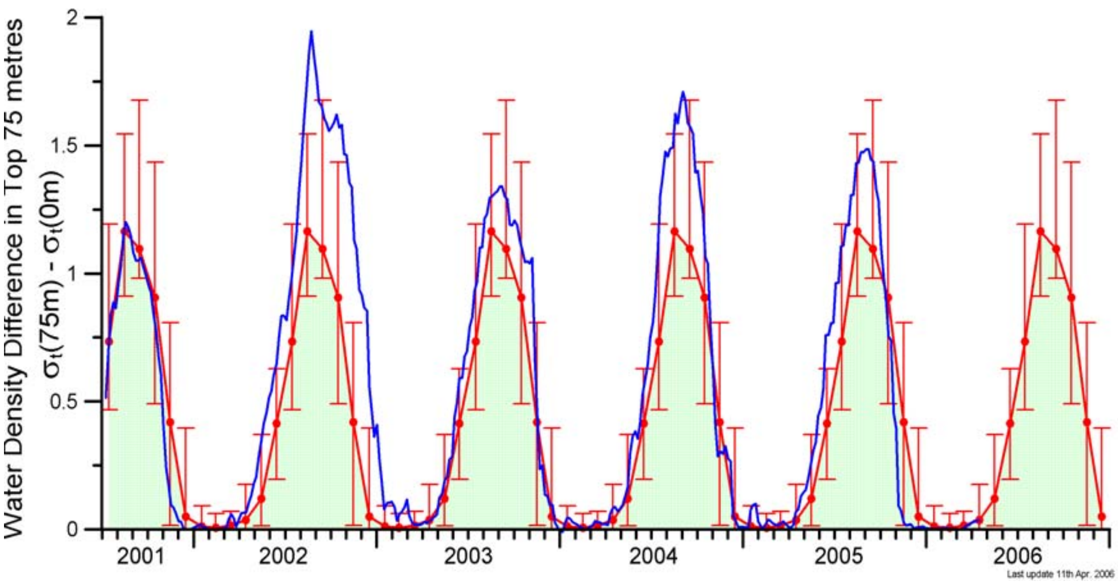


Figure 16: The blue line reveals the difference in water density between the surface and a depth of 75 m at Station Papa, as computed from Argo observations. The red line and error bars show the historical average and 95% confidence bounds of this average.

The mixed layer depth is another index of winter nutrient supply to surface waters (Figure 17). Between 2002 and 2005 mixed layer depths were anomalously low, but as shown in Figure 17 the mid-winter mixed layer depths returned to normal in January 2006.

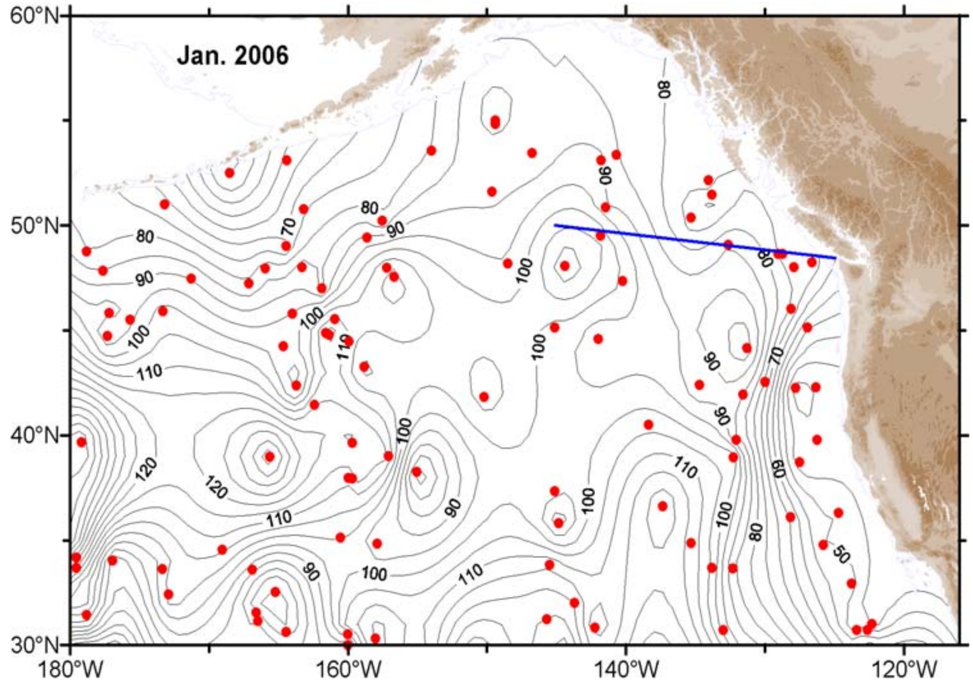


Figure 17: Mixed-layer depths (metres) in the NE Pacific in January 2006. The blue line denotes Line-P.

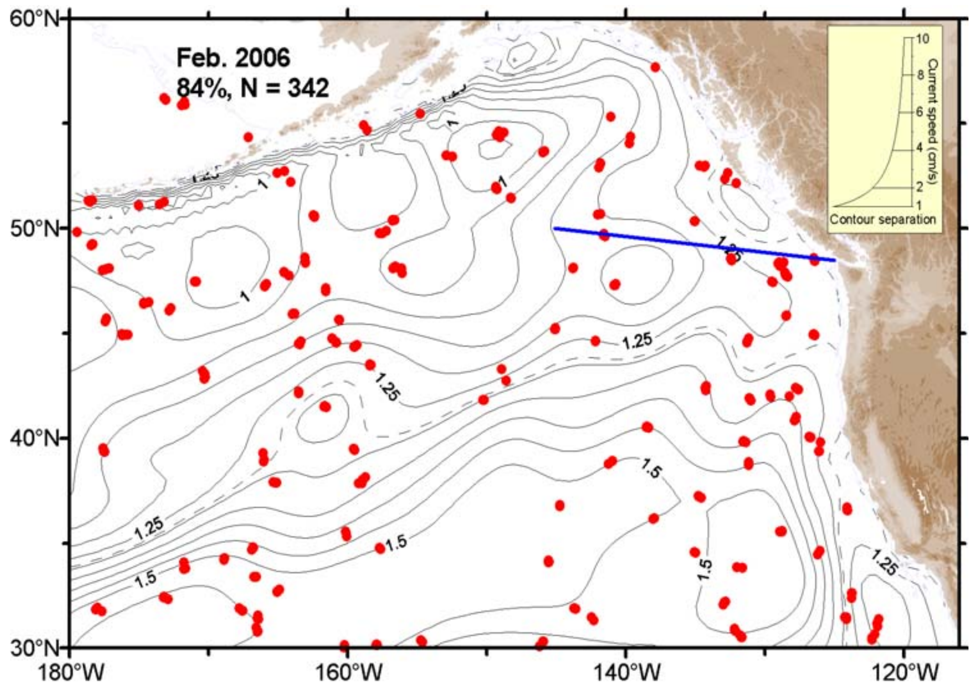


Figure 18: Contours of the near-surface circulation of the NE Pacific. Flow is along contours and is faster when contours are closer together. The dashed line is the "dividing streamline" separating water that ultimately heads north in the Alaska Current from water that ultimately heads south in the California Current. The blue line denotes Line-P.

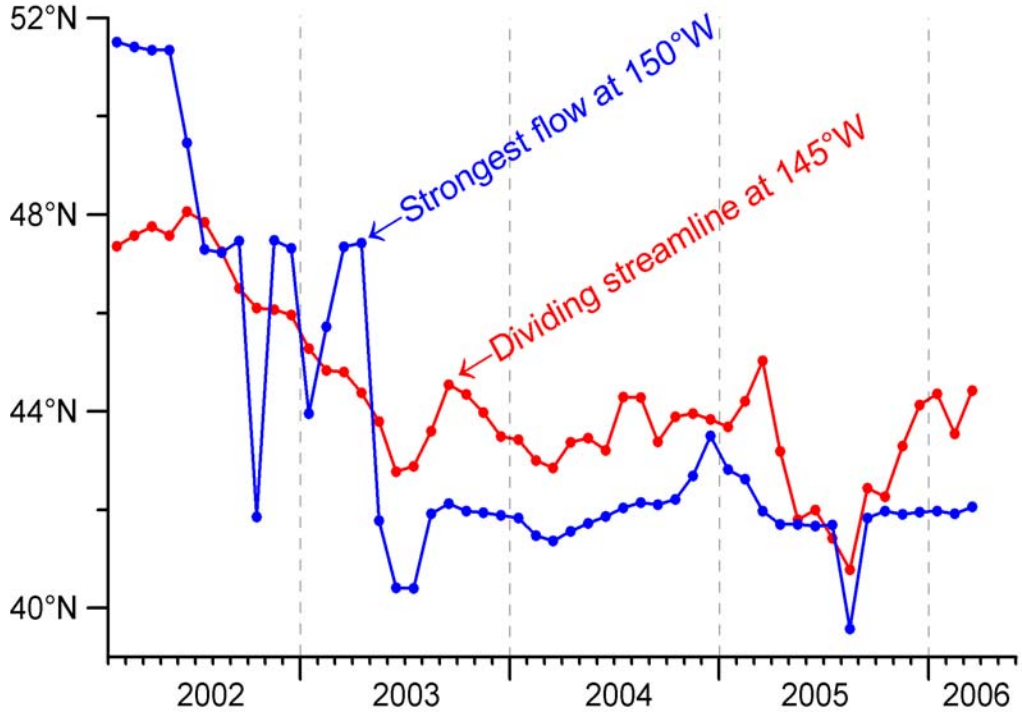


Figure 19: The latitude of the North Pacific Current at longitudes 145 and 150W estimated by two different methods.

Argo also allows us to monitor the circulation of the NE Pacific and to look for changes that are occurring. In early 2005 the North Pacific Current was relatively broad with relatively weak flows. Steadily as we progressed through 2005 the current narrowed and became more intense.

Figure 19 shows the latitude of the central axis of the North Pacific Current that brings water to the Gulf of Alaska from the Kuroshio extension region (This latitude is displayed as the dashed line in Figure 18). Figure 19 shows that it was very far to the north in 2002 and into 2003. Near normal latitude through 2004 (normal defined by Dodimead 1963) and is now heading north again after a dip to the south. The recent trends support the suggestion made early in this report that conditions in the Gulf of Alaska are changing.

Dodimead, A. J., F. Favorite, and T. Hirano. (1963) Salmon of the North Pacific Ocean – Part II. Review of oceanography of the Subarctic Pacific Region. *Int. N. Pac. Fish. Comm. Bull.* **13**, 195p.

SST and wave height at the west coast weather buoys

Jim Gower, Fisheries & Oceans Canada

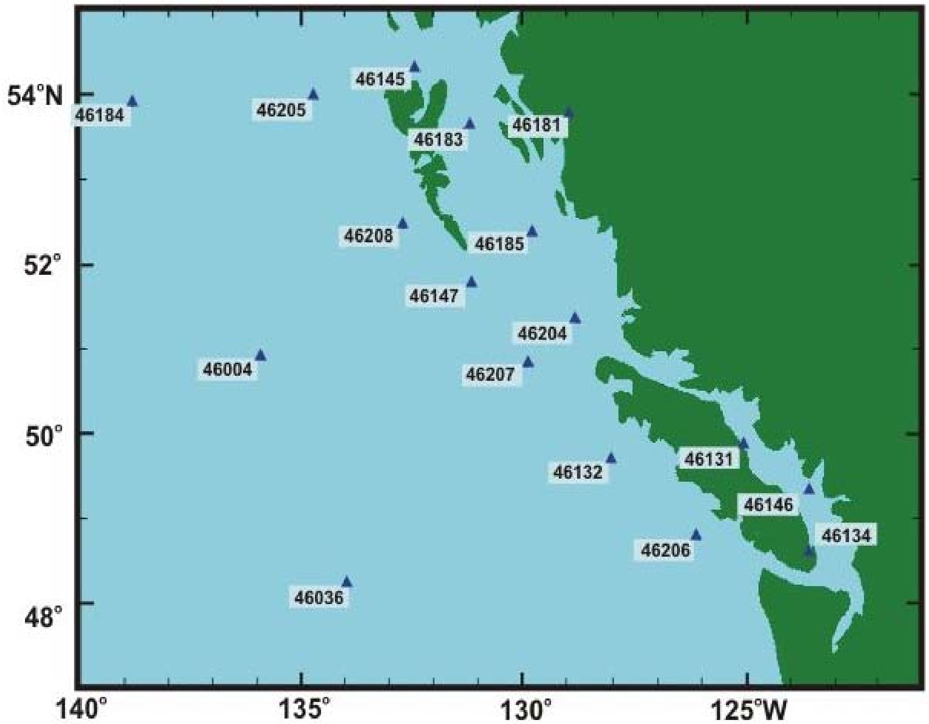


Figure 20. Locations of marine weather buoys operated by Environment Canada and Fisheries and Oceans Canada

Buoy	Years	SST C/y	SWH %/y
46184	18	0.072	-2.25
46004	18	-0.009	-2.6
46036	18	-0.014	-2.09
46205	17	0.024	-1.39
46208	18	-0.023	-0.76
46147	13	-0.043	-2.52
46207	16	-0.008	-0.78
46132	12	-0.024	-2.23
46206	17	0.007	-0.45
46145	15	0.006	-0.81
46183	15	0.005	-0.4
46185	16	0.003	-1.77
46204	16	-0.011	-1.01
46131	13	-0.003	
46146	14	0.006	
46181	16	-0.03	
46134	7	0.1	

Long-term trends for measurements made on the west coast meteorological buoys are shown in the table at left .The top three rows show data from the larger Nomad buoys which are about 350 km offshore. The bottom four rows are for buoys in protected waters of the Strait of Georgia and coastal inlets. Only the North Nomad offshore buoy (46184) shows a significant warming trend. All exposed buoys indicate a decrease in significant wave height of 0.4 to 2.6% per year. Statistical significance of this trend is highest for the offshore Nomad buoys ($p<.001$), with 6 other buoys showing $p<0.1$. If confirmed, the average reduction of 1.5% per year represents a 24% reduction in wave height since 1990.

Real-time processing of wind data from the buoys was changed in about 1999 to record scalar rather than vector wind speed averages. The result appears as a step up in wind speed (data not shown) which masks any real trend.

Graphs on the next page reveal changes in ocean surface temperatures as measured since 1986 by weather buoys.

The long-term SST time series are shown in Figure 21 below with the seasonal temperature cycle for each buoy removed. The buoys indicate a warm summer in 2004 which set records at 12 of the 17 buoys. The 2005 summer was again warm, but set a record only at the Saanich Inlet buoy, which was relatively unaffected by the 2004 warming. Many buoys show warming due to the 1997/98 El-Nino very clearly, then lower temperatures beginning in 1999 until the next warming began in about 2002.

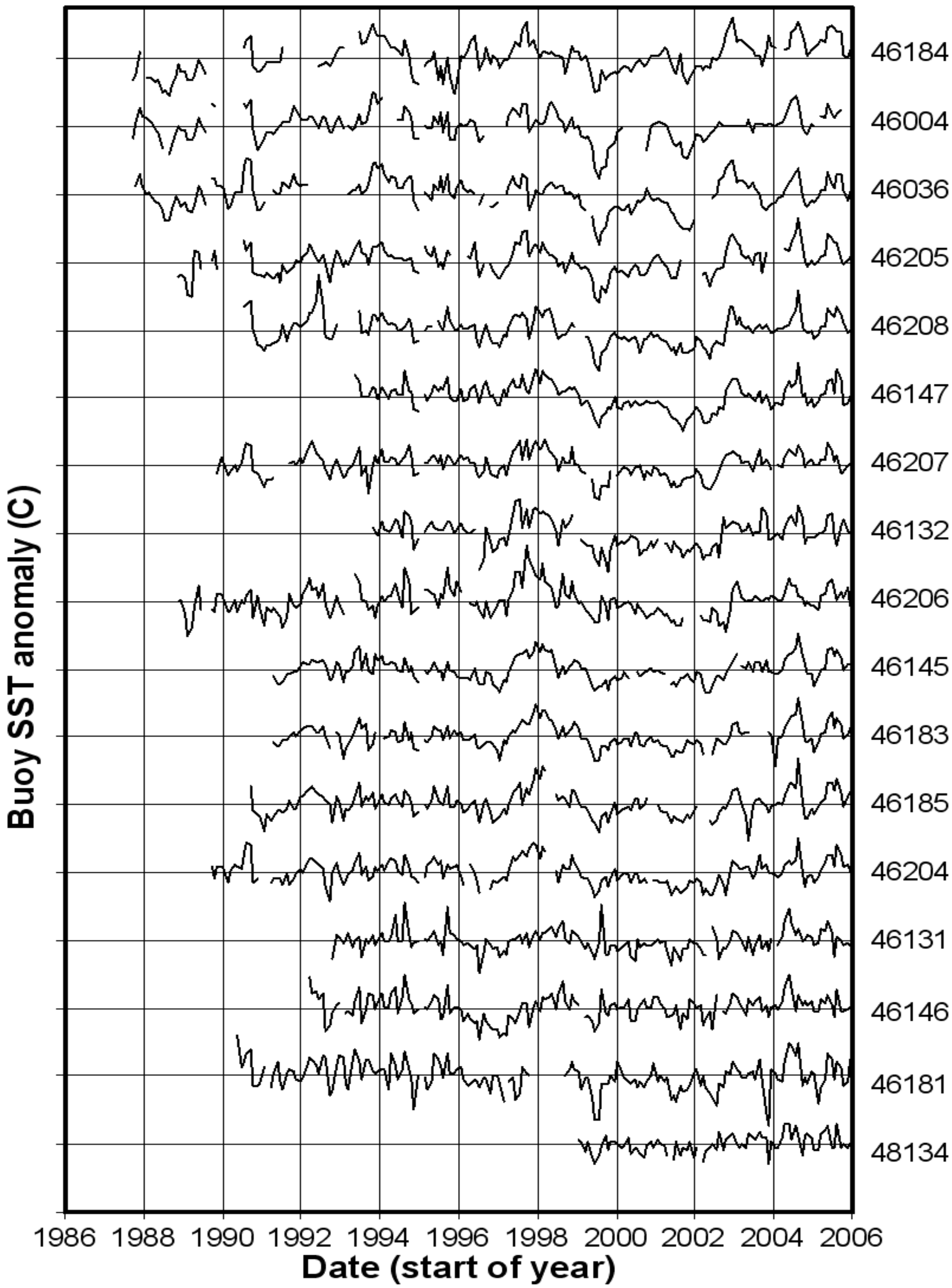
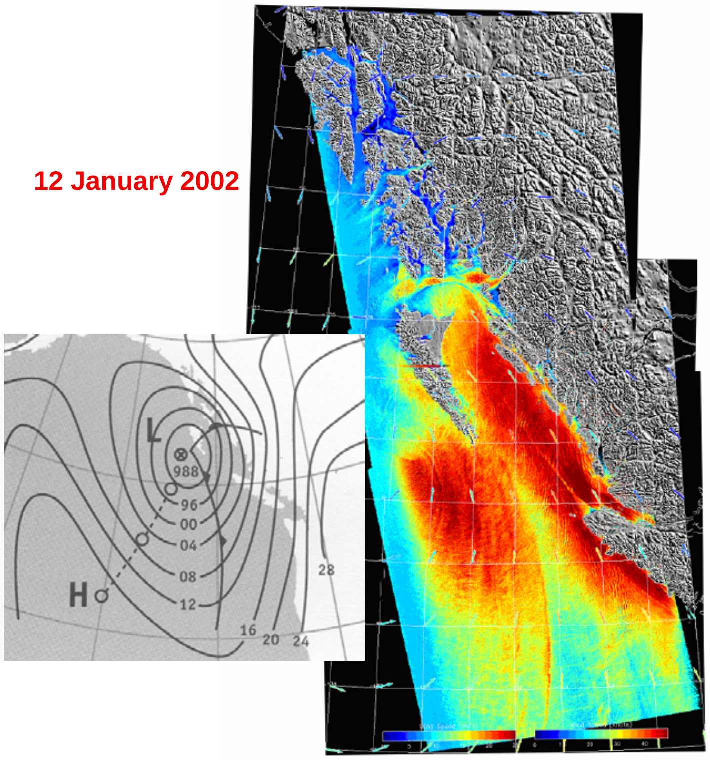


Figure 21. Graphs of sea surface temperature (SST) anomalies at each of the Canadian weather buoys. The seasonal cycle has been removed. Vertical spacing of the horizontal gird represents a temperature anomaly of 4°C.

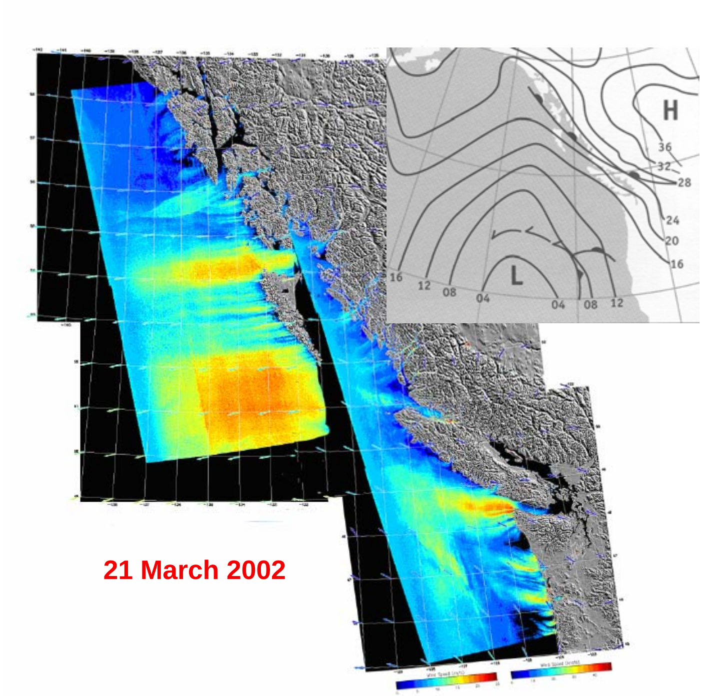
Improved Wind Observations

Paul Whitfield, Environment Canada



Environment Canada is exploring the use of Synthetic Aperture Radar (SAR) and available algorithms to retrieve high resolution ocean surface wind fields on a quasi-operational basis as an aid to marine forecasting. Currently, we are testing the use of derived fields from the Canadian satellite RADARSAT-1. The Synthetic Aperture Radars (SAR) aboard this satellite operate at C-band in either vertical (VV) or horizontal (HH) polarization in transmit and receive. Software has been developed to extract and composite images as is shown here.

Figure 22. (left) Wind speed observed by satellite on 12 January 2002, during a storm centred west of the Queen Charlotte Islands. Red indicates fastest winds, located in the region to the southeast of the low pressure centre. Arrows denote wind direction.



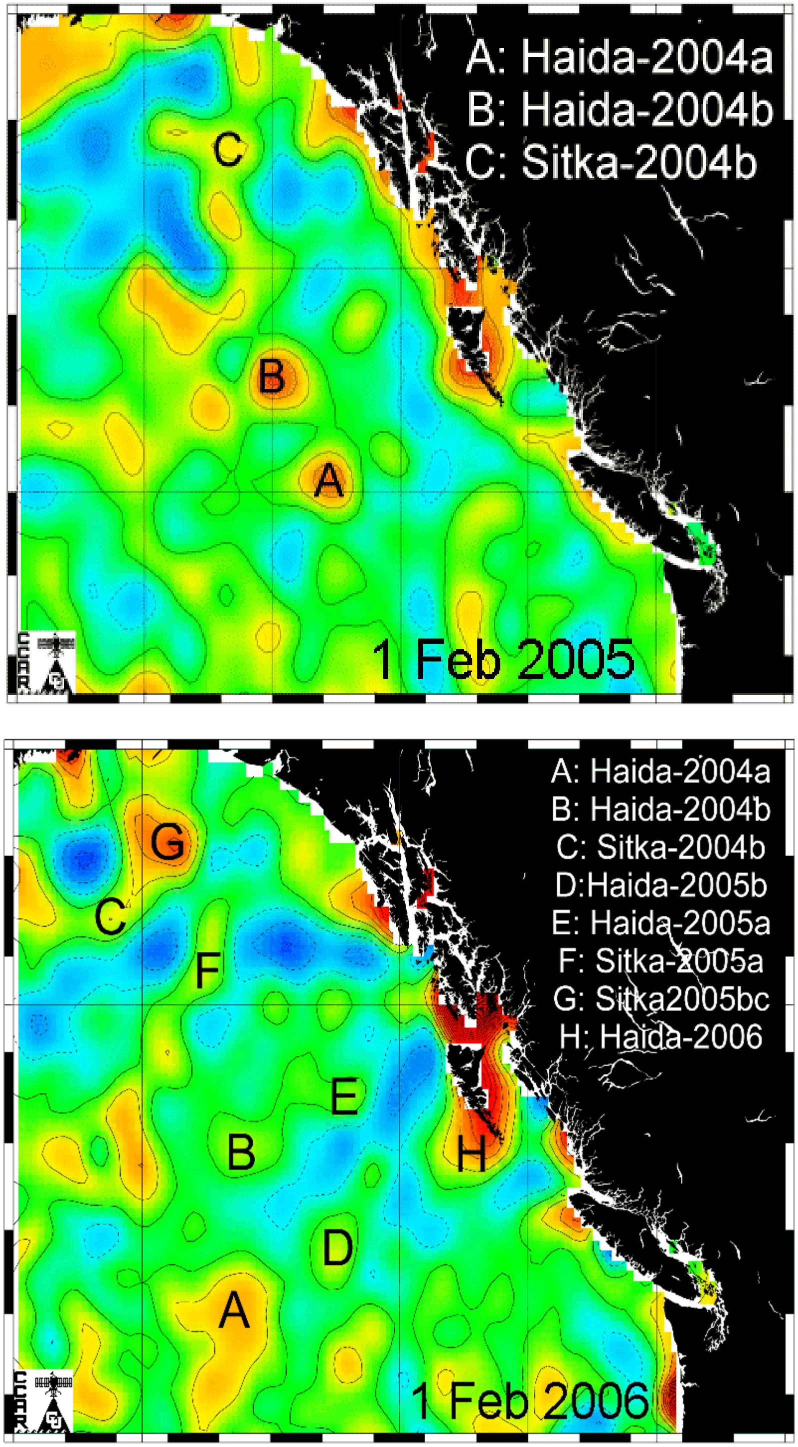
Derivation of the sea surface wind field from SAR is a two step process: In the first step wind directions are extracted, which are a necessary input into the second step to retrieve wind speeds. SAR wind directions are retrieved from wind-induced phenomena, which are aligned in wind direction at a typical spacing of 0.2 to 3 km.

SAR provides images that enhance visualization of winds over water along the BC coast and may become important for studies of wind driven oceanographic phenomena.

Figure 23. (left) Wind speed observed by satellite on 21 March 2002, during an outbreak of cold winds from the interior of British Columbia. Yellow indicates fastest winds in the region. Arrows denote wind direction.

Eddies in the Gulf of Alaska: Big in 2005 and farther south

Bill Crawford, Fisheries & Oceans Canada



Scientists have been tracking large eddies in the Gulf of Alaska since 1998, using satellite measurements of sea level. The eddies, labelled Haida and Sitka for their regions of formation in winter, always rotate clockwise, are up to 350 km in diameter, and drift generally westward into the Gulf of Alaska. They form near shore, and can track more than 1000 km westward before they decay away after a few years.

Images at left display eddies (in red) during Feb. 2005 and Feb. 2006 as regions of higher sea level. Images were provided by the Colorado Centre for Astrodynamics Research. Contours show sea surface height at 4-cm intervals. Red denotes eddies and highest sea levels. Blue denotes low sea levels.

Eddies carry heat, fresh water, nutrients and coastal species into mid Gulf of Alaska, and divert the eastward flow of surface waters. Their role in the ocean is undergoing study.

Haida-2004a was one of the largest eddies observed since 1998, It was still visible in these images two years after its formation, labeled **A** in the lower panel. Scientists on board the Canadian Coast Guard Ship *John P. Tully* in February 2005 observed large populations of seabirds and killer whales along the southern flank of Haida-2004a. Subsequent cruises have also reported abundant marine life including whales in the outer rings of these eddies.

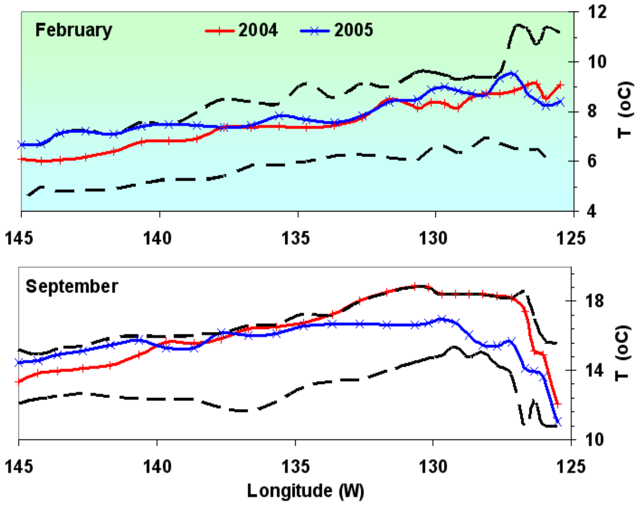
Figure 24. Contours of sea surface height anomaly (SSHA), in Feb. 2005 (top) and Feb 2006 (bottom), with red denoting high sea level anomalies. Labels denoted named eddies in the legend.

Links: Haida Eddy Web Page Animation of Drifters in Eddies

Decreased nutrient drawdown in the surface ocean in 2005

Frank Whitney, Fisheries & Oceans Canada

Some waters off the coast of BC were warmer in 2004 and 2005 than has been recorded in 50 years of measurements of the Line-P program. The very warm waters in 2004 were found west of the continental shelf of southern BC, likely due to summer upwelling that cools coastal waters. In 2005, warm waters were found further offshore along Line-P.



Warm surface waters indicate transport of heat from the atmosphere and the subtropical ocean as well as weak near-surface mixing. Weakened winter mixing results in lower nutrient concentrations in the surface layer during winter, and weaker spring phytoplankton growth.

Surface sampling of nutrients on both Line P and Skaugran ship-of-opportunity surveys provide data to estimate the seasonal drawdown of nutrients. Drawdown is simply the difference of late winter and late summer nitrate concentration within the delineated boxes in Figure 26.

Figure 25 (at left) Temperatures in surface water along Line-P, 2004 to 2005. Dashed lines show maximum and minimum ocean surface temperature along Line-P from 1956 to 2005.

These boxes define regions of high nutrient supply and high drawdown (AC: Alaska coast), high nutrient supply and low drawdown due to iron limitation (HNLC: high nitrate-low chlorophyll) and low supply and drawdown due to influences from the subtropics (TD: transitional domain).

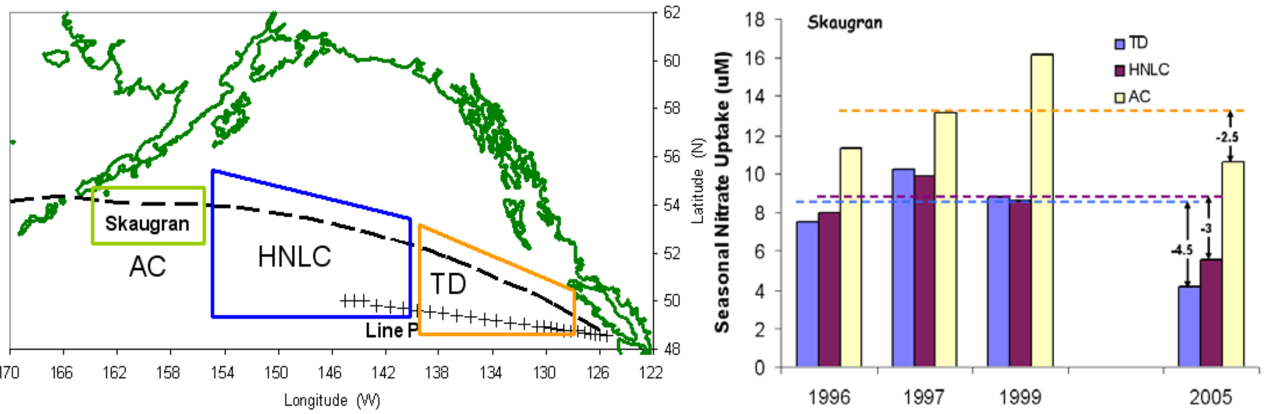


Figure 26. Surface nutrient sampling along Line P and from a ship of opportunity (MV Skaugran) shows that nitrate drawdown between winter and summer was weaker in 2005 than in previous warm (1997) or cool (1999) years. Nitrate drawdown is linked to the production of biomass in the ocean.

In 2005, nitrate drawdown was substantially less than that observed in previous warm (1997) and cool (1999) years. Especially in the Transition Domain (TD in Figure 26), seasonal nitrate decreases were 50% less in 2005 than in the 3 comparison years, as shown in the right panel of Figure 26. Nitrate drawdown by phytoplankton creates the biomass that most marine ecosystems rely on.

Declining oxygen in the ocean interior, an update

Frank Whitney, Fisheries & Oceans Canada

Over the past few decades, an increasing stratification of the upper ocean has been observed in the subarctic Pacific (e.g. Freeland et al., 1997. DSR I 44, 2117-2129). This trend is likely due to global warming, since the upper ocean and atmosphere are warming at similar rates. In this period, several studies have observed declining oxygen levels throughout the subarctic Pacific (Emerson et al., 2004. J. Oceanogr. 60, 139-147).

The 50-year series of measurements at Ocean Station Papa in mid Gulf of Alaska provides details of this change (Fig. 27). Over this period, a steady decline in oxygen is observed at about 0.6-0.7 µmol kg^{-1} y^{-1}. Perhaps a better way to look at oxygen declines is to note the movement of the "hypoxic" boundary. For a great variety of marine organisms (but not those in open ocean), hypoxia has been considered to occur at ~60 µmol oxygen kg^{-1}. Waters with this concentration occurred at ~400 m depth in the 1950s, but are now found at ~250 m.

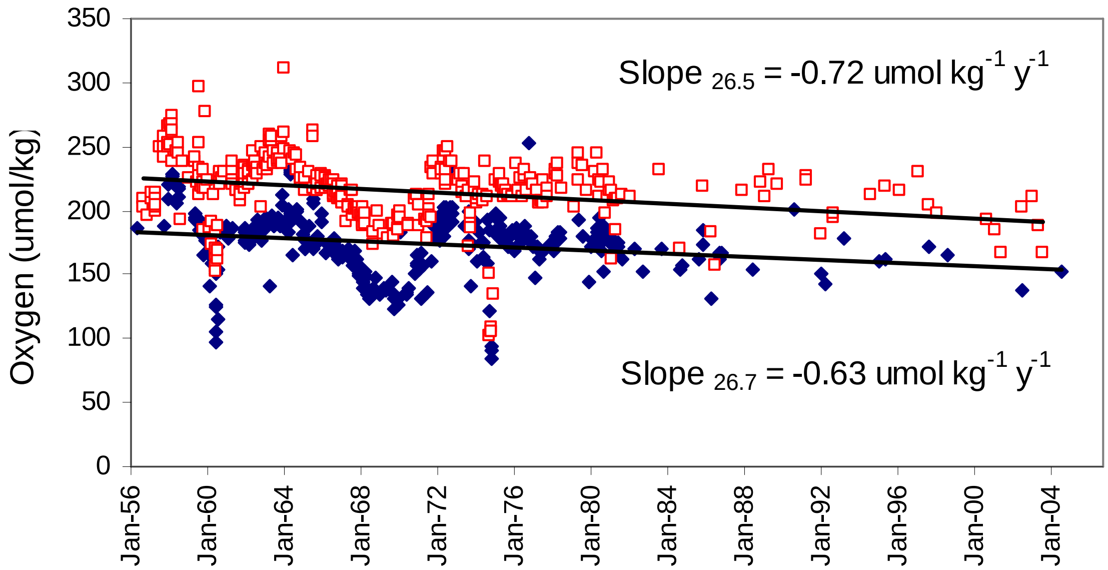


Figure 27. Oxygen trends on density (sigma-t) surfaces of 26.5 and 26.7 at Ocean Station Papa. These surfaces are staying close to the same depth or slightly shoaling, with their depths being in the 125-150 and 150-200 m ranges, respectively.

Similar declines in oxygen are being seen along the BC coast, although observations in coastal waters have not been as frequent, nor have they been collected for as long. However a 23 yr record off the west coast of Queen Charlotte Islands shows oxygen declines of 0.5 to 1.1 µmol kg^{-1} y^{-1} on the same density surfaces, at average depths of 175 and 250 m. The rate of decline is approaching 1% per year at 250 m.

The groundfish fishery harvests most of its catch between about 100 and 300 m (Alan Sinclair, pers. comm.). Some of these species (the more metabolically active) are bound to be intolerant of low oxygen concentrations, whereas others (e.g. some sole) are acclimated to low oxygen conditions and likely use it to avoid predation.

Satellite measurements of surface chlorophyll concentrations.

Jim Gower, Fisheries & Oceans Canada

The two figures below show the latest version of the complete SeaWiFS chlorophyll and water brightness time series (Sept 1997 to Dec 2005) for the BC coast.

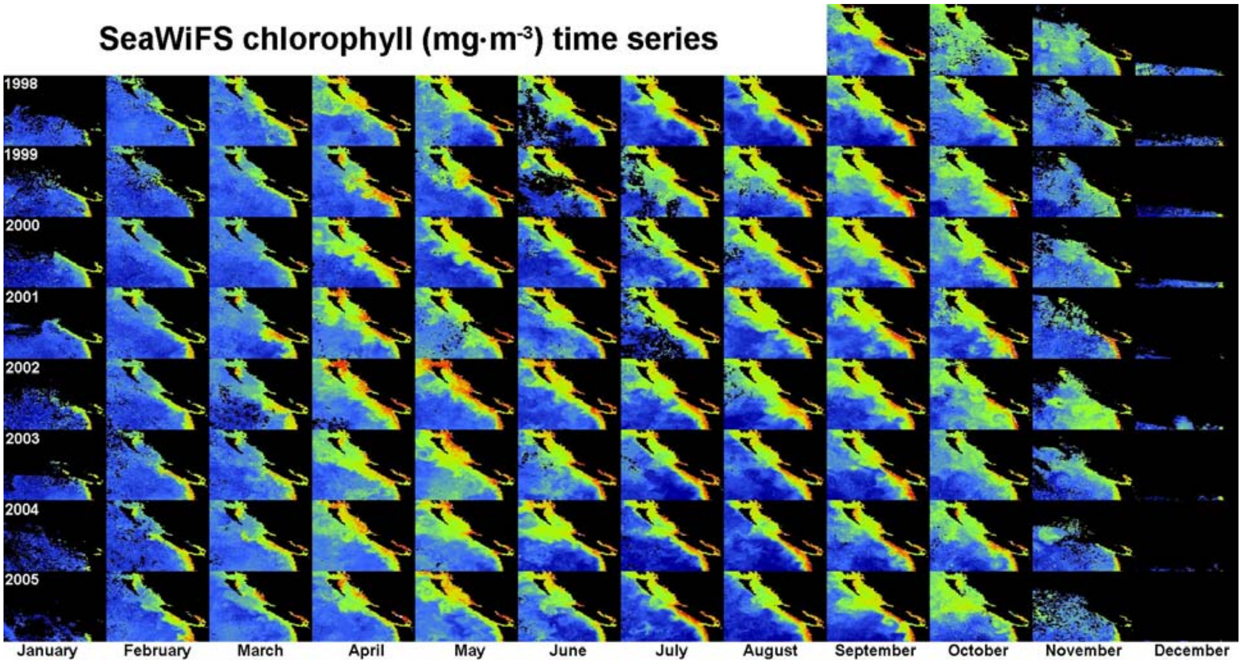


Figure 28. Monthly composite concentration of chlorophyll in surface waters determined from colour measurements by the SeaWiFS satellite sensor. Chlorophyll is an indicator of phytoplankton abundance in ocean surface waters.

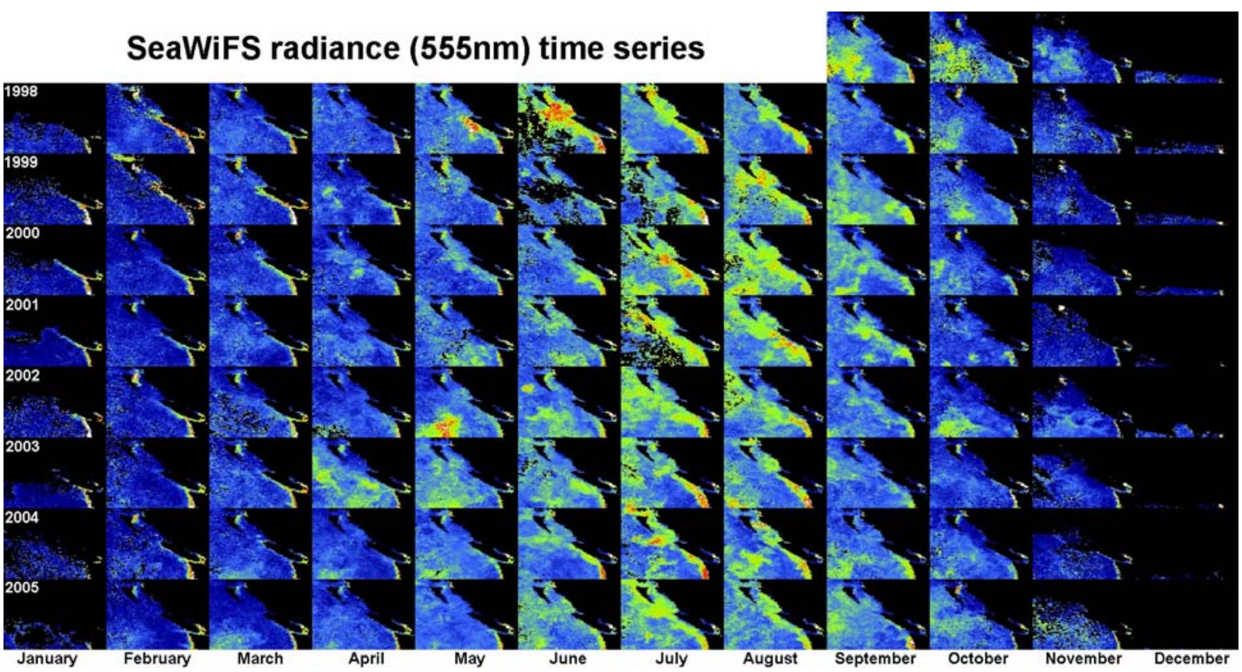


Figure 29. Monthly composite ocean colour measurements by the SeaWiFS satellite sensor, tuned to reveal relative concentrations of coccolithophorids, a type of phytoplankton with a calcite shell.

The February 2005 chlorophyll image in Figure 28 suggests an early start to the spring phytoplankton bloom in 2005 compared to previous years. Figure 30 below shows timing of the spring plankton bloom, estimated by linear interpolation between monthly average chlorophylls illustrated in Figure 28. Threshold concentrations of chlorophyll representing the bloom start were chosen for each of the six regions based on the values so far observed. These threshold values vary with area, but were kept constant for all years.

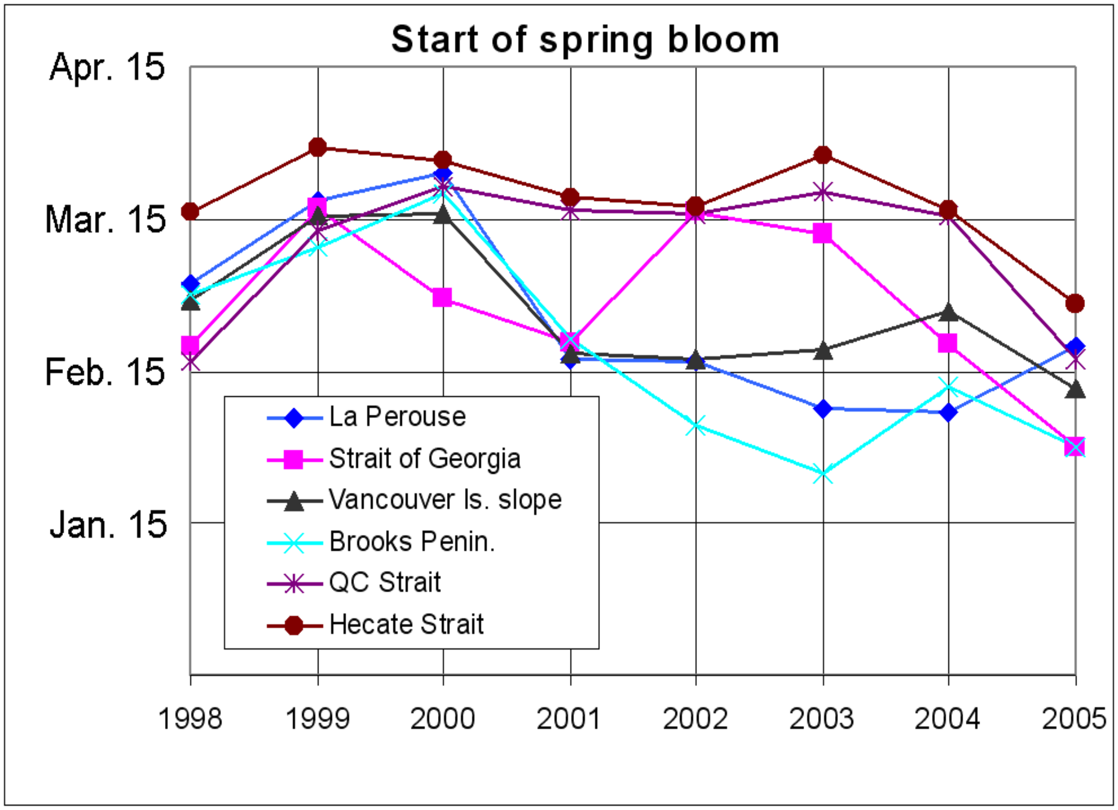


Figure 30. Date of the start of the spring phytoplankton bloom in six regions.

A symbol plotted at Feb. 15 indicates that the threshold was crossed at the time of the average for February. In 2005 the earliest monthly average (in February due to clouds in January) for the Strait of Georgia and the coastal area centered on the Brooks peninsula, showed concentrations already above the chosen threshold. Therefore, a value of Feb. 1 was assigned. Only the La Perouse area showed a later bloom in 2005 compared to 2004.

SeaWiFS data are also available from NASA as 8-day composites. These could be investigated to see if they improve timing estimates, however data gaps due to cloud will be more of a problem.

Links Remote Sensing Image Archive

Mesozooplankton in the Gulf of Alaska in 2005: Still showing 'warm year' pattern

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

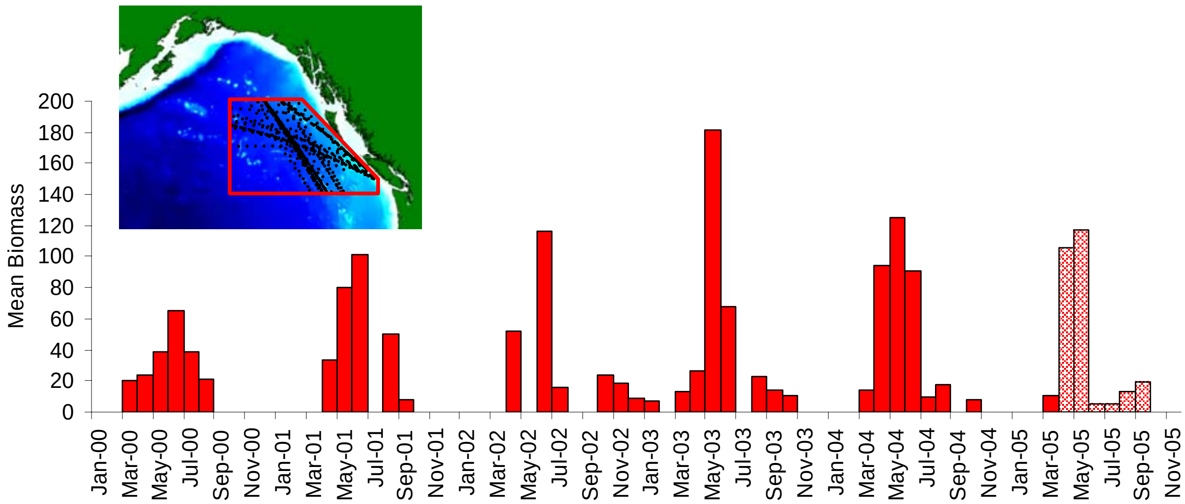


Figure 31. Time series of mesozooplankton biomass as mean monthly biomass in mg dry weight per sample (~3m^3) from Continuous Plankton Recorder sampling (which occurs approximately monthly between March and September) in the off-shore Gulf of Alaska area shown by the box. Shaded bars to the right show where sample analysis has not been completed yet and so data are preliminary.

The 6-year time series of monthly biomass in Figure 31 shows that the peak in biomass has been occurring earlier in the recent warm years. Biomass in 2005 was highest in April/May (as it was in 2004) rather than May/June as it was in previous years.

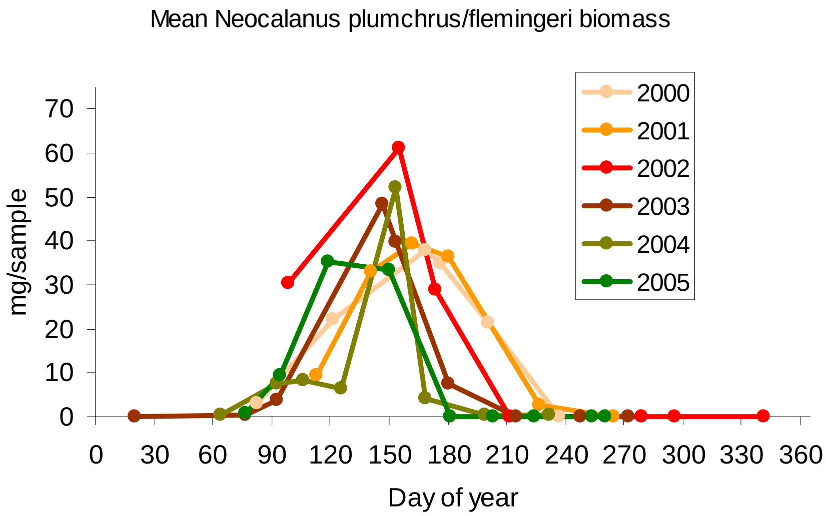


Figure 32. Seasonal cycle of Neocalanus biomass in each year for the same region as in Fig 31.

Links: SAHFOS

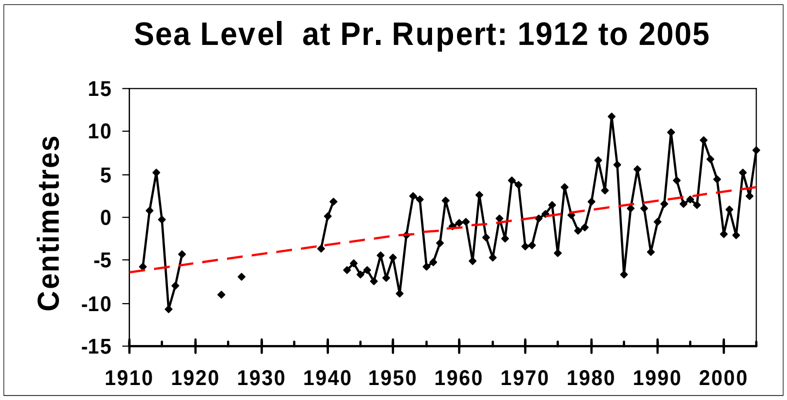
The Pacific Project

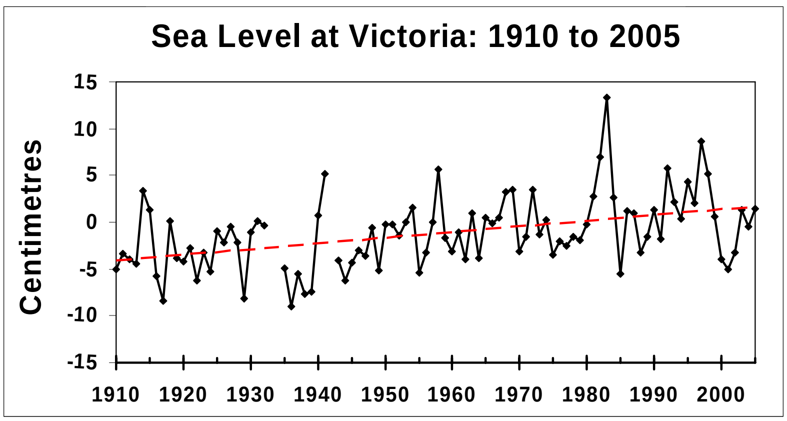
Mesozooplankton biomass in spring is dominated by *Neocalanus plumchrus/flemingeri* copepods and Fig 32 shows that their spring peak was also early. The biomass seems somewhat lower - more similar to 2000/01 than to more recent years but until all the data are available this cannot be confirmed. Change in seasonal timing of biomass has implications for those higher trophic levels that time their migration or reproduction to take advantage of the peak in mesozooplankton.

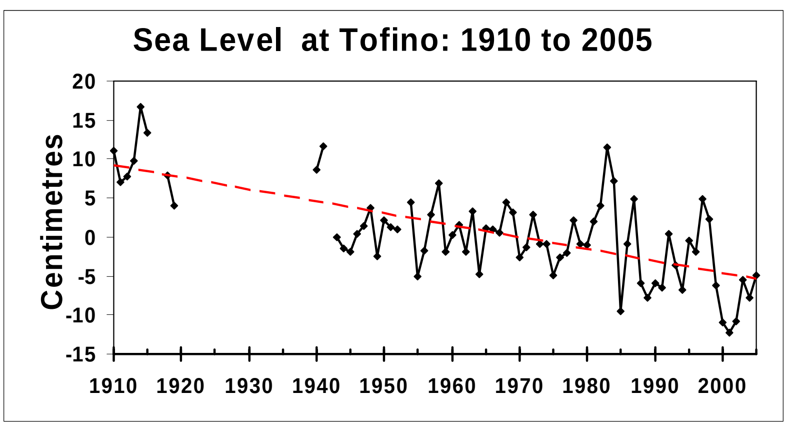
West Coast Vancouver Island

Sea levels: Near normal, but long term rise might accelerate

Bill Crawford, Fisheries & Oceans Canada







The Canadian Hydrographic Service has monitored sea levels along the coast of British Columbia for more than 90 years.

The three 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 there 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 33. Graphs of annual-averaged sea level at three British Columbia ports. Linear trend over the length of record is plotted as a dashed red line.

Global sea levels have risen about 10 to 20 cm over the past 100 years, and are expected to rise between 9 and 90 cm in the next 100 years, so we can expect sea levels to rise more rapidly than we have experienced. Many of the populated regions of southwest British Columbia will see increased erosion and flooding.

Links: Canadian Hydrographic Service

Shore Stations: Warm from late winter to early spring.

Bill Crawford, Fisheries & Oceans Canada

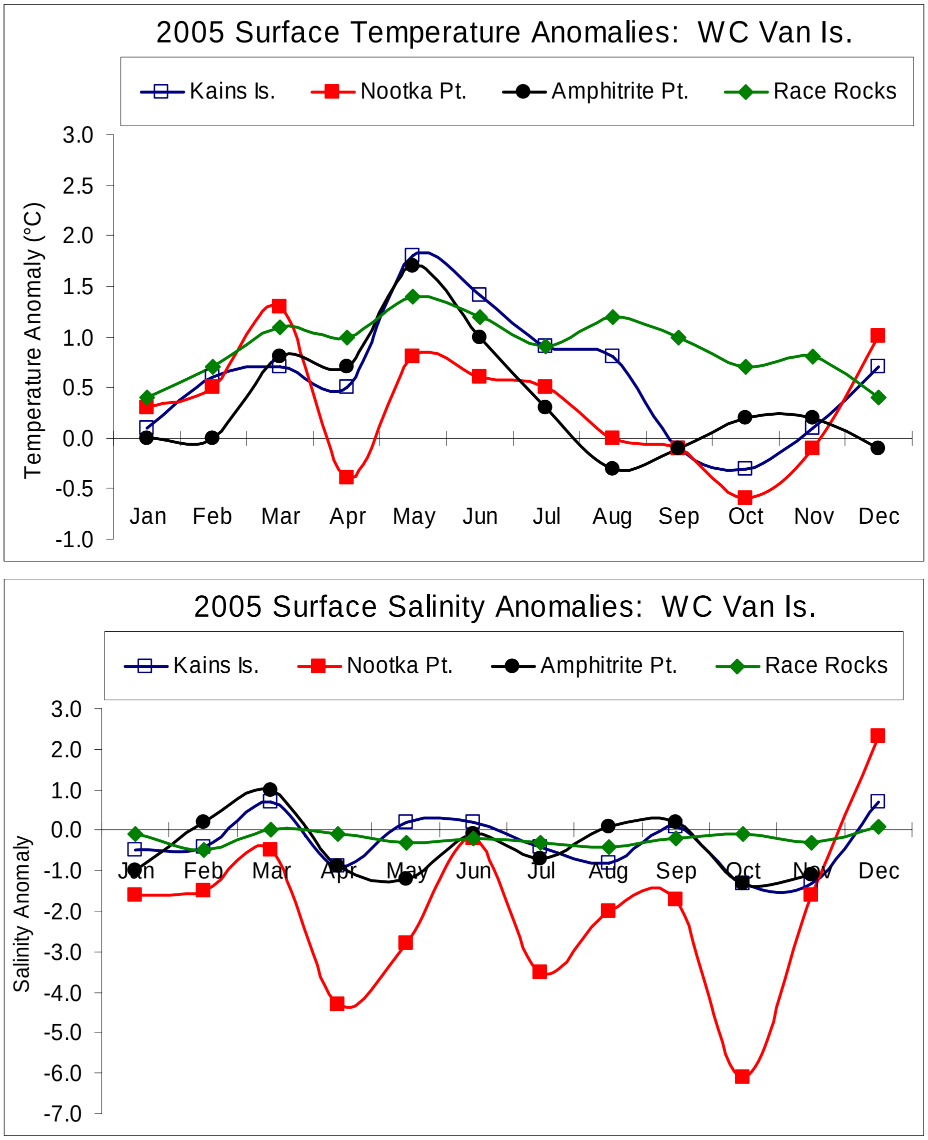


Figure 34: Anomalies of ocean temperature (top panel) and salinity (bottom panel) at three shore stations along the west coast of Vancouver Island and at Race Rocks in Juan de Fuca Strait.

Temperature and salinity are measured daily by light keepers through BC waters as part of a long-term program that began more than 70 years ago. These time series form the longest continuous ocean temperature and salinity record on the Pacific Coast north of San Diego.

In 2005 warm temperature hit all along west coast of Vancouver Island and in Juan de Fuca Strait from late winter into early summer, in a pattern that extended into the Strait of Georgia and south to the Washington and Oregon coasts.

By autumn 2005 some temperatures returned to more normal values, but Kains Island and Nootka Point anomalies increased. The observing station at Nootka Pt. is very sensitive to local rainfall that causes sudden changes in salinity and temperature.

Warm waters are often nutrient-poor, a condition that might have led to the nearly complete failure of seabirds along this coast to raise chicks through their first spring and summer in 2005.

Links: BC Seawater sampling at Lighthouses

The B.C.-to-tropics teleconnection in 2005 and 2006

Skip McKinnell, North Pacific Marine Science Organization

Average sea level pressure (SLP) from December to February in the western tropical Pacific is a reasonable indicator of boreal spring sea surface temperature (SST) along the North American coast, as shown by the graph for Kains Island on the northwestern coast of Vancouver Island. Without exception since 1948, high SLP in winter in the western tropical Pacific was followed by warm SST along the BC coast in the spring. Figure 35 below indicates only Kains Is. SST but similar results are obtained with other lighthouses along the BC coast. This correlation can be applied to predict spring ocean temperature in west coast Vancouver Island waters. Winter average SLP for 2006 (vertical line in Figure 35) is less than the 57 year average suggesting that coastal spring ocean temperatures in 2006 along the BC coast will not be warm (as a consequence of tropical climate) and barring other influences, may be somewhat cooler than average. The winter of 2006 is also the peak year of 18.6 year cycle of diurnal tides and this phase is typically associated with cooler than average SST along the North American coast.

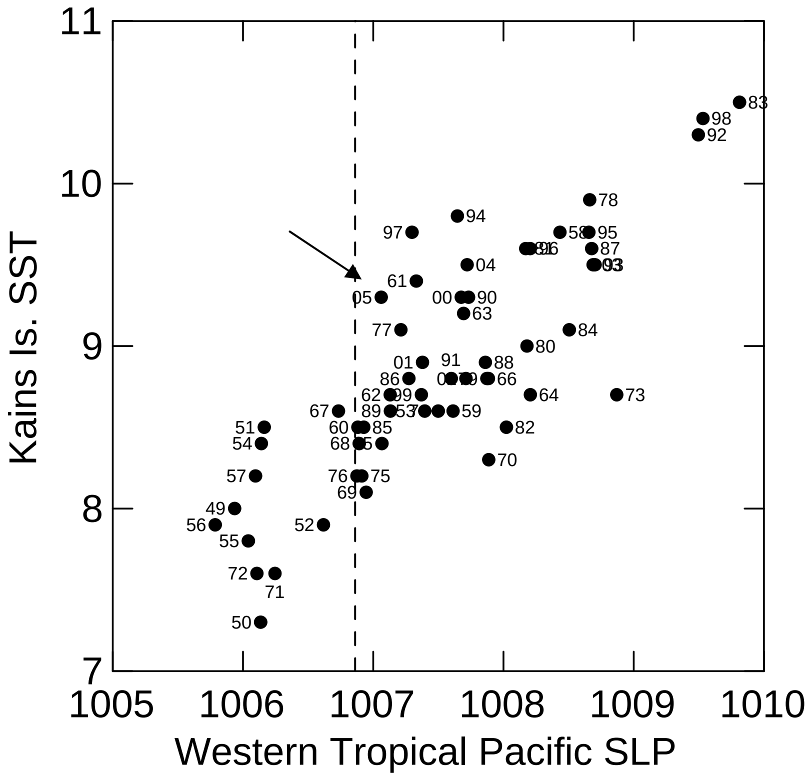


Figure 35

Average sea level pressure (SLP) in the western tropical Pacific near Indonesia compared to sea surface temperature (SST) measured the following April at Kains Island on the west coast of Vancouver Island. Each year's observations provide a dot on this graph, with data coverage from 1948 to 2005. The warmest SST and highest SLP occurred in 1983, 1998 and 1992, all major El Niño events.

Lighthouse keepers have been sampling temperature and salinity daily at many BC stations for more than 70 years, as part of Fisheries and Oceans Canada monitoring programs.

SLP is provided by US National Oceanic & Atmospheric Administration (NOAA).

The arrow in Figure 35 points to the observation for 2005 when Kains Island SST was warmer than average, but not predicted by winter SLP in the western tropical Pacific. Other influences did indeed affect the BC coast in 2005 and as a result, April SSTs were about 0.5 °C greater than would be expected from this relationship alone. The increase temperature in May 2005 at Kains Island was even more striking. Since 1935, the mean monthly SST in May at Kains Is. is highly correlated (r= 0.81) with what was observed in April, but May of 2005 was the highest anomaly (> 3.0°C) in the record and May 2004 was 4th highest. So for the last 2 years, May SSTs have been much warmer than "expected." This warmth in spring SSTs is often a result of a late spring transition that maintains poleward flows of warm surface waters along the coast. Regardless of their exact origins, it is noteworthy that summer ocean temperatures in August of 2004 and 2005 were the highest on record for a non-El Niño year.

Links North Pacific Marine Science Organization (PICES)

Physical Oceanographic Conditions

Richard Thomson & Roy Hourston, Fisheries and Oceans Canada

Low-pass filtered surface wind stress, longshore current velocity and temperature in the upper 200 m off the west coast of Vancouver Island for the period January 2000 to 2005 are shown in Figure 36. There are gaps in the data due to equipment failure, and the depth of the A1 current meters sometimes varied slightly from the nominal depths. These deficiencies are not sufficient to bias the results. The time series are shown from 2000, however meteorological buoy data from site 46206 (48° 50' N 126° 0' W) date back to 1988, and oceanic data from A1 (48° 32' N 126° 12' W) to 1985. Together, these data provide invaluable information characterizing coastal currents and ocean climate on the shelf since the late 1980s.

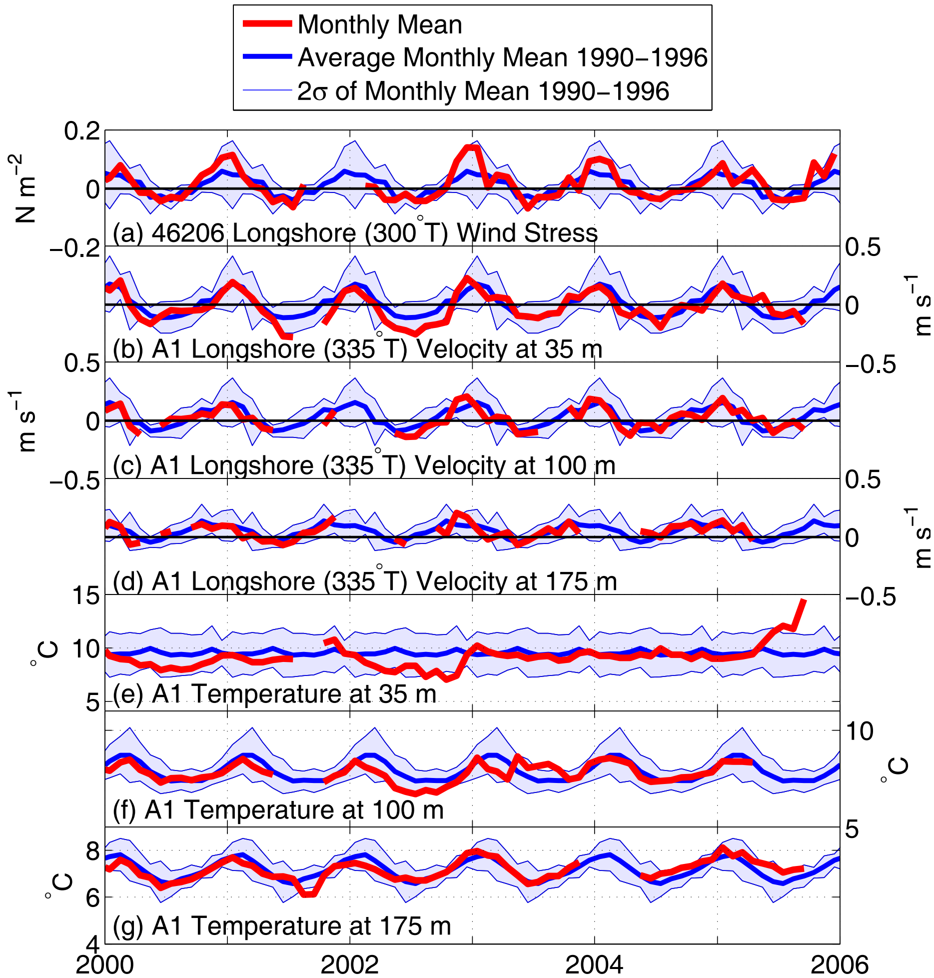


Figure 36. Monthly mean longshore wind stress at meteorological buoy 46206 (a), and both current velocities (b, c, and d) and water temperatures (e, f, and g) at the nominal depths of 35, 100, and 175 m at mooring A1, 2000-2005. They are shown relative to their means and standard deviations over 1990-96, a relatively quiet ENSO period. Positive wind and current velocity values indicate poleward flow, negative values indicate equatorward flow

In 2005, the wind and current reversals in spring -- from poleward to equatorward (the *spring transition*) -- were later than normal. In contrast, the reversal was early in 2004, normal in 2003, early in 2002, and about normal in both 2001 and 2000. A deeper-than-average Aleutian low during late 2005 led to stronger-than-average poleward winds, and likely stronger-than-average poleward coastal current flow. This will need to be confirmed upon mooring recovery slated for the spring of 2006. Stronger poleward wind gives rise to more frequent and longer duration intrusions of relatively warm salty oceanic water into Juan de Fuca Strait.

Temperatures over the shelf in 2005 indicate a warming in the spring and summer relative to the 1990-96 average on the order of 4-5 °C and 0.5 °C at 35 and 175 m, respectively. (There is no temperature record at 100 m for this period.) The warming during 2005 was also observed in the Gulf of Alaska and reported elsewhere in this document. There was also a dramatic increase in 35 m temperature in Dec. 2002, which may have been related to the development of a weak El Niño event.

Interannual 5-year mean variations in upwelling-favourable (equatorward) winds from 1950-2003 along the West Coast of North America, 45-60°N, are shown in Figure 37 below. The time series indicates that upwelling-favourable winds were stronger than average from ~1957-1976, weaker than average from 1976-1999, and stronger than average but weakening from 1999 to present. However, results from 2005 suggest that the west coast of BC may currently be changing from a stronger-than-normal to a weaker-than-normal upwelling regime.

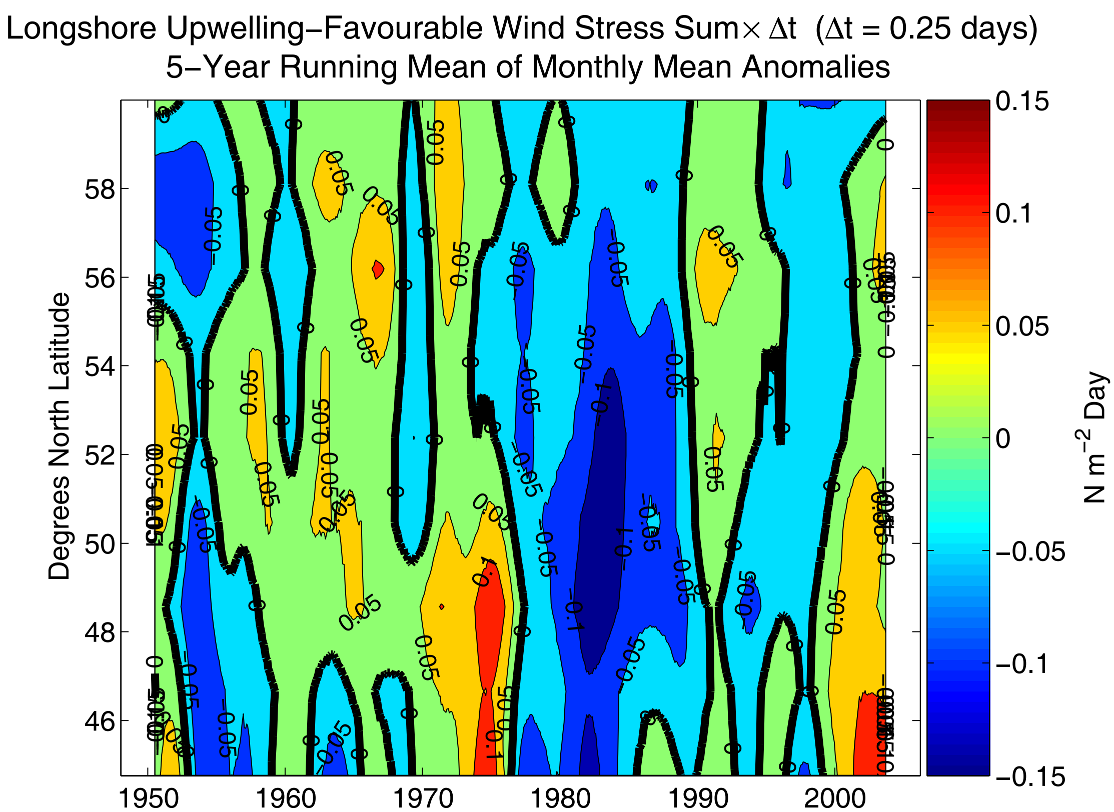


Figure 37. Upwelling index for the West Coast of North America from 45-60°N. This is the five-year running-mean of anomalies of upwelling wind stress. Wind stress data were provided by the NOAA-CIRES ESRL/PSD Climate Diagnostics branch, Boulder, Colorado, USA, from their Web site at http://www.cdc.noaa.gov/.

OVERALL SYNOPSIS: In 2005, the west coast of Vancouver Island experienced stronger-than-average poleward winds and shelf currents, and temperatures in the upper 200 m were above average. This suggests that over the last year we have just made the transition from stronger-than-average to weaker-than-average upwelling conditions and hence lower marine productivity.

Phytoplankton

Angelica Peña, Fisheries and Oceans Canada

Because phytoplankton grow rapidly (exponential growth rates order 0.3 to 1 d^{-1}) their biomass can change very rapidly over a very wide range (2-3 orders of magnitude) making it difficult to monitor by infrequent ship observations. Where possible, we measure phytoplankton concentrations continuously using fluorometers attached to moorings for months at a time. One such fluorometer is located on the continental slope of Vancouver Island on mooring BIO1 (48° 31.8'N and 126° 11.2'W). Time series of phytoplankton fluorescence are shown in Figure 38 below. The mooring was deployed twice each year from March to October of 2003 to 2005. Note that the sampling depth varies for each deployment. Taking into consideration the changes in instrument depth, the spring (March-April) of 2005 was characterized by lower phytoplankton biomass (average of 4.5 mg m^{-3} in 2005) than in spring of the previous 2 years (average of 8.1 and 8.9 mg m^{-3} for 2003 and 2004, respectively). In 2005, the second deployment started more than 2 months late due to a problem in the set up of the instrument. Also, the mooring was 15 m deeper than the nominal depth of 20 m thus observed fluorescence values during July- September are offset to lower-than-expected for that nominal depth. Despite these depth differences, values in July to September of 2005 were higher than those found at the beginning of the year as in previous years. This seasonal pattern of higher concentrations of phytoplankton in summer than in spring has been previously observed in chlorophyll patterns derived from satellite colour sensors in this region.

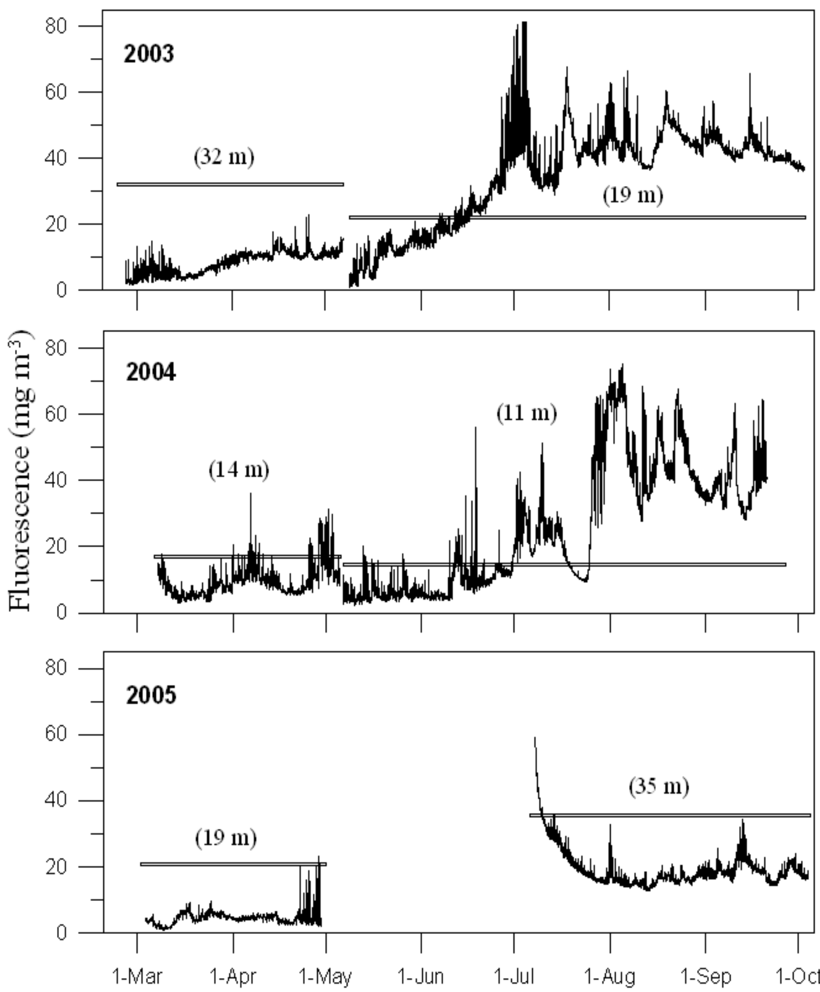


Figure 38. Time series of fluorescence (mg m^{-3}) at mooring BIO1 (48° 31.8'N and 126° 11.2'W) on the continental slope of southwest Vancouver Island from March to October of 2003, 2004 and 2005. The sampling depth is shown by the horizontal lines and numbers in brackets.

Warm ocean conditions in 2005 unfavourable for local zooplankton; point to poor fish recruitment and survival

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

Time series sampling of zooplankton has been carried out 3-6 times per year at standard locations on the continental-shelf and the adjoining deep ocean off Vancouver Island (Fig. 39). 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. Mackas, Thomson and Galbraith (2001) and Mackas, Peterson and Zamon (2004) provide detailed descriptions of sampling and data analysis methods.

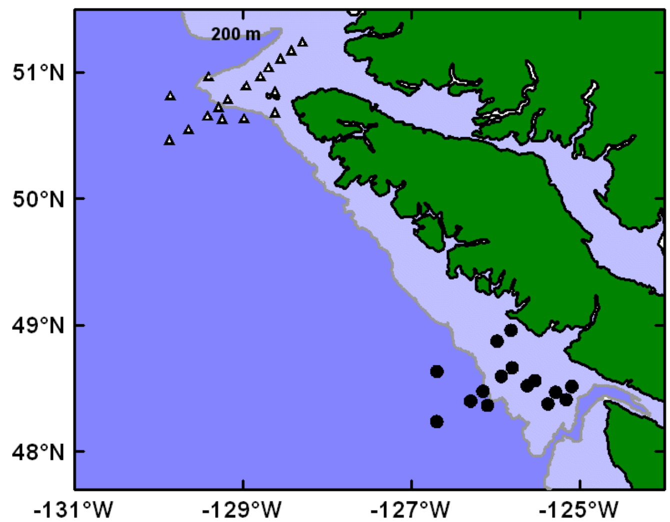


Figure 39. Zooplankton sampling locations for southern Vancouver Island (SVI, circles) and northern Vancouver Island (NVI, triangles) statistical areas. Within each region, sites are further classified as continental shelf (shallower than 200m, light blue) and offshore (dark blue)

Figure 40 (on the next page) shows annually averaged biomass anomalies for three important copepod 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 in that group were on average ten times more common than during the stated reference period; –1 means they were one tenth as common. The anomaly time series are weakly but significantly correlated between SVI and NVI regions (Mackas, Peterson and Zamon 2004), but their magnitudes for these species have usually been greater in the SVI region. Especially large changes occurred at the end of the 1980s and between 1998-1999. Through most of the 1990s, there was a strong and cumulative shift to a more 'southerly' copepod fauna, and reduction of abundance for the boreal-subarctic species. This trend reversed sharply in 1999, following the 1997-1999 El Niño-La Niña event. From 1999-2002, upper ocean temperatures were relatively cool in the NE Pacific, and the biomass of most zooplankton taxa along the Vancouver Island continental margin was similar to the 1979-1991 baseline period. However, warming resumed in 2003, and zooplankton anomalies off SVI have progressively reverted to a 'warm water' pattern, with 'southern' origin copepod species significantly more abundant than average, and 'boreal shelf' copepods much less abundant than average. For both of these groups, the most recent (2005) anomalies are very similar to those during 1997-98.

Reduction in biomass and abundance of the 'subarctic oceanic' copepods (*Neocalanus* spp.) has to date 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 41). These large copepods make up most of the zooplankton biomass in the oceanic subarctic Pacific, and have an annual life cycle that includes a brief growing season from spring into early summer followed by departure from the surface layer for a prolonged dormancy much deeper in the water column (between 400-1500 m). The annual biomass maximum, and maximum availability as food for upper ocean predators, is therefore brief (about 3-4 weeks) and occurs just before the start of this dormant period. The biomass peak and onset of dormancy occur early in the year if spring season temperature of the upper ocean is warm, and late if the water is cool

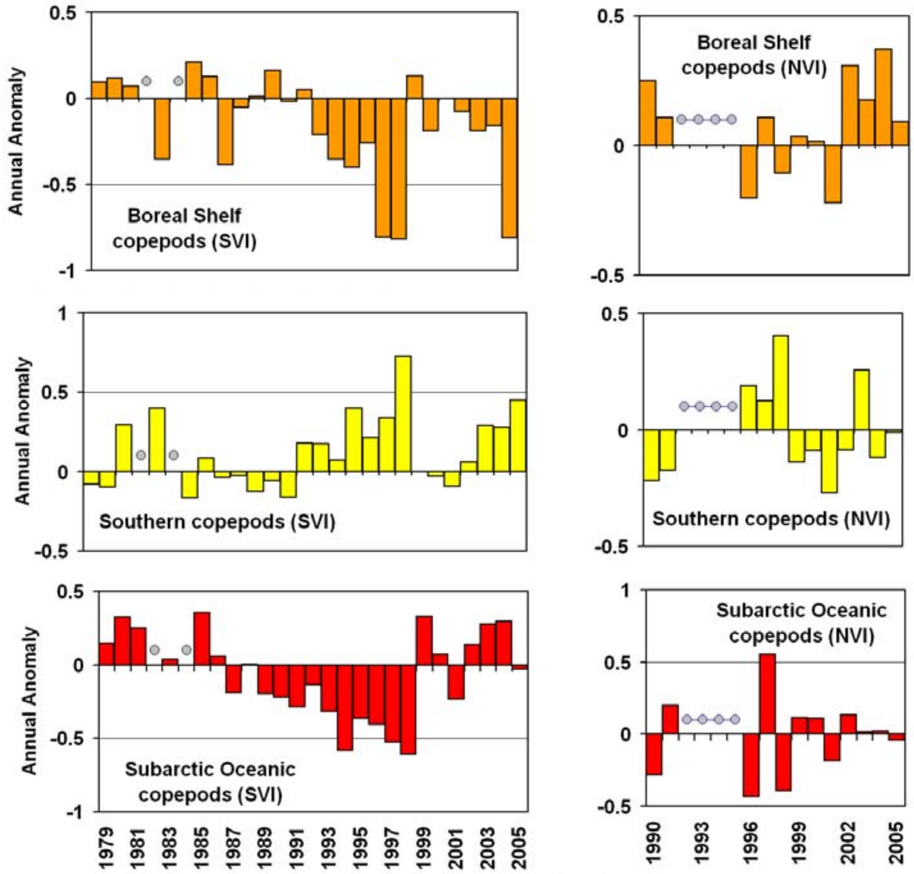


Figure 40. Anomaly time series for three important copepod species groups. Left panels are data from southern Vancouver Island, and are referenced to a 1979-1991 baseline period. Right panels are data from northern Vancouver Island, referenced to 1990-2001. Circles indicate years with no or too few data.

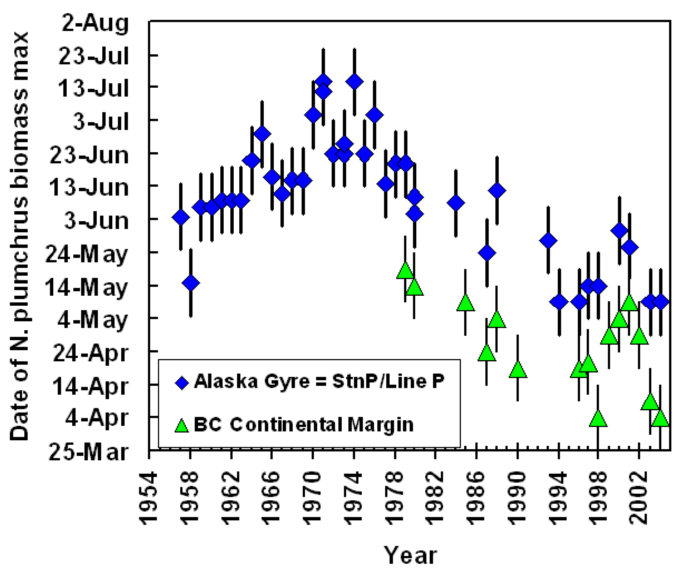


Figure 41. Timing of maximum biomass of the dominant subarctic oceanic copepod Neocalanus plumchrus (updated from Mackas et al. 1998 and Bertram et al. 2001) Early timing is strongly associated with warm upper ocean temperature during the spring growing season.

Over the past 25 years, the zooplankton biomass and life history timing anomalies shown in Figs 40 and 41 have covaried moderately strongly (average r^2 ~ 0.3) with each other, with temperature anomalies at several spatial scales, and also with annual indices of recruitment and early stage survival of 'predators' such as coho salmon, sablefish, and colonial seabirds. We have recently completed (Mackas, Batten and Trudel, in prep.) a Principal Components decomposition of the correlation matrix (Figure 42). The first two component axes account for more than two thirds of the total variance/covariance of the normalized input data series, and show a clear separation between variables indicative of "cool water/favorable for endemic northern species" vs. "warm water/favorable for southern species". Interestingly, the biological variables show a stronger and more consistent "response" to this component (larger absolute values of their eigen vector components) than do the temperature indices. Although 2005 data are incomplete (coho and sablefish recruitment and survival data are not yet available), one important implication of the PC time series is that 2005 fish recruitment and early marine survival off the west coast of Vancouver Island may be about as poor as in 1997 and 1998.

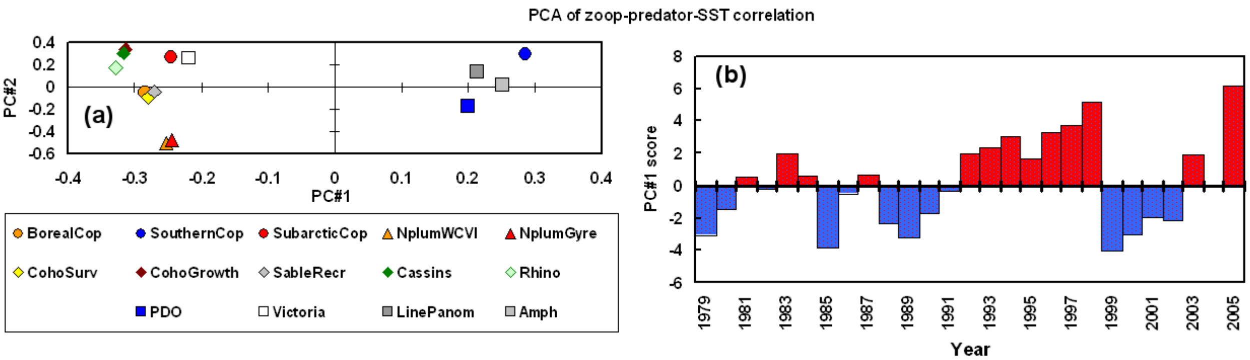


Figure 42. Results of PCA ordination of zooplankton-temperature-predator correlations: (a) Locations of the input variables on the first two component axes (left side are positive when "cool", right side are positive when "warm"). Circles are copepod biomass anomalies, triangles are copepod seasonal timing, diamonds are 'predator' growth/survival/recruitment, squares are indices of upper ocean temperature. (b) Annual scores for 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 copepods.

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Euphausiids and predators: Less food for herring, coho, chum, and sockeye, more hake predation.

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 *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 1991-2005 time series of *T. spinifera* biomass is presented in Fig. 43.

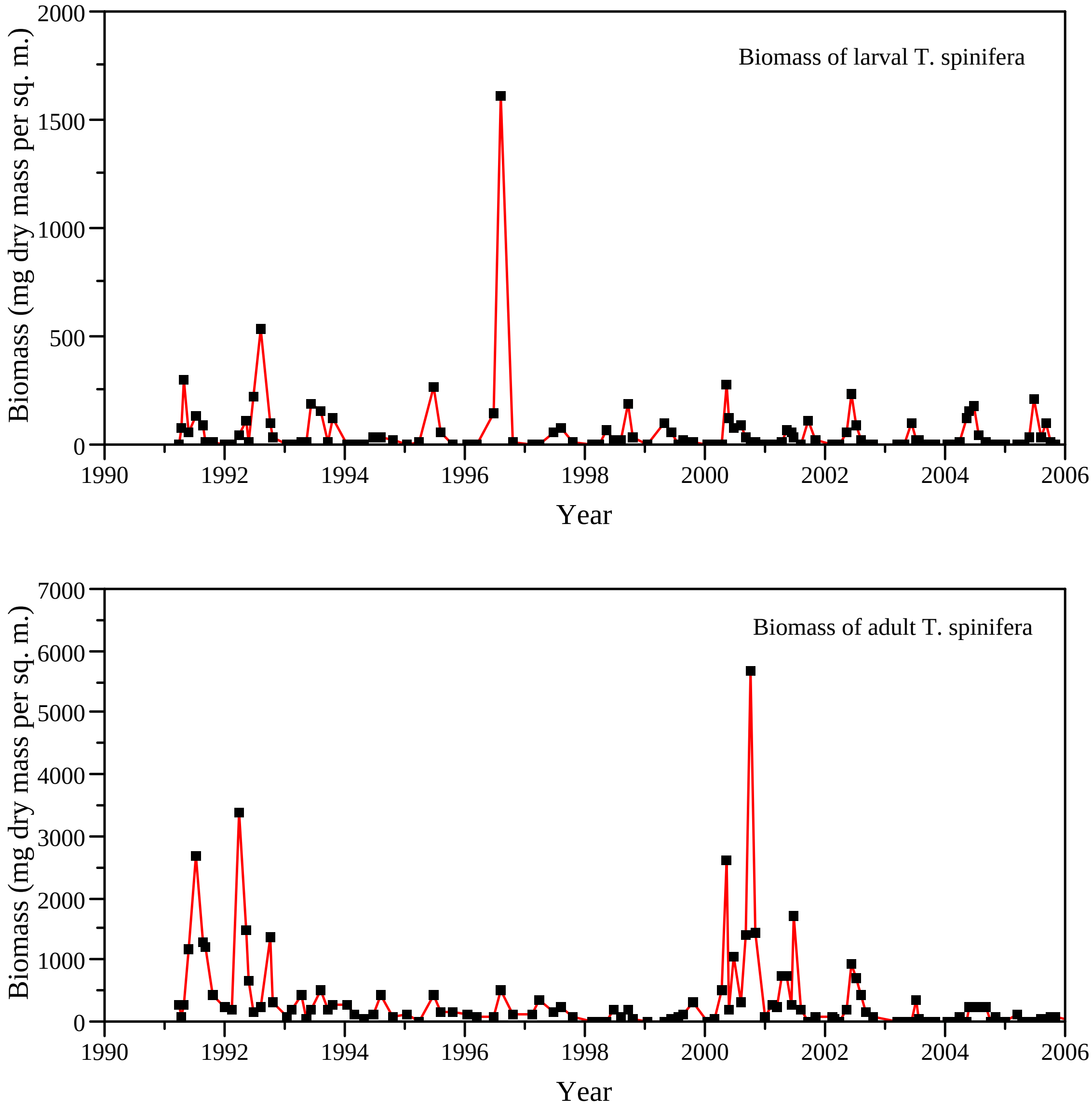

*Figure 43. The 1991-2005 time series of **larval** (top panel, <10 mm long) and **adult** (bottom panel > 9 mm long) T. spinifera biomass. Median larval and adult biomasses in 2005 were the third and second lowest respectively in the time series; they declined by about 45% and 65%, respectively, from 2004.*

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 for hake. 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 1972-2003 time series. In 2004, hake from this yearclass became large enough to start consuming fish.

The biological basis for herring recruitment (production of new spawners) has been suggested by recent analyses. 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 explain changes in growth of WCVI herring, and variation in adult natural mortality rates for WCVI and Strait of Georgia herring. 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. WCVI wild coho, and Barkley Sound (Sproat and Great Central lakes) and Central Coast (Oweekeno and Long lakes) sockeye return variability is related to variations in *T. spinifera* biomass early in marine life. Euphausiid population dynamics is complex enough that predator-specific prey biomass must be estimated. Prey biomasses for coho, chum, sockeye, and herring in 2005 were the lowest in the time series.

The following are the anticipated consequences of 2005 prey and predator biomass levels.

- Herring: Recruitment to all major BC stocks are predicted to decline in 2007 because of the hake predation/competition effect. Growth of WCVI herring should continue to be suppressed, and WCVI and Strait of Georgia adult natural mortality rates should increase;
- WCVI wild coho: Marine survival is forecast to decline to about 3% for the 2006 return year because of reduced food availability in the 2005 smolt year;
- Barkley Sound/Central Coast sockeye: Returns in 2006 are predicted to be similar to 2005 but returns of age 4 fish in 2007 and age 5 sockeye in 2008 will likely be poor because euphausiid biomass in 2005 is the lowest in the time series;
- Nitinat River Hatchery chum: Returns should decline markedly as of 2007 because of hake predation.

Barkley Sound Sockeye Salmon: Low returns forecast

Kim Hyatt, Fisheries and Oceans Canada

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, as observed in Figure 44 (next page). Studies of these variations have determined that on average, annual changes in freshwater and marine environmental conditions each account for about 50 % of observed production variations (Hyatt and Steer 1988). Freshwater effects are difficult to predict but ocean effects co-vary with changes in ocean temperature and salinity (Hyatt and Steer 1988) that are proxies for changes in numbers of salmon predators and prey (Ware and McFarlane 1995, Hyatt and Luedke 1999).

A simple two-state, "survival-stanza", model (SStM, Hyatt and Luedke 1999) has been useful for predictions of (Figure 44a.) stock collapses (late 1980's, mid-1990's) and recoveries (early 1990's, 2000's). 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. 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 %).

Identification of survival covariance for Barkley Sound sockeye and coho salmon has proven useful in developing new forecast procedures (Hyatt et al 2000). For example, because Robertson Creek coho mature and return to freshwater a year earlier than sockeye salmon, marine survival variations observed for the former now serve as the basis for a Coho Leading Indicator (CLI) forecast of Barkley Sound sockeye returns (Figure 44b, Dobson et al. 2005).

2005 Observations:

Barkley Sound sockeye salmon returns fell below the long term average in 2004 followed by a further decline in 2005 as predicted by both the SStM and CLI models (Figure 44). Lower marine survivals experienced by WCVI juvenile salmon during their 2002 and 2003 ocean entry years (adult returns in 2004, 2005 and 2006) were anticipated by positive SST and ENSO indices respectively.

Outlook for 2006 and beyond

In spring 2005, sea surface temperature anomalies at Amphitrite Point and the NOAA multivariate ENSO index were mainly positive (El Niño-like). Consequently, 2006 returns of adult sockeye to Barkley Sound (Fig. 44a) 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 during the winter of 2005-06, if it is sustained, would predict improved survival for WCVI coho and sockeye migrating seaward in 2006 and returning as adults in either 2007 (coho) or 2008 (sockeye) respectively. Differences between this prediction and that on page 40 for sockeye in 2008 reflect different forecast models and assumptions about conditions in early 2006.

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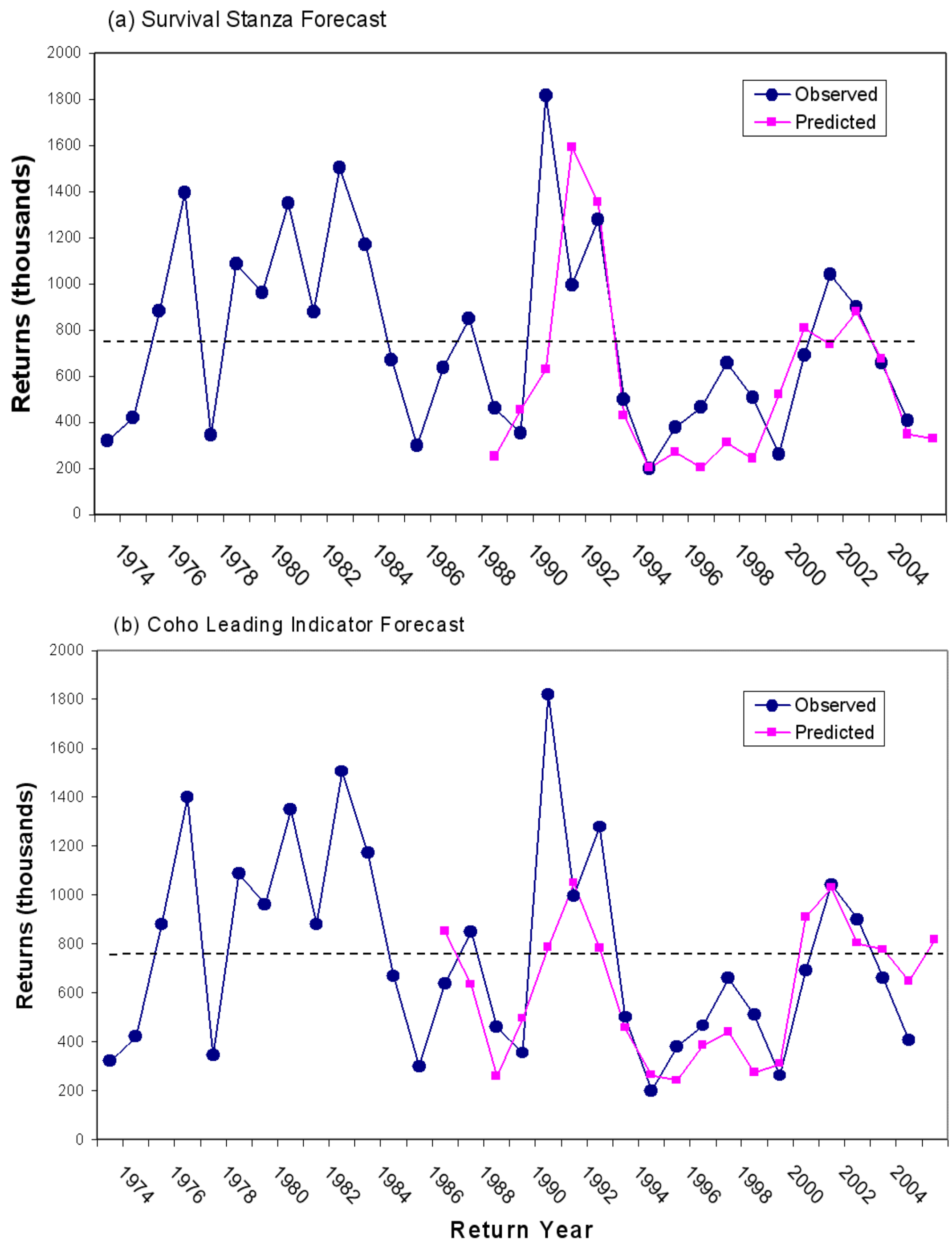


Figure 44. Observed and predicted returns of Barkley Sound sockeye using (a) the survival stanza forecast, and (b) the coho leading indicator forecast

Small-mesh bottom-trawl surveys: Warm waters in 2005 continued low shrimp biomass, but more hake, sole, halibut, Arrowtooth flounder and dogfish.

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 2005 found that the biomass of *Pandalus jordani* shrimp off central Vancouver Island was similar to that in 2004, and was lower than the recent peak in 2002 because of declining recruitment. 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 species such as English sole, Arrowtooth flounder, Pacific halibut and spiny dogfish were at or near record maxima, whereas cold water species such as walleye pollock continued to decline. **These results suggest warm water conditions continued in 2005 in contrast to cooler conditions from 1999 to 2002.**

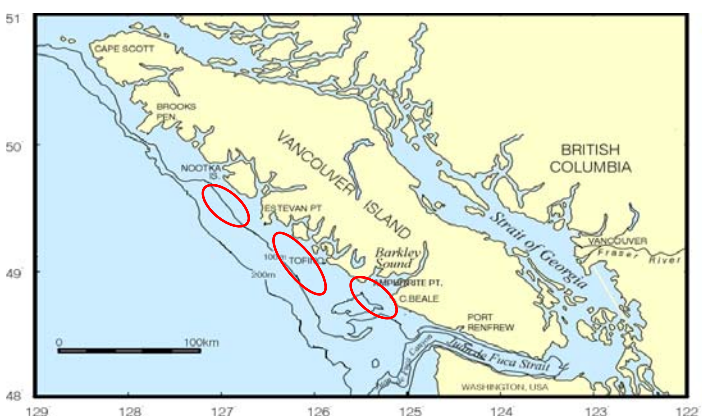
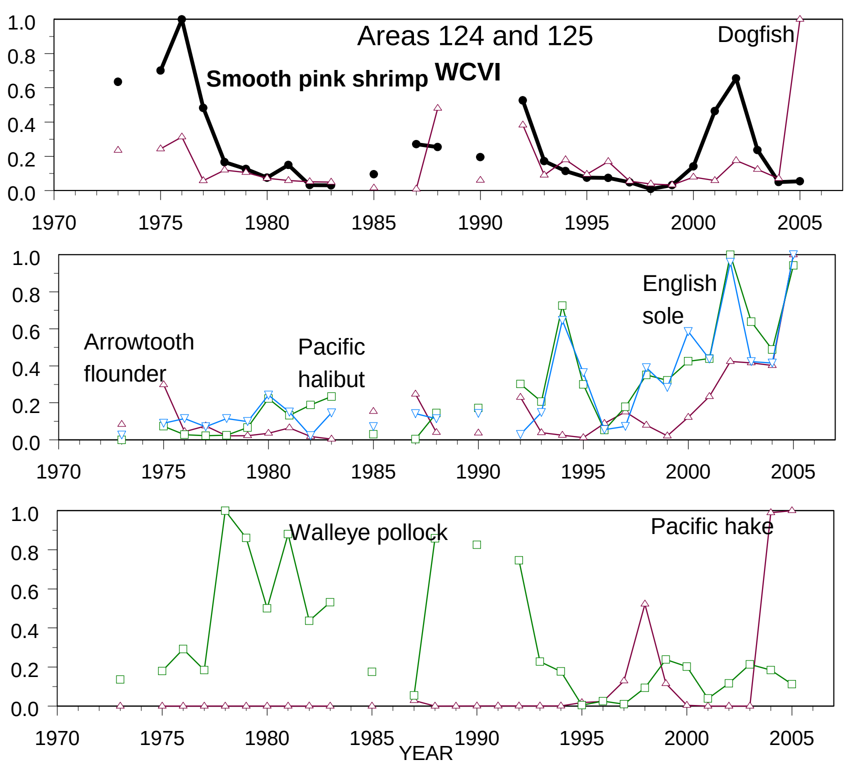


Figure 45 (left) Map showing the three main shrimp (Pandalus jordani) survey grounds off Vancouver Island (red ovals). The Nootka (area 125) and Tofino (area 124) Grounds are the northern and middle ovals, respectively.

Figure 46 (below): Time series of normalised survey catches of smooth pink shrimp, dogfish, Pacific halibut, Arrowtooth flounder, English sole, Pacific hake and walleye pollock.



Lowest growth on record for coho salmon in southwest 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. 47). This could potentially explain the higher marine survival of southeast Alaska coho salmon compared to southern British Columbia stocks. Juvenile coho salmon growth in 2005 was the lowest on record for the west coast of Vancouver Island since 1998, while it remained relatively stable off southeast Alaska and was nearly two-fold higher for this region than off the west coast of Vancouver Island (Fig. 47). Hence, the marine survival and adult returns of coho salmon are expected to be lower for southern B.C. stocks in 2006.

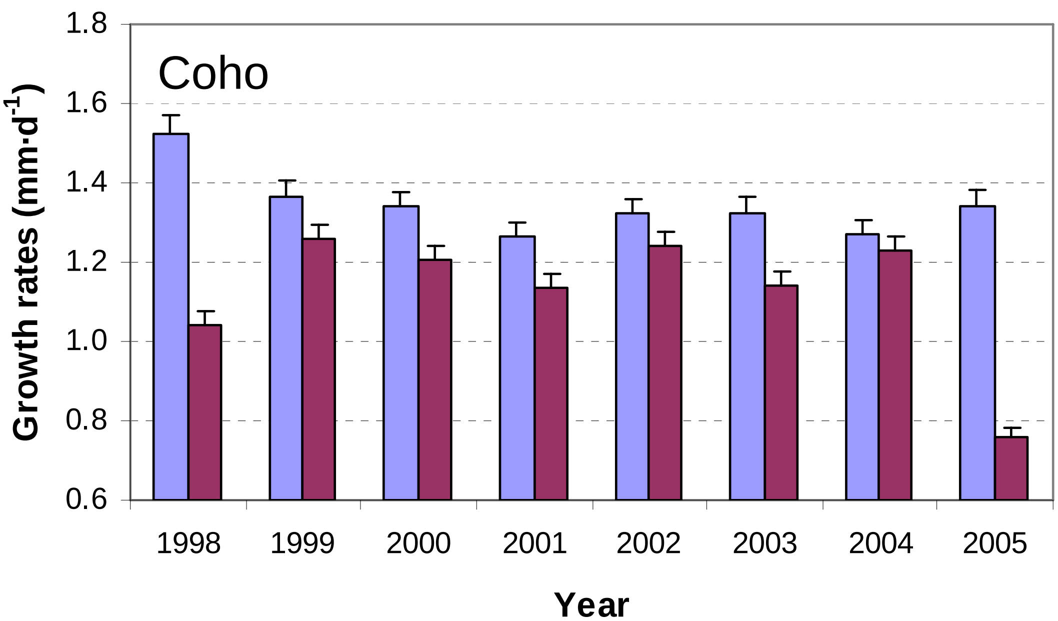


Figure 47. Growth rates (May-October) of juvenile coho salmon off the west coast of Vancouver Island (purple bars) and southeast Alaska (blue bars). The error bars are 2 x standard error.

Small Pelagic Fishes

Jake Schweigert Fisheries & Oceans Canada

Herring recruitment off the west coast of Vancouver Island declined from 1977 to the late 1990s. Abundance in 2005 was similar to the previous year but continued the recent decreasing trend. Warm ocean temperatures appear to be associated with poor recruitment for herring (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 reduced herring survival that may result in reduced recruitment to the stock in 2006 and 2007.

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 2005 sardines appeared in Canadian waters in late June, and were widely distributed in the inlets along the west coast of Vancouver Island and throughout Hecate Strait as far north as Sitka, Alaska. Juvenile sardines were also found throughout the Vancouver Island inlets during the winter of 2004. The exceptionally strong 2003 year-class was an important factor in the widespread distribution of small sardines throughout the area.

Detailed analyses

Herring

Since about 1977, the recruitment of herring off the West Coast of Vancouver Island has been generally poor (Figure 48, next page). The productivity of the west coast of Vancouver Island herring stock has been declining since 1989, primarily because recruitment to this stock has been poor for 6 of the last 10 years (Figure 48) although there are recent signs of some recovery. Since 2002, the pre-fishery biomass (Figure 49) has been stable but remains below the long term average. 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 2003 and 2004 and could result in reduced recruitment to the stock in 2006 and 2007.

Graphs of the long-term changes in **herring** biomass and numbers of recruits are presented on the next page.

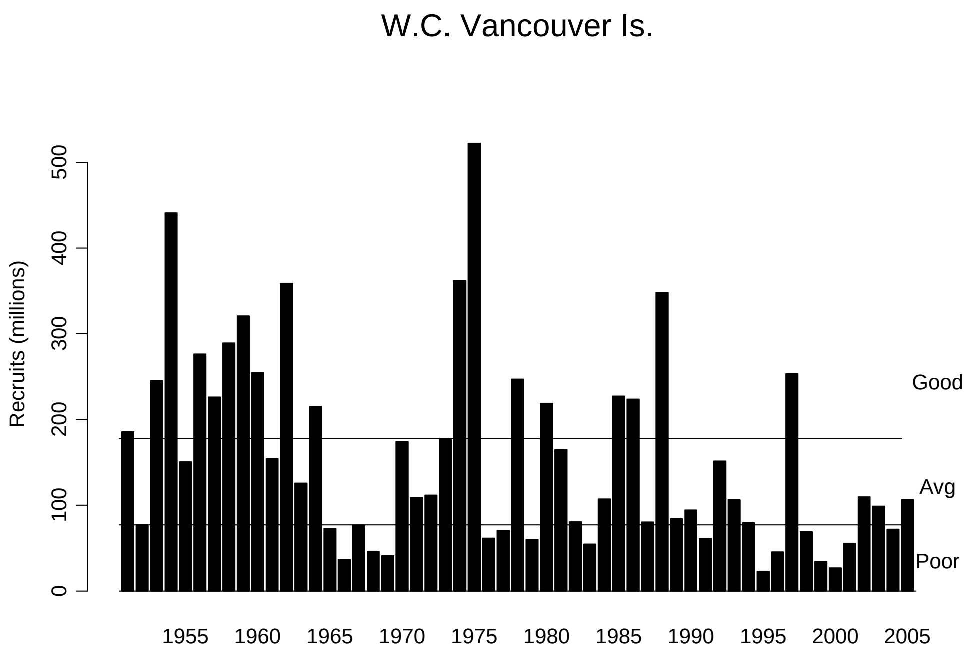


Figure 48. Interannual variability and decadal trends in recruitment to the west coast of Vancouver Island herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 6 of the last 10 recruitments have been 'poor'.

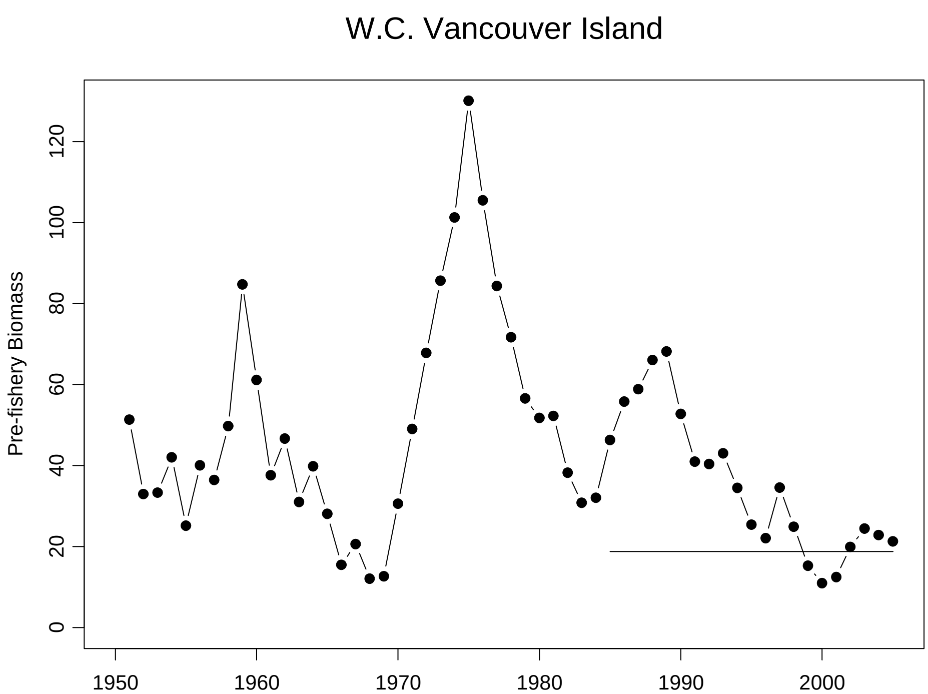


Figure 49. West Coast Vancouver Island herring abundance. Horizontal line is the recommended fishing threshold for this stock.

Pacific Sardine on the west coast of Vancouver Island

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 El Niño, sardine distribution again contracted southward. During 2005, sardines appeared in Canadian waters in late June and were widely distributed throughout the coast and into southeast Alaska. The most recent U.S. assessment suggests a leveling off in sardine abundance (Fig. 50). However, the exceptionally strong 2003 year-class resulted in small sardines overwintering in Vancouver Island inlets in 2004 and widespread distribution throughout Canadian waters in 2005.

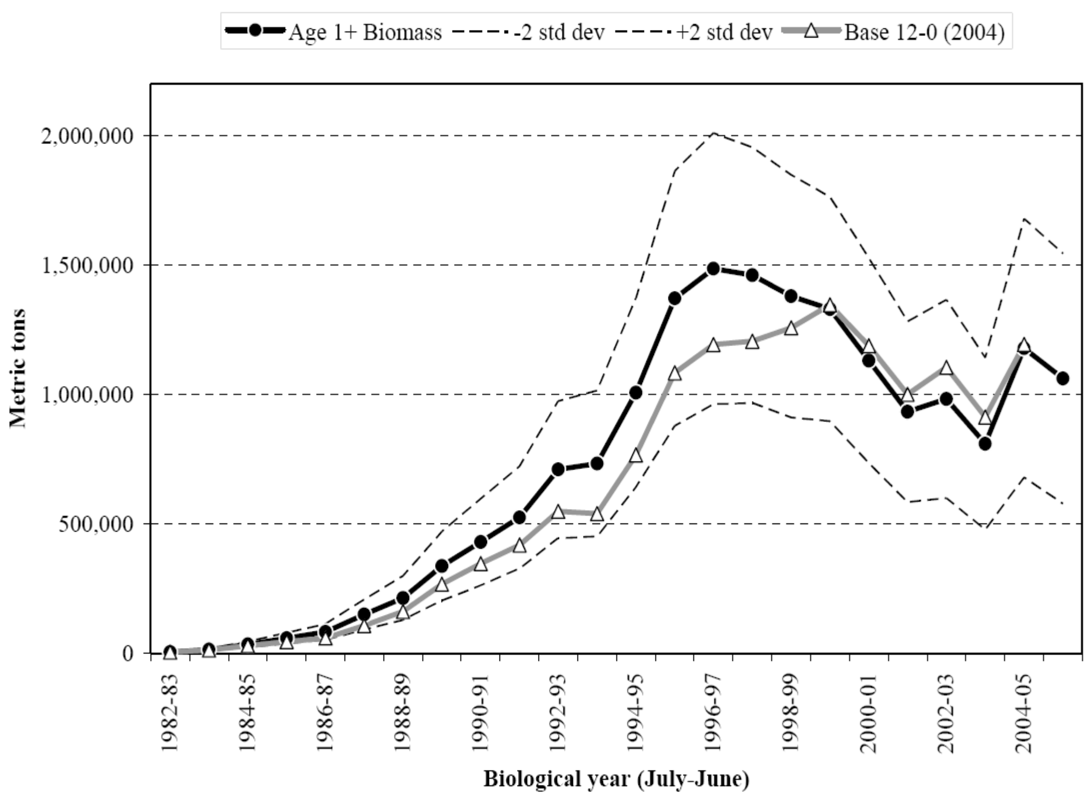


Figure 50. Time series of Pacific sardine stock biomass (x1,000 mt) of age 1 and older fish, estimated from an age-structured stock assessment model (data from Hill et al. 2005).

Interpretation and Speculative Results

Herring on the west coast of Vancouver Island are likely to remain stable or decline slightly unless ocean conditions resulting in a reduction in the abundance of predators in the area improve. Recent conditions have been less favourable for herring survival in 2003 and 2004, and we expect weaker recruitment to the stock during the next couple of years.

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. Warmer conditions and a very strong 2003 year-class resulted in widespread distribution of sardines throughout and Canadian and southeast Alaska waters.

Seabirds on Triangle Island in 2005: All species experienced a very poor breeding season

Mark Hipfner, Environment Canada

Triangle Island Background and Species Natural History

Marine birds can be effective indicators of the state of marine ecosystems because they gather in large aggregations to breed and because, as a group, they feed at a variety of trophic levels (zooplankton to fish). Seabird breeding success is closely tied to the availability of key prey species, and as a result, can vary widely among years, depending on ocean conditions. Triangle Island (50°52' N, 129°05' W) in the Scott Island chain off northern Vancouver Island, supports the largest and most diverse seabird colony along the coast of British Columbia. Since 1994, researchers from the Centre For Wildlife Ecology (a partnership between 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 2005, and places 2005 results within the context of the 1994-2004 time series.

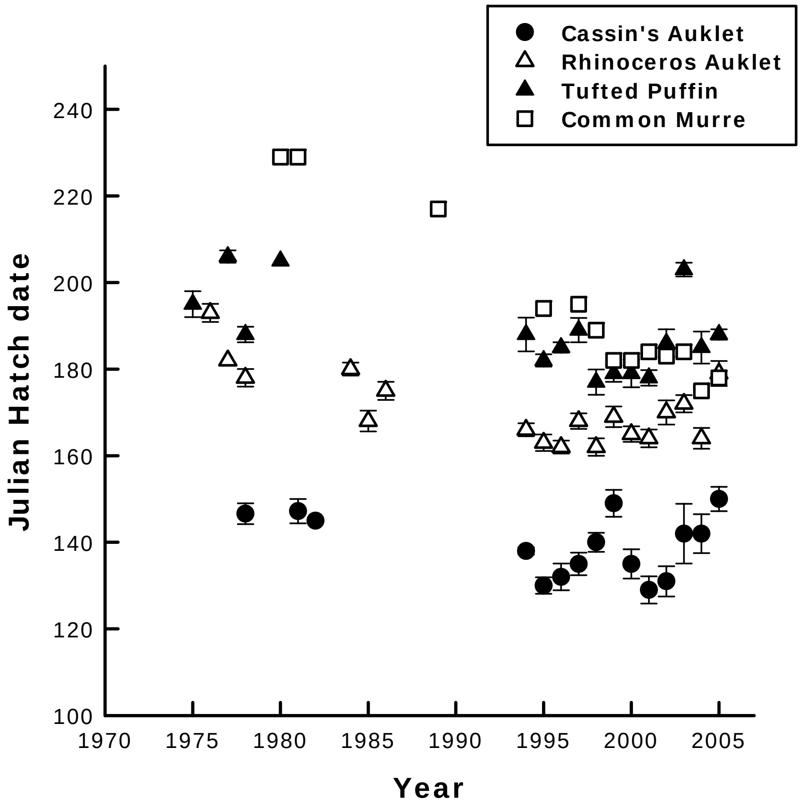


Figure 51. Timing of breeding for seabirds on Triangle Island, British Columbia, 1975-2005. Reported are mean hatching dates, with 95% confidence intervals, for Cassin's Auklets, Rhinoceros Auklets and Tufted Puffins, and dates when nestlings were first seen for Common Murres. All species bred late, except for Common Murres

Timing of breeding

Timing of avian breeding is thought to be 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 very late in 2005, compared to previous years (Fig. 51). The lone exception was the Common Murre, in which timing of laying was again early in 2005. In general, it appears that food was scarce early in the season.

Breeding success

All species of seabirds experienced very poor breeding seasons at Triangle Island in 2005. In fact, success in Cassin's Auklets was the lowest of any year in the time series: only 8% of pairs that laid an egg fledged a chick, and the few fledglings were severely underweight. Success was also extremely low (24%) in Rhinoceros Auklets. Success in both species was substantially lower than predicted from early season sea surface temperatures recorded at Pine Island (Fig. 52). Diets fed to nestlings were low in putatively preferred species: the copepod *Neocalanus cristatus* for Cassin's Auklets, and Pacific sand lance for Rhinoceros Auklets. On the whole, 2005 was a very poor year for the seabirds on Triangle Island.

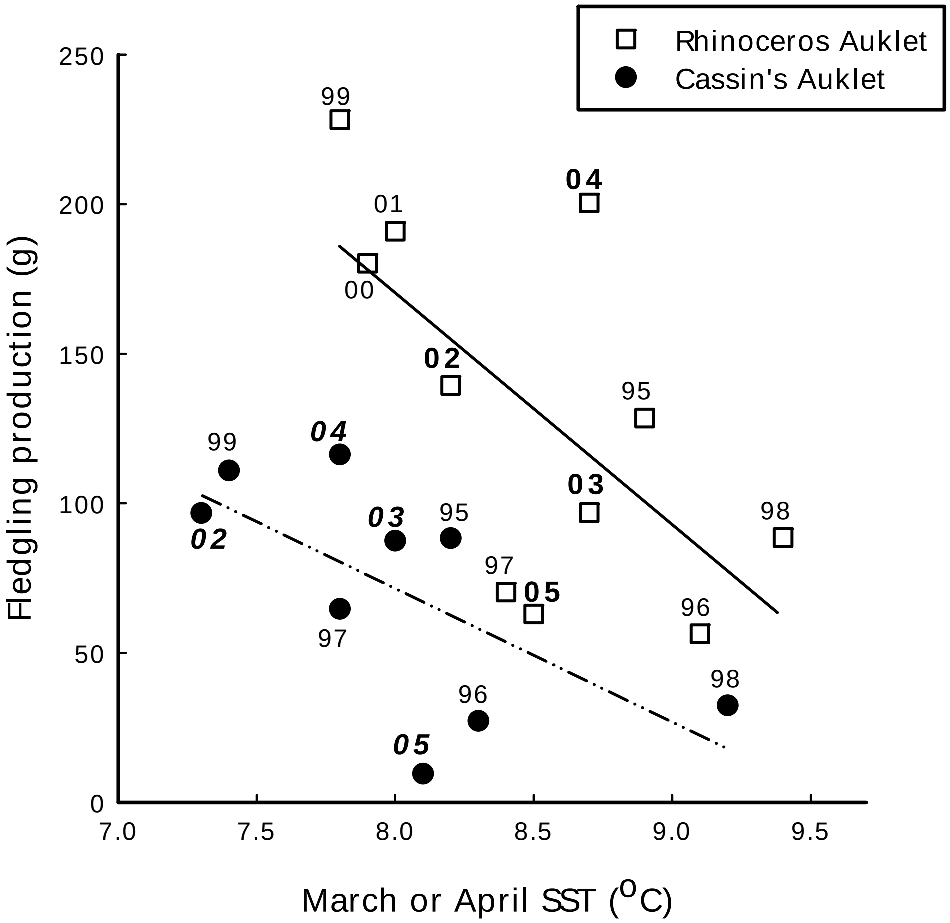


Figure 52. Consequences of April sea surface temperatures (SST), measured at the Pine Island Lightstation (50° 35'N 127° 26'), for Cassin's and Rhinoceros auklets breeding on Triangle Island, British Columbia, 1994-2005. Fledgling production is calculated as: hatching success x % fledging success x mean fledging mass; or in other words, the mean mass of fledged chick produced per egg laid. Note that success was very low in both species in 2005, and much lower than predicted from SST.

Links [Scott Islands Marine Wildlife Area]

[Canadian Wildlife Service bird monitoring in BC]

Pacific hake (Merluccius productus) along the west coast of Canada and the US

Ken Cooke, Fisheries & Oceans Canada

This paper presents results of the joint Canada-US acoustic-trawl survey conducted from June 15 – August 20, 2005 to assess the distribution, abundance and biology of Pacific hake (*Merluccius productus*) along the west coasts of the United States and Canada (Thomas et al. 2006; Figure 53). Engine failure on the CCGS *W.E. Ricker* limited Canadian participation, and loss of acoustic gear on the NOAA ship *Miller Freeman* reduced the survey scope from multi-frequency ecosystem assessment to single-species distribution and abundance estimate. These failures required persistence on the part of ship and scientific crew to complete the assessment. Despite these challenges, investigators recorded some of the most unusual distributions observed to date.

Pacific hake is an ecologically and economically important pelagic marine fish that ranges throughout the California current system. In the fall and winter, hake migrate offshore and southward to spawn, however details of the winter distribution and migration routes are poorly known. Commercial catch records and data collected from assessment surveys show Pacific hake are distributed along the west coast, typically from Monterey, CA (36^{o} N) northward to Queen Charlotte Islands, British Columbia (52^{o} N) from about June through October. In general, aggregations are found near the edge of the continental shelf at depths ranging from 100 to 300 metres. This coastal region is characterised by summer upwelling events which mix cold, nutrient rich waters with warmer, oxygenated surface waters thus providing favourable conditions for euphasiid production, the primary food resource of hake. Some areas of the coast can show wide-spread offshore hake dispersal while others may support dense shelf-break aggregations. The degree of variability in both the northward and offshore spatial patterns suggests hake may be an excellent indicator of change within the California current system.

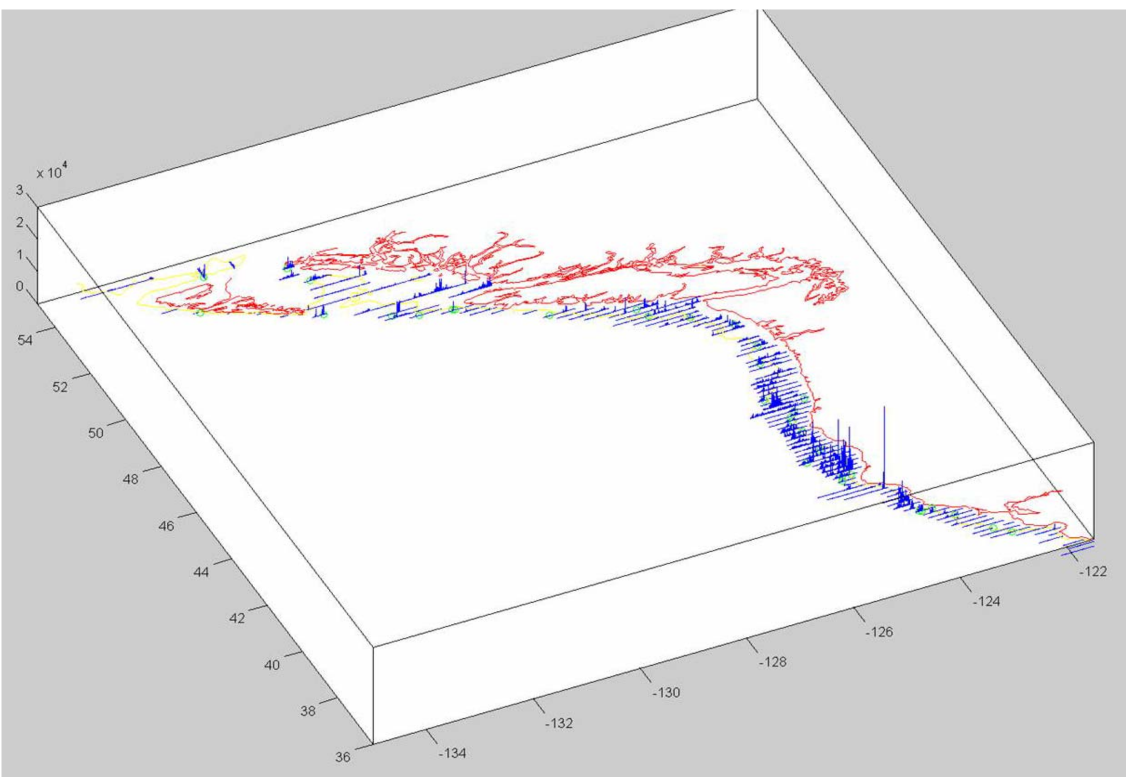


Figure 53. Plot of joint Canada-U.S. Pacific hake acoustic-trawl survey conducted by the US FRV Miller Freeman*, June 15 – August 20, 2005. Horizontal blue lines show survey grid; vertical blue lines indicate distribution of hake along transects. Line height is scaled to maximum recorded acoustic backscatter level (SA; m^2/nmi^2).*

The 2005 survey estimate of total stock biomass was 1.2M metric tons with approximately 0.5M metric tons in the Canadian zone and 58% of the biomass composed of the 1999 year class (Thomas et al. 2006). Survey data show hake distribution and aggregation behavior changed in 2005 compared with results from previous joint surveys (Fig. 54; Wilson and Guttormsen 2000; Helser et al. 2002; Wilson et al. 2003; Fleischer et al. 2006). Hake were distributed well north to 54°N, near the Canada-Alaska border, but they were largely absent from their usual feeding grounds near the shelf edge (Figures 53 and 54). Typical shelf-edge aggregations were seen south of Cape Blanco (42.9°N) however, schools observed further north were generally small in size and dispersed over a wide, shallow range inshore of the 250m contour. Areas supporting the largest concentrations of hake were north of Cape Mendocino (ca. 43°N), near the US-Canadian border off Cape Flattery to La Perouse Bank (ca. 48.5°N), and in Queen Charlotte Sound through Hecate Strait to Dixon Entrance (ca. 51-54°N).

The shallow inshore distribution of hake in the northern part of the range has not been observed in previous joint surveys and may be a response to unusual oceanic conditions. Anomalously warm water persisted along much of the central and northern coastal regions through 2003 and 2004. This condition, coupled with late onset of along-shore winds in the spring of 2005, delayed upwelling, particularly off Oregon and Washington coasts and led to reduced productivity over much of the central coastal region at least until late summer. Mid-water and bottom trawl samples show the 1999 year-class fish (Age 6) has not grown significantly since 2003 (Fig. 55) which suggests poor ocean productivity observed early in 2005 may have persisted from 2003 (DFO, 2004). The reduced availability of shelf-edge food resources may have contributed to more dispersed and shallower feeding behaviour observed in hake in 2005. Variability observed in the last decade suggests the impact of changing ocean conditions on the migratory behaviour of offshore hake may be more significant than previously thought (Dorn 1995).

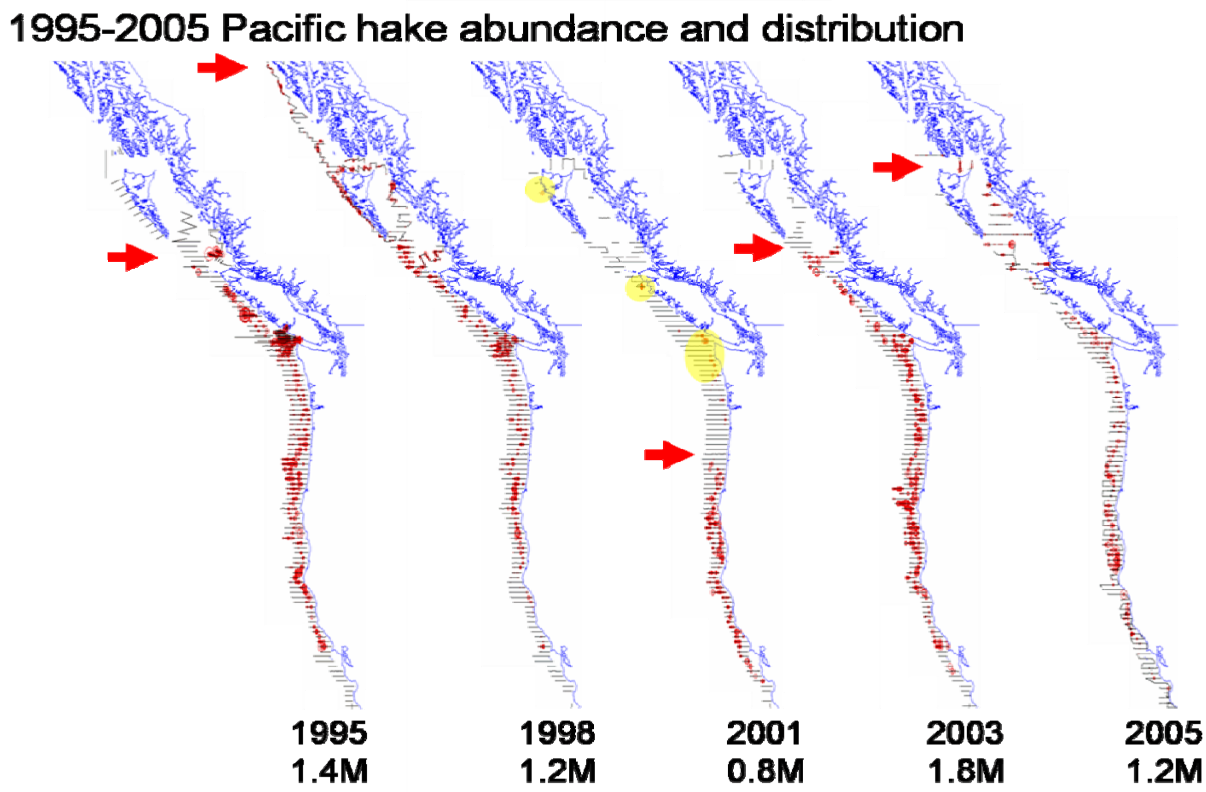


Figure 54. Comparison of hake distribution and abundance between joint Canada-US Pacific hake acoustic-trawl survey years 1995-2005. Blue lines show survey grid, red circles indicate hake acoustic backscatter (SA) along transects with size proportional to the maximum level among years. Red arrows indicate northern extent of stock range each year. Yellow areas show isolated aggregations of hake in 2001. Labels give total biomass by year in millions of metric tons.

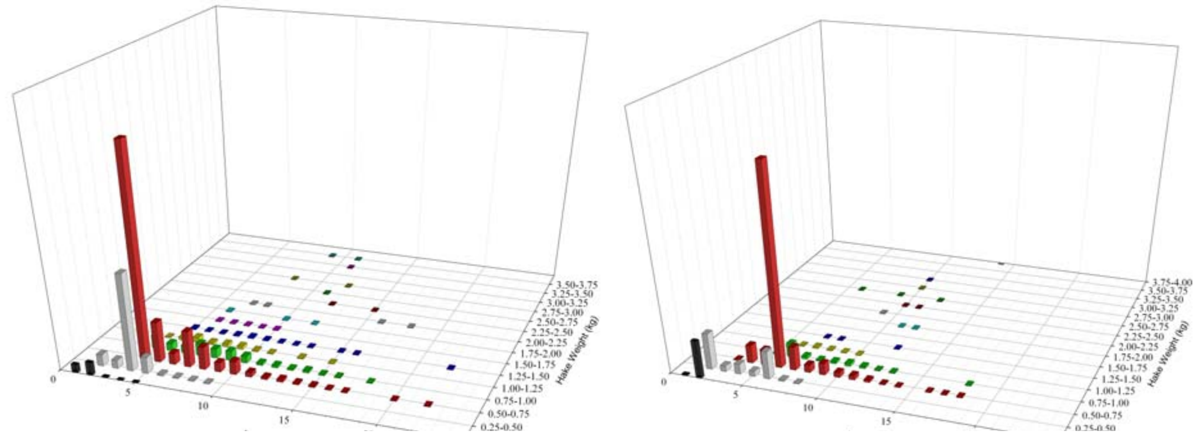


Figure 55. Frequency plot of weight-at-age data based on mid-water and bottom catches from the joint US-Canada Pacific hake acoustic-trawl surveys. 2003 (left) shows 1999 year class (Age 4) weight-at-age is 0.5-0.75kg; 2005 (right) shows same year class (Age 6) unchanged at 0.5-0.75kg.

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Helser, T.E., M.W. Dorn, M.W. Saunders, C.D. Wilson, M.A. Guttormsen, K. Cooke, and M.E. Wilkins. 2002. Stock assessment of Pacific whiting in U.S. and Canadian waters in 2001. *In:* Pacific Fishery Management Council, Appendix: Status of the Pacific coast groundfish fishery through 2001 and recommended acceptable biological catches in 2001: Stock assessment and fishery evaluation. Pacific Fishery Management Council, 2130 SW Fifth Avenue, Suite 224, Portland, OR 97201.

Thomas, R., K. Cooke, P. Ressler, and G. Fleischer. 2006. Echo integration-trawl survey of Pacific hake, *Merluccius productus*, off the Pacific coast of the United States and Canada during June-August, 2005. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-xx (in prep).

Wilson, C.D. and M.A. Guttormsen. 1997. Echo integration-trawl survey of Pacific whiting, *Merluccius productus*, off the west coasts of the United States and Canada during July – September, 1995. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-AFSC-74, 70p.

Wilson, C.D., M.A. Guttormsen, K. Cooke, M.W. Saunders, and R. Kieser. 2000. Echo integration-trawl survey of Pacific hake, *Merluccius productus*, off the Pacific coast of the United States and Canada during July – August, 1998. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-AFSC-118, 103p.

Warm water species in British Columbia and Alaska

Marc Trudel[1], Graham Gillespie[1], Jim Cosgrove[2], Bruce Wing[3]

[1] Fisheries & Oceans Canada, [2]Royal BC Museum, [3]NOAA Fisheries, Alaska

Global warming is expected to be accompanied by a northward shift in the distribution of marine species. Although it is currently difficult to predict the extent of these shifts, El Niño and warming events are particularly useful to forecast how coastal ecosystems will change as a result of global warming. Here, we report some of warm water and oceanic species of fish and invertebrates that appeared in coastal waters of British Columbia and Alaska in 2004 and 2005.

Humboldt squid (*Dosidicus gigas*), a tropical squid normally ranging from central California to southern Chile, was captured incidentally in the summer and fall of 2004-2005 by commercial fishermen and in research surveys throughout British Columbia and as far north as Sitka in Alaska (Figure 56). Until 1997, none had been reported in coastal waters north of Oregon. Due to their fast growth rate, jumbo flying squid are expected to consume large quantities of forage fish such as herring and sardines, and possibly juvenile salmon. Hence, there may be serious impacts on coastal ecosystems in British Columbia and elsewhere if large numbers of Humboldt squid migrate northward as a result of global warming.

In addition to Humboldt squid, subtropical and oceanic fish species were observed in British Columbia and Alaska in 2005. These include sardines (*Sardinops sargax*) in Icy Strait, yellowtail (*Seriola lalandi*) in Portland Canal, Opah (*Lampris guttatus*) near Sitka, and ocean sunfish (*Mola mola*) off the west coast of Vancouver Island (Figure 56). These species can feed on a variety of prey, such as squid, fish, and zooplankton. Ocean sunfish may also consume jellyfish. Although Pacific mackerel (*Scomber japonicus*) are not uncommon in southern BC waters, they are not known to reproduce north of 49°N. Interestingly, a 6 cm Pacific mackerel has been caught on La Pérouse Bank, suggesting that they may have spawned near this area. A closer monitoring of warm water species and an assessment of their diet will be necessary to evaluate their potential impacts on coastal ecosystems of the Northeast Pacific Ocean.

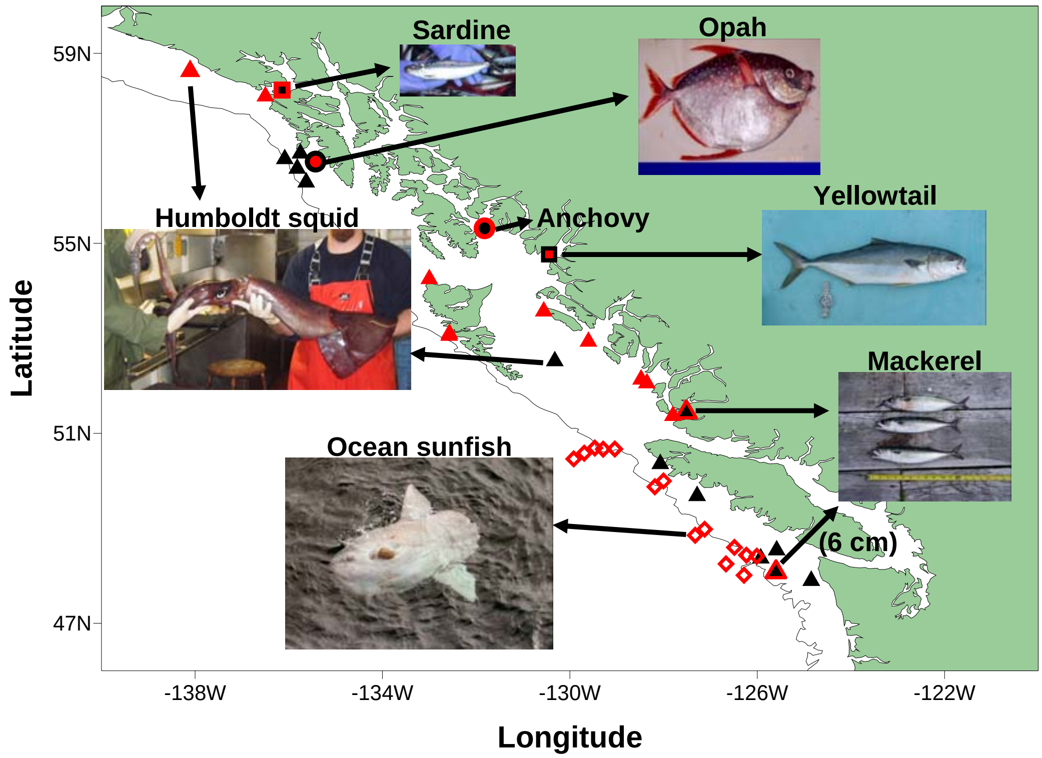


Figure 56. Distribution of warm waters species of fish and squid in British Columbia and southeast Alaska in 2004-2005. Black triangles: Humboldt squid (2004); Red triangles: Humboldt squid (2005); Open red diamonds: Ocean sunfish.

Northern British Columbia

Shore Stations: Warm all year.

Bill Crawford, Fisheries & Oceans Canada

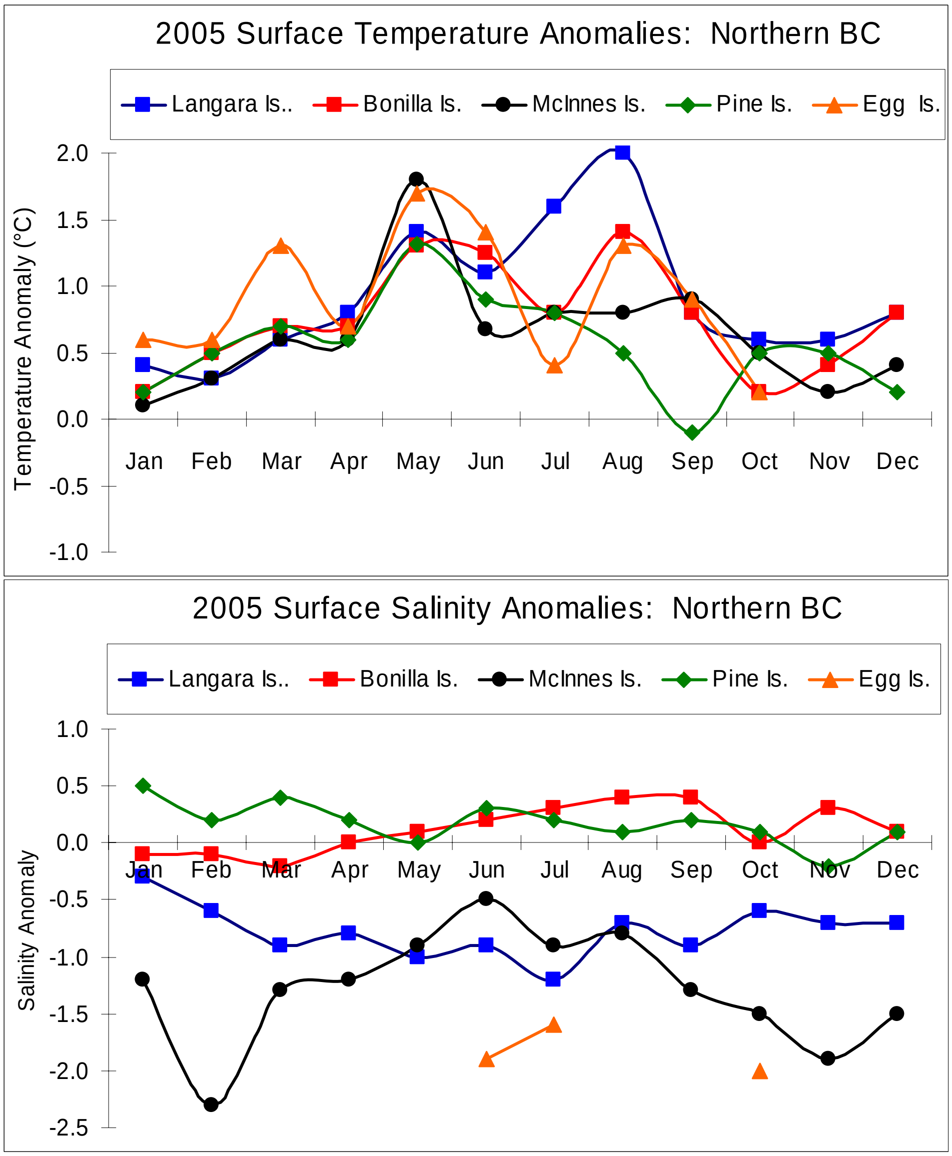


Figure 57: Anomalies of ocean temperature (top panel) and salinity (bottom panel) at four shore stations in northern British Columbia.

Temperature and salinity are measured daily by light keepers through BC waters as part of a long-term program that began more than 70 years ago. These time series form the longest continuous records of ocean temperature and salinity on the Pacific Coast north of San Diego

The warmer surface waters found in northern BC in 2004 persisted into 2005, and even increased in temperature, especially in between May and August. These unusually hot summer waters were likely a cause of the many unusual warm-water species reported in northern BC in the summer of 2005.

Links: BC Seawater sampling at Lighthouses

Small Pelagic Fishes

Jake Schweigert Fisheries & Oceans Canada

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. 58,60,62). Levels of recruitment to the Queen Charlotte Islands have been depressed (Fig. 59) with 4 of the past 10 year-classes being 'poor' while the Prince Rupert stock (Fig. 61) has experienced a good recruitment at least every 4 years since 1980. Recruitment to the Central Coast stock (Fig. 63) has been less regular but the 'good' year-classes that have occurred were very strong. Indications are that the most recent recruitment of the 2002 year-class is average following one of the poorest observed in the historical record. As a result abundance should remain stable or decline slightly in the three northern stocks over the next few years.

Sardines 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. In 2005 sardines appeared in Canadian waters in late June, and were widely distributed in the inlets along the west coast of Vancouver Island and throughout Hecate Strait as far north as Sitka, Alaska. Juvenile sardines were also found throughout the Vancouver Island inlets during the winter of 2004. The exceptionally strong 2003 year-class was an important factor in the widespread distribution of small sardines throughout the area.

Graphs of the long-term changes in **herring** biomass and numbers of recruits are presented on the next three pages.

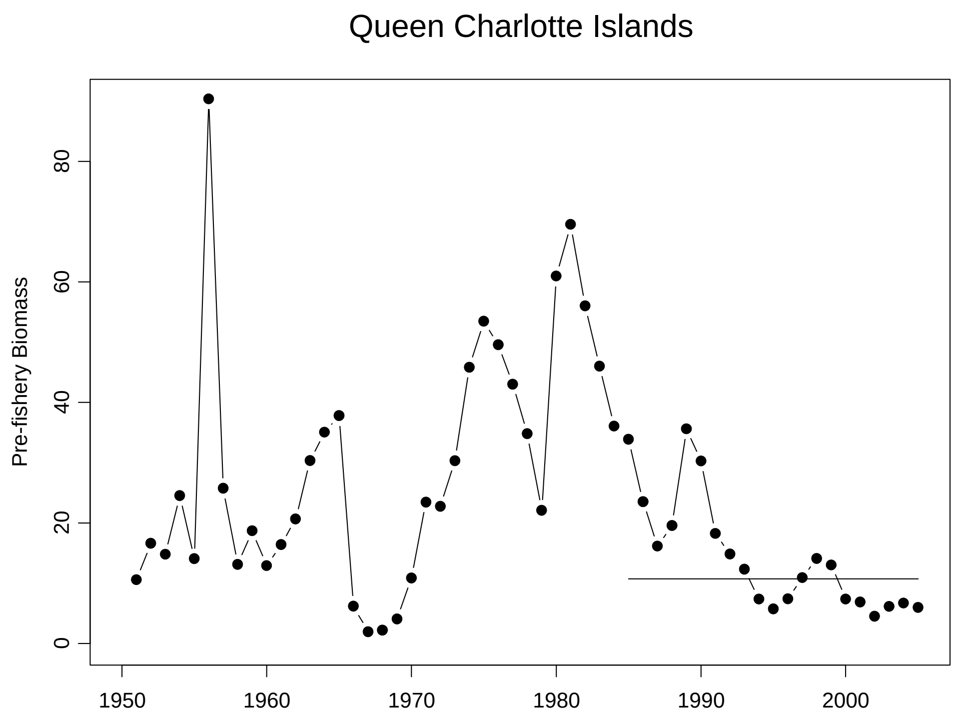


Figure 58. Queen Charlotte Islands herring abundance. Horizontal line is the recommended fishing threshold for this stock.

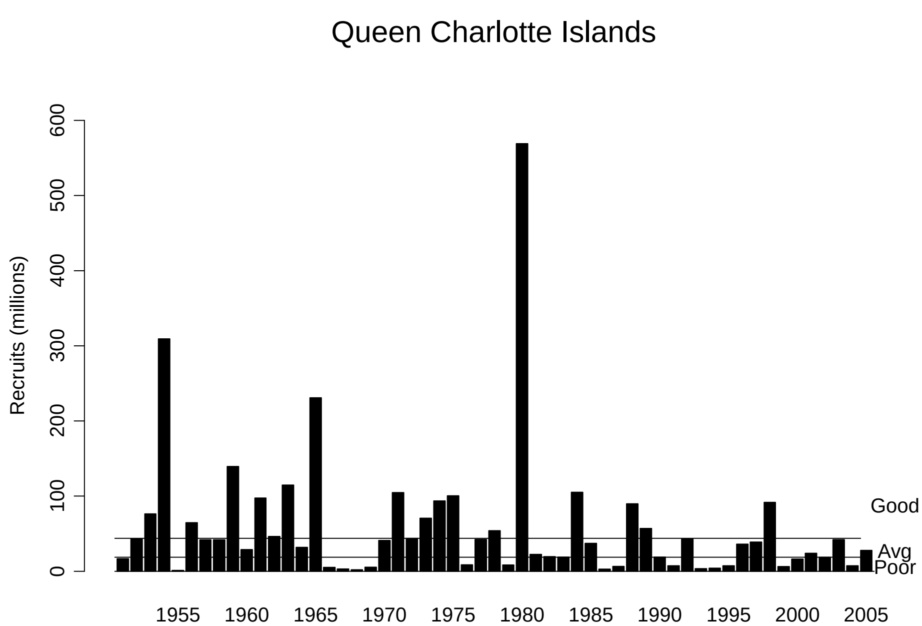


Figure 59. Interannual variability and decadal trends in recruitment to the Queen Charlotte Islands herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

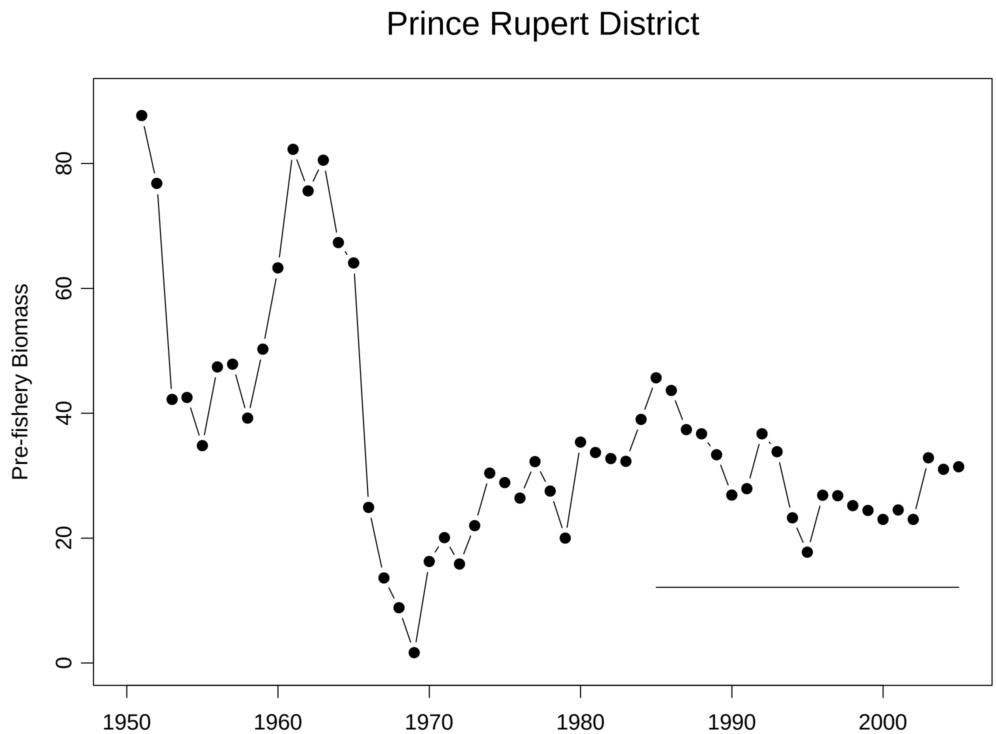


Figure 60. Prince Rupert District herring abundance. Horizontal line is the recommended fishing threshold for this stock.

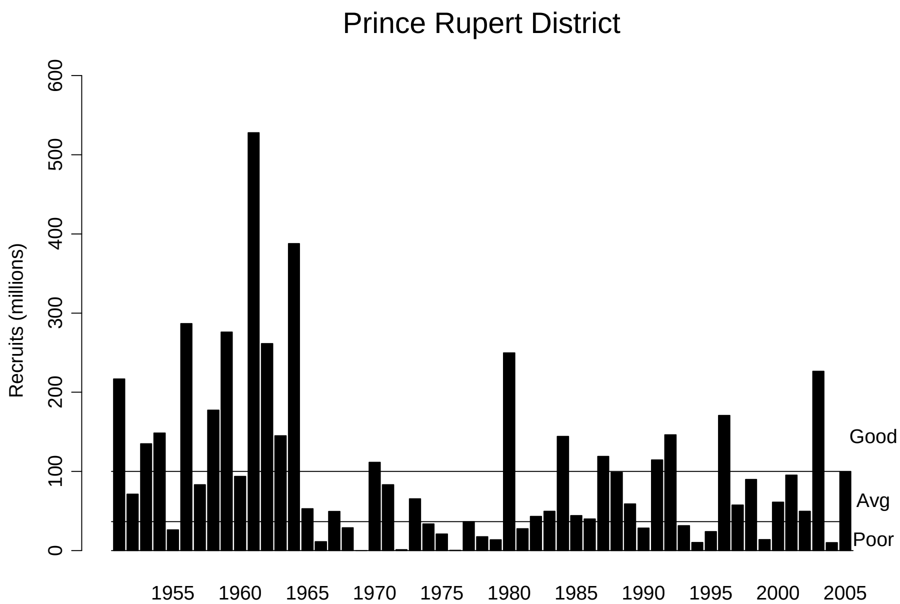


Figure 61. Interannual variability and decadal trends in recruitment to the Prince Rupert District stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 'good' recruitments have occurred almost every four years since 1980.

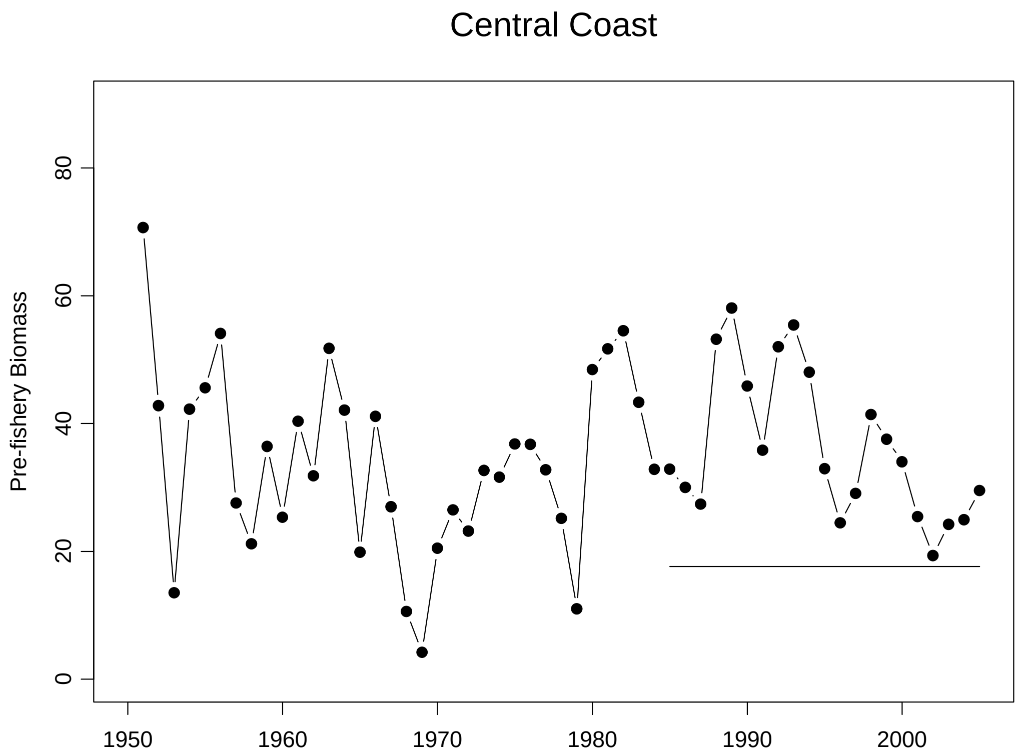


Figure 62. Central Coast herring abundance. Horizontal line is the recommended fishing threshold for this stock.

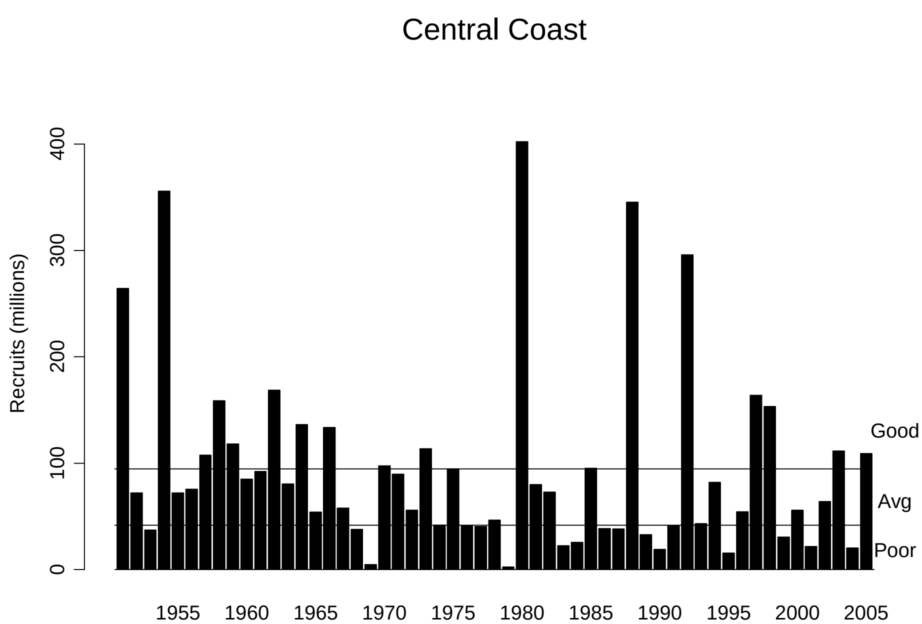
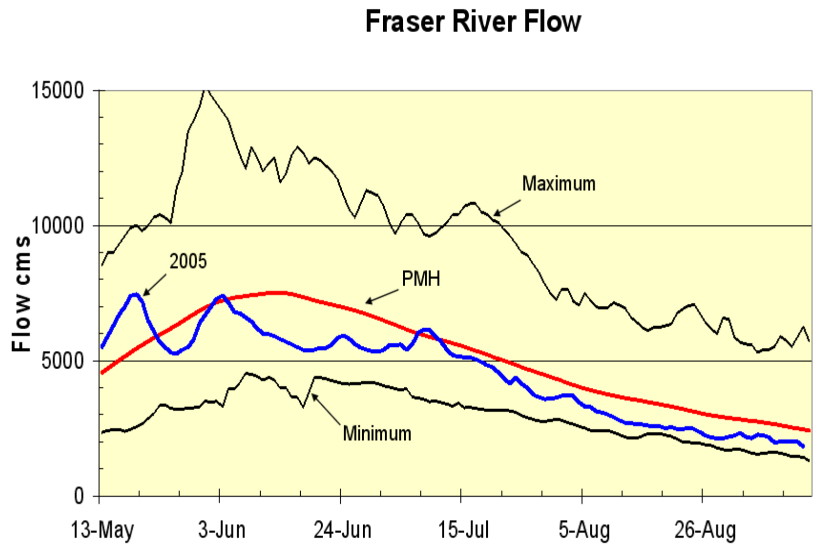


Figure 63. Interannual variability and decadal trends in recruitment to the Central Coast stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

Georgia Basin and Fraser River

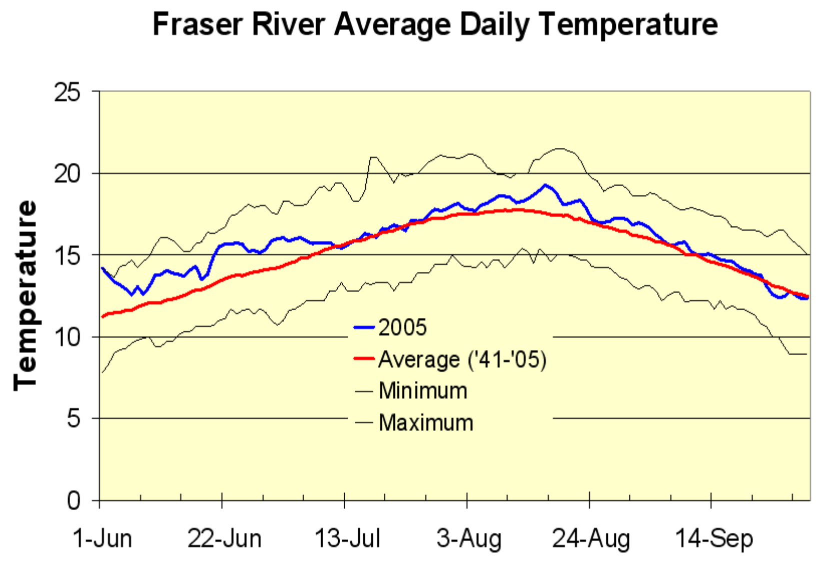
Fraser River Conditions: Summer 2005

John Morrison, Fisheries & Oceans Canada



Fraser River flow has been monitored year round at Hope for the past 90 years and summer water temperature has been monitored in the Fraser canyon, north of Hope, for the past 60 years. High flow and warm water are important factors that can affect the spawning success of sockeye salmon. 2005 was an unexceptional year with near average water temperatures and low flows, except for record warm day on 1 June 2005.

Figure 64. Flow rate of the Fraser River as measured at Hope BC from May to August 2005.



After setting the record high temperature on June 1, the river cooled slightly and then followed the long term seasonal trend. Temperatures in 2005 deviated little from the long term average from mid July until the end of September. Flow peaked very early this year on May 19. A secondary peak of almost the same magnitude occurred on June 3. Both peaks were much earlier than the normal mid-June peak. Following this peak, low flow prevailed until summer's end.

Figure 65. Temperature of the Fraser River from June to September 2005

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Macdonald, J.S., Foreman, M.G.G., Farrell, T., Williams, I.V., Grout, J., Cass, A., Woodey, J.C., Enzenhofer, H., Clarke, W.C., Houtman, R., Donaldson, E.M., and Barnes., D., 2000b. Can. Tech. Rep. Fish. and Aquat. Sci. 2326: 117p.

Links Fraser River Research

Strait of Georgia Temperature and Salinity

Diane Masson, Fisheries & Oceans Canada

Sea surface temperature (SST) in the Strait of Georgia remained above normal for most of 2005, with SST anomalies at Entrance Island reaching a maximum of almost 2 deg C in August (Fig. 66). The sea surface salinity (SSS) also remained higher than average for most of the year, except for the month of February when the surface salinity significantly decreased due to record Fraser River discharge in January caused by heavy rain. The data in Fig. 66 are monthly values measured at Entrance Island for 2005 (dotted line) and for the long term (1936-2005) average (full line). Similar conditions were recorded at other lighthouse stations as well as at the Nanoose station.

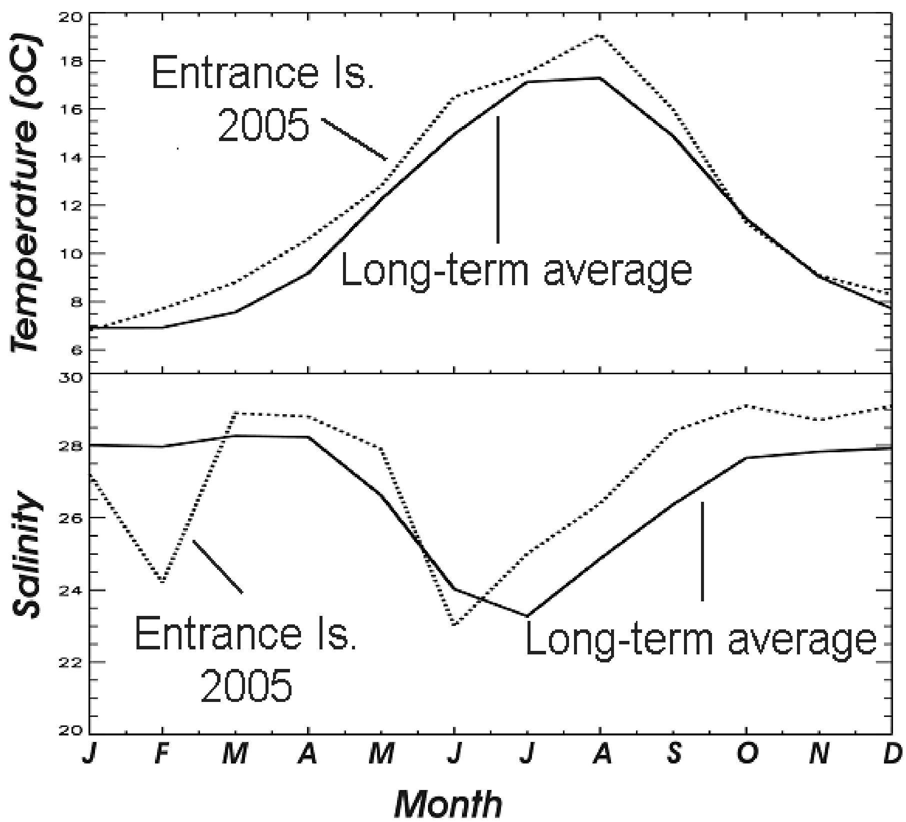

Figure 66: Monthly sea surface temperature and salinity measured at Entrance Island.

Below the surface, the Strait of Georgia was also relatively warm in 2005. Fig 67 (on the next page) gives the time series of temperature measured at the Nanoose station, located in the central deep basin of the Strait. Since the cool episode that started in 1999 and ended in 2003, the sub-surface Strait of Georgia has remained warm relative to the previous two decades. In particular, the spring intrusions into the deep basin were relatively warm in 2005, resulting in the highest summer temperature for the deep waters of the Strait observed since 1970. These intrusions are shown on the next page (Fig 68).

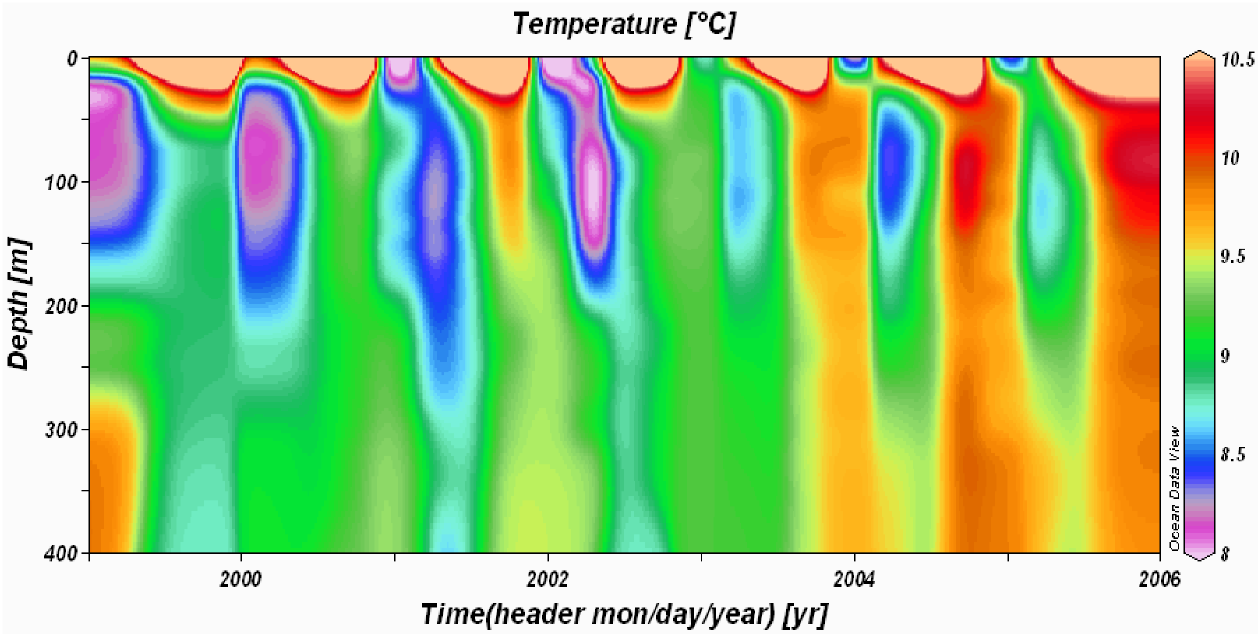

Figure 67: Temperature measured at the Nanoose station at 49° 19'N, 123° 55'W.

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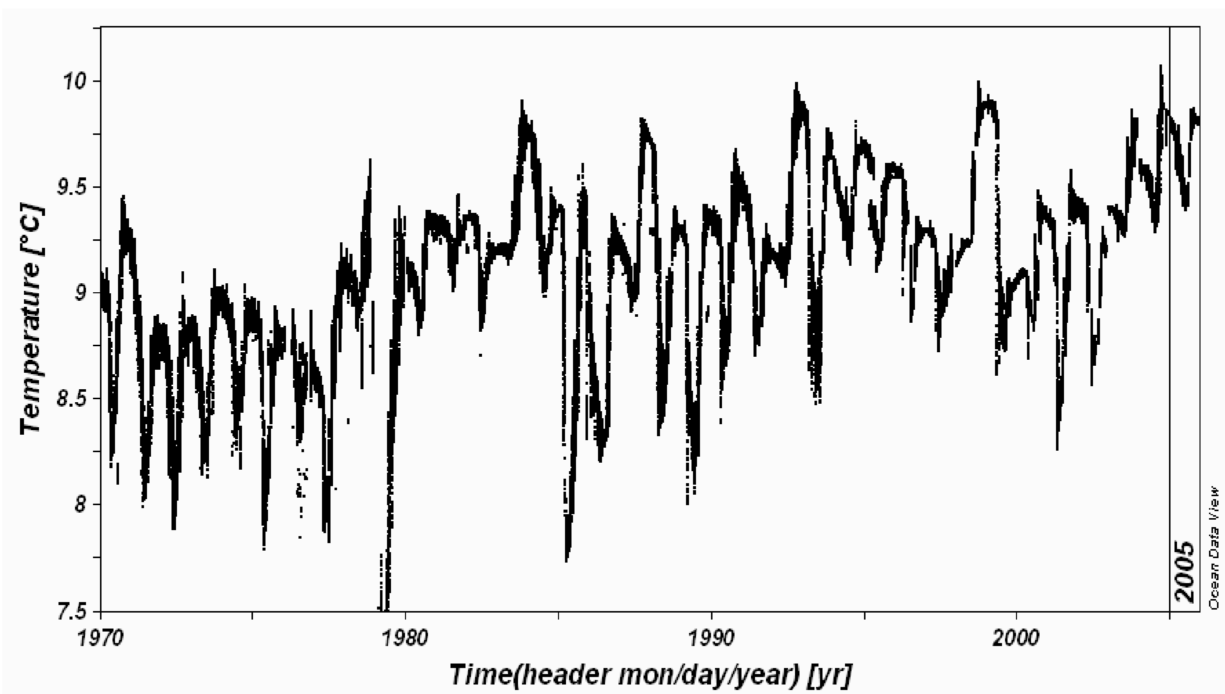
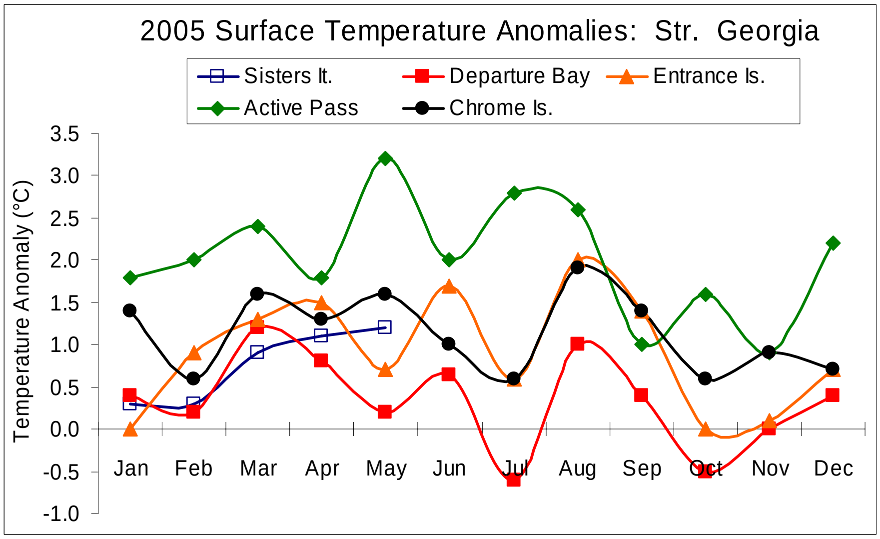


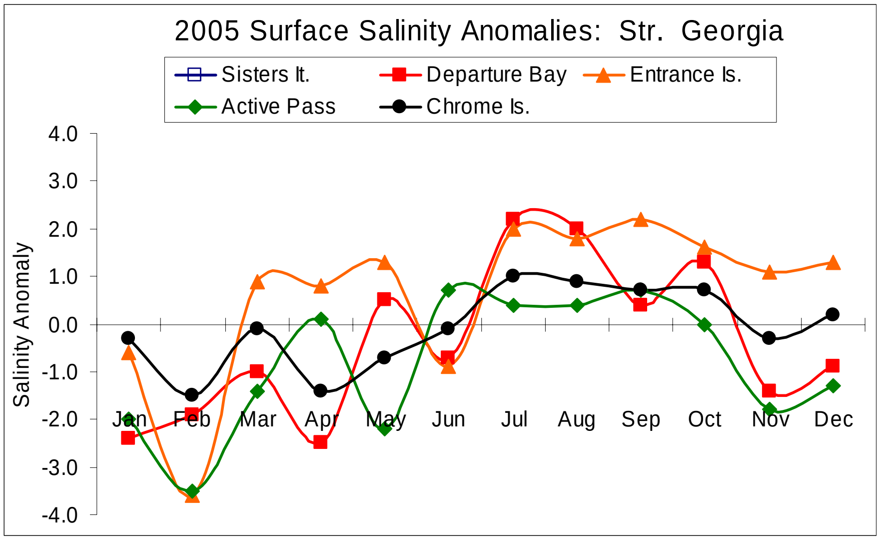
Figure 68: Temperature measured near the bottom (400 m depth) at the Nanoose station.

Links: [Strait of Georgia and Juan de Fuca Strait Research in DFO]

Shore Stations: Warm all year

Bill Crawford, Fisheries & Oceans Canada





Temperature and salinity are measured daily by light keepers through BC waters as part of a long-term program that began more than 70 years ago These time series form the longest time series of ocean temperature and salinity on the Pacific Coast north of San Diego.

Monthly average temperature anomalies in the Strait of Georgia and Active Pass show it was warm all year. Waters in Active Pass were more than 2°C warmer from May through August.

Temperatures recorded at all shore stations in BC and all through the coastal and deep-sea waters west of Canada were alarmingly higher than normal from 2004 through 2005. Previous warm years have been part of El Niño conditions, but this event of 2004 to 2005 may be linked to global warming.

All Strait of Georgia salinity stations were fresher than normal in spring, changing to saltier than normal in summer. Salinity dropped at most stations in September after heavy rain.

Figure 69. Temperature (top) and salinity (bottom) measured at shore stations in the Strait of Georgia.

Links: Seawater sampling at Lighthouses

Phytoplankton, Strait of Georgia

Angelica Peña, Fisheries and Oceans Canada

The concentration of phytoplankton biomass, as measured by fluorometer profiles at 20 stations in the Juan de Fuca / Strait of Georgia Basin, is shown in Figure 70 below. In general, phytoplankton biomass is confined to the upper 40 m and is higher and more variable in the Strait of Georgia sector than elsewhere in this region. Chlorophyll concentrations vary seasonally, being highest during the spring bloom (March-April), low during most the summer and increasing again at the end of the summer. Relative to previous years, chlorophyll concentrations in April of 2005 were slightly lower than those observed in April of 2002 and 2004 but similar to the values observed in 2003 (Figure 70). In contrast, chlorophyll concentrations in September were higher in 2005 than in the three previous years. Although nutrients and grazing are the limiting factor for phytoplankton production during the late spring and summer, we know little about processes responsible for interannual variability in the Strait and their effect on the food web.

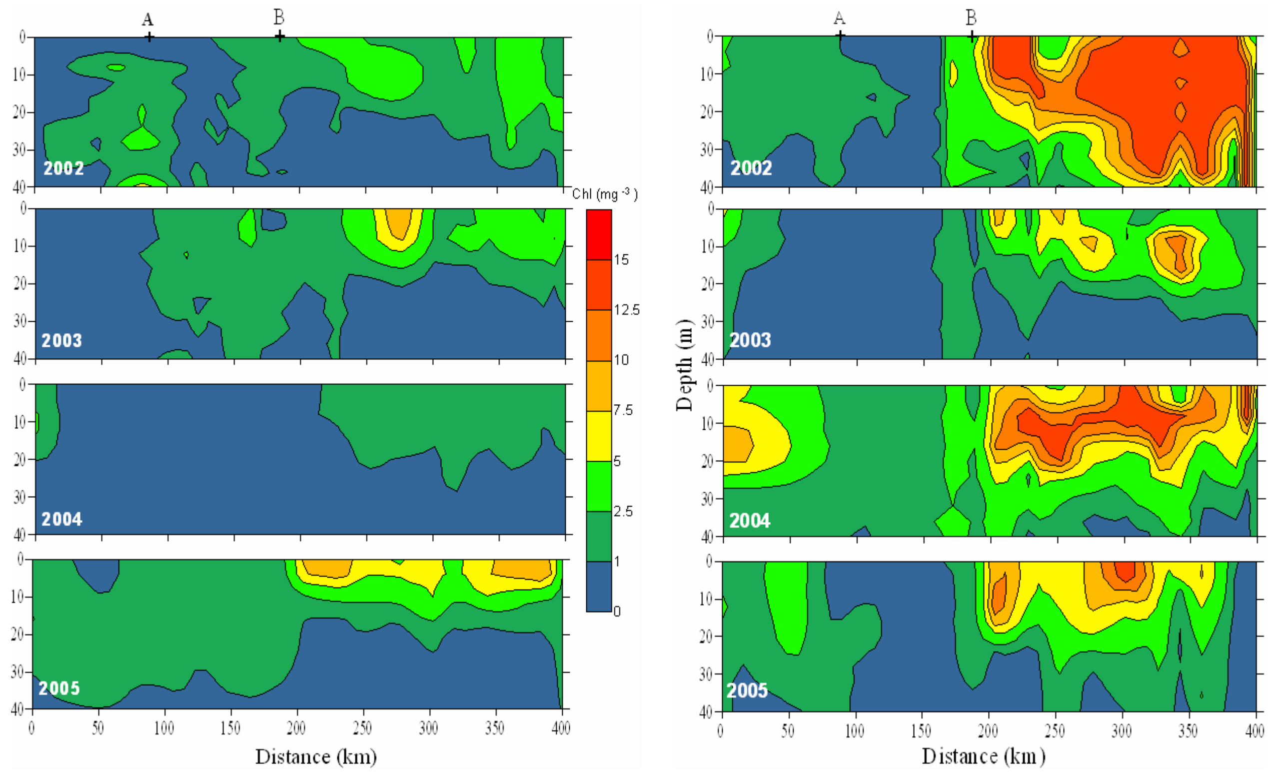


Figure 70. Vertical section of chlorophyll (mg m^{-3}) along a transect from the mouth of the Juan de Fuca Strait (left side of each panel) to the north end of the Strait of Georgia (right side of each panel). The left panel shows average conditions in April 2002 to 2005. Right panel represents average September conditions of 2002 to 2005. The location of the Victoria sill (A) and Boundary Pass (B) are noted for reference.

Collapse of *Neocalanus plumchrus* population in Strait of Georgia

John Dower, Akash Sastri and Rana El-Sabaawi, University of Victoria

As part of the Strait of Georgia Ecosystem Modeling (STRATOGEM - a joint UBC-UVic project, funded by NSERC) we have been monitoring the mesozooplankton community in the Strait since 2002. During the course of analyzing our data, we discovered that the *Neocalanus plumchrus* population in the Strait appears to have crashed during 2005. *Neocalanus plumchrus* (*Neocalanus*, hereafter) is the dominant copepod in the Strait during the spring, and has long been touted as a key prey item for many fish species, including juvenile salmon.

The figure below shows biomass and abundance time-series for the four dominant calanoid copepod species collected in the Strait during STRATOGEM.

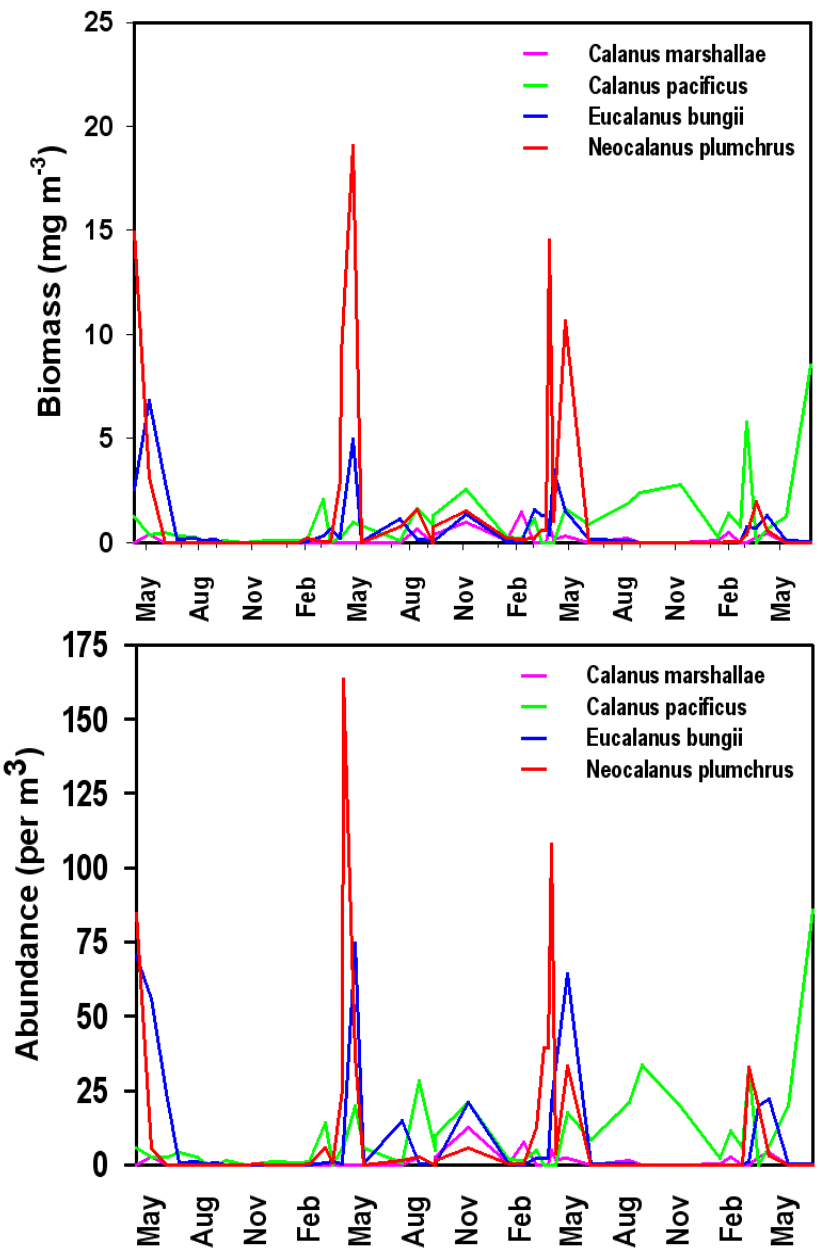


Figure 71: Biomass and abundance of the four dominant calanoid copepod species in the upper 100m of the water column during the STRATOGEM project. Integrated samples covering the entire 400m water column show the same overall trend.

Although quite variable from year to year, *Neocalanus* biomass during 2002-2004 fit within the range of historical observations of this population. However, *Neocalanus* biomass in 2005 was less than half that usually observed. Similarly, whereas the areal abundance of *Neocalanus* (i.e. integrated vertically from 0-400m) has historically been of order 10^4 individuals m^{-2} in the Strait, observations from September and December of 2005 revealed fewer than 100 individuals m^{-2}.

The cause of this collapse is unclear, and we are tracking the population to see if it recovers in 2006. Additional data collected by University of Victoria scientists in the summers of 2003 to 2005 suggests that (i) juvenile *Neocalanus* were growing much slower than usual in 2005, and (ii) they also had extremely low levels of DHA, a fatty acid required for both growth and reproduction. Thus, any surviving *Neocalanus* may not only be limited by low numbers, but also by the inability to reproduce efficiently during the winter of 2006.

Links: UBC and University of Victoria Research in the Strait of Georgia

Herring in the Strait of Georgia

Jake Schweigert, Fisheries and Oceans Canada

Herring survival conditions and recruitment have been unusually good in the Strait of Georgia for the last decade. Abundance of herring reached an historical high in 2003 in excess of 150 000 mt, exceeding the previous high in 1955. Recent surveys of juvenile herring abundance in the Strait of Georgia indicated that 2002 and 2003 should be average year-classes that will result in declining abundance over the next few years. Nevertheless, the recent strong recruitment should maintain the stock at a healthy level in the short term.

The Pacific herring stock in the Strait of Georgia migrates inshore in the fall from the west coast of Vancouver Island 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. 72 exceeding the historical high of 1955. Recruitment to this stock has been very strong with 6 of the last 10 year-classes being average or better (Fig. 73). 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. Recent surveys of juvenile herring abundance within the Strait of Georgia suggest that the 2001 and 2003 year-classes corresponding to the 2004 and 2005 recruitments should be ‘good’ but the latter is only average. Initial indications are that the recruitments for the next couple of years may also be weaker. Nevertheless, the recent strong recruitments should maintain the stock at a healthy level for the next few years.

Interpretation and Speculative forecast

The abundance of herring in 2005 is slightly reduced from the historical high of more than 150,000 tonnes in 2003. Current abundance is well above the lowest abundance estimated in 1968 (11,000 tonnes) in the time series from 1951-2005. The abundance of this stock has been increasing steadily since the recent low of the mid-1980s. Fall surveys of juvenile herring suggest the trend of recent strong recruitment appears to be ending and weaker recruitment and reduced abundance are expected over the next several years.

Graphs of the long-term changes in **herring** biomass and numbers of recruits are presented on the next page.

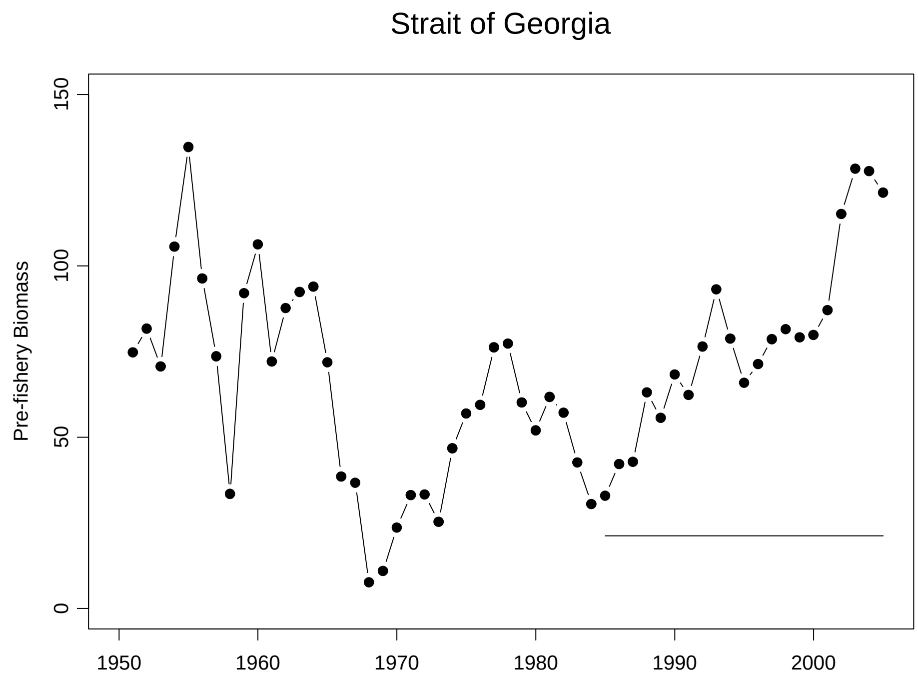


Figure 72. Strait of Georgia herring abundance. Horizontal line is the recommended fishing threshold for this stock.

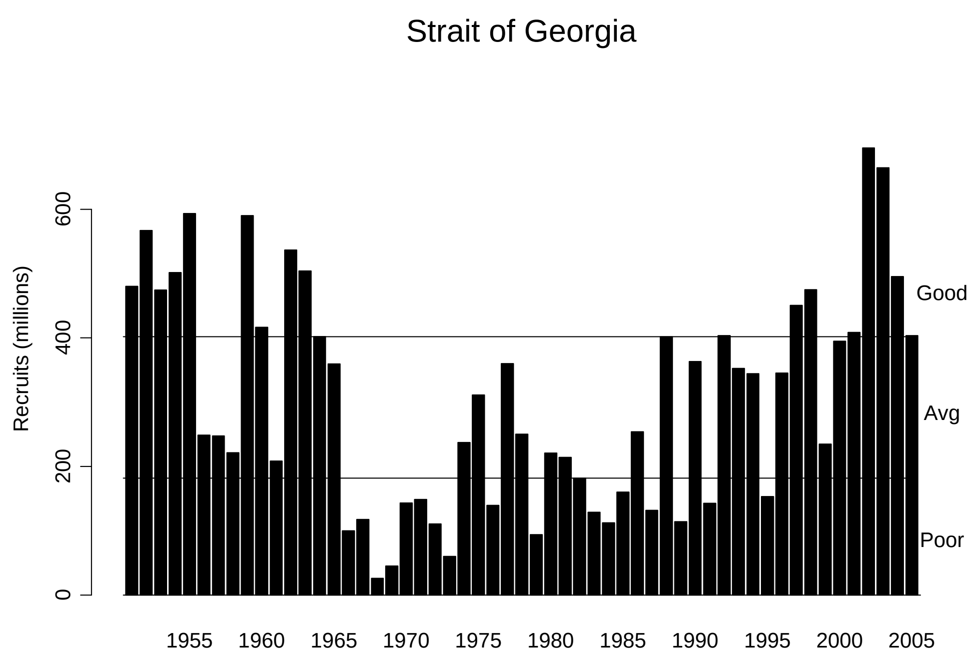


Figure 73. Interannual variability and decadal trends in recruitment to the Strait of Georgia stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 6 of the last 10 year-classes have been 'good'.

Pacific salmon and the Strait of Georgia

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

We report exceptional changes in the trends of juvenile Pacific salmon production in 2005 in the Strait of Georgia, which are related to climate. Because the scale of change is decadal, the next regime shift could occur as early as the fall of 2007. If this were to happen, ecosystem changes could occur in the Strait of Georgia by about 2009.

The total catch of all Pacific salmon by all countries is near historic high levels of abundance (Figure 74). The highest catches occurred in 1995 and the second highest catches occurred in 2003. However, the situation in the Strait of Georgia differs because while pink, chum and sockeye stocks are healthy, coho and Chinook stocks are not.

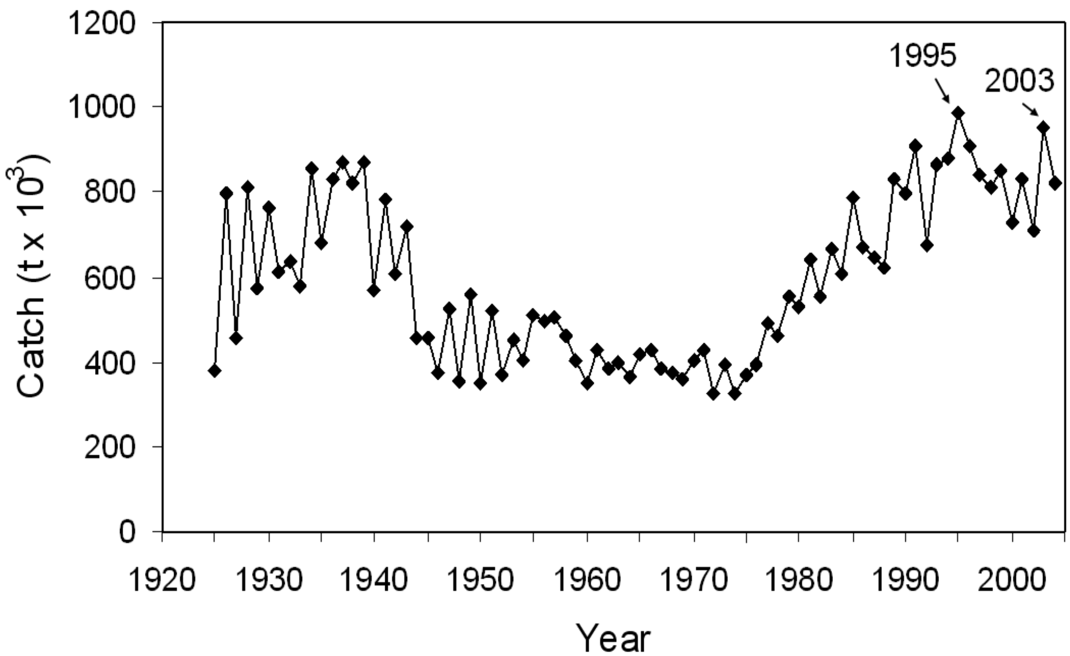


Figure 74. All nation catch of Pacific salmon 1925-2004.

In the Strait of Georgia in July 2005 we had the lowest catch per unit effort (CPUE) of juvenile coho salmon since our surveys started in 1997 (Figure 75). However, we also had the largest CPUE of juvenile chum salmon. We interpret these results to indicate that the plankton production in the Strait of Georgia in 2005 was early and benefited chum salmon that generally enter the Strait of Georgia earlier than coho salmon. Most coho salmon in the Strait of Georgia are produced in hatcheries (Sweeting et al. 2003) and their release is controlled, occurring between May 1 and May 31. It is possible that there was a general collapse of the production of prey for juvenile coho and chinook salmon. The poor survival will likely result in poor returns of coho salmon in 2006 and chinook salmon in subsequent years. There is a good relationship between the CPUE of coho salmon in our surveys and marine survival (Figure 76A, Simpson et al. 2003) that suggests a survival rate of around 0.5% in 2005. However, the few coho salmon that were captured were large, which is inconsistent with another relationship suggesting that larger fish are usually associated with higher CPUE's (Figure 77). Despite this inconsistency, we speculate that marine survival of coho salmon that will be observed in 2006 could be poor.

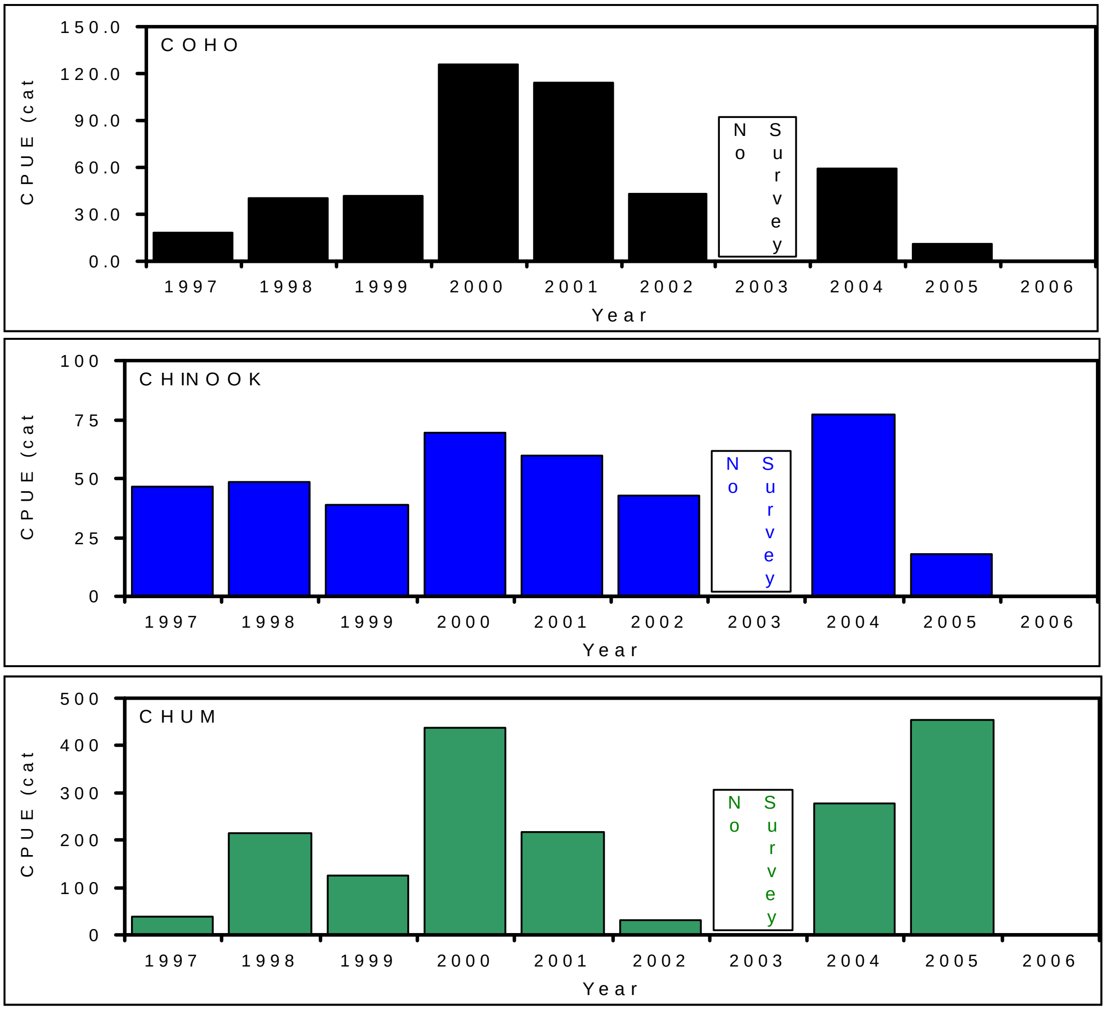


Figure 75. Catch per unit effort (CPUE) of juvenile coho, chinook and chum salmon in the Strait of Georgia in July 1997 to 2005.

The declining survey CPUE of coho and chinook salmon in the Strait of Georgia in 2005 was associated with increasing CPUE of pink and chum salmon. Thus, the Strait of Georgia remained productive for Pacific salmon in 2005, but the dominant groups of salmon shifted from coho and chinook to pink and chum. Other recent changes include a reduction in survey CPUE of coho in the northern Strait of Georgia. This change appears to be associated with a warming of the northern part of the strait.

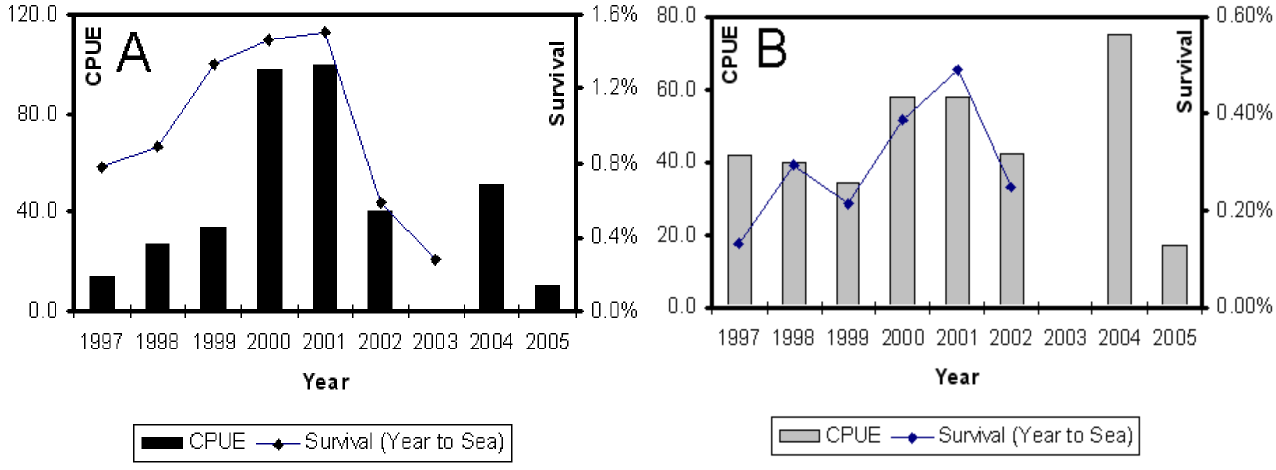


Figure 76. Catch per unit effort (CPUE) and marine survival of (A) coho and (B) chinook salmon in the Strait of Georgia for years-to-sea 1997 to 2005.

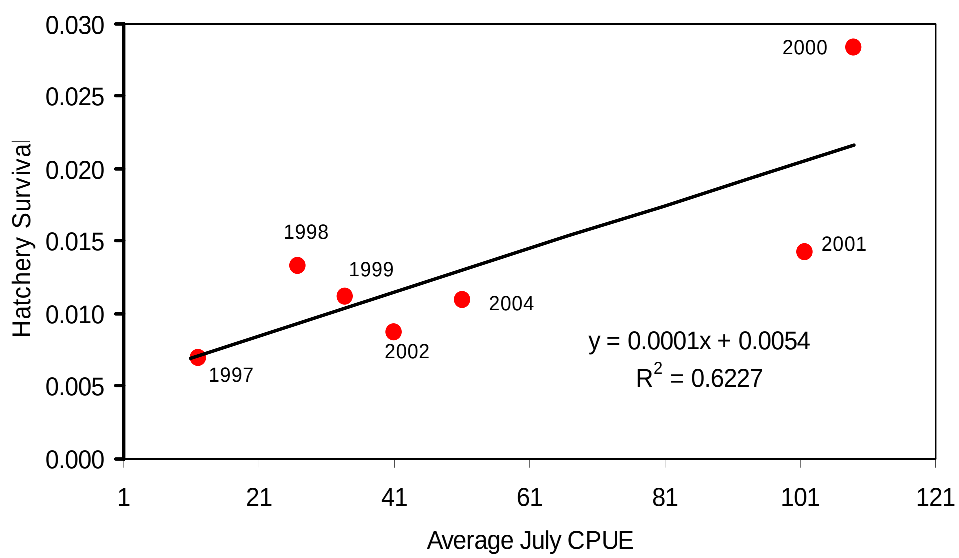


Figure 77. Correlation between hatchery survival of coho salmon, and the average catch per unit effort (CPUE) in July for years between 1997 and 2004. (No observations available for 2003)

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Additional Sources of Information

On-Line access to this report: Ocean Status Reports

Environment Canada. 2006. Climate trends and variations bulletin. Temperature and precipitation in historical perspective. Annual 2005. Available at: http://www.msc-smc.ec.gc.ca/ccrm/bulletin/

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