2002 Pacific Region State of the Ocean

Background

This report documents the state of the ocean for the year 2002. The physical, chemical and biological state of the marine environment impacts the yield (growth, reproduction, survival, distribution) of marine organisms as well as the operations of the fishing industry. Changes in the state of the ocean may contribute directly to variations in resource yield, reproductive potential, catch success, year-class strength, recruitment, and spawning biomass, as well as influence the perceived health of the ecosystem and the efficiency and profitability of the fishing industry.

Because of the importance of environmental changes to marine resources, extensive physical, chemical and biological data are collected during research vessel surveys. These data are augmented by time series measurements from coastal lightstations, moored subsurface current meters, coastal tide gauge stations, and moored meteorological (weather) buoys. Additional information is provided by satellite remote sensing (thermal imagery, chlorophyll, and sea level heights), by observations from ships-of-opportunity and fishing vessels, and by satellite-tracked drifting buoys.

Vessel survey data, tide gauge records, moored surface meteorological observations and drifting buoy data are edited prior to transmission to Canada's Marine Environmental Data Service (MEDS) for archival in the national database. A working copy of the database is maintained at the Institute of Ocean Sciences in Sidney, British Columbia along with current meter, lighthouse and zooplankton data.

Executive Summary

Oceanographic and meteorological conditions for the northeast Pacific and coastal British Columbia in 2002 indicated weak El Niño conditions occurred in the second half of the year. This event was mainly evident at the equator from about September 2002 through January 2003. Associated with the event were anomalously warm SST conditions and anomalous downwelling favourable cyclonic winds in the Gulf of Alaska from October 2002 and into January 2003. This is a change from moderate La Niña conditions recorded in 2000 and 2001. However, ENSO cycles are only one mode of variability that affects ecosystem dynamics. Decadal-scale variability in regimes are increasingly being recognized as causing sudden shifts in marine production trends, especially for Pacific salmon. Even longer modes (70-90 years) of variability may be important for longer-lived species.

In general, there has been a continuation of some of the changes that were described in last year's report. Length of day measurements continue to decrease, the sea surface height index remains unchanged and the Aleutian Low Pressure index became more intense, indicating a continuation of present regime conditions.

However, values for the Southern Oscillation index and the Pacific Decadal Oscillation index indicate a low to moderate El Niño late in 2002. The effects of this event were restricted to areas near the equator The changes detected in large-scale climate indices correspond to generally improved productivity for a number of species. For example, increased growth of juvenile coho was recorded from the west coast of Vancouver Island, and overwintering stocks of chum, pink and sockeye juveniles were captured in surveys off the west coast of Vancouver Island, which had not been captured in 2000 or 2001 surveys. Strait of Georgia herring abundance rivalled the maximum attained in 1955, and ocean conditions in the Hecate Strait area appear to be favourable to improved Pacific cod recruitment. The impact for longer lived species remains to be determined, however there are initial indications that a number of groundfish species may be experiencing improved year class strength since 1999.

Oceanographic data from the Gulf of Alaska revealed dramatic changes in salinity and temperature conditions, resulting in sustained cooler, less saline waters. Coupled with below average storm activity through the winter, the surface mixing layer was the shallowest on record by the end of 2002. This may have consequences for productivity in the Gulf of Alaska in the coming year.

Table of Contents

Background 1
Executive Summary 1
Summary by Region 4
Climate 4
Gulf of Alaska 4
West Coast of Vancouver Island 4
North Coast 7
Strait of Georgia 8
Climate Indices 9
Introduction 9
Global Air Temperature 9
El Niño Impacts 9
Southern Oscillation 12
Pacific Decadal Oscillation 12
Sea Surface Height 13
Arctic Oscillation 15
Aleutian Low Pressure 15
Length of Day 16
Gulf of Alaska 17
Physical Conditions 17
Temperature at 10 metres and 100 metres depth 20
Zooplankton 22
West Coast of Vancouver Island 23
West Coast Lighthouse Data 26
Upwelling Indices 27
Water Level 28
Southwest Vancouver Island Continental Slope (La Perouse Region) 28
Zooplankton 29
Status of euphausiid populations and implications for fish production along the southwest coast of Vancouver Island 32
Herring 35
Growth & Energetic Status of Pacific Salmon 36
Seabird Reproductive Performance on Triangle Island 39
Triangle Island Background and Species Natural History 39
Timing of breeding 40
Fledgling production 40
North Coast 41
Average temperature and salinity 41
Winter sea level and temperature 41
Set-up of eddies along the continental margin 41
Long-term sea level change 43
Incorporating an environmental index in the assessment of Pacific Cod 44
Herring in Hecate Strait 44
Strait of Georgia 46
Fraser River 46
Temperature and salinity 48
Salmon 48
Fishery Interpretation and Speculative Results 51
West Coast Vancouver Island 52
North Coast Major 52
Strait of Georgia 53
Contributors 53
References 54
Correct citation for this publication: 54

Summary by Region

Climate

- Climate/ocean conditions that shifted in 1998/1999 continued to remain in the new state, supporting the hypothesis of a regime shift in those years.

- Southern Oscillation Index values for 2002 appear to indicate that a low to moderate El Niño was building in the last half of 2002.

- Mean global air temperatures in 2002 surpassed 2001 as the second warmest on record next to 1998. Sea surface temperatures were warmer than average along the coast, and cooler than average in the central North Pacific, characteristic of a positive Pacific Decadal Oscillation (PDO). The PDO changed from weakly negative or neutral in January, to strongly positive by November 2002. Data from 2002 indicate that the cool phase of the PDO that was recorded in the last two years may be coming to an end.

- A sea surface height index (SSH) is presented in which the 1998 shift is evident. The 1998 shift is associated with an apparent return of the north Pacific to a pre-1976/1977 state; i.e. a return to the cold phase of the PDO. The SSH based index indicates these changes persisted in 2002, even though the PDO index changed sign late in 2002.

- The Aleutian Low Pressure Index measured extremely intense Aleutian Low pressure value in 1998, and moderate intensity was measured from 1999 to 2001. In 2002, the index returned to an extremely high value, indicating a strong Aleutian Low. Intense Aleutian Lows are associated with increased upwelling and increased productivity.

- Length of day measurements continue to decrease, representing a "speeding up" of the Earth's rotational speed, which indicates a continuation of the present regime conditions.

Gulf of Alaska

- In 2002, the Gulf of Alaska developed anomalous conditions during the spring and summer, which persisted into 2003. The temperature/salinity relationship values collected in June 2002 were well outside the range of values for previous years. The subsurface waters along Line P were generally colder and less saline than previously recorded.

- Surface warming was similar to that seen during and immediately after the 1997/1998 El Niño event. However, the timing of this warming, and the low to moderate intensity of the 2002/2003 El Niño event indicate that the anomalous conditions recorded in the Gulf of Alaska in 2002 were not the result of El Niño forcing.

- These conditions resulted in a very stable upper ocean. In addition, fewer storm events occurred in the winter, resulting in shallower mixing and a very shallow mid-winter surface layer. This could limit nutrients such as nitrate, silicate or iron, and have an impact on Gulf of Alaska ecosystems during 2003.

West Coast of Vancouver Island

- In 2002, sea surface temperatures cooler than the 1990 – 1996 average monthly mean were recorded along the coast, while sea surface temperatures warmer than the

1990 – 1996 average monthly mean were recorded in the central North Pacific, characteristic of a positive Pacific Decadal Oscillation index (PDO). However, the PDO changed from weakly negative or neutral in January 2002, to strongly positive by November 2002.

- Moderately strong periods of upwelling favourable winds were recorded for most of the year, with the exception of a few days of downwelling favourable winds recorded in early spring (January-February) and winter (November-December).

- Upwelling favourable winds of 2002 were stronger than those for most years of the last decade.

- Wave heights were typically higher than the 1994-2000 average monthly mean until spring, when they returned to near average. October was an exception, as low wave heights were recorded all month.

- In general, sea surface salinity was near or above the 1990-1996 average monthly mean for the west coast of Vancouver Island.

- Sea surface salinity at Kains Island was near the 1990-1996 average monthly mean in January – February, and greater than the 1990-1996 average monthly mean for the rest of the year. One exception was recorded in November; a 5-7 psu negative spike, following the onset of strong upwelling winds.

- Sea surface salinity at Amphitrite was near the 1990-1996 average monthly mean from January to February, and above the 1990-1996 average monthly mean for the rest of the year. Again, November was the exception, as salinities strongly below the 1990-1996 average monthly mean were recorded.
- The above 1990-1996 average monthly mean periods of sea surface salinity were comparable to those in the late 1970s, mid 1960s and early 1950s.

- Upwelling was strong in the spring, and near the 1990-1996 average monthly mean along the coast in the summer. Upwelling for the west coast of Vancouver Island and northwest Washington in 2002 was near the 1990-1996 average monthly mean, with the strongest upwelling in April, coincident with the occurrence of northeasterly (upwelling favourable) winds. Exceptions were recorded in early spring and winter as strong periods of downwelling occurred, coincident with downwelling favourable winds.

- Water levels were 10-20 cm lower than the 1990-1996 average monthly mean from January to May, then near the 1990-1996 average monthly mean for the remainder of the year. Two episodes of 2-3 weeks each in November and December occurred where water levels were 20 – 40 cm above the 1990-1996 average monthly mean due to storm activity. Water levels were comparable with those recorded during the 1998 – 1999 La Niña.

- Subsurface temperatures at 35m, 100m, 175m and 400m depth were below the 1990-1996 average monthly mean.

- Alongshore current velocity over the continental slope was poleward and near the 1990-1996 average monthly mean magnitude during most of the winter and spring. A reversal occurred for about 1 week in January, then the current remained below average velocity for most of February.

- Current flow direction changed to mainly equatorward during March – April, then became more strongly equatorward in May – September.

- Alongshore current measured near Amphitrite was as strong southward in spring and summer as has ever been recorded.

- In the spring, temperature at 100m dropped to equal the temperature at 175m, due to strong upwelling. This type of temperature drop has not been recorded since 1991.

- As described last year, the trend of zooplankton assemblages has been to return to baseline (near 0 anomaly) abundances and taxa since 1999, following a trend of more southerly copepod taxa dominating the 1990s. An anomalous increase in Pteropods since 1999 is the only exception recorded. This trend is evident from data collected from north and south Vancouver Island. However, the shift to southerly fauna, and the reversal of this trend, was not as pronounced in data from north Vancouver Island as it was in data from south Vancouver Island.

- Euphausiid biomass has been in a recovery phase since 1999, following a 66% reduction from high levels recorded in 1991 – 1992. Euphausiid biomass appears to still be recovering, but is not at the levels recorded during 1991 – 1992. Euphausiid biomass has been linked to the biology of important fish species such as herring, coho salmon, eulachon, and spiny dogfish.

- Herring recruitment off the west coast of Vancouver Island declined from 1977 to the late 1990s. Abundance in 2002 increased to near the average for the past two decades. 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) were more favourable for herring survival in 2000 and 2001, and may result in improved recruitment to the stock in 2003 and 2004.

- 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. However, in 2002 sardines did not appear in Canadian waters until late July, and were confined to coastal inlets along Vancouver Island and the central coast. A limited trawl survey off Vancouver Island in 2002 suggest fewer sardines were present than in the warmer water conditions of 1997 – 1999.

- Salmon growth surveys were initiated in 1998. Growth patterns in 1998 indicated juvenile coho salmon off the west coast of Vancouver Island experience poorer ocean conditions than those in northern British Columbia and southeast Alaska. After a change in ocean conditions in 1999 coho size was similar in northern and southern regions. The results in 2002 indicate juvenile coho had attained the largest sizes since the start of the survey in 1998, and improved salmon returns could be anticipated for 2003 and later. Improved growth of chinook, pink and sockeye in 1999 – 2001 was followed by an increase in the adult returns. In 2002 coho growth conditions exceeded all prior study years off the west coast of Vancouver Island. This may lead to larger returns of Strait of Georgia and Fraser River salmon in 2003.

- Marine survival rates are likely to be greater than what was recorded through the 1990s. 2003 February surveys indicated that juvenile pink, chum and sockeye had overwintered off the west coast of Vancouver Island, unlike 2001 and 2002, suggesting high returns of overwintering stocks may be expected. This may lead to increases in pink and coho adult abundances in 2003, followed by chinook and sockeye adult abundance increases in 2004, and chum in 2005.

North Coast

- As in 2000 and 2001, sea surface temperatures were cooler than those observed during most of the 1980s and 1990s. Except for the unusually warm El Niño winter of 1998 the past seven years were cooler than the average of 1981-1994, but warmer than the average found from the mid-1960 to mid-1970s. Again, 2002 mean sea surface temperatures at Bonilla were a few tenths of a degree higher than those at Langara, which follows the historical pattern.

- Surface salinities at Langara Island continue the long term decline that began in the early 1970s, while annual average salinity from 1998 to 2002 at Bonilla Island in Hecate Strait remains higher than the 1961-2000 average.

- Annual average sea level (adjusted for changes in atmospheric pressure) continued its decline following the El Niño highs of 1998 and was low enough to indicate reasonably good levels of Hecate Strait cod recruitment.

- As was described last year, offshore transport through coast eddies was low. The 1998 eddy was the largest ever observed, while eddies formed from 1999 to 2002 have been much smaller.

- A transport hypothesis was used to explain recruitment anomalies for the Pacific cod stock in the Hecate Strait area. High sea levels reflect high transport (currents), which remove larvae from Hecate Strait resulting in poor recruitment. Throughout the 1990s sea levels were considered high, and unfavourable for recruitment. Sea levels (transport) have decreased since 1998, and sea levels in 2002 were sufficiently low to indicate reasonably good levels of Hecate Strait cod recruitment.

- Exploitable herring biomass in the north coast area is an amalgamation of migratory stocks from the Queen Charlotte Islands, Prince Rupert area and Central Coast area. Recruitment in the Queen Charlotte Stock has been low for the past ten years, resulting in low abundance, while recruitment in the Prince Rupert and Central Coast stocks has been generally good, because of sporadic very strong year classes. Indications are that recent year classes in the Queen Charlotte Islands remain weak, while Prince Rupert and Central Coast stock year classes have been getting stronger. Abundance in the Queen Charlotte Island and Prince Rupert stocks are expected to remain similar to recent levels, while Central Coast stocks will likely decline slightly from levels seen in 2002.

Strait of Georgia

- Sea surface temperatures were slightly above the 1992-2000 average in 2002.

- Sea surface salinity remained higher than the 1992-2000 average for most of the year, except for July and August, due to the Fraser River freshet.

- Mean annual daily discharge of the Fraser River in 2002 (2909 m^3/s) was slightly higher than the 1915-2000 average (2720 m^3/s) due to higher than normal snow pack levels throughout its watershed. The freshet peaked in mid-June, following a trend from the last three years of a later freshet.

- Herring survival conditions and recruitment have been unusually good in the Strait of Georgia for the last decade. Abundance of herring reached a recent high in 2002 at well over 100 000 mt, which rivals the 1955 record high. Surveys of juvenile herring abundance in the Strait of Georgia for 2000 and 2001 indicate that 2003 and 2004 will be “good” year-classes, and the recent strong recruitment should maintain the stock at very healthy levels for the next few years.

- Juvenile salmon surveys indicate a continuation of the improved productivity seen in 2001. 2002 estimated abundances are near or slightly lower than 2001 abundances.

- 2002 juvenile salmon were less abundant and smaller than seen in 2000 and 2001, which indicates a potential for reduced marine survival for their respective brood years.

- An approximate 3 fold increase in river lamprey wounds was recorded for 2002 over 2001. River lamprey prey mainly on herring, therefore the near-record abundance of herring, and the lower abundance of sturgeon in the Strait of Georgia may result in larger abundances of lamprey.

- Survey cruises have recorded a progressive decline in species in catches in the Strait of Georgia over the past six years.

- In 2002 coho did not return to the Strait of Georgia in the numbers expected, despite good growth of juveniles. Coho possibly did not return because of low salinity, or those that did return in spring moved back out of the Strait of Georgia as salinity declined through the summer. It appears that the behaviour of coho leaving the Strait, first noted in the 1990s, is continuing.

Prepared by:

Fisheries Oceanography Working Group
G. A. McFarlane (Chair)

Climate Indices

Introduction

It is now generally accepted that patterns in fish abundance can be linked to patterns in climate-ocean conditions. These conditions can be relatively stable on decadal scales, but can shift abruptly from one state to another. A number of indices have been developed to monitor the climate-ocean state. In this section we present and discuss a number of these indices. Generally, a shift in the subarctic Pacific in 1998-1999 was captured by these indices and this new state continues through 2002.

Global Air Temperature

Global air temperature is an important index of the state of the global climate. Air temperature rose dramatically during the 1990s with 1997 and 1998 setting records for high temperature for sixteen consecutive months. Since 1998 the global temperature has moderated but still remains significantly above pre-1976 levels. Globally, 2002 has been the second warmest on record although southern Canada was a relatively cool (Fig. 1).

Coastal air temperatures remained near-normal in 2002 at B.C. locations as seen in Fig. 1. However, North America and Europe continued with temperatures significantly higher than the 1961 to 1990 average; the moderate conditions on the BC coast are not expected to persist. The continued warming of Alaska and northern Canada is evident in the anomalies exceeding 2°C. Fig. 2 shows that even though the global anomaly has decreased from the record levels of 1998, the warmer than normal conditions which characterized the 1990s have continued in 2002 with air temperatures over land areas more affected than those over the oceans.

El Niño Impacts

In 1999, La Niña brought some moderation of the upward trend in B.C. coastal sea temperatures, continuing with mild La Niña conditions throughout 2000 and early 2001, easing to neutral conditions for the rest of 2001. Throughout most of 2002, a moderate sized El Niño has prevailed in the tropical Pacific. Sea surface temperatures off the B. C. coast were normal for the first half of the year but rose to about 1ºC above normal starting in July and persisting into early 2003. By that time, the El Niño seemed to be ending, (see SOI Index on Fig. 3), although prediction skill is poor in late winter.

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

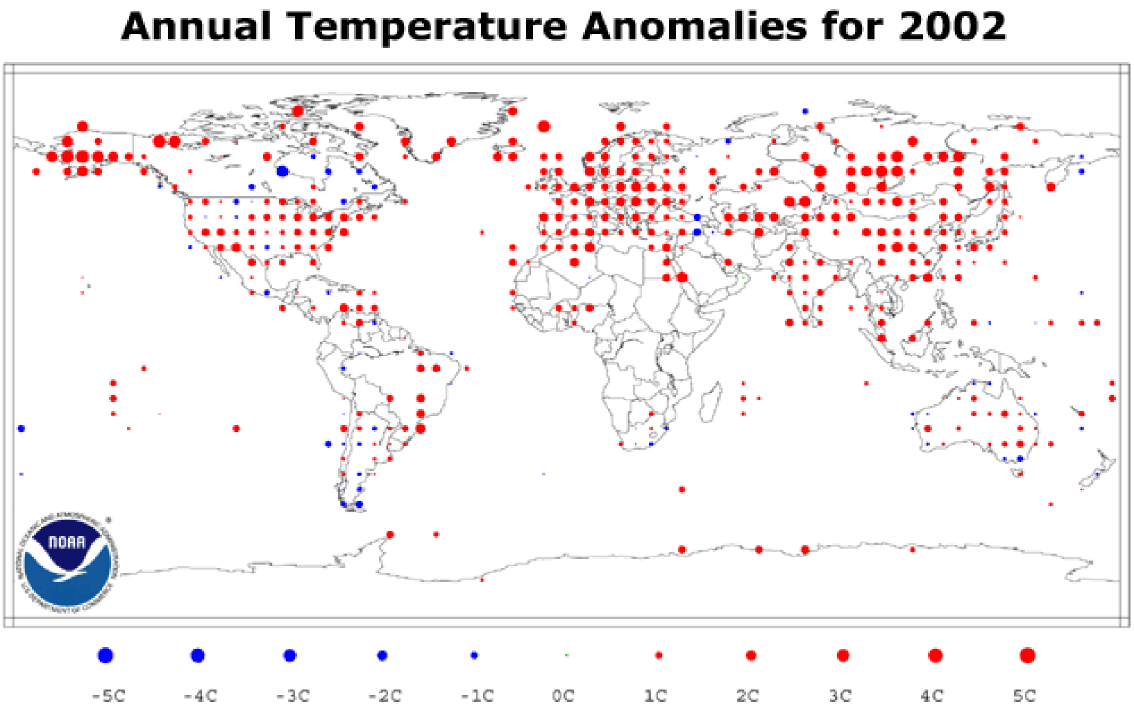

Figure 1. The distribution of year 2002 temperature anomalies relative to the 1960-1991 average, NOAA. Southern Canada temperatures were at or below normal, in contrast to other places around the globe which drove the average to the second-highest on record (see Fig. 2).

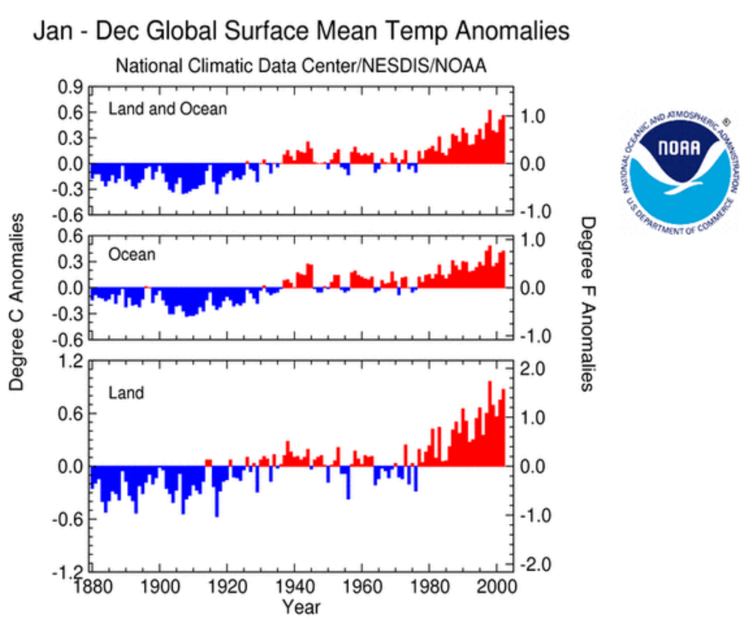

Figure 2. Time series of global temperatures.

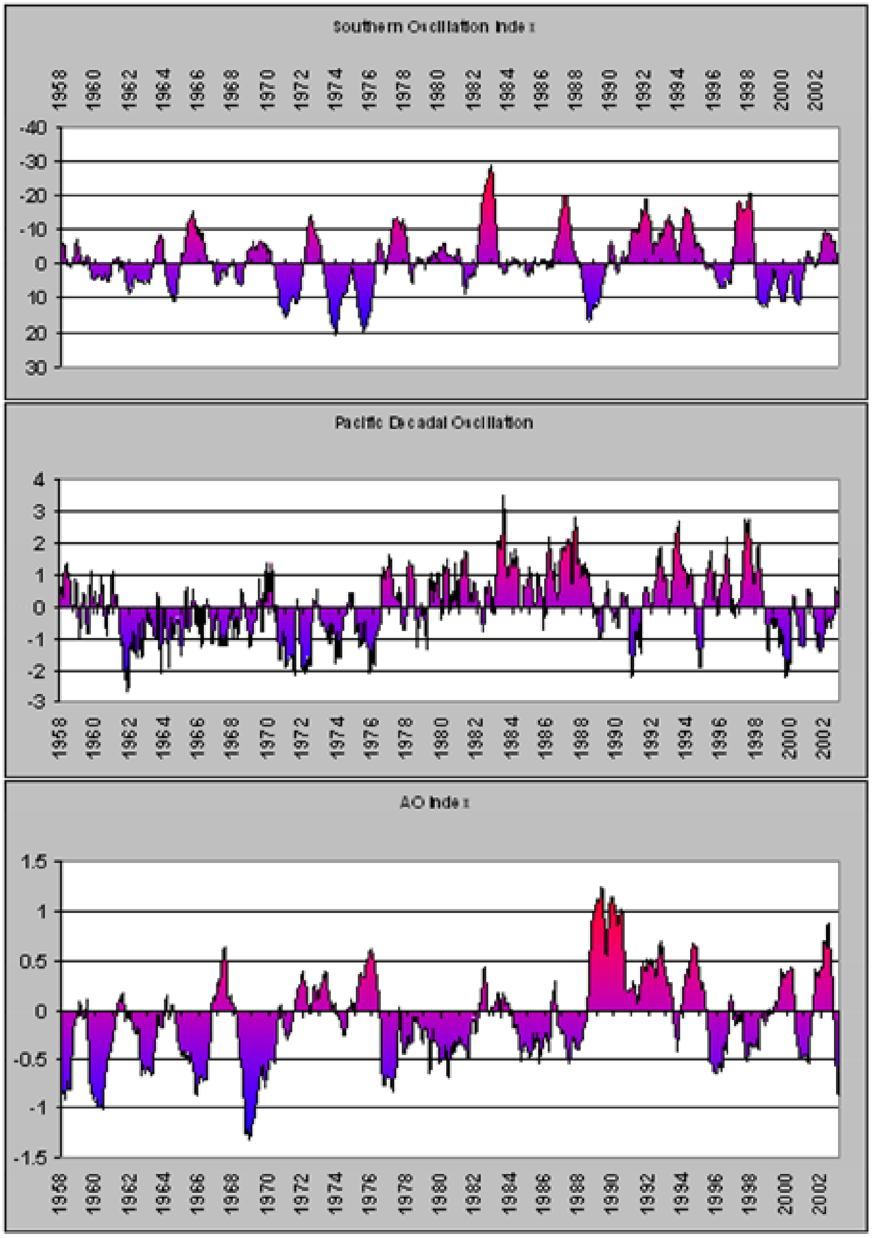

Figure 3. Variations in selected indices from 1958 to Feb. 2003. The scale in the top panel (SOI) was inverted to reflect warmer coastal conditions with negative index.

Southern Oscillation

The Southern Oscillation Index (SOI) (Fig. 3) indicates the occurrence of El Niño and La Niña events in the equatorial Pacific. El Niño events are generally associated with warm climatic conditions throughout the eastern north Pacific and North America as a whole. La Niña events have not received the same amount of attention as El Niño events, but they also represent anomalous climatic conditions that are generally cooler. The 1990s have been unprecedented with the frequency and persistence of El Niño events. This persistence was interrupted by the La Niña event of 1998/99 which has also turned out to be a persistent occurrence lasting through 2001. Consensus is that a moderate El Niño was building for the last half of 2002 but there is little predictive skill in the early stages. The last La Niña event occurred during the regime shift year of 1989.
http://www.bom.gov.au/climate/current/soihtm1.shtml

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) Index (Fig. 3) is a measure of the spatial variability in sea surface temperature throughout the North Pacific. It generally typifies 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. In 1977, the annual PDO switched from a negative phase to a positive phase. In 1999, the annual PDO returned to a negative phase which has persisted through 2001 and into 2002 with minor excursions in to positive numbers similar to the period before 1977. The patterns of wind and sea level pressure associated with the PDO are shown in Figure 4. At the end of 2002, the PDO returned to a positive phase.

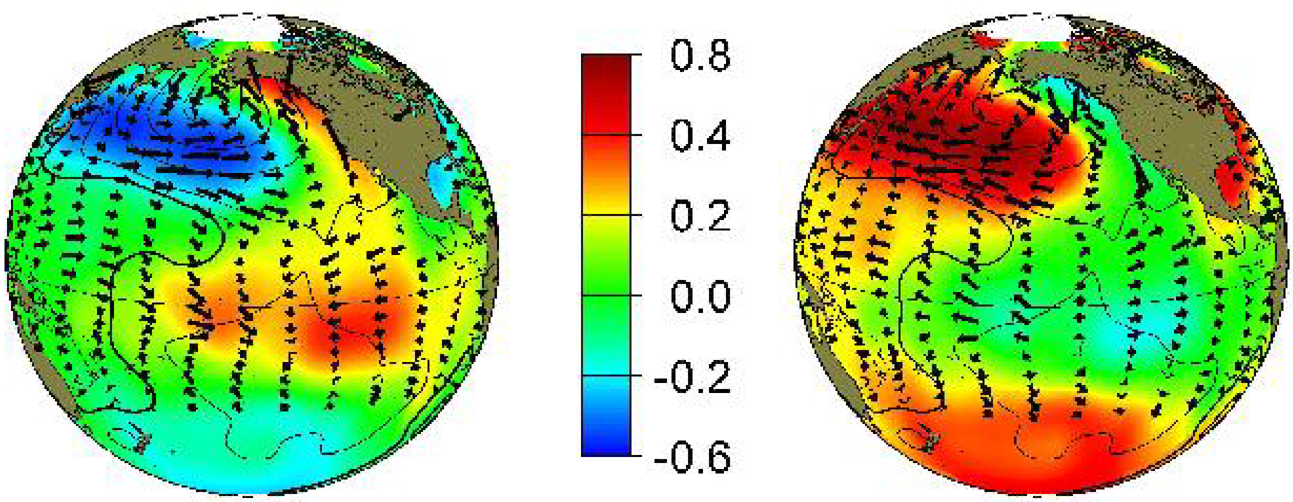

Figure 4. Typical wintertime sea surface temperature (colors), sea level pressure (contours) and surface wind stress (arrows) anomaly patterns during warm (left) and cool (right) phases of PDO.

Associated with El Niño conditions in 2002, and an increasing Pacific Decadal Oscillation Index, coastal British Columbia had above normal water temperatures in the second half of 2002. However, the PDO may not be the most reliable index of long-term changes of the upper ocean. The PDO timeseries encompasses variability on a range of time scales, and it includes relatively short period fluctuations. This is because the SST may respond to the atmosphere on relatively short time scales.

Sea Surface Height

An alternative to the PDO is presented based on observations of sea surface height (SSH), as monitored by satellite borne altimeters. Like the PDO, this index is defined as the time series associated with the leading mode from an EOF analysis of the SSH variability.

There is now 10 years of SSH data available from the Topex/Poseidon altimeter for this analysis. The index based on SSH is clearly related to the PDO, but has less high frequency variability (Fig. 5). The reason for this is that SSH is an integrated measure of the mass field of the upper ocean. This has greater "inertia" than the SST, and so is less subject to short term variability. Consequently, an index based on SSH is believed to be a more reliable indicator of the long-term persistent changes.

It is clear from the SSH index that a change occurred during 1998. This change is associated with an apparent return of the North Pacific to the pre-1976/77 state, i.e., a return to the cold phase of the PDO. The SSH based index indicates that these changes persisted through 2002, while the PDO index itself changed sign in 2002. As mentioned above, this variability in the PDO is an artifact of the high frequency variability retained by this index.

Fig. 5 shows the spatial pattern associated with these recent changes. The cold phase is associated with a change to lower sea level and cooler SST over a region extending about 1000 km from the coast. Further offshore, the changes are reversed with higher sea level and warmer SST following 1998. Given that the SSH index changes only slowly, it is likely that the North Pacific in 2003 will remain in the "cold phase" regime that has characterized the years since 1998.

These changes are further illustrated in Figure 6, which shows the difference in SST averaged over the period 1999-2001 relative to the average of 1993-1997. (Observations from 2002 were not included in this calculation, but it is not expected that their inclusion would lead to any qualitative changes.) Figure 6 provides clear evidence for the recent mean cooling that has occurred in the surface waters along the west coast of North America, along with evidence for the warming further offshore. These changes are consistent with the North Pacific returning to the cool phase of the PDO.

Note that the fraction of variance associated with this mode (23.2%) is deceptively low. This is because there is a great amount of small scale eddy variability with the south west portion of the region (where we find the Kuroshio Extension). Using a somewhat smaller region (with southwest corner at 30N, 180W) leaves the timeseries and spatial pattern essentially unchanged, but increases the fractional variance of the mode to about 50%.

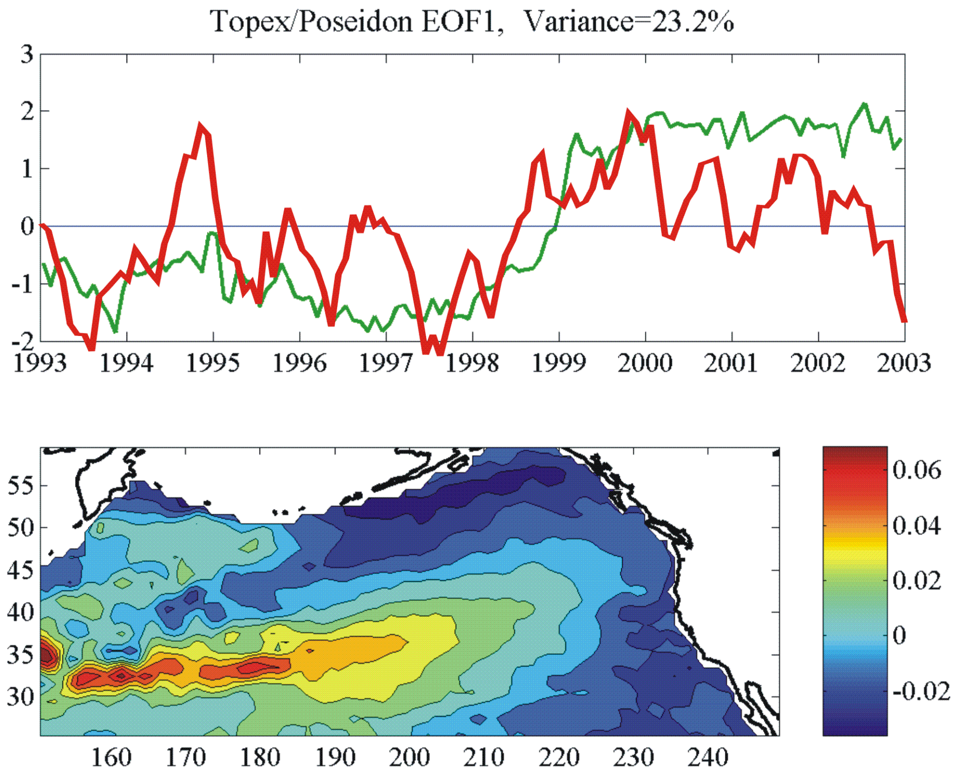

Figure 5. The upper panel shows the time series of the index of long term change based on SSH variability (green curve), along with the usual PDO index (red curve). The lower panel shows the spatial pattern associated with this SSH mode. Since 1998 the positive value of the index is associated with lower sea level near the North American continent and elevated sea level in the central Pacific. This corresponds to the cold phase of the PDO, with cooler sea surface temperature along North America and warm SST in the central Pacific.

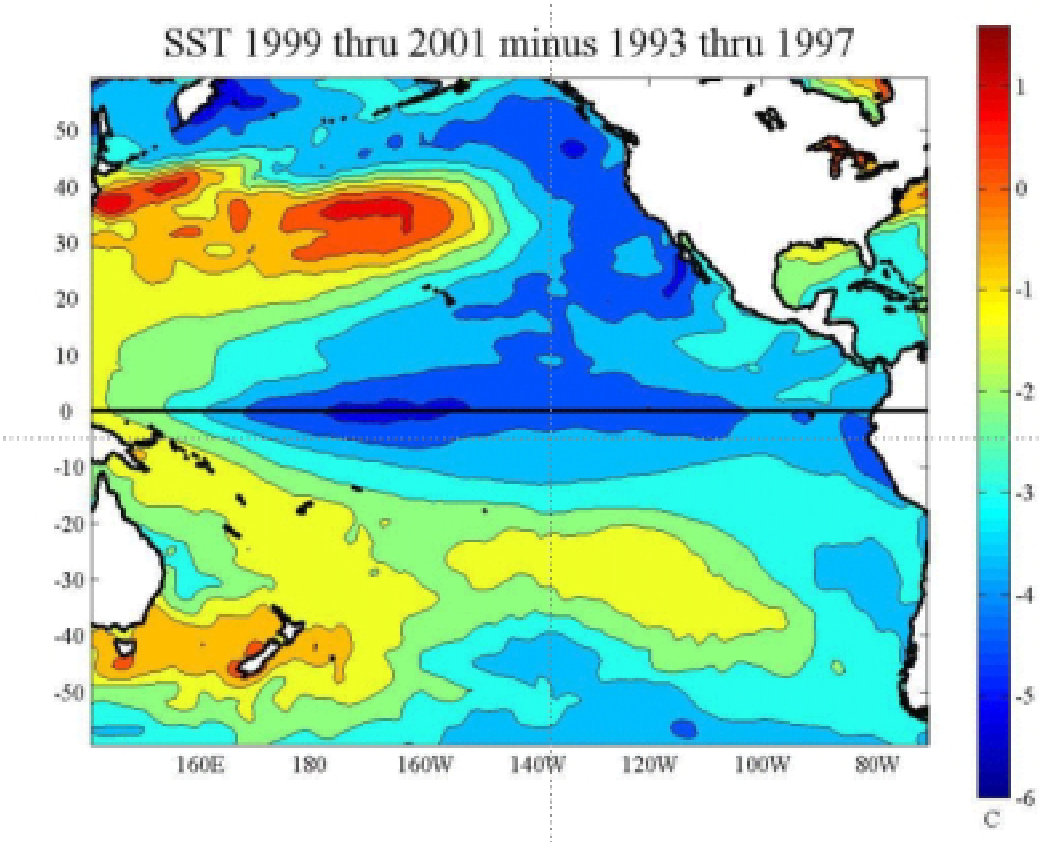

Figure 6. Contour map showing changes in sea surface temperature (SST) over the Pacific Ocean. Plotted is the difference in the average SST over the period 1999-2001 with the average over the period 1993-1997. A long term change to cooler SST along the west coast of North America is evident.

Arctic Oscillation

The Arctic Oscillation Index (AO Index, Figure 3) is the area weighted sea-level air pressure anomaly poleward of 20°N and, so, is related to both the PDO and the Atlantic Oscillation. Positive anomalies occur with the strengthening of the polar vortex which causes the deflection of storms to the south of the B.C. coast, while negative anomalies bring winter outbreaks of Arctic air into central North America. While the 2002 values for AO appear positive the overall pattern since 1996 suggests a continuing regime through to early 2003.

http://jisao.washington.edu/analyses0302/

Aleutian Low Pressure

The Aleutian Low atmospheric pressure system is a semi-permanent feature of the North Pacific whose relative intensity has been linked to patterns in marine productivity. Following the 1989 regime shift, the Aleutian Low exhibited a moderate intensity as measured by the Aleutian Low Pressure Index (ALPI, Figure 7). In 1998, the Aleutian Low was extremely intense. A return to moderate intensity was measured in 1999 and 2000 with a return to small positive values in 2001, (Figure 7). In 2002, the index returned to an extremely high value, indicating a strong Aleutian Low. This suggests a continuance of a regime initiated in 1998 that is characterized by a high degree of variability.

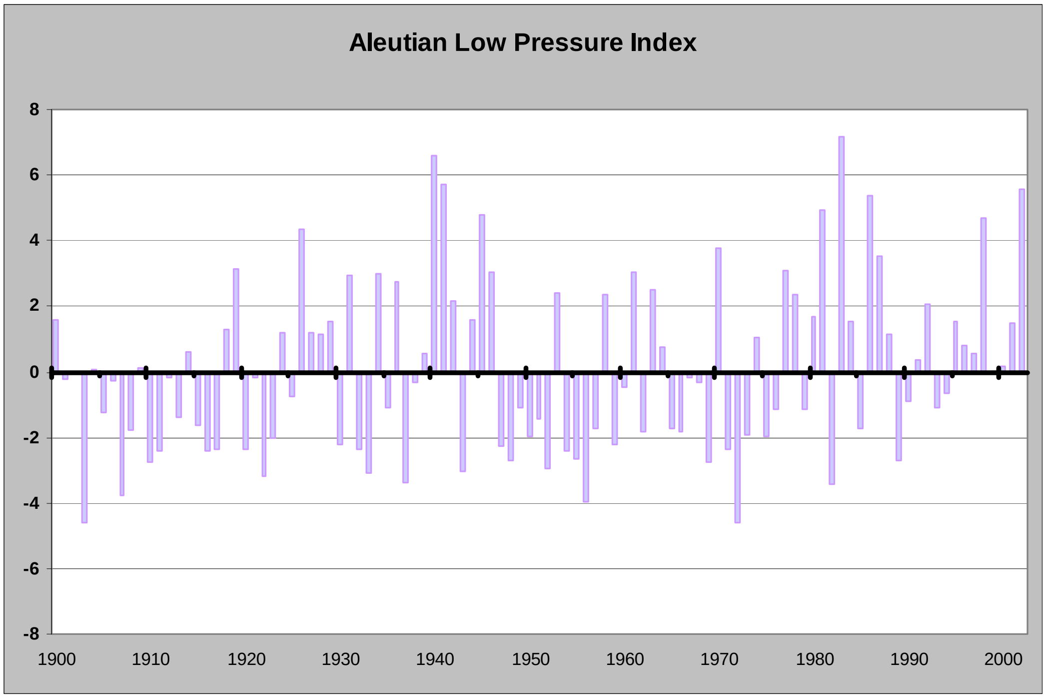

Figure 7. Aleutian Low Pressure Index.

http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx_alpi.htm

Length of Day

The Length of Day is a measure of the rotational speed of the solid earth. It is measured as the annual mean difference (milliseconds) between the astronomically derived and the atomically derived lengths of day. A period of decreasing Length of Day values represents a 'speeding up' of the Earth's rotational speed. The last such speeding up period preceded the 1977 regime shift by several years (Figure 8). A slowing down period preceded the 1989 regime shift by several years (Figure 8). The 1998 regime shift was preceded by a speeding up period (Figure 8). In 2002, the Length of Day continued to decrease indicating a continuation of the present regime conditions.

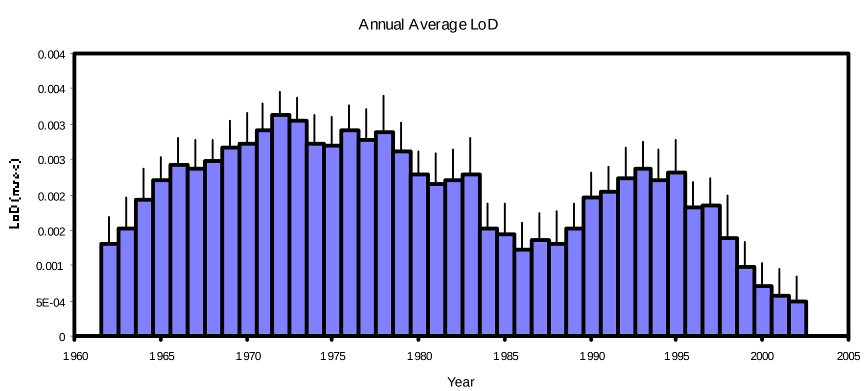

Figure 8. Length of Day Index.

http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx_lod.htm

Gulf of Alaska

Physical Conditions

The Gulf of Alaska developed extremely anomalous conditions during the spring and summer of 2002. These conditions persisted into 2003 and will likely have a significant impact on ecological conditions in the Gulf during 2003. Figure 9 outlines the locations of the sampling station comprising Line P, from which oceanographic data for the Gulf of Alaska is collected and compared, and the Newport Line, surveyed by scientists at Oregon State University, School of Oceanography. There data are presented in Figures 10 and 11.

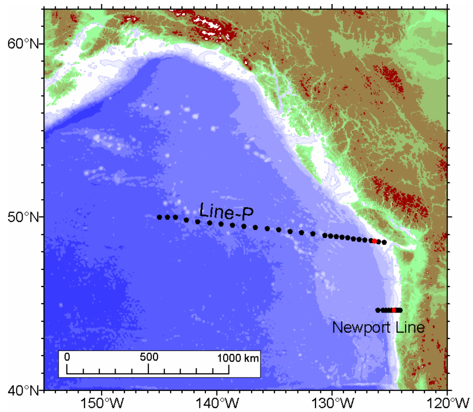

Figure 9. The locations of the Newport Line and Line-P, the red dots are stations NH-25 and MP-03 along those lines respectively.

The Newport Line does not have the long historical background that Line-P has, and does not extend far offshore, but has shown similar anomalies to those recorded for Line P in 2002. Figure 10 is a plot of the relationship between temperature and salinity at station NH-25 along the Newport Line, shown by the southern red dot on Figure 9. The black lines show the long term average relationship along with the ranges, and the coloured lines show the relationship for some recent years. In particular, the blue line shows the observed relationship in June 2002. Apparently, the relationship in 2002 lies entirely outside the envelope of all previous observations.

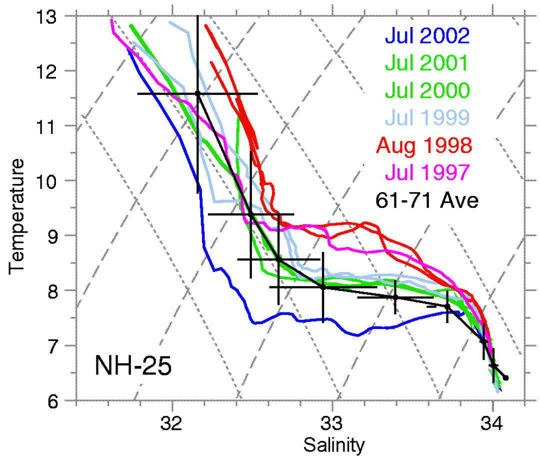

Figure 10. Observations of the temperature/salinity structure at station NH-25 along the Newport Line.

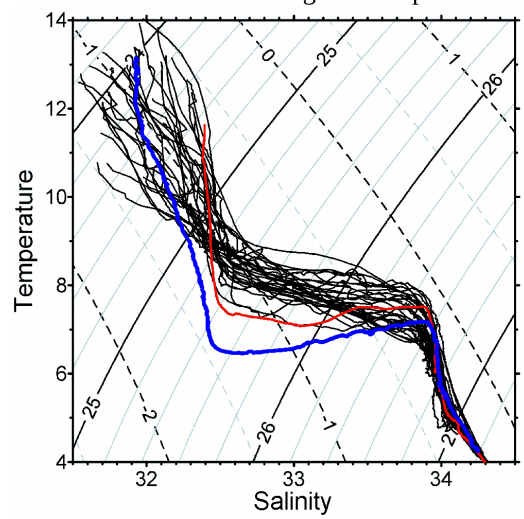

Figure 11. Observations of the temperature/salinity structure at station MP03 along Line-P.

Figure 11 is a plot of the relationship between temperature and salinity at station MP03. This shows that the same behaviour was recorded along Line-P. In Figure 11 the black lines are all previous CTD observations at this station in either June or July. The red line shows the relationship between temperature and salinity in June 2001 and the blue line shows data for June 2003. Again, properties of the waters along Line-P have changed dramatically and lie outside the envelope of all previous observations.

Figures 12 and 13 show the month-by-month evolution of the unusual climate anomaly mapped using the Argo array of floats in the

Gulf of Alaska. The Argo floats drift at a depth of 2000 metres, and every 10 days adjust their buoyancy so that they float to the sea surface, measure a profile of temperature and salinity on the way upwards and then report the data to a land station via the Service Argos satellite communication system. Fifteen nations are now deploying floats in support of the Argo project and all are making the data freely available to all users in near real time.

Figures 12 and 13 show that the cold and fresh water anomaly invaded the Gulf of Alaska very early in the year, and may actually have started very late in 2001. By the spring this subsurface anomaly, lying between depths of 70m and 120m, had become very intense.

Atmospheric signals responsible for contributing to the sub surface anomalies also created conditions conducive to extreme warming in the near surface layers. Though the sub-surface anomalies are completely outside of all previous experience, the surface anomalies are not. Larger surface temperature anomalies were seen during and immediately after the 1997/98 El Niño event.

Both the subsurface and the surface anomalies were quite extreme by mid-summer of 2002; however, the El Niño did not start until October 2002. The 2002/03 El Niño event was a small to moderate event that was unlikely to have influenced oceanographic conditions at this latitude. The pattern of anomalies continued to the end of 2002 though the plots in Figures 12 and 13 do suggest that the event is waning in strength.

The warm surface anomaly had the effect of creating a very stable cap on the waters of the Gulf of Alaska. Figure 14 illustrates the density difference at Ocean Station Papa (50°N and 145°W, the offshore end of Line-P, see Figure 9).

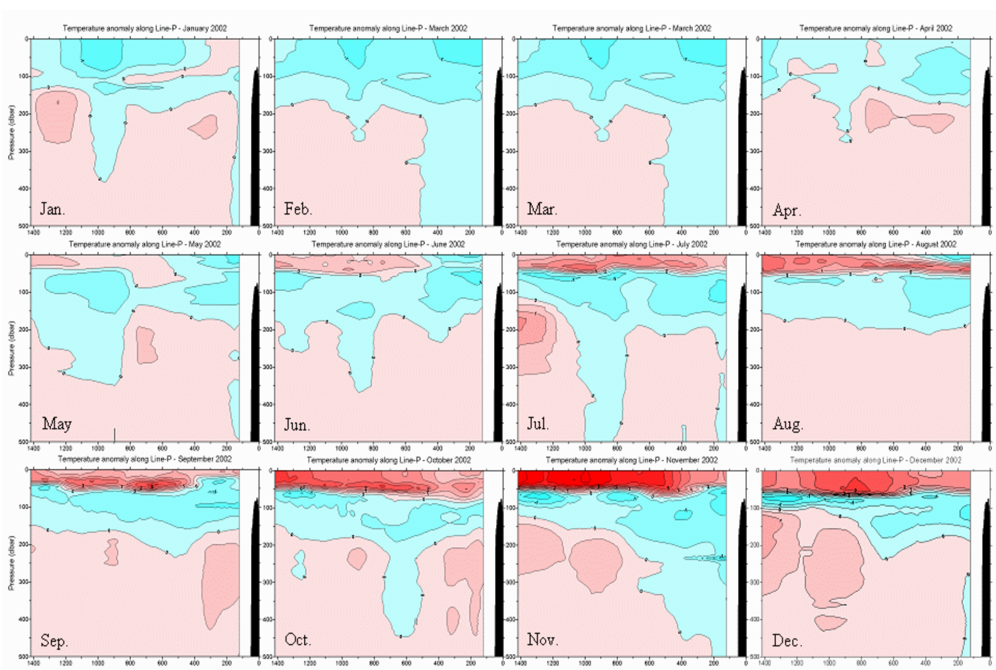

Figure 12. Temperature along Line-P mapped from the Argo array in the Gulf of Alaska minus the climatological average conditions along the line for that month.

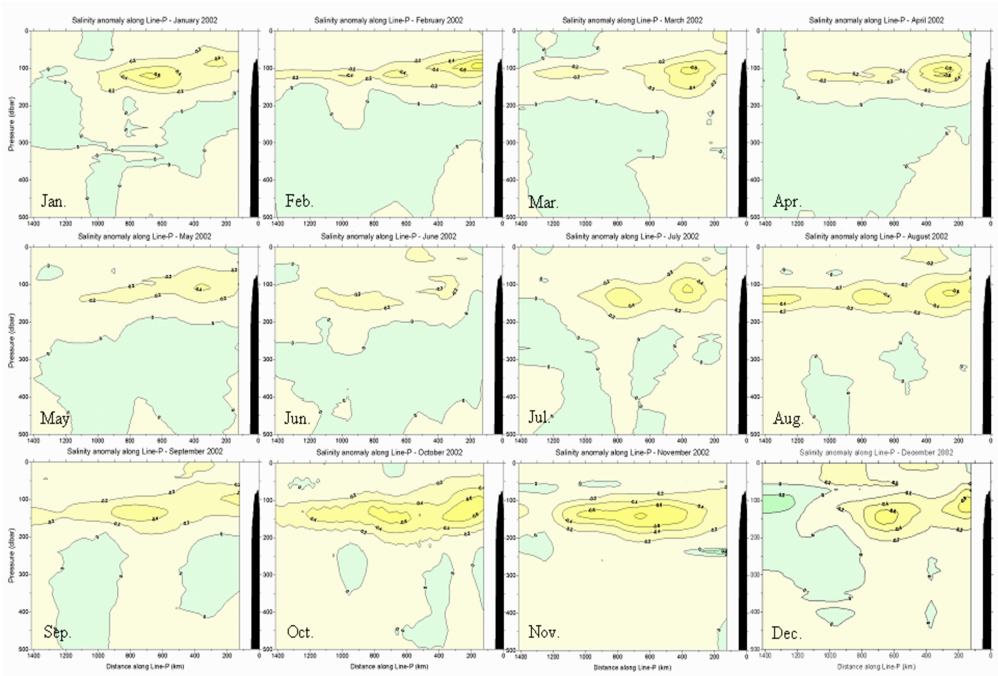

Figure 13. Salinity along Line-P mapped from the Argo array in the Gulf of Alaska minus the climatological average conditions along the line for that month.

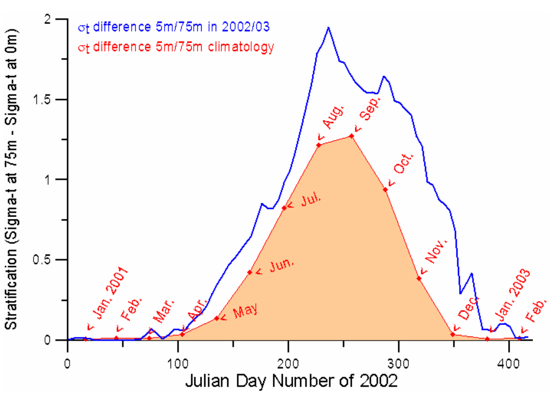

Figure 14. The density difference between surface water and water at a depth of 75 metres from January 2002 into early 2003.

In Figure 14 the brown area bounded by a red line indicates the density difference expected at Ocean Station Papa, based on the long-term climatology. The blue line is the difference as observed by interpolating nearby Argo data onto Line-P at 5-day intervals. The stratification of the upper water column exceeded the climatological profile for almost all of 2002. By mid-summer the difference had become very large, and during the winter storm period of November 2002 the background stratification was almost 3 times greater than normal. The stratification, by this measure, appeared to vanish in February 2003. Although the February 2003 The Line-P survey clearly indicates that there was considerable stratification slightly deeper than 75 metres.

The supply of nutrients to the upper water column is determined by how deeply mid-winter mixing penetrates into the deeper levels of the ocean. This includes the macro-nutrients such as nitrate and silicate as well as micro-nutrients such as iron. If there is high stratification in autumn, then the ocean has a particularly low potential energy. Storms generate turbulent kinetic energy and this energy ultimately is dissipated by mixing dense water upwards. As more energy is input by storms, the mixed layer deepens. Consequently, if the potential energy of the ocean is lower than normal in November then the same amount of energy input by winds will produce shallower winter mixing.

In 2002, there was a dramatically stable upper ocean by November, and warm surface waters displaced storm tracks northwards so that the energy input was unusually low. The result was an exceptionally shallow mid-winter surface layer as shown in Figure 15.

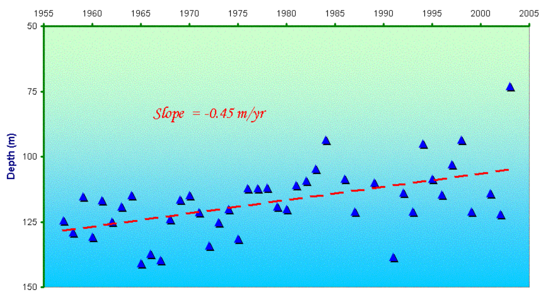

Figure 15. Winter mixed layer depth at Ocean Station Papa. In the early years this is an average over observations in Dec-Mar, in the later years (after about 1983) it is the single observation on the February survey.

The warming and freshening of the upper waters of the Gulf of Alaska is leading to shallower mixing in the Gulf of Alaska. Previously the shallowest mid-winter mixing occurred after the winter of 1997-98, and was the direct result of the biggest El Niño of the century. Moderate El Niño did occur during the winter of 2002/03, but, started after many of the impacts were recorded.

The mixing depth in February 2003 is about 75 metres. This is the shallowest on record; 3.5 standard deviations away from the regression line shown on Figure 15.

Mid-winter mixing was extremely low over a large part of the Gulf of Alaska, which may have reduced the supply of all nutrients to the photic zone. In most parts of the Gulf of Alaska there is an abundance of nitrate and reducing the supply would not have a major effect. However, parts of the Gulf of Alaska closer to the coast can become limiting in nitrate. Also, there are other nutrients, such as silicate, or micronutrients such as iron, which may be limiting already, and will have been further reduced. These effects may have an impact on the Gulf of Alaska ecosystems during 2003.

Temperature at 10 metres and 100 metres depth

Figure 16 shows maps of temperatures at 10 and 100 metres depth in summer. Neutral Summer Ocean Temperature maps were prepared from archived profiles of observed temperature during years with neither El Niño nor La Niña taking place in the tropical Pacific Ocean. 2002 Summer Ocean Temperature maps were prepared from observations taken between 21 June and 21 September 2002. Each data point contributing to the temperature contours is also plotted in the 2002 summer maps.

The maps below show the waters at 10 metres depth were a bit warmer in 2002 compared to a typical summer in the SE gulf, with too many regions of missing observations to determine differences elsewhere. The maps of temperature at 100 metres depth, plotted below, show significantly cooler-than-normal waters in the southeast gulf, as noted along Line-P and off Oregon earlier in this report. Some analysis of recent Argo profile observations suggest this cool water near 100-metre depth last had contact with the ocean surface the previous winter in the eastern Gulf of Alaska, west of the Queen Charlotte Islands, which indicates it formed there and slowly drifted southwards in spring.

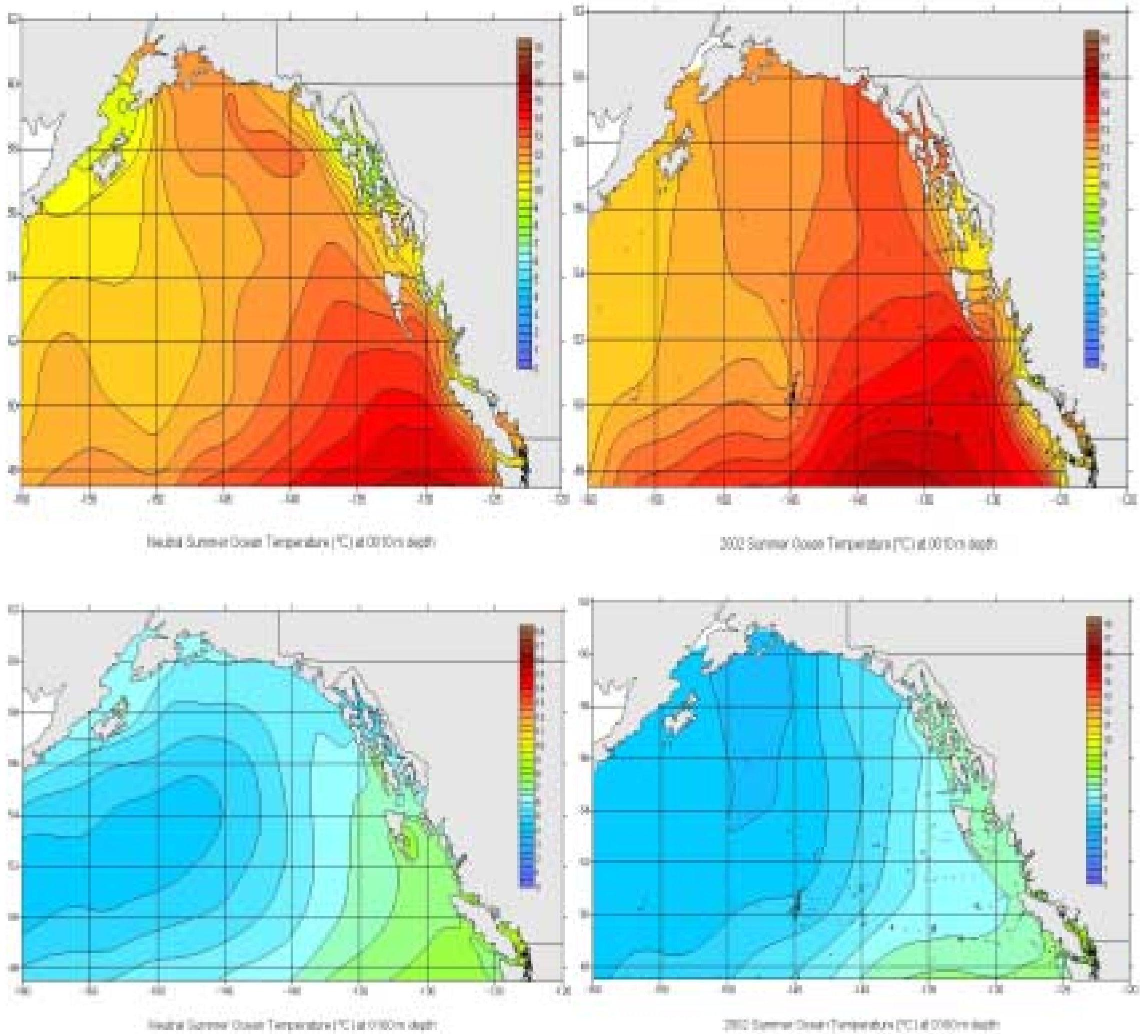

Figure 16. Summer temperatures at 10m and 100m depth. Neutral summer ocean temperatures taken from data during years with neither El Niño nor La Niña taking place.

A long-term perspective of this water mass is provided in Figure 17, showing anomalies of vertically integrated temperature (relative units) from ocean surface to 200 m depth along Line-P, based on archived observations within 50 km of Line-P. This plot includes the 2002 observations, and reveals that the cooling trend that began during the 1999 La Niña has continued. The El Niño of 2002 began in the summer of 2002, after the winter 2002 temperature measurements, and is therefore not present in this graph. Many of the past changes in the temperature structure evident in this plot can be related to El Niño events in the Tropical Pacific. Warmer waters usually coincide with an El Niño winter, cooler waters with a La Niña winter.

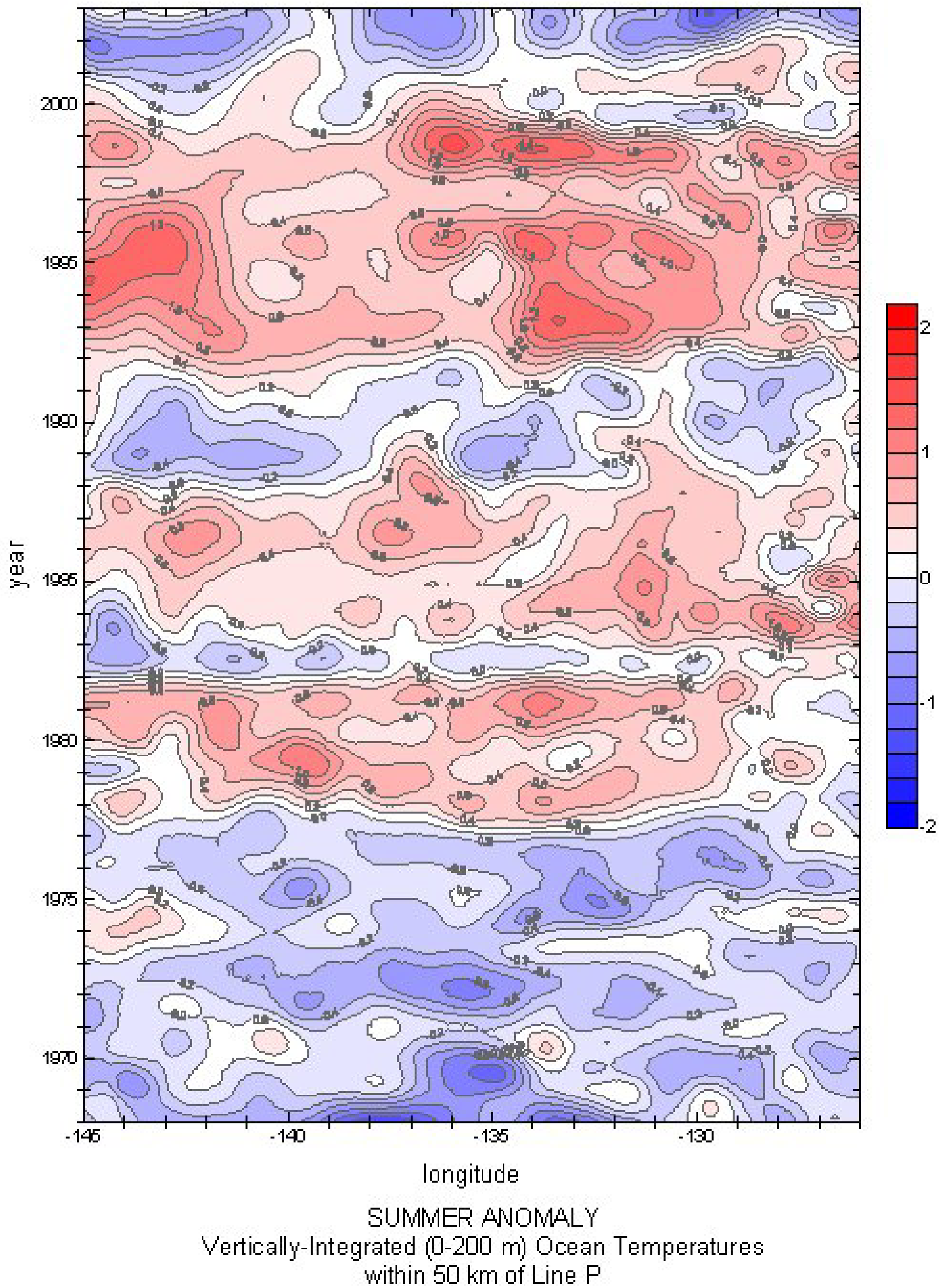

Figure 17. Vertically integrated temperature anomalies from ocean surface to 200 m depth along line-P.

Zooplankton

Time series of upper water column (0-150 m) zooplankton abundance in the Gulf of Alaska have been collected since the early 1990s at 5 locations along Line P, and opportunistically during other surveys (such as the summer research/ training cruise of the Japanese vessel *Oshoro Maru*). This renews the more intensive time series sampling that was done from the Stn P weatherships 1957-1981. McKinnell and Mackas 2003) completed a recalibration and reanalysis of the weathership time series, and confirmed the existence of large low frequency changes in zooplankton biomass. Seasonal coverage of the more recent research survey sampling is not sufficient to reliably measure the strong and narrow late spring annual peak in upper ocean biomass of the dominant copepods (*Neocalanus plumchrus*, *N. flemingeri*, and *N. cristatus*). However, DFO is also collaborating with PICES and the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) on ship-of-opportunity sampling of open-ocean zooplankton using a Continuous Plankton Recorder (CPR) towed behind commercial cargo vessels. CPR sampling in the eastern Gulf of Alaska is concentrated in this critical spring-early summer season. Fig 18 (provided by Dr. Sonia Batten of SAHFOS) shows spatially-averaged copepod biomass estimates for the 14 CPR surveys completed to date. PICES Scientific Report #21 (2002) provides detailed information on sampling methods and locations.

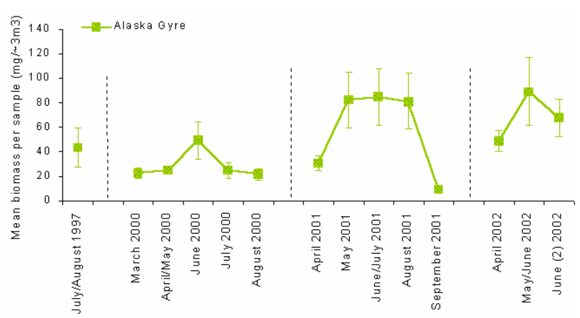

Figure 18. Open-ocean zooplankton biomass estimates provided by the North Pacific CPR sampling program.

West Coast of Vancouver Island

Physical, biological and chemical oceanographic conditions off the west coast of Vancouver Island undergo pronounced seasonal cycles in response to corresponding variations in coastal winds, freshwater runoff, solar heating, light conditions, atmospheric pressure, and offshore oceanic conditions. The seasonal cycles are, in turn, modified over a wide range of time and space scales, with especially marked changes arising from major El Niño/La Niña events in the North Pacific. Observations of these oceanic changes are monitored by Fisheries and Oceans Canada using environmental data collected from research vessels, coastal monitoring stations, and moored instrumentation. Shipboard surveys provide detailed information on the spatial distributions of oceanic water properties (temperature, salinity, nutrients, water clarity), fish, plankton (chlorophyll) and zooplankton. Moored weather buoys (Fig. 19) provide hourly time series information on winds, atmospheric pressure, wave height and period, and air/water temperature; lighthouse stations (Fig. 20) provide long-term time series of daily sea surface temperature and sea surface salinity. Tide gauge stations (Fig. 21) provide long-term series on hourly sea level variability and moored current meters (Fig. 22) yield hourly time series of current velocity, water temperature, and salinity at specified depths through the water column.

.

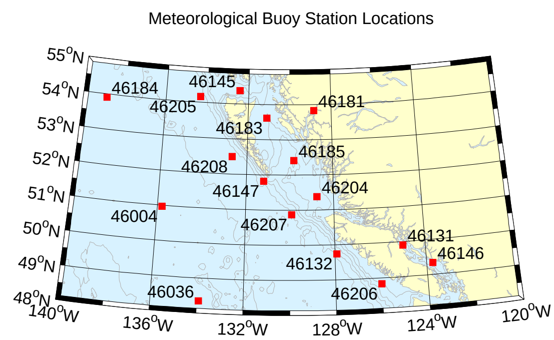

Figure 19. Weather Buoy locations.

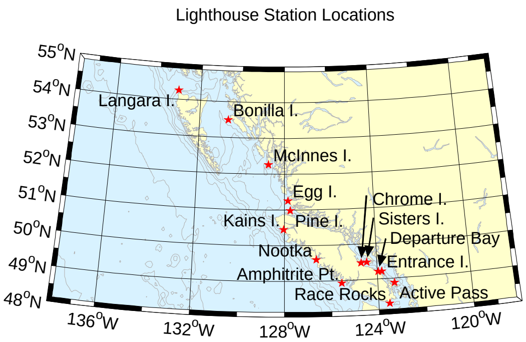

Figure 20. Lighthouse locations.

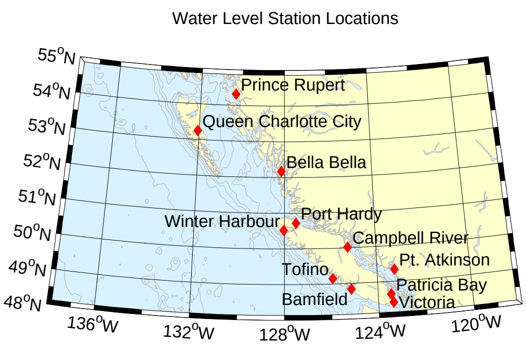

Figure 21. Tide Gauge locations**.**

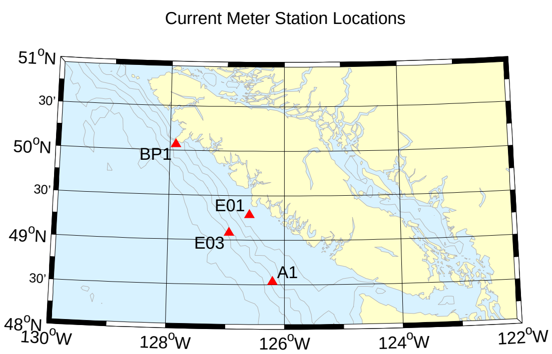

Figure 22. Current meter locations.

Mean global air temperatures in 2002 surpassed 2001 as the second warmest on record next to 1998 (National Climatic Data Center, NOAA). Oceanographic and meteorological conditions for the west coast over 2002 reflected the development of moderate El Niño (warm) conditions (Fig. 23) which are expected to persist into early 2003. Warmer than the 1990 - 1996 average monthly mean sea-surface temperatures (SSTs) along the coast, accompanied by cooler than the 1990 - 1996 average monthly mean SSTs in the central North Pacific, are also characteristic of a positive Pacific Decadal Oscillation (PDO) Index. The index changed from weakly negative/near neutral in January through until fall, to strongly positive in November 2002.

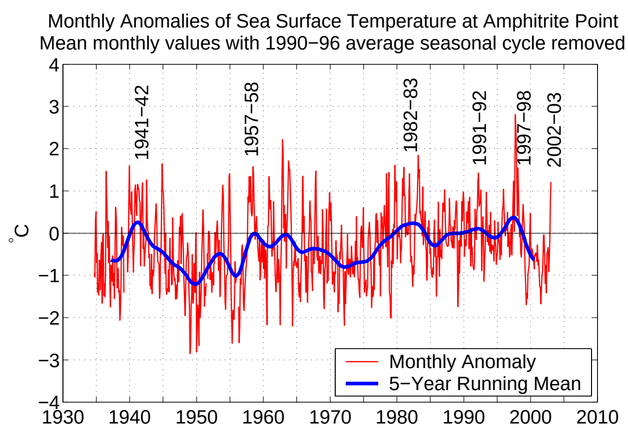

Figure 23. SST anomalies at Amphitrite Point from 1935 to 2002 and El Niño event years.

Surface oceanic conditions were similar for both the north and south coastal regions of offshore Vancouver Island, reflecting a transition late in the year from cool to warm conditions characterized by a moderate El Niño and a positive Pacific Decadal Oscillation Index. Upper ocean temperatures were below the 1990 - 1996 average monthly mean until December when they became warmer than the 1990 - 1996 average monthly mean. Salinity was near or above the 1990 - 1996 average monthly mean. Upwelling was strong in the spring and near the 1990 - 1996 average monthly mean along the coast in summer. Water levels were below the 1990 - 1996 average until the spring, after which they returned to near average.

West Coast Meteorological Data

Environment Canada (with support from DFO) has maintained weather buoys since 1989 off the west coast of Vancouver Island.

In 2002, there were periods of a few days duration having strong southeasterly winds during January-February and November-December, with November-December almost completely dominated by these downwelling-favourable events (positive alongshore wind stress in Fig. 24). Moderately strong periods of northwesterly, upwelling-favourable winds (negative values in Fig. 24) were recorded throughout the year, except during November-December. There were several prolonged events (a week or longer) during April and from June-September, when upwelling was capable of bringing nutrients to the base of the mixing layer at a time when nutrients and not light would have been possible limiting factors for biological productivity.

Relative to previous years, the upwelling-favourable winds of 2002 (negative along-shore wind stress anomalies in Fig. 25) were stronger than most years over the last decade.

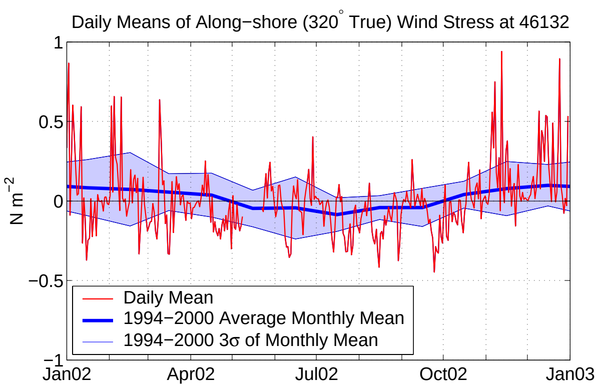

Figure 24. Alongshore wind stress for year 2002. Negative values favour upwelling.

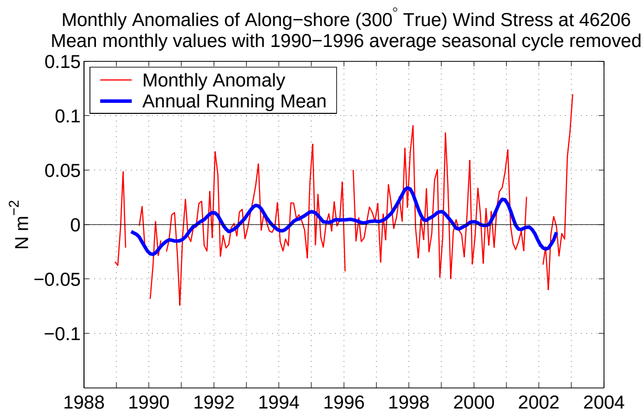

Figure 25. Alongshore wind stress anomalies from 1989 to 2002.

Wave heights were typically higher than the 1994-2000 average monthly mean over periods of a few days in most months (Fig. 26). Excluding these short-term events, wave heights were near the 1994-2000 average monthly mean throughout the year, except during October when relatively low wave heights were recorded over the entire month.

Relative to previous years, wave heights were moderately below the 1994 – 2000 average monthly mean in 2002 (Fig. 27).

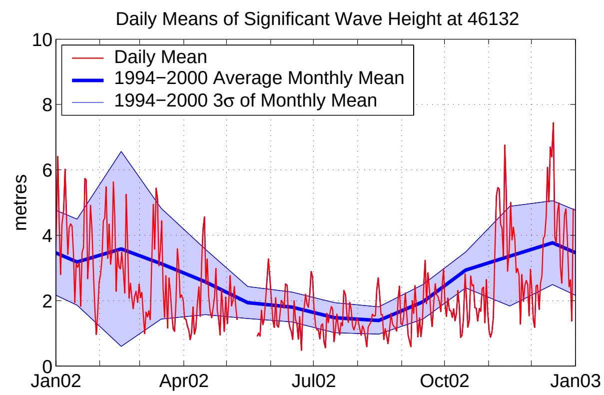

Figure 26. Significant wave height for year 2002.

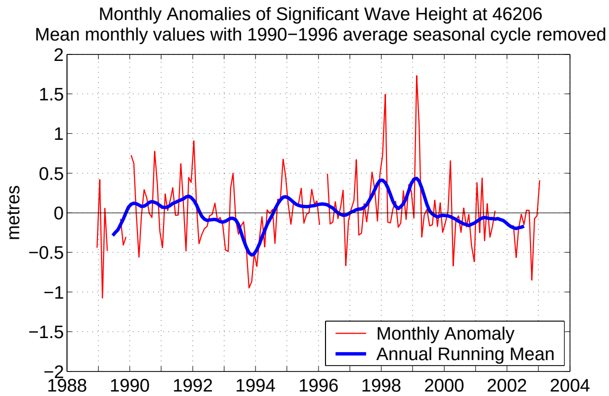

Figure 27. Significant wave height anomalies from 1991 to 2002.

West Coast Lighthouse Data

Sea-surface temperature (SST) on the inner continental shelf was generally 1°C below the 1990-1996 average monthly mean for most of the year (Figs. 28a,b). This is typical of negative PDO Index values, as occurred at the beginning of the year. Over the summer season (July-September), there were several episodes of about a week of higher than the 1990 - 1996 average monthly mean SSTs that returned to below the 1990 - 1996 average monthly mean values shortly afterwards. In November, SSTs were near the 1990 - 1996 average monthly mean values consistently, and were above the 1990 - 1996 average monthly mean in December, reflecting the strengthening El Niño and positive PDO Index. Cooling during early 2002 reflected a continuation of cold conditions observed over the 1998-2001 La Niña event years, and was greater than recorded during earlier La Niña events in 1988-1989 and 1984-1985. The cooling was comparable to the 1970-1971 La Niña event, and not as cold as La Niñas in 1975-1976, 1955-1956, and 1950-1951 (Fig. 23).

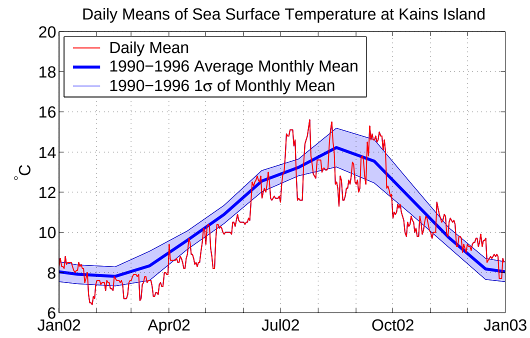

Figure 28a. Northern SST for year 2002.

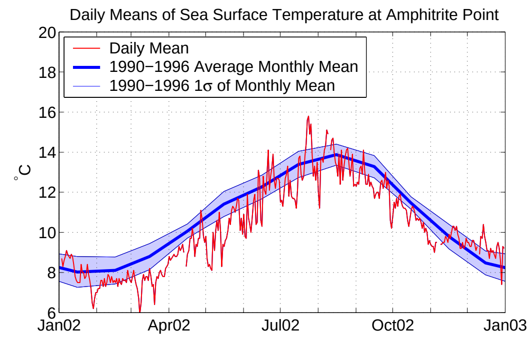

Figure 28b. Southern SST for year 2002.

Sea-surface salinity (SSS) at Kains Island was near the 1990-1996 average monthly mean over January-February, and 1-2 psu greater than the 1990 - 1996 average monthly mean the rest of the year (Fig. 29a). Of note was a strong negative spike of 5-7 psu in mid-November immediately following the onset of strong downwelling winds (Fig. 24). At Amphitrite Point, SSS was also near the 1990 - 1996 average monthly mean during January-February, above the 1990 - 1996 average monthly mean by 1-2 psu during the spring and fall of 2002, into December. SSS was generally near the 1990 - 1996 average monthly mean through the summer (Fig. 29b). The large (~7 psu) negative spike in November was also present at Amphitrite Point.

Relative to previous years, the above 1990 - 1996 average monthly mean surface salinities in 2002 are comparable to those recorded in the late 1970s, mid-1960s, and early 1950s (Fig. 30).

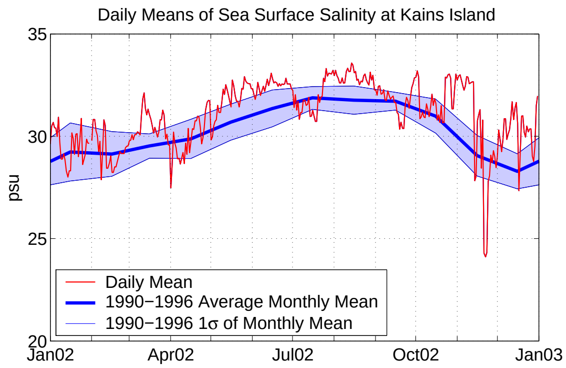

Figure 29a. Northern SSS for year 2002.

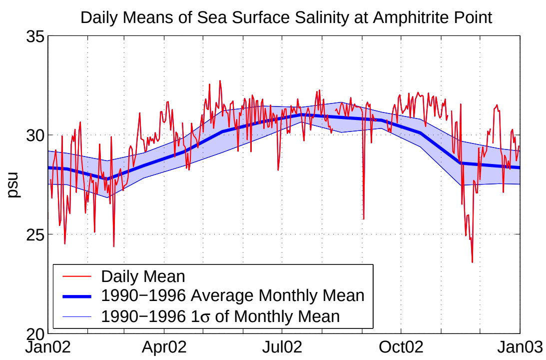

Figure 29b. Southern SSS for year 2002.

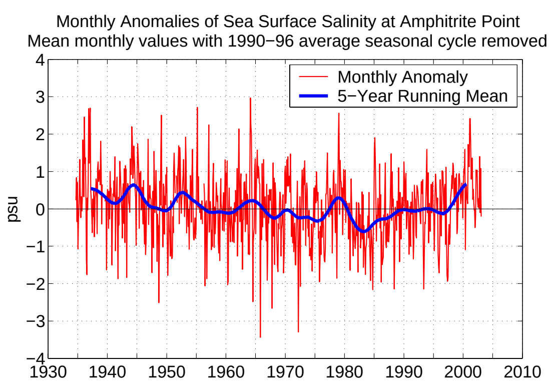

Figure 30. SSS anomalies at Amphitrite Point from 1935 to 2002.

Upwelling Indices

The PFEL (Pacific Fisheries Environmental Laboratory) FNMOC (Fleet Numerical Meteorology and Oceanography Center) Upwelling Index for the west coast of Vancouver Island and northwest Washington State (48° N, 125° W) is shown in Figs. 31 and 32. This index characterizes the seaward component of the wind-induced Ekman transport. The year 2002 had strong periods of downwelling (negative values) in the winter and spring months (Fig. 31). Weak to moderate upwelling events (positive values) occurred throughout the period April-September with the strongest upwelling in April. This coincides with the occurrence of northeasterly (upwelling-favourable) winds recorded by the meteorological buoys.

As in 2001, upwelling in 2002 was near the 1990-1996 average monthly mean, and in contrast to the below average upwelling period over 1993-2000 (Fig. 32).

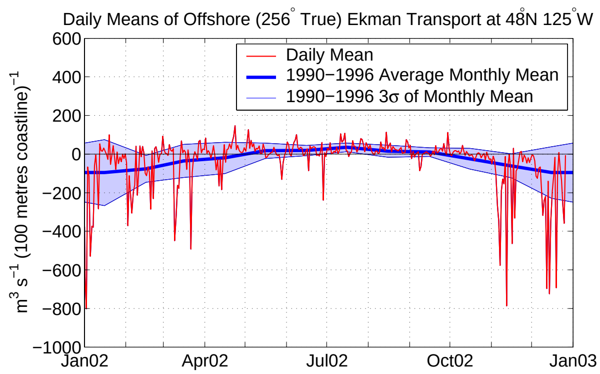

Figure 31. Upwelling index at 48° N, 125° W for year 2002. Wind driven seaward flowing transport is replaced by upwelling water from below.

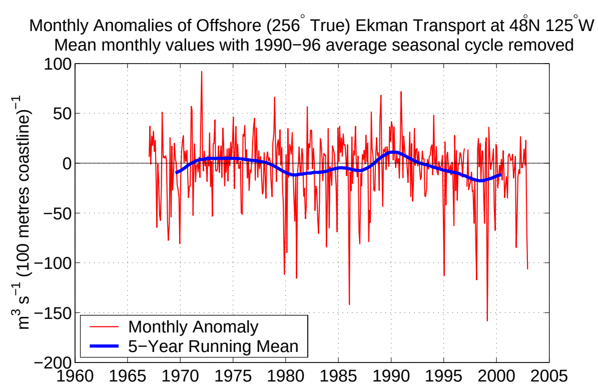

Figure 32. Upwelling index anomalies at 48° N, 125° W from 1967 to 2002.

Water Level

Water level was 10-20 cm lower than the 1990-1996 average from January through May, after which it returned to near the 1990 - 1996 average monthly mean for the remainder of the year (Fig. 33). The exceptions were during November and December when two episodes of 2-3 weeks in duration pushed water levels 20-40 cm above the 1990 - 1996 average. This was due to storm activity as measured by the meteorological buoys (strong southeasterly winds generating storm surges and low air pressures with decreased depression of the sea surface through the inverse barometer effect).

Water levels below the 1990 - 1996 average in 2002 are in marked contrast to the above average values during the 1997-1998 El Niño (Fig. 34). Water levels during 2002 are comparable to those recorded during the La Niña of 1988-1989.

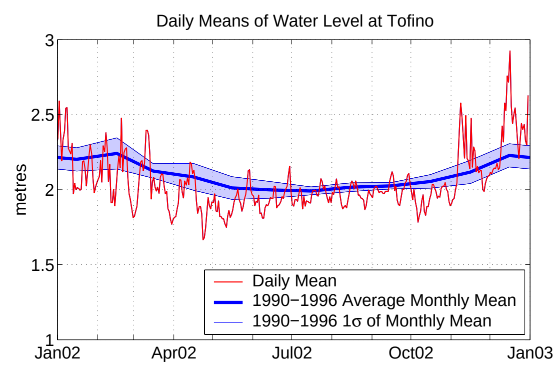

Figure 33. Water level at Tofino for year 2002.

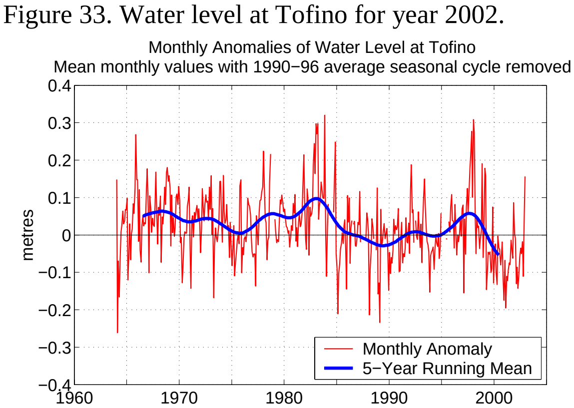

Figure 34. Water level anomalies at Tofino from 1970 to 2002.

Southwest Vancouver Island Continental Slope (La Perouse Region)

Subsurface temperatures at 35, 100, 175 (Fig. 35), and 400 (not shown) m depth over the continental slope as measured at mooring A1 were below the 1990-1996 average monthly mean during 2002 (data series ends in late September). Negative anomalies of 2, 1, and < 0.5 °C were recorded at the nominal depths of 35, 100, and 175 m, respectively. (Note that the actual depth of the top mooring was 27 m, January-May, all other deployments were very close to the nominal depths.)

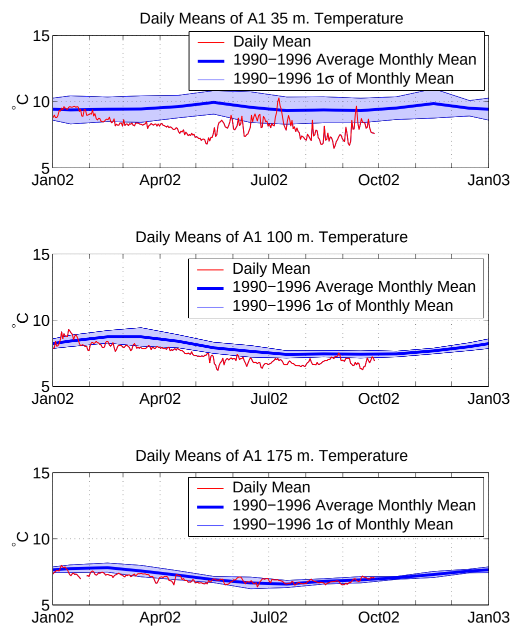

Figure 35. Temperature at 35, 100, and 175 metres depth at mooring A1 for year 2002.

Alongshore current velocity over the continental slope in 2002 as measured at A1 was poleward with magnitude near the 1990 – 1996 average monthly mean throughout most of the winter and spring (peaking at around 40 cm s^{-1} in early January at 35 m depth) (Fig. 36). There was a dramatic reversal for about a week in mid-January after which the along-shore current remained below average through most of February. Flow direction switched to mainly equatorward during the

March-April period, and became more strongly equatorward than normal for the remainder of the data series (May-September). Under normal wind and runoff conditions, currents are poleward in winter and early spring at all depths on the continental slope. Currents reverse abruptly sometime in spring (the "Spring Transition") and flow equatorward until late summer to early fall under the influence of the prevailing northwesterly (upwelling favourable) winds. Reversals to poleward flow begin progressively earlier with depth in the water column. For most of the 1990s, annual mean transport was primarily poleward over the southwest coast of southern Vancouver Island.

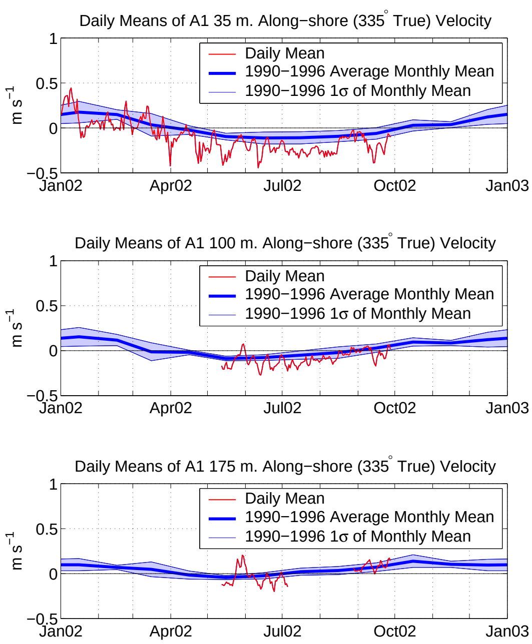

Figure 36. Alongshore (poleward) current velocity at 35, 100, and 175 metres depth at mooring A1 for year 2002.

Relative to previous years, along-shore current at A1 during the spring and summer of 2002 was as strong southward as it has ever been since measurement began in 1985 (Fig. 37). This was also evident but not as strong at 100 m. Temperatures were as low at 35 and 100 m as at any time over 1985-2002, but nearer the 1990 - 1996 average monthly mean at 175 m. In the spring, temperatures at 100 m dropped dramatically to equal those at 175 m, an occurrence not seen in the record since 1991. This deep isothermal layer was due to strong upwelling of deeper cool water moving up the water column.

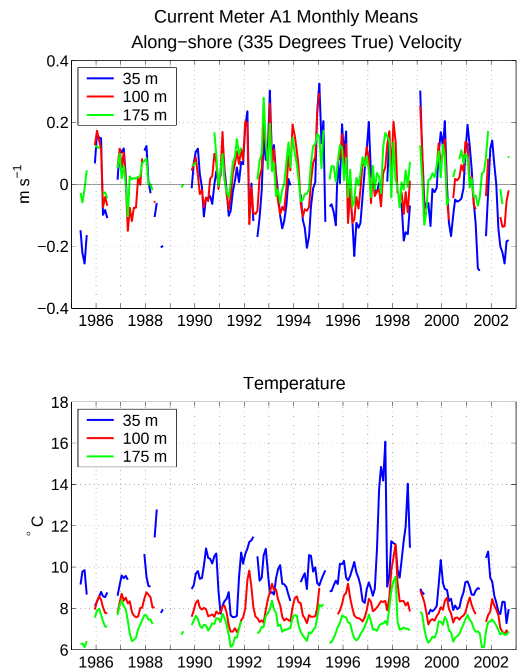

Figure 37. Alongshore (poleward) current velocities and temperatures at 35, 100, and 175 metres depth at mooring A1 from 1985-2002.

Zooplankton

Time series of zooplankton samples collected since 1979 off southern Vancouver Island (SVI, 48°-49°N) and since the early 1990s off northern Vancouver Island (NVI, 50º-51.5ºN) allow us to estimate annual anomalies of most of the major zooplankton species, relative to their long term baseline average annual seasonal cycle. The west coast sampling and data analysis has been continued in both regions through 2002. The previously published southern Vancouver Island anomaly time series (Mackas, Thomson and Galbraith, 2001) has been updated through 2002, and compared with newly-calculated zooplankton anomalies for northern

Vancouver Island and central Oregon (Mackas, Peterson and Zamon, in press). See these manuscripts for detailed description of sampling and analysis methods.

Year-to-year biomass variations for several of the major SVI zooplankton species groups are summarised in Fig 38. The zooplankton anomalies are shown on a logarithmic scale: an anomaly of +1 means that the zooplankton in that group were on average ten times more common than during the 1979-1991 reference period; an anomaly of –1 means that they were one tenth as common.

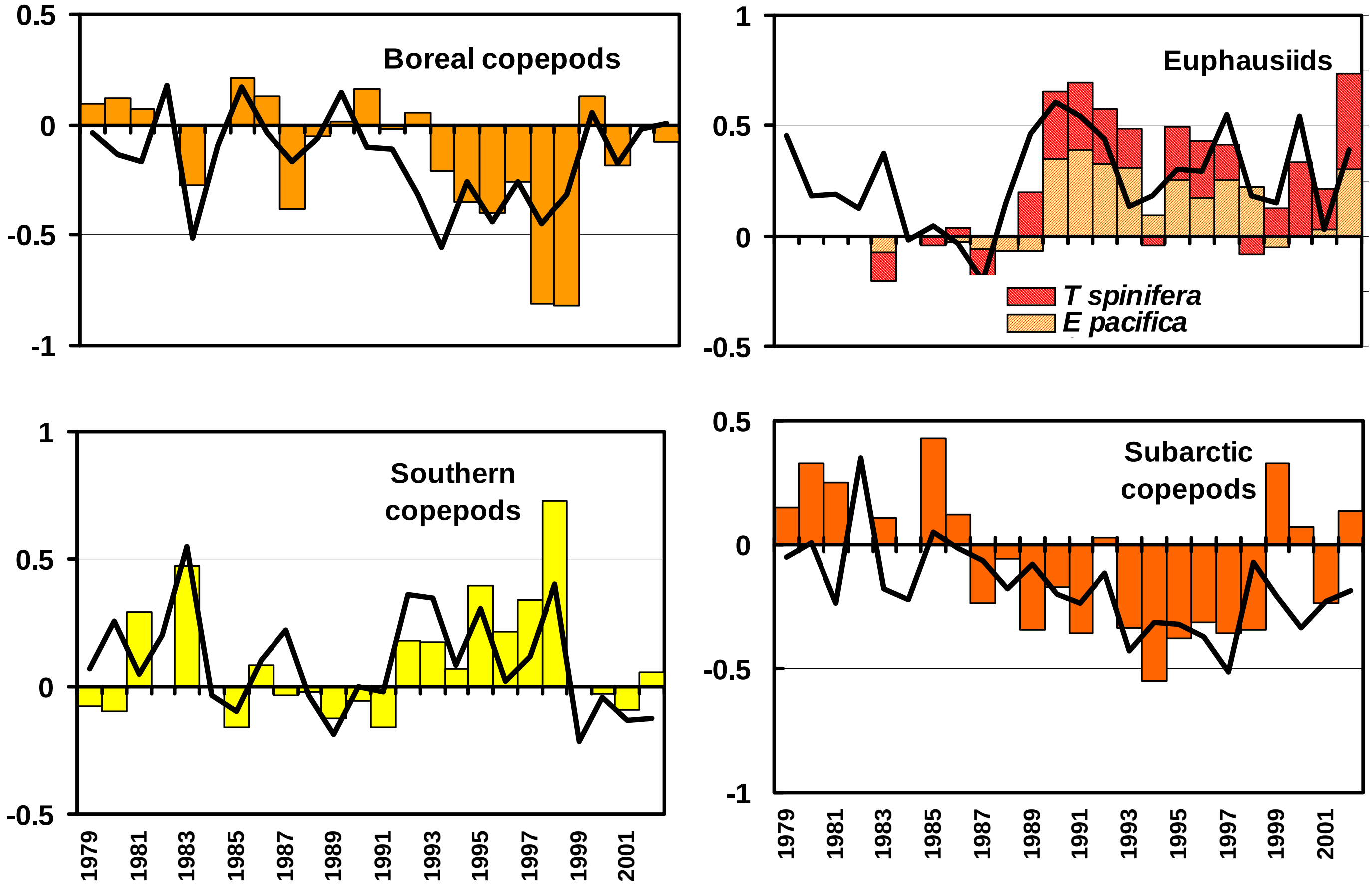

Figure 38. 1979 – 2002 time series of annual zooplankton anomalies averaged across southern Vancouver Island statistical areas and within groups of ecologically similar species (coloured columns Lines show fits to the zooplankton anomaly time series from stepwise regressions on 1985 – 1998 time series of environmental indices: large-scale (solid lines) and local water properties (dashed lines). Note the continuing “predictive” fit 1979–2002.

The time period 1990-2000 included some very strong (factor of ten or larger) variations in concentrations of all major species groups. Shifts were particularly strong 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. This trend reversed sharply in 1999, following the 1997-1999 El Niño-La Niña event. Since 1999, biomass of most zooplankton taxa along the Vancouver Island continental margin has been similar to the baseline period. The most notable exception is a recent increase in pteropods. Most of the zooplankton anomaly time series are correlated with time series of local and basin-scale environmental indices. Fits derived from 1985-1998 stepwise regressions are shown as solid and dashed in Fig. 38. Note that for most taxa, the 1979-1983 and 1999-2002 zooplankton anomalies (not included in the fitting operation) also track the environmental regressions.

Comparable time series, shown in Fig. 39, have now been developed for northern Vancouver Island (also by our NOAA collaborators for central Oregon). The main differences from the southern Vancouver Island time series data are greater along-line average abundance of the oceanic copepods (probably because of the progressive northward narrowing of the Vancouver Island continental shelf) and a superimposed latitudinal gradient of species composition among the shelf species, such that the mid 1990s replacement of boreal shelf copepods by California Current species, and the reversal of this trend in 1999, are less pronounced further to the north.

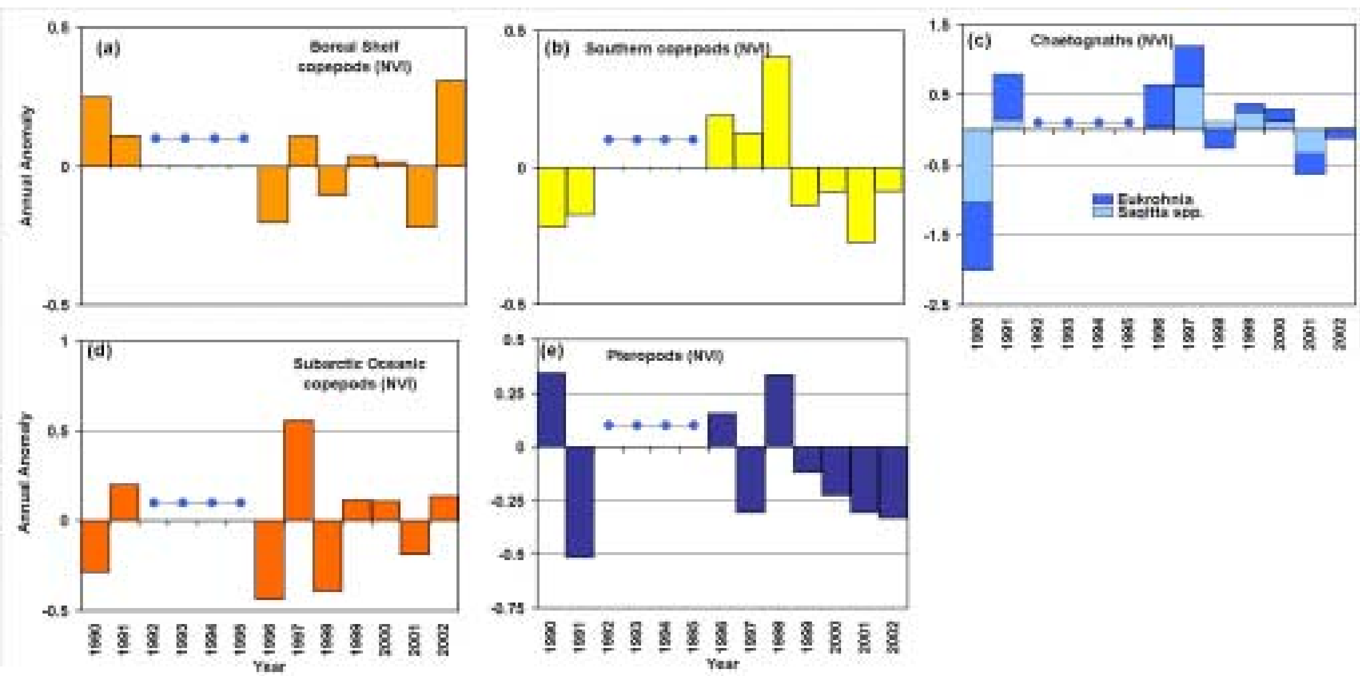

Figure 39. 1990 – 2002 time series of annual zooplankton anomalies averaged across northern Vancouver Island statistical areas and within groups of ecologically similar species (colored columns). Circles indicate years with too few samples to estimate annual anomalies.

Status of euphausiid populations and implications for fish production along the southwest coast of Vancouver Island

Sampling of euphausiids continued in 2002. Figure 40 shows the time series of median dry biomass of adult *T. spinifera* (>9 mm) for 1991-2002. The biomass trend can be described generally as relatively high in 1991-92 (median biomass = 330 mg • m^{-2}), a 66% reduction over 1993-99 (median biomass = 110 mg • m^{-2}), followed by an incomplete recovery (median biomass = 260 mg • m^{-2}) relative to 1991-92 since 2000.

Growth in herring continues to be depressed as of the 2002 return year. Tanasichuk (2002) reported that size-at-age of recruit herring for the 1993-95 year-classes was unusually low. He suggested that low euphausiid biomass during the pre-recruit phase had disrupted compensatory density-dependent growth for the SWCVI herring population. The suppression of pre-recruit growth has persisted until at least the 1999 year-class which returned as age 3 fish in 2002 (Fig. 41). The depression of size-at-age has implications for the growth of adult fish of the same year-class because Tanasichuk (1997) reported that growth rates of adult fish are determined mainly by size at the beginning of the growth season. Since fecundity (egg number) is closely related to fish size, the suppression of growth could reduce the egg production of the SWCVI herring population. The 2000-2002 median biomass of euphausiids that herring feed on is about three times than that for 1991-92. In other words, food availability for the 2000 year-class, which returned as age 3 in 2003, is the highest in the time series. Sampling data are not available for these fish yet but preliminary results from the August 2002 offshore survey indicated that size-at-age 3 was high. Therefore, it is possible that food availability is no longer suppressing herring growth.

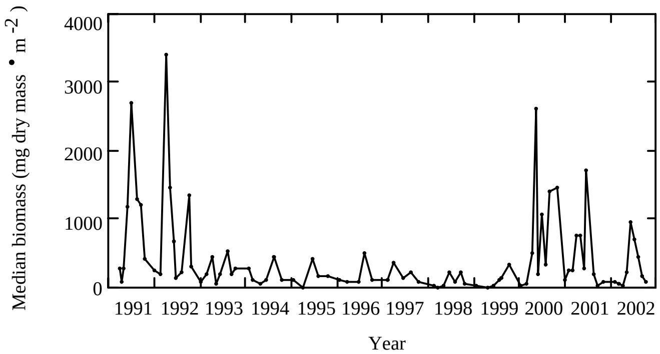

Fig 40. Median biomass of adult Thysanoessa spinifera.

The observation that euphausiid availability affects marine survival rates of Carnation Creek wild coho (*Oncorhynchus kisutch*) and Barkley Sound (Great Central and Sproat lakes) sockeye (*O. nerka*), presented in last year's status report, continues to be supported by new data. The measure of euphausiid availability relevant to coho is the median abundance of 9-12 mm *T. spinifera*, the species and size composition of prey that is most commonly reported for Oregon Coast (Petersen et al. 1982) and Barkley Sound (Tanasichuk, unpubl. res.) coho smolts. Results showed that smolt and euphausiid abundance collectively explain 97% of the variation in number of adults returning to Carnation Creek. Fig. 42 shows how the relationship, expressed as a rate so that it can be applied to other WCVI wild coho populations, is used to forecast marine survival. An increase in the abundance of 9-12 mm *T. spinifera* for the 2002 smolt year suggests that wild coho survival will be slightly higher. It is anticipated to be average for the 1990s but below the historic (1975 – 2002) time series mean. Sockeye smolts eat 3-5 mm *T. spinifera* while they are in Barkley Sound or on the continental shelf (April-June). Results of analyses showed that smolt abundance and euphausiid biomass explained at least 70% of the variation in number of returning adults for all ages (4_2,4_3,5_2,5_3 and 6_3) and both lakes. Variations in sockeye prey, and an example of the fit of the relationships to the observed values, are presented in Fig. 43. These relationships have substantial fisheries management implications if they persist. Sockeye returns can be predicted one year in advance for age 4_3 fish, two years in advance for ages 4_2 and 5_3 sockeye and three years in advance for ages 5_2 and 6_3 returning adults. Ages 4_2, 5_2 and 5_3 account for most of the returning fish. Food availability for sockeye smolts was good in 2000 and less favourable in 2001 and lower still in 2002.

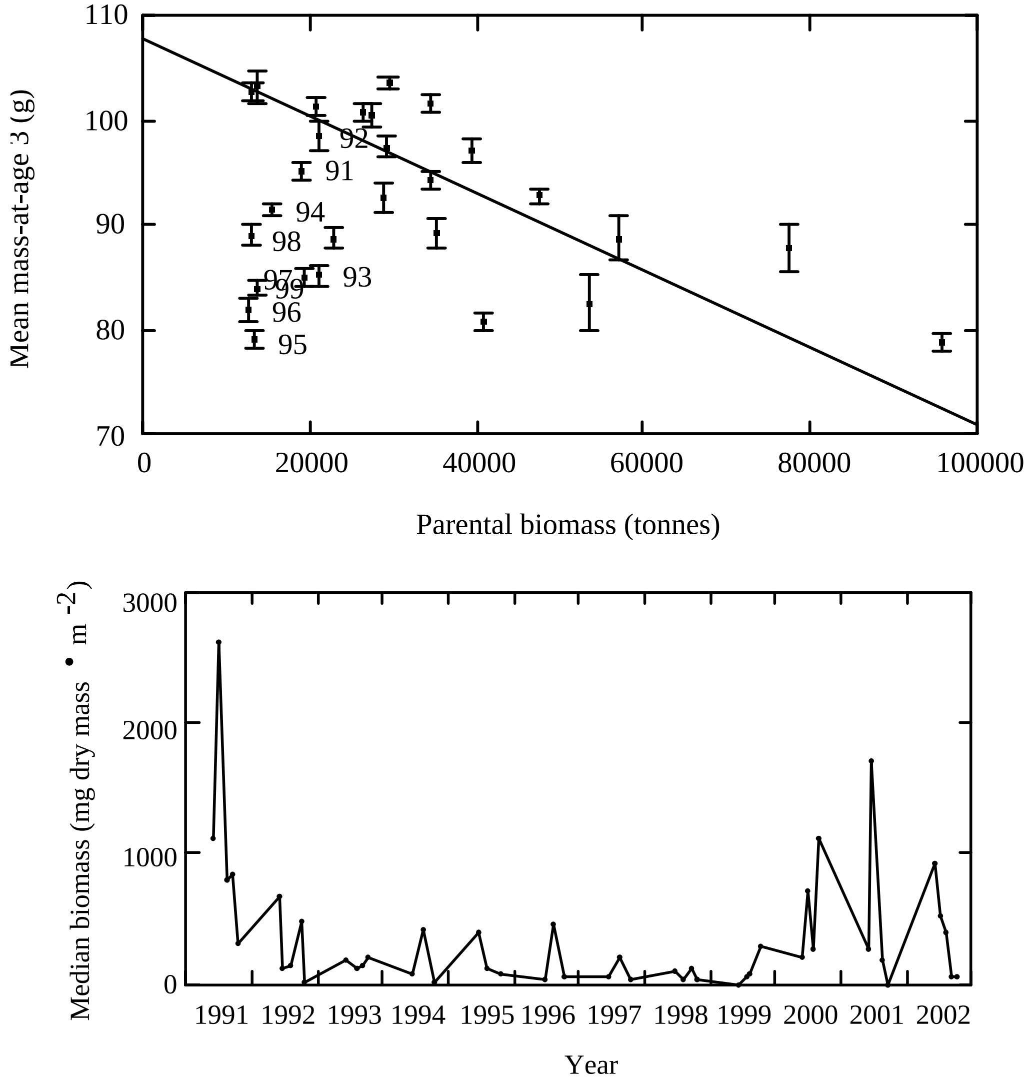

Figure 41. Upper panel: interannual variations in the biomass of herring prey (T. spinifera, > 17mm long) over the feeding season. Lower panel: relationship between parental biomass and mean size-of recruit herring; line shows the density-dependent effect on growth; labels are year-class.

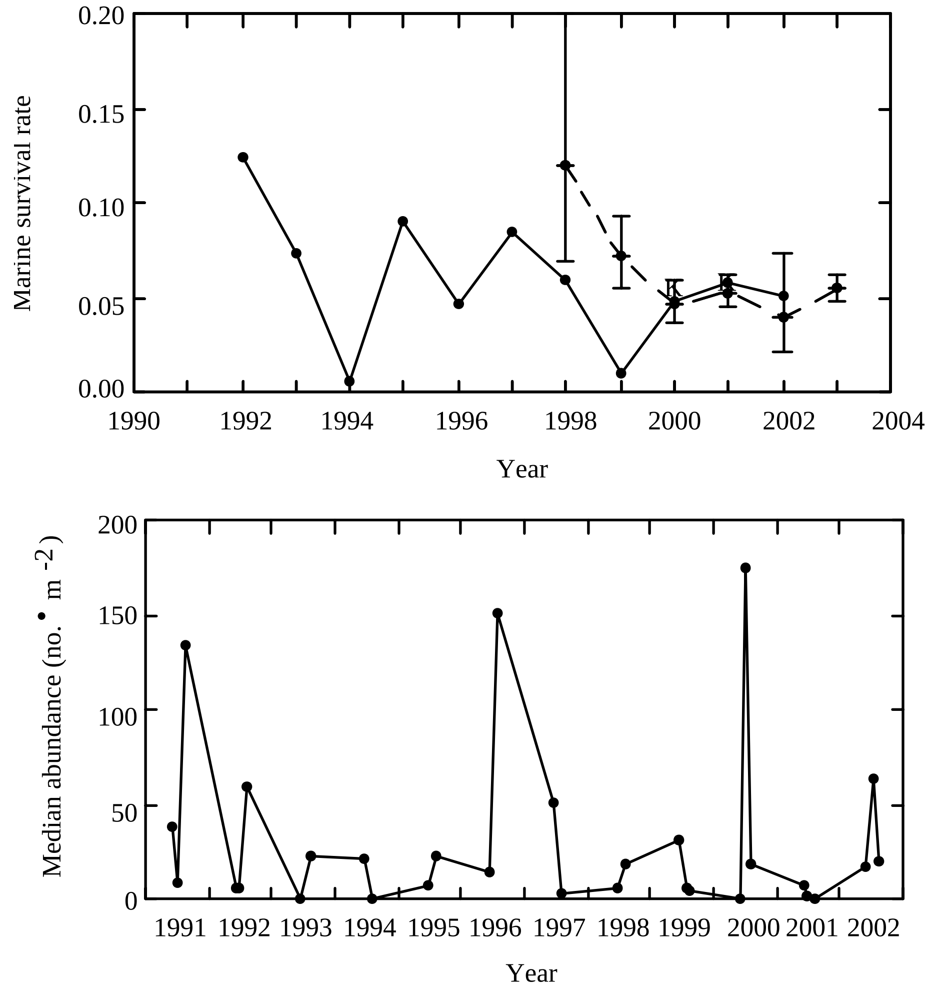

Figure 42. Upper panel: interannual variations in the abundance of 9-12 mm T. spinifera over June-August. Lower panel: results of retrospective analysis of forecasting accuracy of smolt-euphausiid regression for Carnation Creek coho. Solid line – observed survival rate. Dashed line – predicted survival rate. Error bars – 95% CL of predicted value. K – observed marine survival rate for coho for Kirby Creek, a wild indicator stream located about 100 km east of Carnation Creek.

It appears that variations in eulachon (*Thaliechthys pacificus*) production may be related to euphausiid availability as well. Eulachon feed on *T. spinifera* > 17 mm, the same fraction of the euphausiid biomass consumed by herring and hake. An offshore eulachon biomass index is derived from the May shrimp bottom trawl survey when eulachon by-catch is assumed to be unbiased.

Figure 44 shows plots of the index as well as median biomass of *T. spinifera* > 17 mm. The biomass index is lagged one year which suggests that prey availability for age 1 eulachon influences productivity. The median biomass of *T. spinifera* > 17 mm in 2002 (400 mg dry mass • m^{-2}) was relatively high, exceeding about 80% of the values in the 1991-2002 time series.

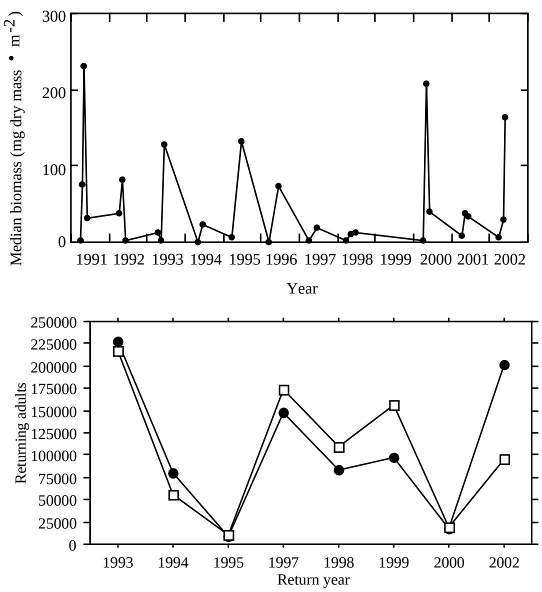

Figure 43. Upper panel: interannual variations in the biomass of 3-5 mm T. spinifera over April-June. No data are plotted for 1999 because sampling coverage was inadequate. Lower panel: plots of observed (solid circles) and fitted estimates (open squares) of number of returning adults for age 4 Great Central Lake sockeye returning after two years at sea.

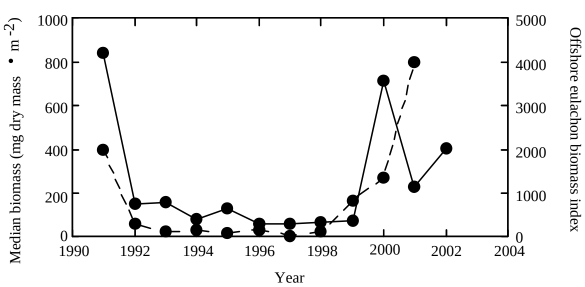

Figure 44. Time series of median euphausiid biomass (T. spinifera > 17 mm, solid line) and the offshore eulachon biomass index (dashed line). The biomass index is lagged one year.

Herring

Since about 1977, the recruitment of herring off the West Coast of Vancouver Island has been generally poor (Figure 45). The productivity of the west coast of Vancouver Island herring stock (Figure 46) has been declining since 1989, primarily because recruitment to this stock has been poor for 6 of the last 10 years (Figure 45). In 2002, the spawning biomass (Figure 46) increased to near the average for the past two decades. A long-term research program has shown that herring recruitment in this region tends to be below average when ocean temperatures are warm and the summer biomass of migratory predators (primarily hake and mackerel) is high. The negative correlation between herring recruitment and temperature probably reflects: 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. Several field studies designed to measure the predation rate have confirmed that the negative correlation between herring recruitment and hake biomass could be caused by predation. Apart from predation by hake and other predators, ocean conditions were more favourable for herring survival in 2000 and 2001 and should result in improved recruitment to the stock in the year 2003 and 2004.

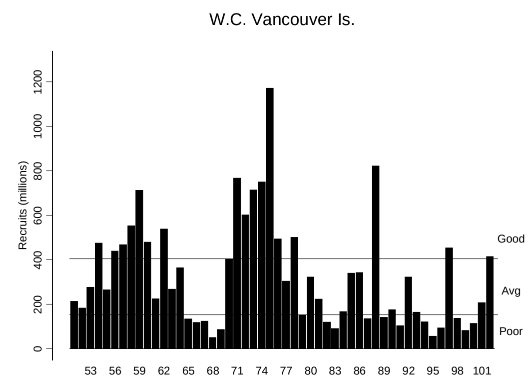

Figure 45. Interannual variability and decadal trends in recruitment to the west coast of Vancouver Island herring stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown. Note that 6 of the last 10 recruitments have been ‘poor’.

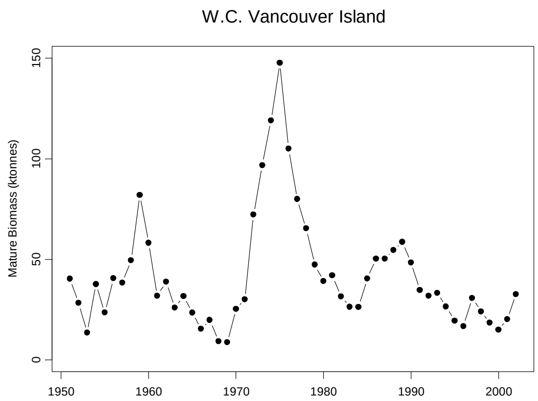

Figure 46. West Coast Vancouver Island herring abundance.

Pacific Sardine

Pacific sardine is a migratory species. When the northern sardine stock is large and ocean conditions are favourable, sardines migrate to British Columbia in the summer to feed. Most of these summer migrants make a return migration in the fall to the waters off central and southern California where they spawn. 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 2002, sardines did not appear in Canadian waters until late-July and were confined to coastal inlets along Vancouver Island and the Central Coast. The most recent U.S. assessment suggests a leveling off in sardine abundance (Fig. 47). The 2002 trawl survey off Vancouver Island (Fig. 48) was limited but suggests that fewer sardines were present than in 1997-1999 when water conditions were warmer.

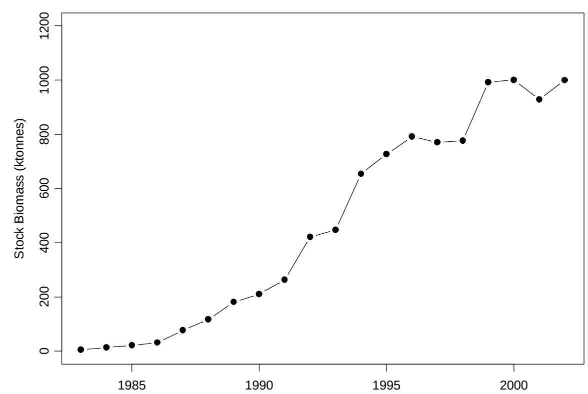

Figure 47. Time series of Pacific sardine stock biomass (x1,000 mt) of age 1 and older fish, estimated from an age-structured stock assessment model (data from Conser et al. 2002).

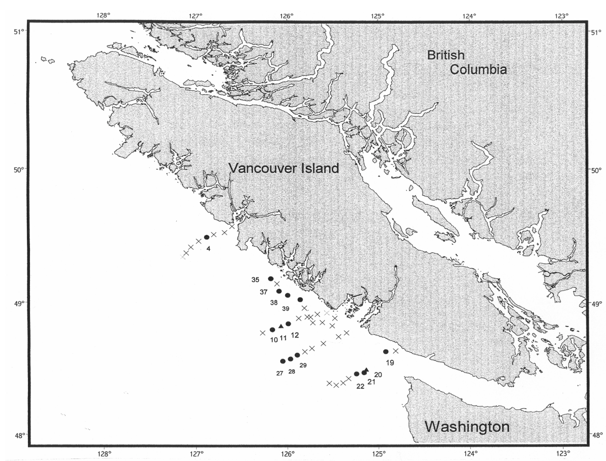

Figure 48. The distribution of Pacific Sardine was concentrated in southern offshore areas in 2002. The X's represent sets at depths of 45m or shallower, in which no sardines were captured. Dots represent sets at depths shallower than 45m where sardines were captured, and triangles represent sets deeper than 45m where sardines were captured.

Growth & Energetic Status of Pacific Salmon

Ocean surveys for juvenile salmon using the *CCGS W.E. Ricker* have been used to assess growth, condition, and survival of salmon in different parts of the British Columbia coastal ecosystem since 1998. The results for October 2002 indicate that juvenile coho salmon off southern British Columbia had attained the largest sizes since the start of the survey in 1998 and that improved salmon returns should be anticipated in 2003 and later years. The year when significantly higher salmon returns should occur depends on which species is being forecast.

In 1998 and earlier years the size of juvenile coho was much smaller in the area off the west coast of Vancouver Island than northern B.C. or SE Alaska (Fig. 49). Proximate analysis indicates that coho salmon found off the west coast of Vancouver Island in 1998 had lower stored energy and were in poorer condition at the end of the growing season than animals foraging farther north (Fig. 50). The disparity in growth should have caused a large difference in the survival of salmon resident in the southern area or those stocks that migrate through the area, because smaller fish have higher mortality rates. Consistent with this expectation, it is known that the B.C. salmon stocks resident in the southern area of our survey (Strait of Georgia coho, west coast of Vancouver Island chinook) have poorer marine survival than stocks from northern B.C. or SE Alaska resident in the northern survey area.

The 1999, 2000, and 2001 surveys provided a test of this idea, as the changed ocean climate resulted in very similar growth for all areas of the survey (Fig. 49). In addition, it appears that these animals were also in good condition with high energy reserves in all the surveyed areas (Fig. 50). This improved growth was subsequently followed by an increase in the adult returns of salmon that entered the ocean in 1999 and subsequent years. Columbia River chinook and steelhead and Fraser River pink and sockeye salmon entering the ocean during these years as juveniles subsequently had record adult returns despite very low adult escapements. Coho returns were also observed to improve.

The 2002 survey found that coho growth conditions substantially exceeded those of any of the prior years off the west coast of Vancouver Island (Fig. 49). This suggests that we may expect to see significantly larger returns of Strait of Georgia coho and Fraser River pink salmon returns in 2003, as their juveniles entered the ocean in 2002. Coded wire tag analysis of marine survival shows that SE Alaska coho stocks had marine survival rates of 20-25% through most of the 1990s while Strait of Georgia coho stocks had marine survival rates of only 2-4%. Our results suggest that in 2003 significantly higher marine survival for southern British Columbia coho is thus also likely, since their growth performance was similar.

Additional support for these projections of improved salmon returns comes from our end of winter surveys. Since 2001, we have also been surveying salmon in February-March to determine overwinter growth and distribution, and to evaluate salmon status at winter’s end. Our March surveys found that very few pink, chum, and sockeye salmon overwintered in these areas in 2001 or 2002 (Figure 51). However, in February 2003 large numbers of juvenile pink, chum, and sockeye salmon were found to have overwintered on the west coast of Vancouver Island and off northern British Columbia (Figure 51). This suggests that high returns of overwintering stocks of these species may possibly also be expected for pink, chum, and sockeye salmon juveniles that entered the ocean in 2002. If correct, increases in adult abundance should be seen first in pink and coho salmon in 2003 as these species spend only 16-18 months in the ocean, followed by chinook and sockeye salmon in 2004, and then chum salmon in 2005.

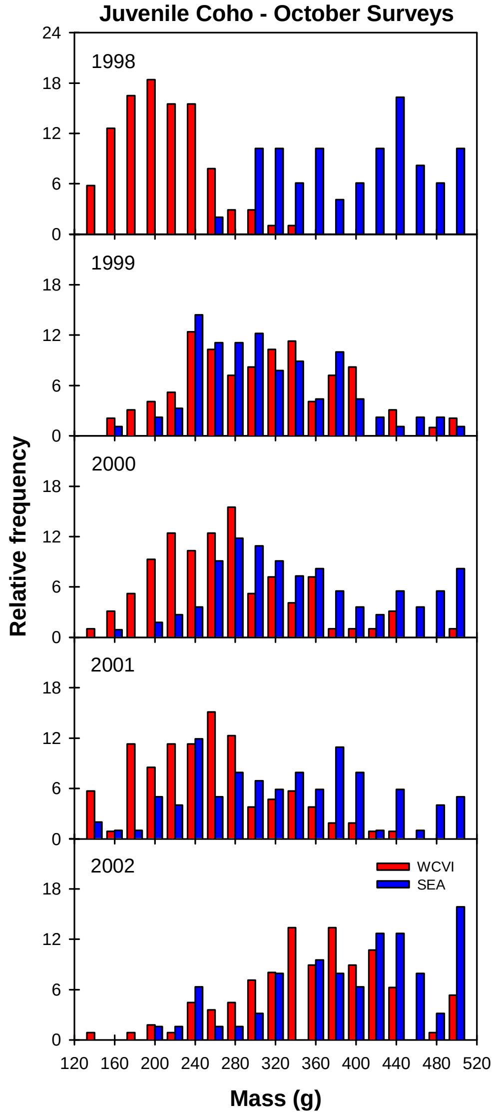

Figure 49. Size frequency distribution of juvenile coho salmon collected on the west coast of Vancouver Island (WCVI) and south east Alaska (SEA) in October 1998-2002.

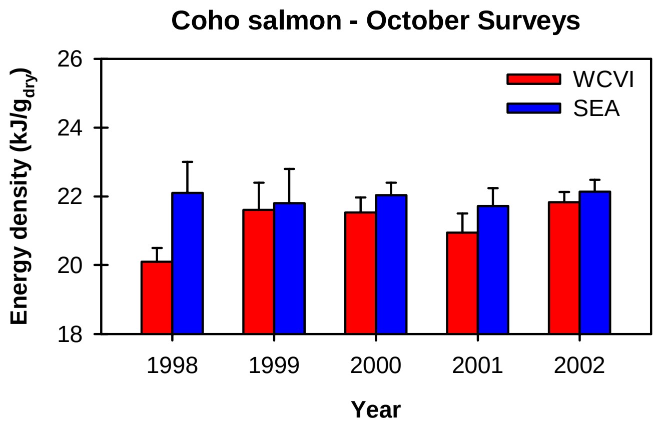

Figure 50. Energy density of juvenile coho salmon collected on the west coast of Vancouver Island (WCVI) and south east *Alaska (SEA) in* October 1998-2002. Energy density was determined using a bomb calorimeter in 1998-2001, and estimated from water content of fish in 2002. Energy density was significantly lower for coho salmon collected on WCVI in 1998. The error bars represent 2 x SE.

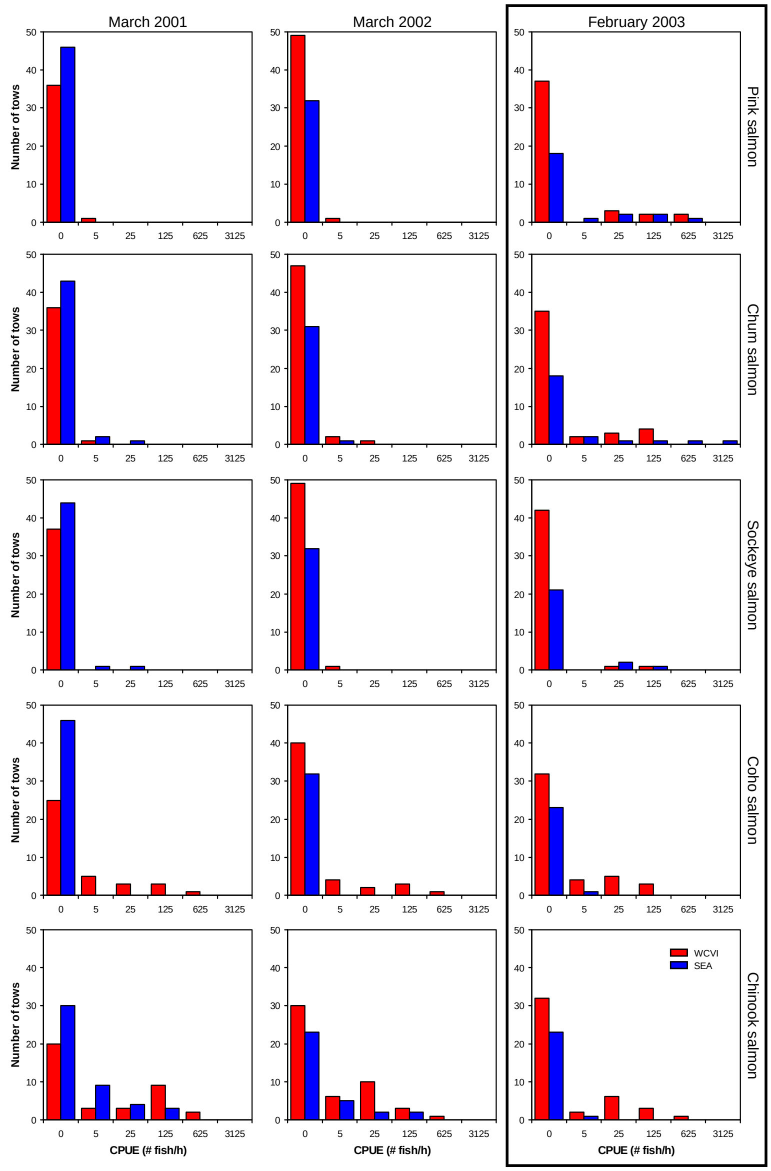

Figure 51. Catch per unit effort (CPUE) of juvenile pink, chum, sockeye, coho and chinook salmon collected at the end of winter off the west coast of Vancouver Island (WCVI) and south east Alaska (SEA) (February/March 2001-2003). Numbers on the x-axis represent the upper limit of each interval, and have been ordered on a log_5 scale. Note the large increases in catch of pink, chum and sockeye salmon at the end of winter in 2003 (third column) compared to prior years.

Seabird Reproductive Performance on Triangle Island

Triangle Island Background and Species Natural History

Triangle Island (50*52'N 129*05'W) supports the world's largest population of Cassin's Auklet (*Ptychoramphus aleuticus*; 1.1 million breeders) and a large population of Rhinoceros Auklet (*Cerorhinca monocerata*; 82,000 breeders) in addition to significant populations of Tufted Puffin (*Fratercula cirrhata* 52,000 breeders) and Common Murre (*Uria aalge*; 8,200). All of the species have single egg clutch. The Cassin's Auklet is a small (190g) primarily planktivorous, burrow nesting seabird which visits the colony only at night. The Rhinoceros Auklet (Cerorhinca monocerata) is a 550 g piscivorous, burrow nesting species which also visits the colony at night. The Tufted Puffin is a 750 g, piscivorous, burrow nester which visits the colony at multiple times throughout the day when feeding young. The Common Murre is a large (950g), piscivorous, cliff nesting, diurnal species.

Since 1994 researchers from Canadian Wildlife Service (CWS) and Simon Fraser University have been visiting Triangle Island colony annually (April – August) to collect time series information on seabird breeding propensity, timing of breeding, hatch success, nestling growth and development, nestling diet, fledging success, adult survival and population trends. Coupled with available historical information, time series data for timing of breeding and production of fledglings are reported. In 2002, leadership of the Triangle Island program was passed from Doug Bertram to Mark Hipfner.

Timing of breeding

In 2002 the timing of hatching for the fish eating Rhinoceros Auklet and Tufted Puffin was approximately 1 week later than in 2002 (Figure 52). In contrast, Common Murres and Cassin's Auklet exhibited similar timing to values reported for the species in 2001. For the first time in the data series Common Murre chicks were observed prior to mean hatching dates of Tufted Puffins.

Fledgling production

Estimates of fledgling production, presented for this data set for the first time (Figure 53), incorporate the percentage of eggs laid that hatch and the percentage of hatchlings that fledge, multiplied by the average mass of chicks when they leave the burrow nest (fledge). For both Cassin's Auklet and Rhinoceros Auklet, fledgling production declines significantly with increasing sea surface temperatures in spring. The values for 2002 fall either on (Cassin's Auklet) or close to (Rhinoceros Auklet) the regression line. In general for both species, the values for 2002 appear closer to those observed from 1999 onwards than for values in the 1990s prior to the ocean climate regime shift.

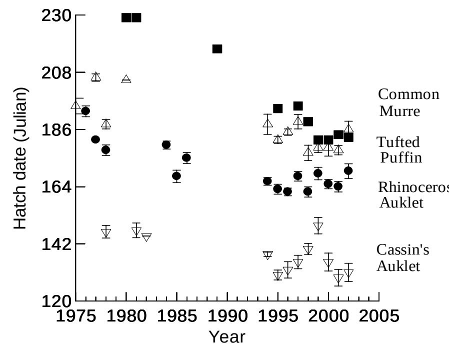

Figure 52. Timing of breeding for seabirds on Triangle Island, British Columbia, Canada (1975-2002). Values are mean hatch dates (with 95 % confidence intervals) for Cassin's Auklet (downward triangles), Rhinoceros Auklet (circles) and Tufted Puffin (upward triangles). Values for Common Murre (squares) are dates when nestlings were first observed.

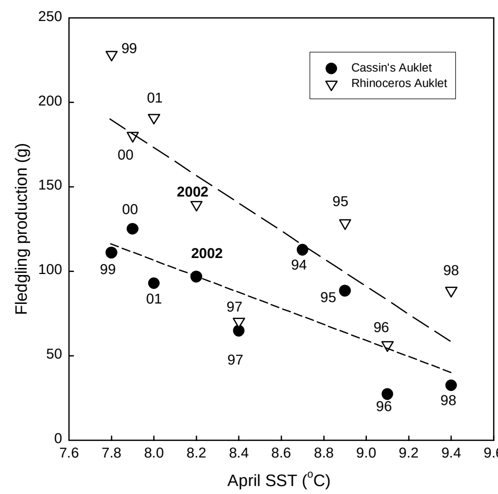

Figure 53. Consequences of interannual variation in spring SST for Cassin's Auklet and Rhinoceros Auklet fledgling production on Triangle Island, British Columbia, Canada (1994-2002). Fledlging production for Cassin's Auklet and Rhinoceros Auklets are

generally lower when spring is early and sea surface temperatures are warm. The slopes of the lines are statistically significant for both the Cassin's Auklet (slope -48 g/degree; F 1,7 = 10.6, P = 0.14) and the Rhinoceros Auklet (slope = -82 g/degree; F1,7 = 10.7; P = 0.017). Shown are estimates of fledgling production (calculated as hatching success * fledging success * mean fledging mass) in relation to the average SST in April at Pine Island (50°35'N 127°26') Lightstation.

North Coast

Average temperature and salinity

The annual average temperature at Bonilla and Langara Lighthouses are plotted in Figure 52, for the period 1962 to 2002. The average temperatures of the four years following the 1997/98 El Niño have been cooler than observed during most of the 1980s and 1990s. Salinity at Langara is continuing its long-term decline that began in the early 1970s.

Winter sea level and temperature

Water temperature at Bonilla Island (Figure 55a) and pressure-adjusted winter sea level at Prince Rupert (Figure 55b) have been used as indicators of winter currents in Hecate Strait and recruitment strength of Pacific cod. Generally, winters with high pressure-adjusted sea levels at Prince Rupert have strong currents through Hecate Strait and are poor recruitment years. "Winter" is the three month period of January to March inclusive.

The term "pressure-adjusted" denotes a time series of sea level plus local air pressure, reported in the same pressure or height units. For the graph in Figure 55 the air pressure observations at Prince Rupert Airport were converted to an equivalent height of seawater, assuming that one centimetre of seawater exerts a pressure of one millibar. Ocean currents respond to the total pressure above, which is the sum of seawater and air pressure as described above.

Two curves in Figure 55 represent long term changes in Prince Rupert winter sea levels. The blue line shows measured winter values since 1962. The red line is winter sea level with a correction to remove long-term sea level trend at Prince Rupert. This long-term trend is due to a combination of local land movement and a general global sea level rise, both of which are irrelevant to local cod recruitment. Therefore it is the red curve that denotes interannual variability in winter sea level relevant to cod recruitment in Hecate Strait and possibly Dixon Entrance.

Pressure-adjusted sea level at Prince Rupert in winter, 2002, continued its decline following the high in the El Niño winter of 1998. The level of 1401 centimetres at Prince Rupert in the 2002 winter was low enough to indicate reasonably good levels of Hecate Strait cod recruitment, with significantly higher recruitment than observed during the 1998 El Niño winter.

Set-up of eddies along the continental margin

With the aid of sea level measurements from satellites, we can observe the set-up and movement of 200-km wide anticyclonic (clockwise rotating) eddies off the West Coast of the Queen Charlotte Islands in British Columbia and the Alexander Archipelago of Southeast Alaska. Eddies are named Sitka and Haida after local geographic features along the coast where they are formed. One or two Haida Eddies form during most winters along the West Coast of the Queen Charlotte Islands, whereas Sitka Eddies form along the Alaska coast. Eddies were larger in winters of very strong El Niño events, such as 1982-1983 and 1997-1998. The 1998 eddy was the largest ever observed, whereas eddies formed in 1999-2002 have been much smaller. Generally, winters with very high pressure-adjusted sea levels at Prince Rupert will set up strong Haida Eddies. The coincidence of weak eddies and low pressure-adjusted sea levels at Prince Rupert in 2002 supports the reverse side of this relationship.

Much, if not most of the source water for Haida Eddies originates in Queen Charlotte Sound and Hecate Strait. The 1998 eddy contained about 5,000 cubic kilometres of seawater, a volume roughly equal to the entire volume Queen Charlotte Sound and Hecate Strait combined. Figure 56 displays images of eddies in the eastern Gulf of Alaska during four seasons in 2002. This image was prepared from observations by TOPEX/POSEIDON, Jason-1 and ERS-2 satellites, using software provided by the Colorado Centre for Astrodynamics Research. Contours show sea surface height at 5 centimetre intervals. Red denotes highest levels, blue denotes lowest.

Eddies in Figure 56 are denoted with labels of the form "Haida-2002a", which indicates in this case the first Haida Eddy to form in the year 2002. In February, only the eddies formed in the previous two years were clearly visible in the satellite imagery. By June, both of these eddies had drifted westward and decreased in height, and an additional five eddies had formed to the east. By September, only the 2002 eddies were still visible. Sitka-2001a had drifted westward past 150°W and Haida-2000a had decayed. In December, only three eddies could be observed in the images, with Haida-2002b barely visible.

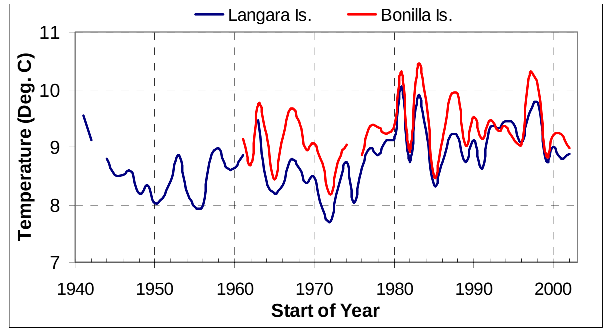

Figure 54a. Annual average temperatures in northern British Columbia.

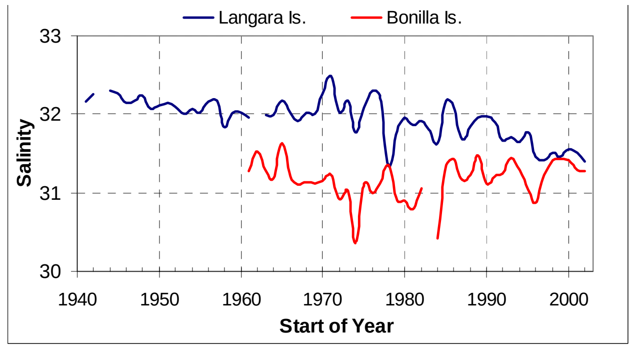

Figure 54b. Annual average salinities in northern British Columbia.

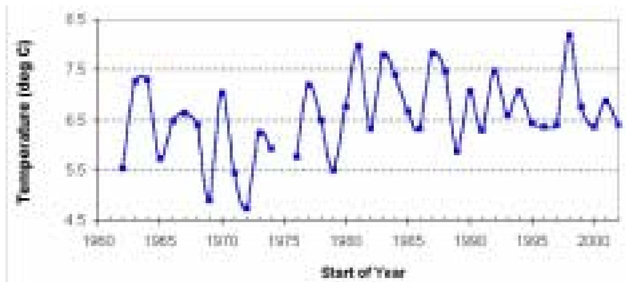

Figure 55a. Water temperature (°C) at Bonilla in winter (1962 – 2002).

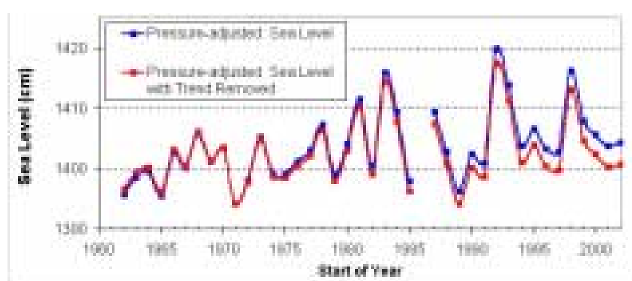

Figure 55b. Pressure-adjusted sea level at Prince Rupert in winter relative to Chart Datum.

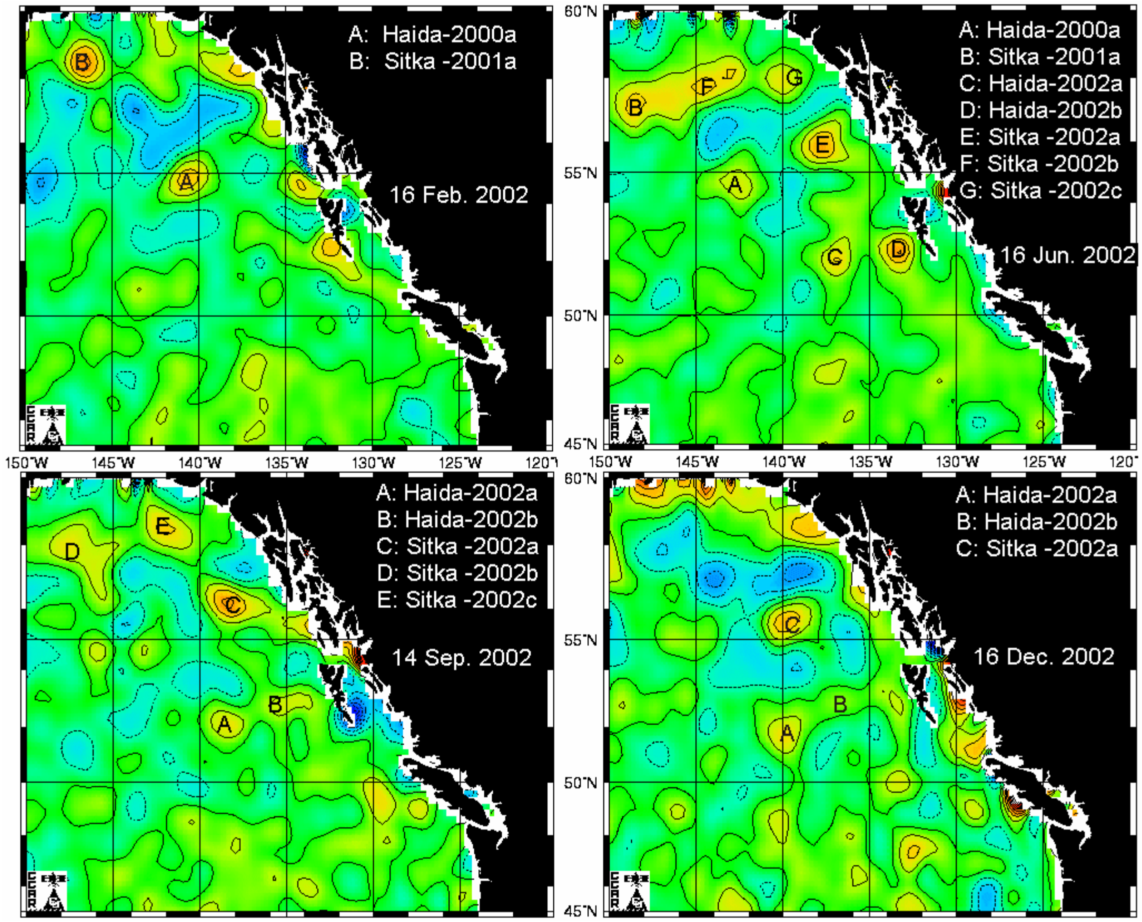

Figure 56. Eddies in the eastern Gulf of Alaska during four seasons in 2002.

Long-term sea level change

Monthly average sea levels are available since 1910 or so at several British Columbia ports. Annual average levels are presented in Figure 55 for the ports of Victoria, Tofino and Prince Rupert. The record at Victoria is almost continuous, other ports are missing data through the early years.

Elevations at each port are measured relative to benchmarks in nearby bedrock. A long-term rise or fall at each port can be attributed to both vertical bedrock motion and sea level rise. At Tofino the upward movement of the bedrock exceeds the rate of sea level rise; therefore the local sea level is falling at a rate of 14 centimetres per century. At Victoria and Prince Rupert the local sea level is rising, at rates of 6 and 11 centimetres per century respectively. Red lines denote a linear trend through each series computed over the length of the record, showing increasing relative sea level at Victoria and Prince Rupert, and decreasing relative sea level at Tofino. Any cumulative relative sea level reduction at Tofino is expected to be reversed abruptly during a major earthquake along the Cascadian Subduction Zone west of Vancouver Island.

Years marked by large diamonds denote major El Niño events that coincided with high sea levels at these ports. Elevations at Tofino and Victoria have declined since the latest El Niño in 1997/98, and have been well below the long term trend for each of the past three years, whereas Prince Rupert sea levels have maintained heights close to the long term trend.

Global sea level rise has been 10 to 20 centimetres per century for the past 100 years. Over the next 100 years, according to the most recent report of the Intergovernmental Panel on Climate Change, one can expect global sea level to rise an additional 9 to 90 centimetres. This range of almost 80 centimetres acknowledges the uncertainty in predicting sea levels under a wide range of expected climate variability and change. Both glacier melting and ocean expansion due to warming contribute to this rise. The cumulative sea level rise along the British Columbia coastline in the next 100 years is likely to be within a few centimetres of the global rise.

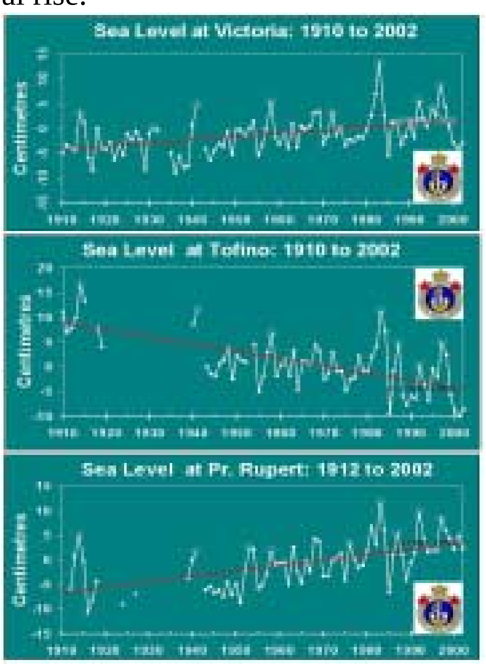

Figure 57. Long-term sea level change. Monthly average sea levels are available since 1910 or so at several British Columbia ports. Annual average levels are presented for the ports of Victoria, Tofino and Prince Rupert. The record at Victoria is almost continuous, other ports are missing data through the early years

Incorporating an environmental index in the assessment of Pacific Cod

Sea level at Prince Rupert during the spawning period (January – March) is used as an index of transport. High sea levels indicate high transport through Hecate Strait, resulting in low recruitment success due to removal of cod eggs and larvae from the area. This index of sea level height in Prince Rupert was incorporated as an environment covariate in the stock assessment model for Pacific cod in Hecate Strait (Sinclair et al. 2001). Inclusion of the sea level series improved the assessment model fit significantly. Sea level conditions were unfavourable for most of the 1990s; however, sea levels began to decline following the 1998 El Niño winter, and continued to decline through 2002. The sea level at Prince Rupert in 2002 was low enough to indicate reasonably good levels of Hecate Strait cod recruitment.

Herring in Hecate Strait

The exploitable biomass of herring in the Hecate Strait area is an amalgamation of the three major migratory stocks in the Queen Charlotte Islands, Prince Rupert, and in the Central Coast. Over the past decade, abundance in the Queen Charlotte Islands has been depressed whereas abundance in both Prince Rupert and the Central Coast has remained at healthy levels (Fig. 58,60,62). Levels of recruitment to the Queen Charlotte Islands have been depressed (Fig. 59) with 6 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 recent year-classes in the Queen Charlotte Islands have remained weak while those in the Prince Rupert District and Central Coast have been getting stronger suggesting better survival conditions in the latter areas. Abundance in the Queen Charlotte Islands and Prince Rupert is expected to remain similar to recent levels while the Central Coast will most likely decline slightly from the levels of 2002.

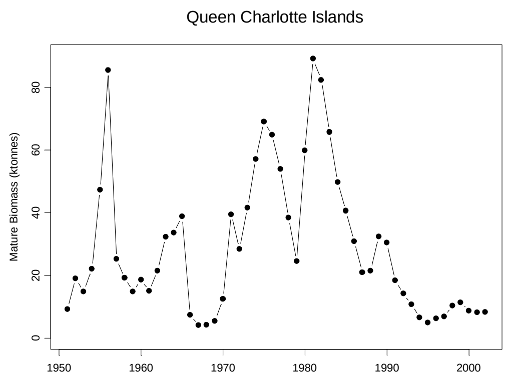

Figure 58. Queen Charlotte Islands herring abundance.

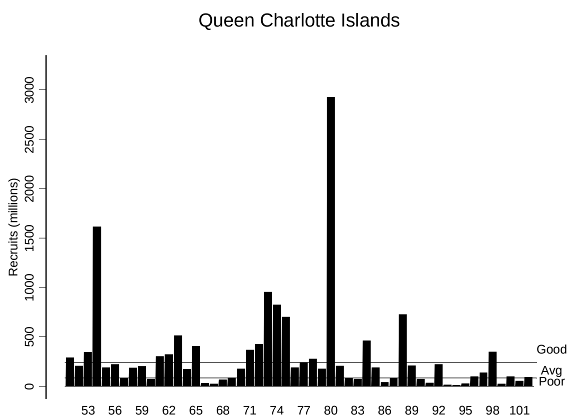

Figure 59. Interannual variability and decadal trends in recruitment to the Queen Charlotte Islands herring stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown. Note that 5 of the last 10 recruitments have been ‘poor’.

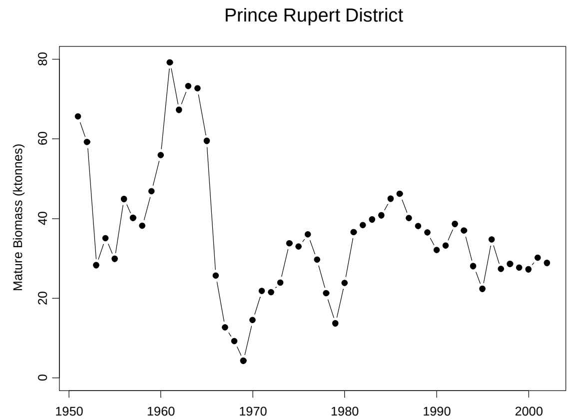

Figure 60. Prince Rupert District herring abundance.

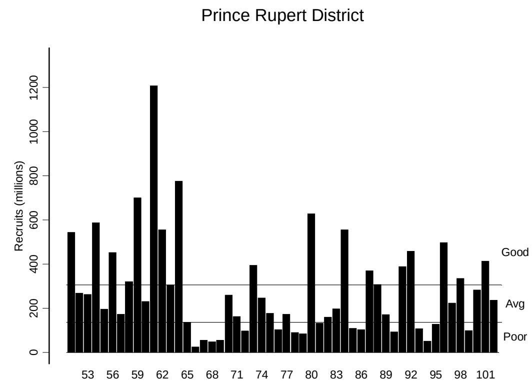

Figure 61. Interannual variability and decadal trends in recruitment to the Prince Rupert District stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown. Note that ‘good’ recruitments have occurred almost every four years since 1980.

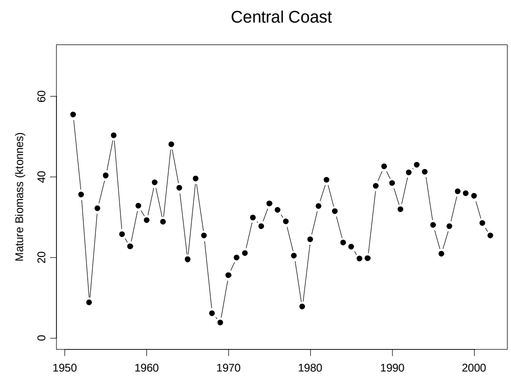

Figure 62. Central Coast herring abundance.

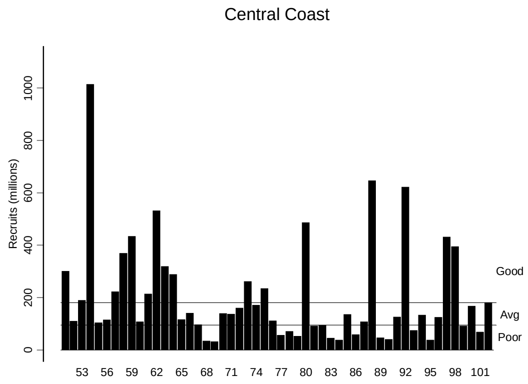

Figure 63. Interannual variability and decadal trends in recruitment to the Central Coast stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

Strait of Georgia

Fraser River

Due to slightly higher than normal snow pack levels throughout its watershed, the discharge rate for the Fraser River in 2002 was close to the long term average during most of the year. The freshet peaked in the middle of June with maximum discharge reaching large values of about 10000 $m^3\ s^{-1}$ (Fig. 64).

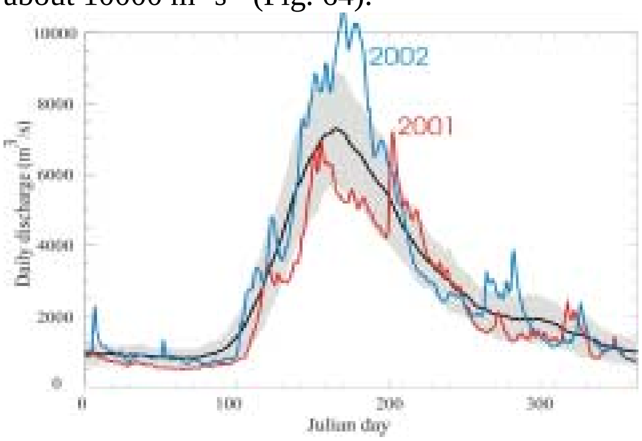

Figure 64. Fraser River discharge at Hope. The black line indicates the long term average discharge rate, and the shaded area the standard deviation about the mean.

The mean annual daily discharge of 2909 m^3/s was slightly higher in 2002 than the long term average of 2720 m^3/s (Fig. 65). Also, the timing of the freshet was very close to the long term average, with maximum flow rate reached around June 19 2002. This follows a three year period (1999-2001) for which the maximum freshet discharge was slightly later than the long term average.

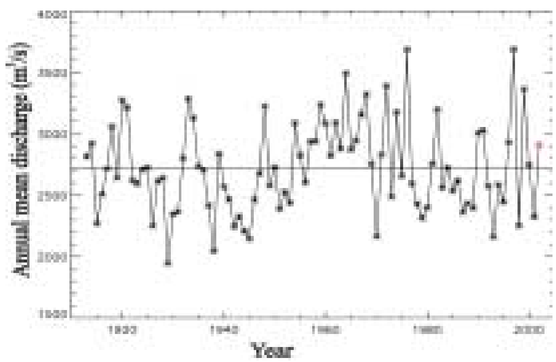

Figure 65. Annual mean discharge for the Fraser River at Hope.

Due to a lower than average snowfall this winter, the present snowpack is significantly lower than normal over most of the province. Fig. 64 shows that, as of April 1 2003, the snowpack in the Fraser basin is between 70% and 85% of normal range. This will likely result in a freshet with smaller discharge than the long term average for the Fraser.

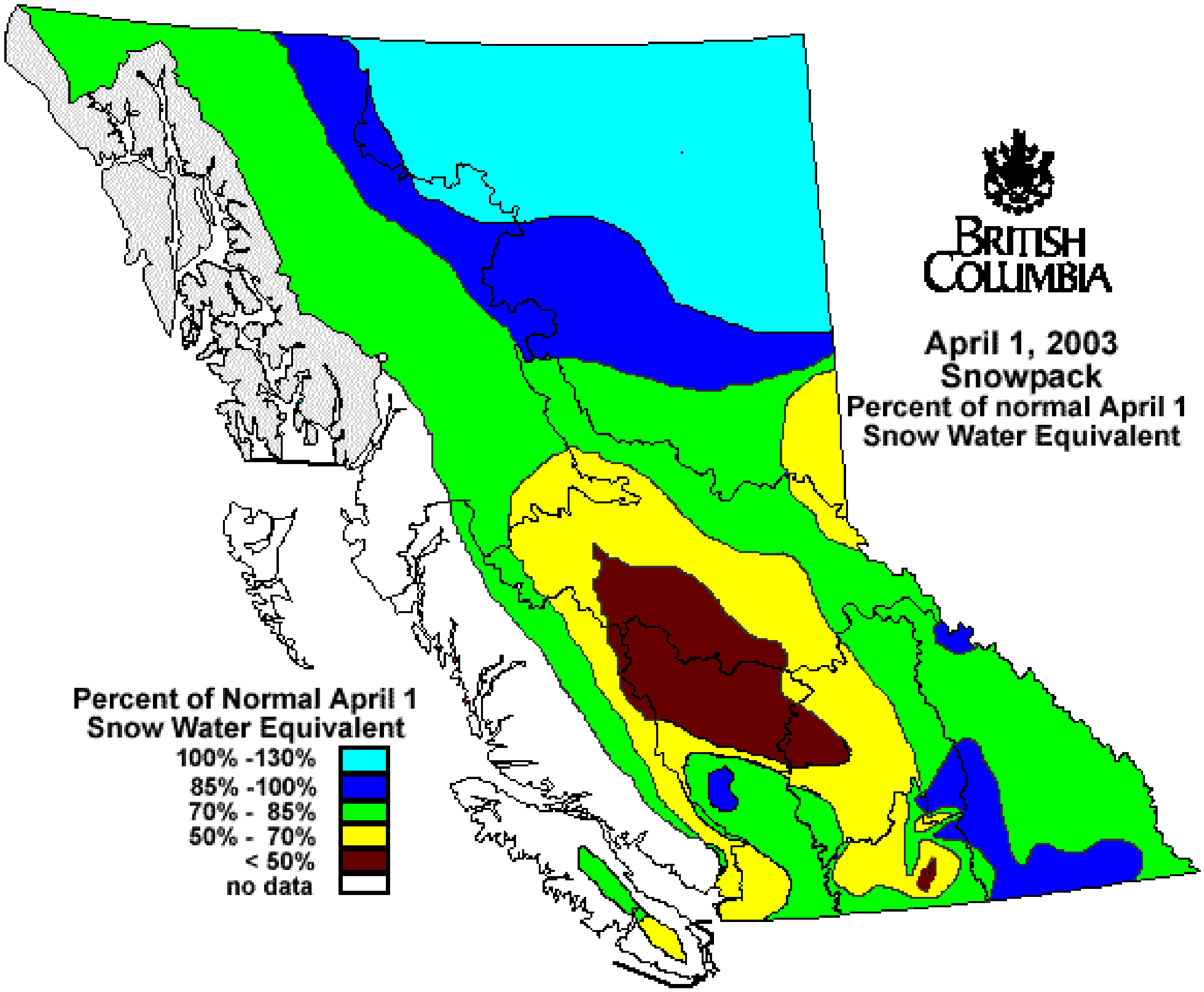

Figure 64. Snow water equivalent as of April 1 2003, expressed as a percentage of the 1971-2000 normal.

Temperature and salinity

Sea surface temperature (SST) in the strait remained above normal for most of 2002, with SST anomalies of about 1°C in the second half of the year (Fig. 67). The sea surface salinity (SSS) remained higher than average for the most of the year, with SSS anomalies varying from about 1 to 2 psu, except for the months of July and August following the large Fraser freshet discharge. The data in Fig. 67 are monthly values measured at Entrance Island. Similar conditions were recorded at other lighthouse stations as well as at the Nanoose Bay station.

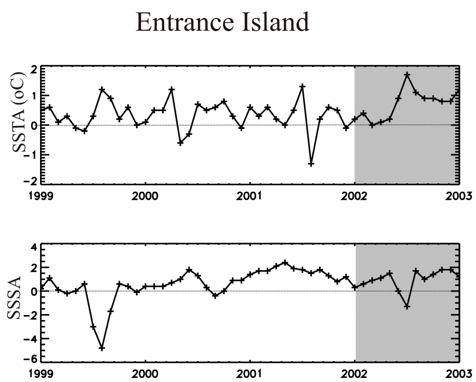

Figure 67. Monthly sea surface salinity (SSSA) and temperature (SSTA) anomalies measured at Entrance Island.

Figure 68 gives the time series of near bottom temperature (the average temperature below 300 m) measured at Nanoose Bay, located in central deep basin of the Strait of Georgia. Since the warm temperatures associated with the last El Niño of 1998, the deep Strait of Georgia has remained cool relative to the previous two decades. This corresponds to the 1998/99 "regime shift" indicated in other coastal time series. Conditions during 2002 seem to be a continuation of this relatively colder period (see section on Indices of decadal variability).

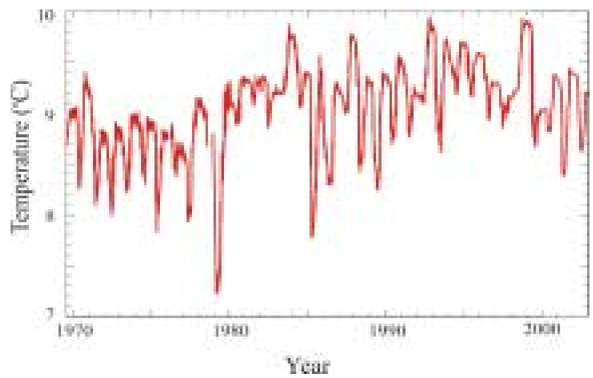

Figure 68. Near bottom temperature measured at the Nanoose Bay station.

Salmon

The new regime that was seen in climate indicators in May of 1998 and in the Strait of Georgia in 2000 persisted through 2002 and should continue through 2003. The improved productivity of the Georgia Basin is evident in the improved growth of juvenile Pacific salmon, the exceptional production of pink salmon that returned to the Fraser River in 2001, the excellent return of sockeye salmon to the Fraser River in 2002, and the largest biomass of Pacific herring in 2003 since 1952. We use the length of day index (Figure 69) to show that the new regime shifted in 1998 and is persisting, despite changes in the Strait of Georgia in 2002 and despite a change in the Pacific Decadal Oscillation (PDO) back to a positive index.

In 2002, in the Strait of Georgia, we observed that juvenile salmon were less abundant and smaller than in 2000 and 2001 (Table 1, Table 2). We also observed that euphausiids were smaller. We interpret these changes to be part of the natural interannual variability within the current regime. The smaller size of juvenile salmon and the reduced catch per unit effort (CPUE) is an indication of reduced marine survival for the brood years of the various salmon species that entered the Strait of Georgia in 2002. Thus, reduced abundances resulting from reduced marine survival should be expected when these brood years return in subsequent years.

We observed an approximate three-fold increase in river lamprey wounds in the Strait of Georgia in 2002 compared to the rates observed from 1997-2001 (Table 3). River lamprey are a major predator of juvenile Pacific salmon. The apparent increase in abundance would indicate that higher predation mortality of juvenile Pacific salmon occurred in 2002. River lamprey are anadromous fishes that rear in the sediments of the lower Fraser River and feed in the summer in the Strait of Georgia. Their main prey are herring, and the high abundance of Pacific herring may result in even larger abundances of river lamprey in the future. It is believed that sturgeon are a major predator of lamprey in the Fraser River, and the current reduced abundance of sturgeon in the Fraser River may also be contributing to the increased abundances of river lamprey.

We are recording a progressive decline in the diversity of species in our catches within the Strait of Georgia over the past 6 years. We have no explanation for these changes, although interspecies interactions within the surface waters in the Strait of Georgia in the 1990s may have some role. The Strait of Georgia has a broad range of species that are important components to the ecosystem and this diversity is a key indicator of the overall health of the ecosystem. Many of these species are not of commercial importance and information is therefore not available from sport or commercial fisheries. For these reasons, it is important that we continue to monitor species diversity within the Strait of Georgia.

In the spring and summer of 2001, coho returned to the Strait of Georgia as juvenile adults for the first time since 1994. It appears that the change in behaviour that started for the first time in the 1990s had been reversed and coho would be available for the traditional recreational fishery in the Strait. However, in 2002, coho did not return to the strait despite good growth of juveniles in 2001 and an apparent trend to higher surface salinities in the Strait of Georgia. Beginning in 2002, surface salinities remained lower than in 2001. In June of 2002, there was a reduction in surface salinity that characteristically is associated with the peak of Fraser River discharge (Figure 70). However, surface salinity in July continued to decline to levels that were observed in 1999, but still lower than in the mid-1990s. At the same time, we observed that catches of juvenile coho salmon were largest in the northern part of the Strait of Georgia. We propose that juvenile adult coho salmon either did not return to the Strait in early 2002 because of this low salinity or that those which did return in the early spring left as the salinity declined in the summer. It is apparent that the behaviour of leaving the Strait of Georgia that started in the 1990s is continuing.

There has been a significant change in the pattern of flow of the Fraser River in recent years. The trend towards earlier flows has changed to later flows (Figure 71). In fact, the percent of the total flow in 2002 that occurred in March was the lowest in over 50 years. We show the percentage of the total flow that occurred in March and April (Figure 72) that clearly show this trend. We also show the variability in the total annual discharge (Figure 73) increased about the same time and was similar to the variability observed in the late 1990s through to the mid 1970s.

	1997	1998	1999	2000	2001	2002
COHO	13.6	27.1	33.8	98.0	99.0	37.2
CHINOOK	41.7	40.2	34.7	75.5	57.9	39.1
CHUM	23.8	109.2	84.2	285.5	154.4	21.8
PINK	0.5	46.8	0.3	68.6	0.8	53.3
SOCKEYE	65.0	10.5	15.1	10.8	23.3	4.4

Table 1. Catch per unit effort (CPUE; catch per hour standardized) of juvenile salmon in the Strait of Georgia for July surveys from 1997-2002.

		1997	1998	1999	2000	2001	2002
COHO	Anom	-22.32	-8.94	-13.94	18.13	2.89	-12.98
	Std Err	22.54	23.78	22.30	23.65	21.04	22.72
CHINOOK	Anom	1.70	-17.77	0.41	5.09	7.39	-2.42
	Std Err	33.83	36.87	37.41	36.86	32.30	28.76
CHUM	Anom	-2.53	-1.15	-8.29	3.83	6.37	-9.46
	Std Err	25.63	14.95	19.35	17.98	17.47	15.18

Table 2. Fork length (mm) data (anomalies and standard errors) for juvenile coho, chinook and chum salmon in the Strait of Georgia for July surveys from 1997-2002. Anomalies are calculated from overall average length of each species over the entire July surveys.

		1997	1998	1999	2000	2001	2002
Coho	No. Fish	520	1220	1639	3361	2957	1887
	Scars	6	20	14	1	20	63
	Index	**1.15**	**1.64**	**0.85**	**0.03**	**0.68**	**3.34**
Chinook	No. Fish	1585	1411	1664	1994	2211	1984
	Scars	21	29	19	7	38	100
	Index	**1.32**	**2.06**	**1.14**	**0.35**	**1.72**	**5.04**
Chum	No. Fish	907	1206	1227	2609	2192	1067
	Scars	5	35	4	44	38	27
	Index	**0.55**	**2.90**	**0.33**	**1.69**	**1.73**	**2.53**
Sockeye	No. Fish	1655	371	641	473	877	227
	Scars	40	4	5	3	21	12
	Index	**2.42**	**1.08**	**0.78**	**0.63**	**2.39**	**5.29**
Pink	No. Fish	-	1432	-	1985	-	2188
	Scars	-	30	-	36	-	50
	Index		**2.09**		**1.81**		**2.29**
	AVG INDEX	1.36	1.95	0.78	0.90	1.63	**3.70**

Table 3. Lamprey scars (wounds) observed on juvenile salmon in the Strait of Georgia 1997 to 2002. Index is percent of observed fish with lamprey scars.

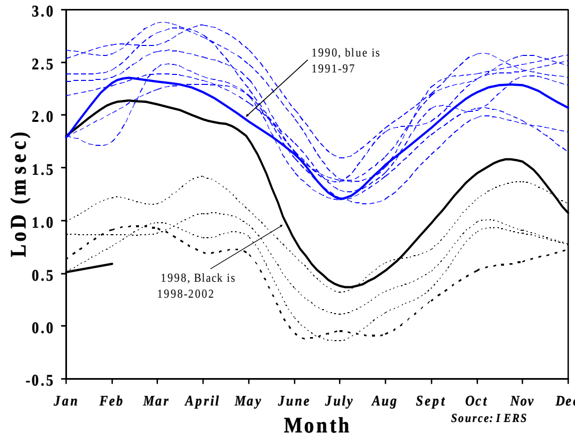

Figure 69. Length of day anomaly. Duration of daily Earth rotation either excess of or short of 24 hrs. Blue dashed lines represent years 1990-97, with heavy solid blue line as 1990, the year of regime shift. Black dotted lines represent years 1998 to present (Feb., 2003). The heavy black line represents 1998 (year of regime shift), and the dashed black line represents 2002. Note both the seasonality and the regime differences. Data from International Earth Rotation Service, Paris, France.

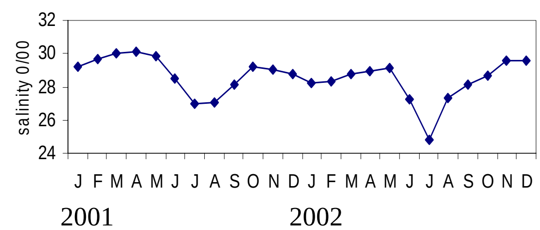

Figure 70. Surface salinity at Chrome Island 2001 and 2003.

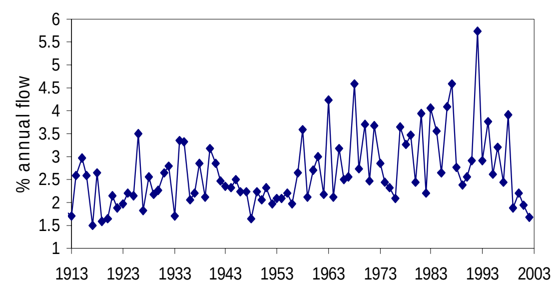

Figure 71. March Fraser River flow at Hope as a percentage of total annual flow (1913-2002).

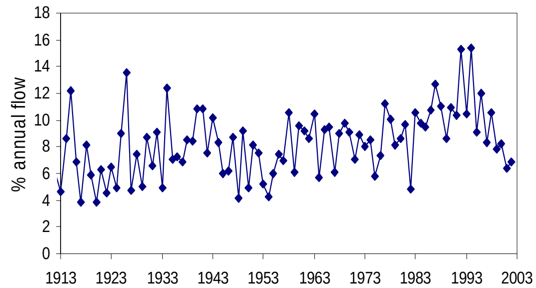

Figure 72. March and April Fraser River flow at Hope as a percentage of total annual flow.

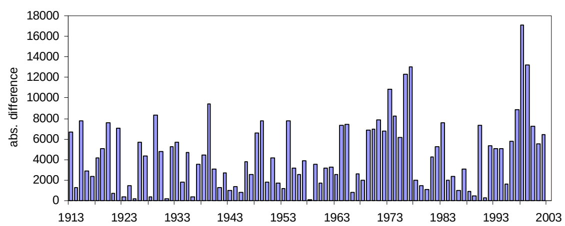

Figure 73. Fraser River flow at Hope represented as the absolute interannual difference in Total Annual flow (eg. Interannual difference$_{1978}$= (1977-1978)).

Herring

The Pacific herring stock in the Strait of Georgia migrates inshore in the fall and leaves the Strait in the spring following spawning. Survival conditions for juvenile herring in the Strait of Georgia have been unusually good during the last decade. Abundance of herring in the Strait of Georgia reached a recent high level in 2002 at well over 100,000 tonnes (Fig. 74) rivaling the historical high of 1955. Recruitment to this stock has been very strong with 9 of the last 10 year-classes being average or better (Fig. 75). Juvenile rearing conditions within the Strait of Georgia appear to be the main determinant of recruitment success for this stock since most juveniles do not leave the area until their second summer. Surveys of juvenile herring abundance within the Strait of Georgia for 2000 and 2001 corresponding to the 2003 and 2004 recruitments suggest that both should be 'good' year-classes. The recent strong recruitment should maintain the stock at very healthy levels for the next few years.

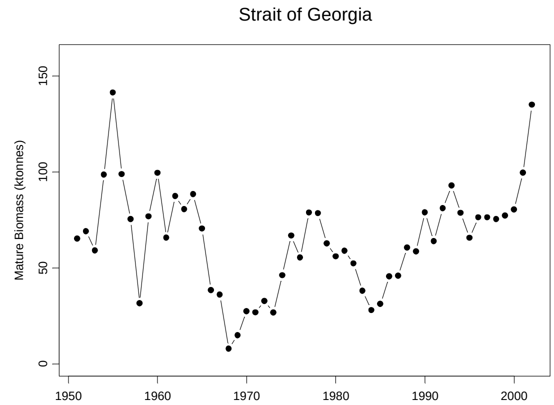

Figure 74. Strait of Georgia herring abundance.

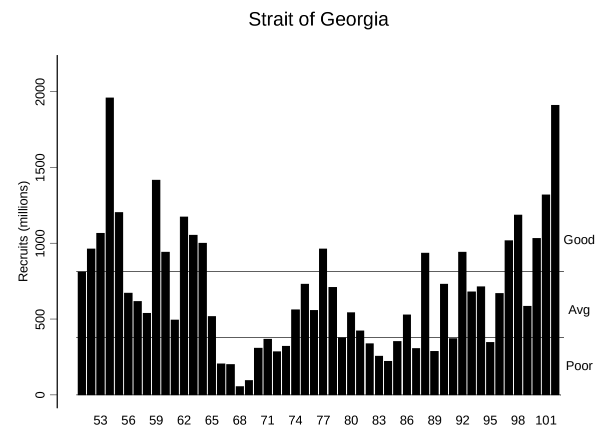

Figure 75. Interannual variability and decadal trends in recruitment to the Strait of Georgia stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 6 of the last 10 year-classes have been 'good'.

Fishery Interpretation and Speculative Results

This section contains both interpretative and speculative information regarding major fish stocks for the West Coast of Vancouver Island and the Strait of Georgia regions. Results are based on observations but might be subject to differing interpretation.

Numerous environmental factors effect ecosystem re-organization and the health of British Columbia's major commercial fish species. Water temperature, wind speed, ocean currents, mixed layer depth and upwelling intensity are among the many variables that are commonly used as indicators of fish stock variability and the impact of the ocean on the timing and production of prey and the behaviour of predators. Fishing and salmon enhancement further complicate the dynamics of the ecosystem response. Because there has been little research linking west coast fisheries to regional and basin-scale oceanographic/ meterological factors, we can only speculate on the impacts.

West Coast Vancouver Island

Salmon: Total Pacific salmon catches will remain below the historic average of 60 000 tonnes and total catches from all countries will continue to decline from historic high levels, in conjunction with changes in large-scale climate indicators that appear to have changed trends in 1998. From 1999 to 2001 the total catches of Pacific salmon in Canada were the lowest on record (starting in 1925). Catches in 2002 remain low, but there are indications that the productivity of Pacific salmon is improving in the southern range of their distribution. It is important to note that large escapements were recorded in 2001 for a number of species however, these were related to management constraints. For example, the escapement of pink salmon to the Fraser River was twice the highest recorded and sockeye escapements in Barkley Sound were the highest recorded. Many coho stocks along the coast also had exceptional escapements. Sockeye returns to the Fraser River in 2002 were much higher than forecast. Finally, chinook returns to the Columbia River in 2001 and 2002 were also among the highest in the century. Thus, it appears that climate and productivity conditions have improved for all species of salmon on the west coast.

Herring: Herring on the west coast of Vancouver Island are likely to show some trend of increasing abundance given the reduction in the abundance of predators in the area. Since ocean conditions were more favourable for herring survival in 2000 and 2001, we expect an improvement in recruitment to the stock, beginning in 2003.

Sardine: Sardines reappeared off the west coast of Vancouver Island in 1992. During the 1990s their distribution expanded northward from southern Vancouver Island through Hecate Strait to Dixon Entrance. However, in 2001 and 2002, the distribution of sardines in B.C. was again reduced and limited to areas around western and northern Vancouver Island.

North Coast Major

Pacific Cod: A transport hypothesis was used to explain recruitment anomalies for the Pacific cod stock in the Hecate Strait area, and inclusion of an index of sea level height improved the assessment model fit for Pacific Cod. High sea levels indicate high transport, which removes Pacific cod eggs and larvae from Hecate Strait, resulting in poor recruitment. High transport is associated with lower production, lower target stock biomass, and lower target fishing mortality. Throughout the 1990s sea level conditions were unfavourable for recruitment, but sea levels have decreased since the El Niño winter of 1998, and have continued to decline in 2002. The sea level at Prince Rupert in 2002 was low enough to indicate reasonably good levels of Hecate Strait cod recruitment, and significantly higher recruitment than was observed during the 1998 El Niño winter.

Herring: Herring stocks in the Hecate Strait area consist of migratory stocks from the Queen Charlotte Islands, Prince Rupert and central coast areas. For the past ten years, recruitment and abundance of the Queen Charlotte Island stock has been low while recruitment and abundance of the Prince Rupert and Central Coast stocks have been generally good. Recently, survival conditions have deteriorated in the Central Coast but have improved in the Prince Rupert and Queen Charlotte Island regions. Abundance is therefore expected to increase in the Queen Charlotte Island and Prince Rupert regions, and decline in the Central Coast region.

Strait of Georgia

Salmon: Despite the persistence of the new regime that began in May 1998, conditions in the Strait of Georgia in 2002 were different than in 2001 and 2000. In 2002 juvenile salmon were smaller and less abundant, euphausiids were smaller, and there was a dramatic increase in river lamprey predation on juvenile salmon. Together these changes contributed to a reduction in marine survival of the 2002 mean-entry year. Based on this, we expect reduced abundances from the 2002 mean entry-year for the various Pacific salmon species in subsequent years.

Unlike 2001, juvenile-adult coho did not reside in the Strait of Georgia in 2002. Because the size and condition of juveniles entering the Strait in 2001 was significantly greater than that in 1997-1999, we propose that, unlike the 1990s, the reason the adults failed to return in 2002 was not related to juvenile size. We attribute the recent failure to return to anomalously low sea surface salinity in the southern Strait. The low salinity water left the Strait through Juan de Fuca in late summer. At the same time, high catches of juveniles were observed in the northern Strait.

It is probable that future returns of coho to the Strait will be dependent on summer surface salinity, which is related to Fraser River discharge. There are indications that the pattern of Fraser River flows is changing, both in the timing and in the year to year variation in total discharge. We expect that this increased variability will be reflected in coho returns.

Herring: The abundance of herring in 2002 is considerably stronger than recent years at well over 100,000 tonnes. Current abundance is second only to the historical high of 1955 (140,000 tonnes) and well above the lowest abundance estimated in 1968 (11,000 tonnes) in the time series from 1951-2002. The abundance of this stock has been increasing steadily since the recent low of the mid-1980s. Juvenile surveys in 2000 and 2001 suggest the trend of recent strong recruitment is likely to continue at least over the next few years.

Contributors

Richard Beamish
Doug Bertram
Bill Crawford
Patrick Cummins
Howard Freeland
Mark Hipfner
Jackie King
David Mackas
Dianne Masson
Sandy McFarlane - Chair
Chrys Neville
Ron Perkin
Jake Schweigert
Rusty Sweeting
Ron Tanasichuk
Richard Thomson
Marc Trudel
David Welch

References

Conser, R.J., K.T. Hill, P.R. Crone, N.C.H. Lo, D. Bergen. 2002. Stock assessment of Pacific sardine with management recommendations for 2003. Submitted to the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland OR. Available at http://swfsc.nmfs.noaa.gov/frd/Coastal%20Pelagics/Sardine/sardine_2002_revised.pdf

Hare, W.R., N.J. Mantua and R.C. Francis (1999): Inverse production regimes: Alaskan and west coast salmon. Fisheries, 24, 6-14.

Mackas, D.L., R.E. Thomson and M. Galbraith. 2001. Changes in the zooplankton community of the British Columbia continental margin, and covariation with oceanographic conditions, 1985-1998. Can. J. Fish. Aquat. Sci. 58: 685-702.

Mantua, N.J., W.R. Hare, Y Zhang, J.M. Wallace and R.C. Francis (1997): A Pacific interdecadal climate oscillation with impact on salmon production. Bull. Amer. Meteror. Soc., 78, 1069-1079.

McKinnell, S.M. and D.L. Mackas. 2003. Intercalibrating SCOR, NORPAC & bongo nets and the consequences for interpreting decadal-scale variation in zooplankton biomass in the Gulf of Alaska. Fisheries Oceanogr. 12: 126-133.

Peterson, W. T, Brodeur, R. D., and Pearcy, W. G. 1982. Food habits of juvenile salmon in the Oregon coastal zone. Fish. Bull. 80:841-851.

PICES Scientific Report #21 (C.B. Miller, ed.). 2002. Report of the PICES 2002 Volunteer Observing Ship Workshop. 38 pp.

Tanasichuk, R. W. 2002. Implications of interannual variations in euphausiid population biology for fish production along the south-west coast of Vancouver Island: a synthesis. Fish. Oceanogr. 11:18-30.

Sinclair, A.F., Martell, S., and Boutillier, J. 2001. Assessment of Pacific Cod off the West Coast of Vancouver Island and an Hecate Strait, Nov. 2001. Canadian Stock Assessment Secretariat Research Document 2001/159.

Tanasichuk, R. W. 1997. Influence of biomass and ocean climate on the growth of Pacific herring (*Clupea pallasi*) from the southwest coast of Vancouver Island. Can. J. Fish. Aquat. Sci. 54:2782-2788.

This report is available:

PSARC Secretariat
Pacific Biological Station
Nanaimo, BC V9T 6N7
Phone: (250) 756-7208
Fax: (250) 756-7209
E-Mail: psarc@pac.dfo-mpo.gc.ca
http://www.dfo-mpo.gc.ca/csas

ISSN 1480-4913 (for English series)

Correct citation for this publication:

DFO, 2003. 2002 Pacific Region State of the Ocean. DFO Science Ocean Status Report 2003 (2003).