2001 Pacific Region State of the Ocean

Background

This report documents the state of the ocean for the year 2001. 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 2001 reflected the moderate La Niña conditions in the equatorial Pacific which began in 2000, following several previous years of strong El Niño like conditions (highlighted by the major events of 1991/92 and 1997/98). However, ENSO cycles are only one mode of variability that affects fish population dynamics. Decadal-scale variability on regimes are increasingly being recognized as causing sudden shifts in 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 the changes that were described in last year's report. These changes were observed in large-scale climate indices and resulted in generally improved

productivity for a number of species. For example, record escapements were recorded for Fraser River pink salmon and Barkley Sound sockeye salmon. Coho salmon escapements were reported to be high for many coastal systems. This appears to reverse the state characterized by lower productivity throughout the 1990s. 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. The accumulating evidence of the profound impacts of climate and oceans on fish dynamics is an indication that the assessment of fishing impacts with respect to future production will have to include bio-physical data.

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- Climate/ocean conditions that shifted in 1998/1999 continued.

- Global air temperatures continue to be significantly higher than the 1961 – 1990 average, but showed some decrease from the record levels reached in 1998. In contrast, coastal temperatures remained near normal in BC in 2001, following the pattern of air temperatures over land areas being more affected than those over the oceans.

- Southern Oscillation Index values for 2001 appear to be near the long term mean.

- In 1999 Pacific Decadal Oscillation entered a negative phase, after a 22 year positive phase. A negative phase is associated with a cooling of the surface waters in the eastern North Pacific and a warming in the central and western North Pacific. The negative phase has persisted, with some short periods of positive numbers similar to the period before 1977.

- The Aleutian Low Pressure Index measured extremely intense Aleutian Low pressure values in 1998, and moderate intensity was measured in 1999 and 2000, with a slight increase in intensity in 2001. 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.

- The Atmospheric Forcing Index for 1999 and 2000 were near normal following an extreme positive value in 1998. 2001 indicates a return to moderate positive values, which in general, represents stronger Aleutian lows, above average frequency of westerly and southwesterly winds, and a winter warm phase of the Pacific Decadal Oscillation which is characterized by a spatial pattern of cooler sea surface temperature in the central North Pacific and warmer coastal waters.

Summary by Region

Gulf of Alaska

- In 2001, the Gulf of Alaska surface waters were cooler than the long term average (1961-1990) as they were in 2000. At depth, there was no significant deviation from long term average temperatures.

- Concentrations of nitrate continued at long-term average levels.

- Seasonal timing of the annual *Neocalanus* biomass peak was very early (late April-May) in the mid 1990s but has shown a return to long term average timing (mid-late June) since 1999, continuing through 2001.

- Northern resident killer whales were commonly spotted in the Queen Charlotte Strait and Johnstone Strait, similar to the occurrences in the 1970s and 1980s, but different from the mid-to late-1990s when they were rarely observed in the Queen Charlotte Strait. Large aggregations of humpback whales were reported in Hecate Strait, and several were reported near the northern tip of the Queen Charlotte Islands in late summer.

- The distribution and biomass of phytoplankton were similar to those observed in previous years. However, coccolithophorids were not dominant as in the previous year.

West Coast of Vancouver Island

- Sea surface temperatures from off the west coast were below the 1990-1996 mean for most of the year. Subsurface temperatures in the La Perouse area were near the 1990-1996 mean throughout the year.

- In the Estevan Point region, temperatures at 25 m (Station E01) were near or above the 1990-1996 mean throughout the spring, below the 1990-1996 mean in June and July, and returned to near the 1990-1996 mean by October. Temperatures at 35 m and 75 m were near to below the 1990-1996 mean until August-September, then showed above mean spikes at the beginning of September and October.

- In the Brooks Peninsula region, subsurface temperatures were near or below the 1990-1996 mean from May to July and normal or above the mean from August to September.

- Sea surface salinity for offshore Vancouver Island and the inner continental shelf area was near or above the 1990-1996 mean for most of the year. Surface salinities measured at Amphitrite Point were above the 1990-1996 mean for most of the year, and comparable to conditions in the late 1970s, early 1950s and late 1930s.

- Subsurface salinities measured in the La Perouse area were below normal until May when they returned to near 1990-1996 mean values. Subsurface salinities in the Estevan Point region were near or above the 1990-1996 mean until October, with a below the mean phase in January and at the beginning of August at 35 m and 75 m. Subsurface salinities in the Brooks Peninsula region were near or above the 1990-1996 mean from June to July, and near or below the mean in August and September.

- There were a few days of strong southeasterly (downwelling favourable) winds in January and March, while the October-December period was completely dominated by these events. Moderately strong upwelling favourable northwesterly winds were recorded through the year, particularly May-October. Upwelling-favourable winds throughout 2001 were similar in magnitude to 1992 and 1990, and stronger than most years over the last decade.

- The Pacific Fisheries Environmental Laboratory (PFEL) Upwelling Index from the west coast of Vancouver Island and northwest Washington

State marks a return to 1990-1996 mean values from below average upwelling since 1993. Upwelling was near or above the 1990-1996 mean during the summer.

- Mean alongshore currents were near the 1990-1996 mean throughout the winter, and near mean values or more strongly equatorward than the 1990-1996 mean in the summer. Daily mean speeds peaked at about 40 cm s^{-1} at 35 m in January along the slope, 80 cm s^{-1} at 25 m in January at Estevan Point, and 60 cm s^{-1} in February at Brooks Peninsula. As noted last year, inner shelf currents were predominantly poleward, with short term reversals throughout the year. Summer reversals were possibly caused by strong northwesterly winds.

- Water levels were below the 1990-1996 mean until spring. Storm activity in November may account for the brief periods in that month where water levels were 40 cm above normal. The below average water levels at the beginning of 2001 are comparable to those recorded during La Ninas of 1988-1989 and 1975-1976. Wave heights were near or below the 1990-1996 mean throughout the year, except for short-term above mean heights recorded in January, March, and August through December. This marks a change from predominantly below-mean wave heights in 1999 and 2000.

- As was noted last year, concentrations in all major zooplankton taxa rapidly returned to baseline (near 0 anomaly) levels in 1999, following a trend of more "southerly" copepod fauna dominating the assemblage during the 1990s. One exception this year is an anomalous increase in Pteropods.

- Stocks of *Pandalus jordani* shrimp continue to build on the southern part of the continental shelf. Age composition of the catches were similar this year to catches in 2000. If present conditions continue a build-up of shrimp is expected along the west coast of Vancouver Island over the next 6 to 8 years.

- Herring recruitment off the west coast of Vancouver Island has been declining since 1977. Abundance in 2001 remained low, and recruitment has been poor for 6 to 10 years. Warm ocean temperatures tend 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. Ocean conditions were more favourable for herring survival in 1999 and 2000, and may result in improved recruitment to the stock in 2002 and 2003.

- 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, the 2001 trawl survey indicated fewer sardines than were present in 1997 or 1999 when ocean conditions were warmer.

- Hake biomass has been declining since the mid-1980s when stock abundance increased due to three successive very strong year classes. In the 1990s the hake distribution pushed northward with over half the biomass present in Canadian and Alaskan waters in 1998. This northward shift seems to have reversed in 2000 and 2001. A joint Canada/US survey of hake conducted in 2001 indicated that the total biomass had declined to 738,000 mt from 1.2 million in 1998. This is the lowest biomass since the triennial surveys began in 1977.

- 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 2001 show similar growth to that observed in 1999 and 2000. Adult salmon returns in 2001 were very good, indicating good survival for juveniles which entered the ocean in 1999. Thus, the continued good juvenile salmon growth seen in 2001 may translate to continued improved salmon returns in subsequent years. Measurement of stored energy reserves of the coho collected in 2001 indicates that these animals are in good condition with high energy reserves, suggesting ocean conditions have improved since 1998. Size differences seen in 2001 suggest that growth conditions favourable to good salmon returns have continued.

- Breeding timing for Cassin's Auklet has advanced over the last two years, with 2001 being the earliest hatch date on record. Nestling growth in 2001 was improved for Rhinoceros Auklets compared to 2000. Growth was below average for the Tufted Puffin and Cassin's Auklet, in both cases possibly due to changes in prey species availability.

- Cassin's Auklet were foraging significantly further north than observed in the past two years, and growth of nestlings was lower than expected. This may be a result of prey species (*Neocalanus cristatus*) availability being mismatched with breeding times in years exhibiting warm spring sea surface temperatures (SST's). In general, the relationship between April SST's and nestling growth rate indicates that growth rate declines significantly as SST increases.

- Ancient Murrelet chick departures in Laskeek Bay (Queen Charlotte Islands) were later in 2001 than in the previous 14 years. Breeding success was similar in 2001 to 2000, continuing the trend from 1998 of breeding success returning to pre-ENSO levels.

- Monthly composite of colour satellite data (SeaWIFS) show that in 2001 the spring bloom of phytoplankton started in March, rather than April, as observed in the three previous years where data are available. Otherwise, the distribution and concentrations of chlorophyll was similar to those observed in previous years.

North Coast

- As in 1999 and 2000, sea surface temperatures were slightly cooler than the 1981-2001 average. 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 in the mid 1960 to mid 1970s. Again, 2001 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 remain lower than the 1944-2000 average, while the annual average salinity from 1998 to 2001 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 about as low as the 1990 level.

- As was described last year, offshore transport through coastal eddies was low, and the two eddies formed in the 2001 winter were two of the weakest observed to date.

- The decline in recruitment observed for Rock sole and English sole in the 1990s has leveled off. Rock sole biomass show little trend between 1998 and 2001 while English sole biomass increased slightly over the same period.

- A transport hypothesis was used to explain recruitment anomalies for the Pacific cod stock in the Hecate Strait area. High sea levels which reflect high transport (currents), may remove larvae from Hecate Strait resulting in poor recruitment. Throughout the 1990s sea level conditions were unfavourable for recruitment. Sea levels (transport) have decreased in the last two years and recruitment may be improving.

- 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, and abundance has been low, while recruitment in the Prince Rupert and Central Coast stocks has been generally good, or less regular but with sporadic very strong year classes. Abundance has also been at good levels in Prince Rupert and the Central Coast. Recent data suggest survival conditions have been declining in the Central Coast while they are improving in the Prince Rupert and Queen Charlotte Island areas. Abundance is expected to increase in the Queen Charlotte Island and Prince Rupert areas, and decrease in the Central Coast region.

Strait of Georgia

- Sea surface temperature was slightly above the 1992-2000 average in 2001.

- Sea surface salinity remained higher than the 1992-2000 average throughout the year due to lower than normal Fraser River runoff.

- Mean annual daily discharge of the Fraser River in 2001 (2320 m^3/s) was lower than the 1915-2000 average (2720 m^3/s) due to lower than normal snow pack levels throughout its watershed. The freshet peaked in early summer, following a trend from the last three years of a later freshet.

- The dominant euphausiid in the Strait of Georgia is *Euphausia pacifica*, but there is variation in euphausiid species composition within adjacent inlets. This variation may contribute to the distribution and health of hake and other fish within these inlets.

- 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 2001 at more than 100 000 mt, which rivals the 1955 record high. Surveys of juvenile herring abundance in the Strait of Georgia for 1999 and 2000 indicate that 2002 will be an “average-good” recruitment while 2003 could be a “good” year.

- Juvenile salmon surveys indicate a continuation of the improved productivity seen in 2000. 2001 estimated abundances are near or slightly lower than 2000 abundances, but are 1.3 to 7.1 times higher than estimates from the years 1997 to 1999.

- Individual size and condition of coho were significantly greater than the 1997 to 1999 period. In addition, the incidence of empty guts decreased for coho, chinook and chum in 2000 and 2001, and average gut volume increased. The larger size of juvenile coho was related to the improved marine survival. Improved marine survival is forecast to continue for 2002 based on the large size of juveniles in the 2001 surveys.

- Distribution of ocean age 0 salmon remained consistent with previous years.

- As forecast last year, coho returned to the Strait of Georgia and had increased marine survival, and returning fish were larger.

- There was a record escapement of pink salmon to the Fraser River, resulting from one of the weakest brood years on record.

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, during "regimes", 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 2001.

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. The rate of change was equivalent to 3°C per century from 1976 to 1998, but only 2°C per century if taken between 1976 and 2001. Global climate model predictions range from 1.5°C to 4.5°C temperature rise in the next century.

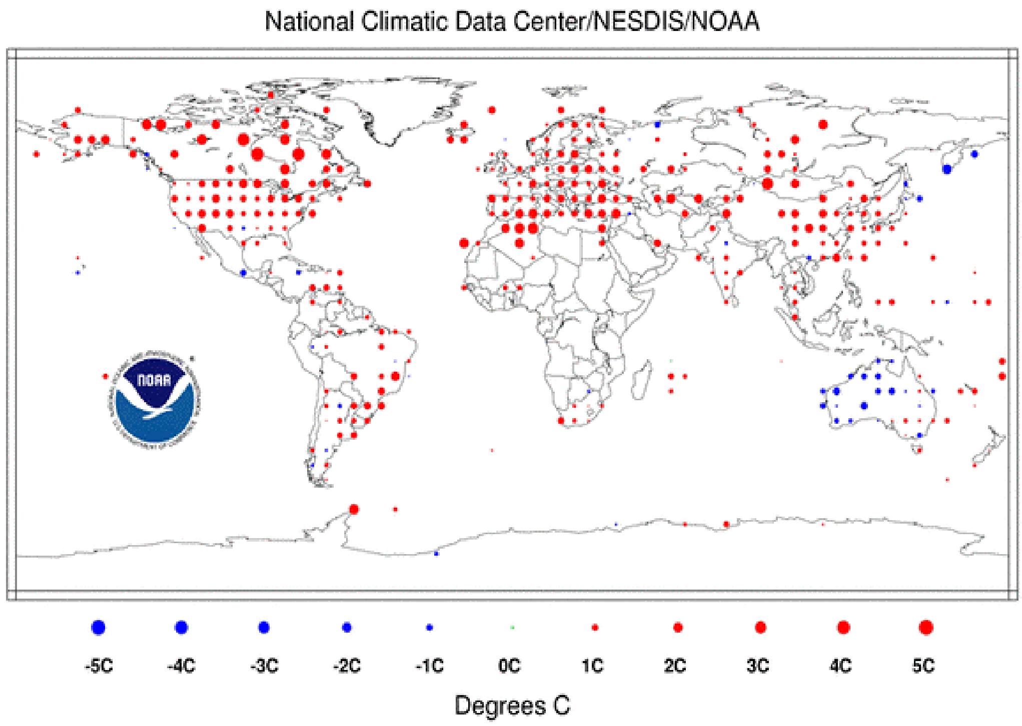


Figure 1. The distribution of year 2001 temperature anomalies relative to the 1960-1991 average, NOAA. Canada was strongly warmer than normal except for the Pacific coast.

In 1999, La Niña brought some moderation of the upward trend in B.C. coastal air temperatures, continuing with mild La Niña conditions throughout 2000 and early 2001. Throughout most of 2001, neutral conditions have prevailed but there is some suggestion that a moderate El Niño is building. Prediction skill is poor in late winter and there is no indication yet of an event strong enough to impact the B.C. coast. Coastal temperatures remained near-normal in 2001 at B.C. locations as seen in Fig. 1.

The continued warming of Alaska and northern Canada is evident in average 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 year 2001 with air temperature over land areas more affected than those over the oceans.

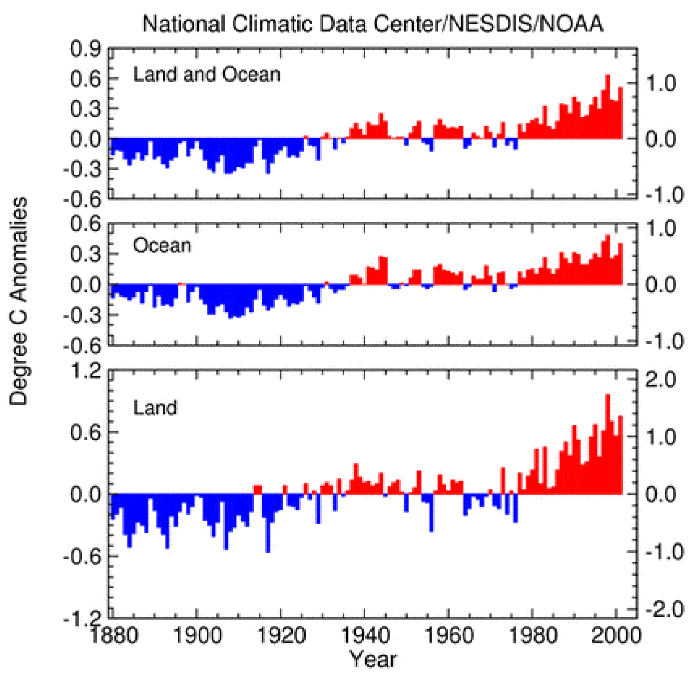


Figure 2. January – December 2001 Surface Mean Temperature Anomalies. Globally, 2001 was one of the warmest years ever recorded, second only to the strong El Nino year, 1998. (NOAA)

A number of regional indices have been developed to document local climate states and to explore the connections between regions. These indices are plotted in Fig. 3.

Southern Oscillation

The Southern Oscillation Index (SOI) (Figure 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 generalised as cooler. The 1990s have been unprecedented with the frequency and persistence of El Niño events. This persistence was interrupted by the La

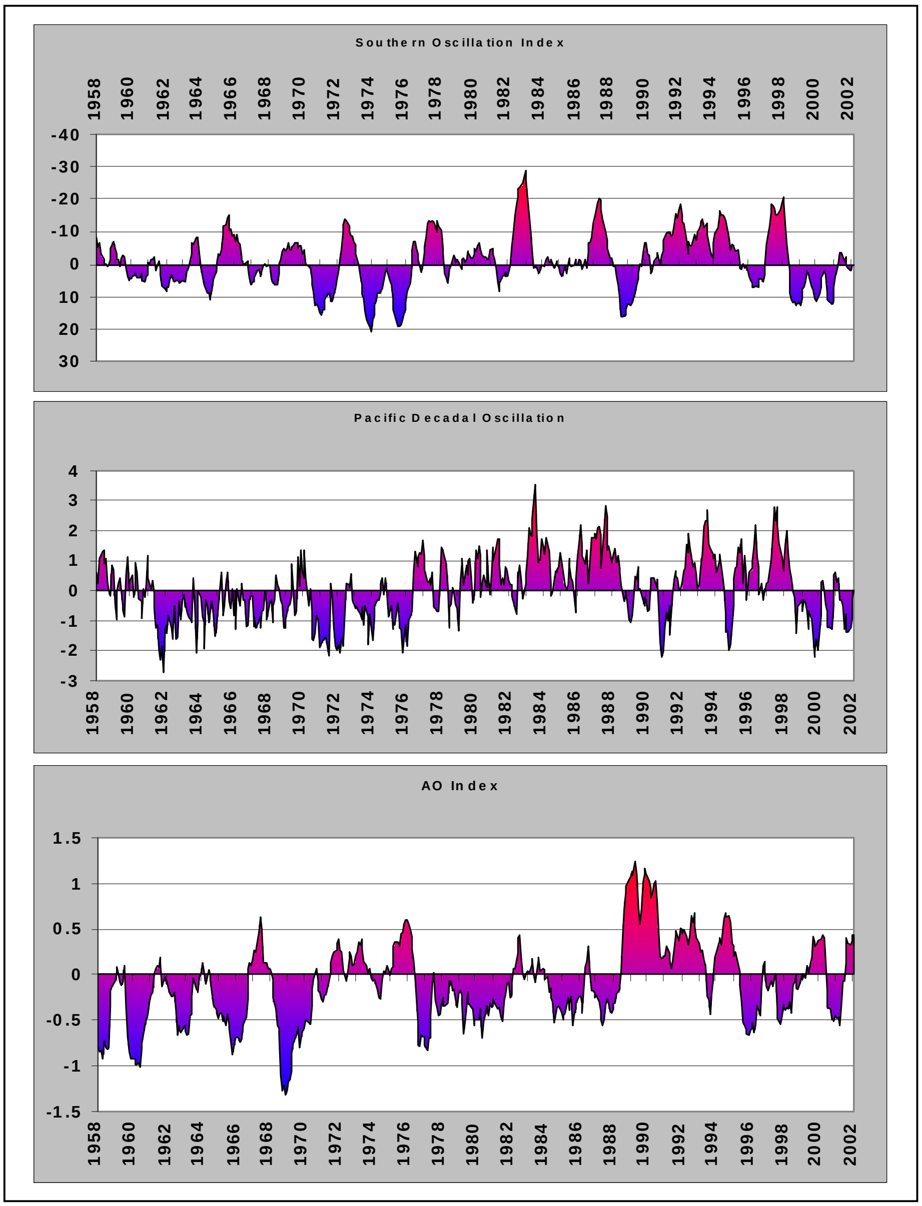


Figure 3. Variations in selected indices since 1958. The scale in the top panel (SOI)was inverted to reflect warmer coastal conditions with negative index.

Niña event of 1998/99 which has also turned out to be a persistent occurrence lasting through 2001. 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 (Figure 3) is a measure of the spatial variability in sea surface pressure and temperature throughout the North Pacific. It generally typifies two states only, 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 into positive numbers similar to the period before 1977. The patterns of wind and temperature associated with the PDO are shown in Figure 4. (http://tao.atmos.washington.edu/pdo/)

Associated with La Niña conditions and a dip in the Pacific Decadal Oscillation Index, coastal British Columbia had near normal water temperatures in 2001. Ocean temperatures measured at lighthouses off British Columbia followed this trend.

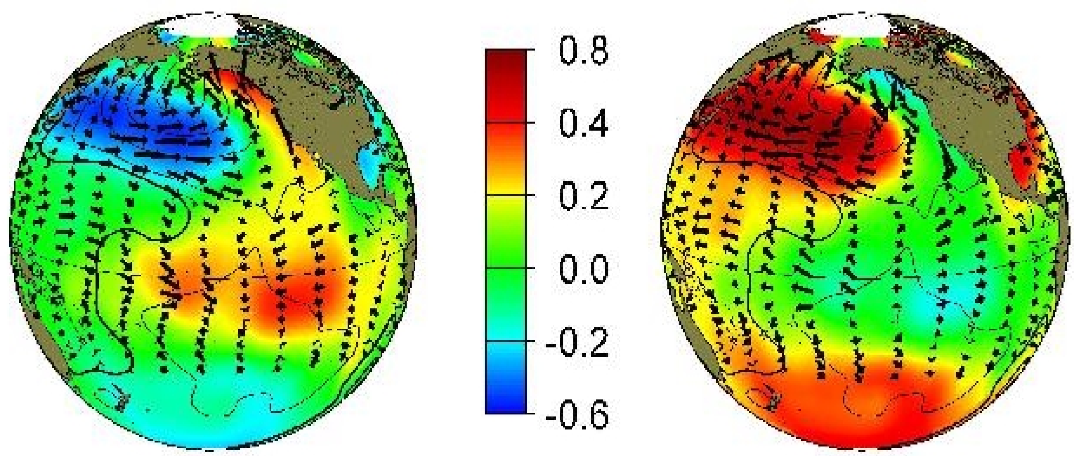


Figure 4. Typical wintertime sea surface temperature (colors), sea level pressure (contours) and surface wind stress (arrows) anomaly patterns during warm (left) and cool (right) phases of PDO.

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(Thompson and Wallace, 1998). 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.(http://tao.atmos.washington.edu/data_sets/ao/)

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 5). In 1998, the Aleutian Low was extremely intense. A return to moderate intensity was measured in 1999 and 2000. In 2001 the Aleutian Low was stronger, measured as a positive ALPI value (Figure 5) (http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx.htm).

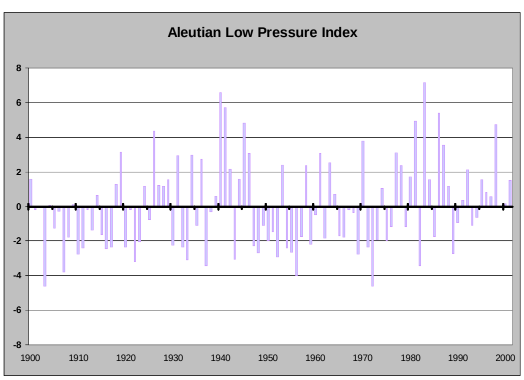


Figure 5. Aleutian Low Pressure Index.

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 6). A slowing down period preceded the 1989 regime shift by several years. The 1998 regime shift was preceded by a speeding up period. In 2001, the Length of Day continued to decrease indicating a continuation of the present regime conditions. (http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx.htm).

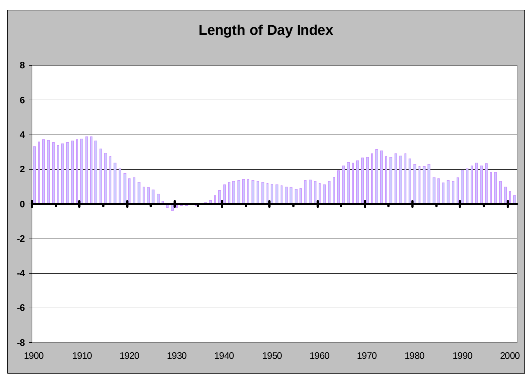


Figure 6. Length of Day Index.

Atmospheric Forcing Index

The Atmospheric Forcing Index (AFI) is a composite index based on three aspects of climate and ocean conditions: the Aleutian Low pressure system, the spatial sea surface temperature patterns captured by the Pacific Decadal Oscillation index and north Pacific wide atmospheric circulation patterns.

(McFarlane et al., 2000). The AFI has been linked to decadal-scale changes in environmental conditions and marine fish productivity. In general, positive values represent intense Aleutian lows, above average frequency of westerly and southwesterly winds, cooling of sea surface temperatures in the central North Pacific in winter, and warming within North American coastal water in winter. While an extreme positive value represented 1998, the AFI values for 1999 and 2000 were near long-term average conditions and 2001 saw a return to a moderate positive value (Figure 7). (http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx.htm)

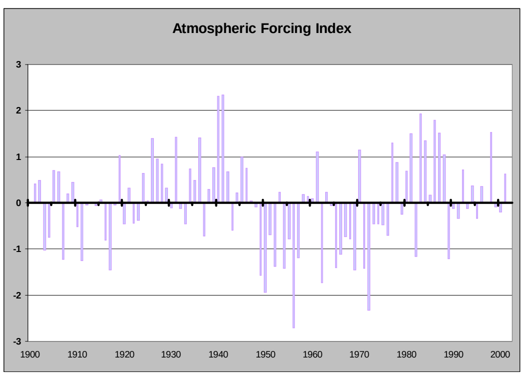


Figure 7. Atmospheric Forcing Index.

Gulf of Alaska

Physical Conditions

For the last few years the Gulf of Alaska has been dominated by cold conditions initiated by the La Niña of 1999.

Figure 8 outlines the locations of the sampling stations comprising Line-P, from which oceanographic data for the Gulf of Alaska are collected and compared. These data are presented in Figures 10, 11 and 12.

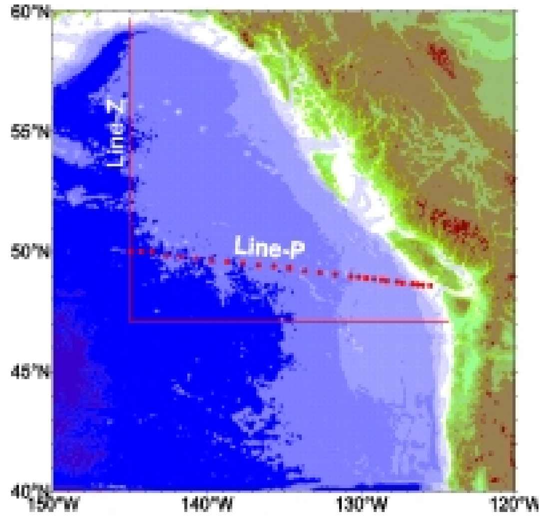


Figure 8. Map of the Gulf of Alaska showing the location of the sampling stations (red dots) comprising Line-P. Some other survey lines completed in recent years are also shown.

Figure 9 shows a plot of an index called "the southern oscillation index" which is a rough measure of the tendency towards or away from El Niño/La Niña conditions. The blue line is a raw plot of daily observations, the red line is a 31-day running mean of the observations in blue. This clearly shows the strong El Niño of 1997/98, the abrupt transition that occurred in spring 1998, and the on-again, off-again La Niña-like conditions that have dominated since.

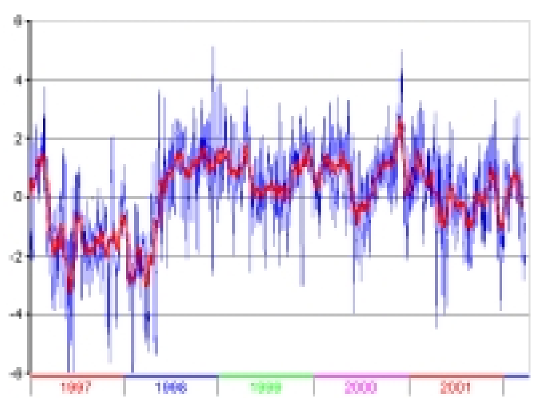


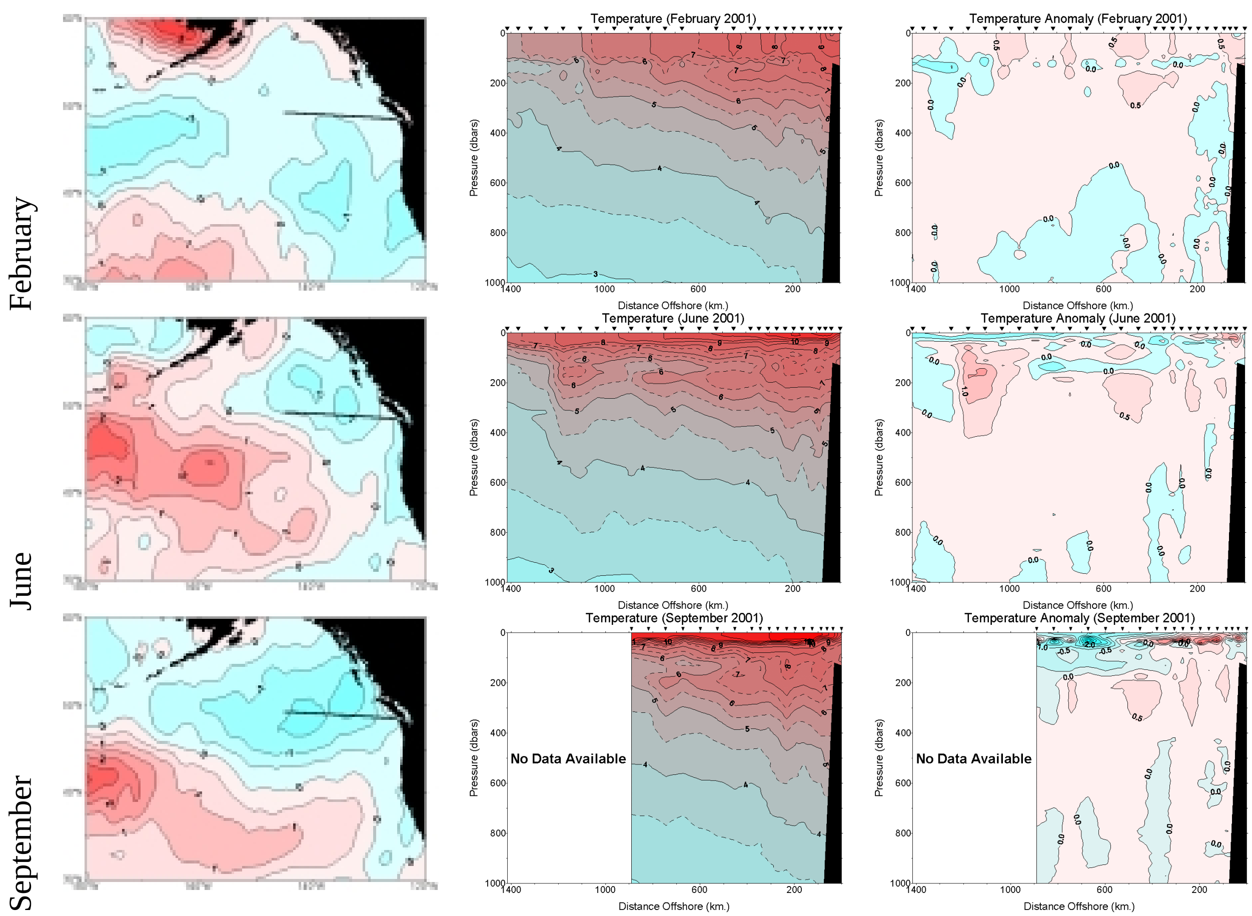
Figure 9. The southern oscillation index for the years 1997 to present. Positive values indicate a tendency towards La Niña conditions, and negative numbers a tendency towards El Niño conditions.

For the last 12 months the air pressure distribution along the equator has been in a near-neutral state, neither El Niño nor La Niña-like. However, there is some expectation that an El Niño event is imminent.

This idea, that an El Niño is imminent stems from several observations:

Wind conditions along the equator have shown some instability over the past 6 months and events known as "westerly wind bursts" have occurred. One of these, in December 2001, was strong enough to initiate an "equatorial Kelvin Wave". In 1997 three such bursts occurred before the El Niño actually began.

Computer models have gained some experience and credibility since the 1997 El Niño event, which was not predicted with a useful lead time. Most models



SST anomalies in the Gulf of Alaska

Temperature section along Line-P

Temperature anomaly section along Line-P

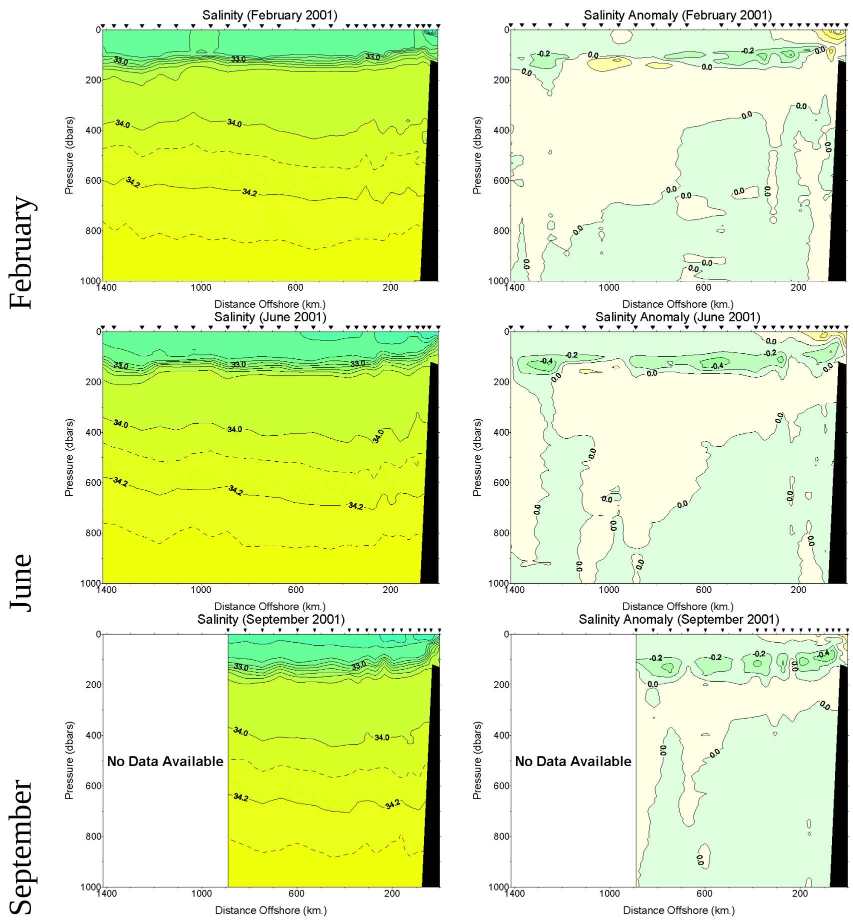
Figure 10: Temperature variations in the Gulf of Alaska during 2001.

are now predicting a transition to some kind of El Niño event in 2002.

Anomalous warming of the southern ocean is occurring in the tropical Pacific.

Computer models are not unanimous, some of them predicting a spring/summer start to an event, but most predicting an event in October to November. At least one model disagrees profoundly and suggests that we should expect La Niña-like conditions in 2002. Figure 10 contains diagrams in three columns. The left-hand panels show the distribution of sea-surface temperature in the Gulf of Alaska for three months for which there were surveys along Line-P. The panels in the center column shows the distribution of measured temperature along Line-P, from the surface to a depth of 1000 metres plotted against distance offshore, see Figure 8 for location. Those in the right-hand column show the deviations of temperature from normal.

It is apparent that though surface conditions (see left-hand column) in the Gulf of Alaska have been dominated by temperatures that are below normal, this is not apparent in the deeper waters of the Gulf of Alaska. It may be noted that



Salinity section along Line-P

Salinity anomaly section along Line-P

Figure 11: Salinity variations along Line-P the Gulf of Alaska during 2001.

the anomaly diagrams in Figure 10, columns 1 and 3 are not in complete agreement. For example, the SST map for February 2001 indicates temperatures below normal over all of the area sampled by Line-P. However, the differences from normal in each case are rather small. Further, the SST anomaly maps are based on averaged conditions over the period 1972 to present, whereas the Line-P averages are based on the period 1956-present. So these apparent differences are not significant. The diagrams all indicate that the Gulf of Alaska was colder than normal at the surface, but below the surface there were no significant deviations from the long-term normal.

The salinity sections in Figure 11 indicate that some significant deviations from normal were apparent, particularly in June and September of 2001 near depths of about 100 to 130 metres. This results from the near surface low temperatures which have dominated the Gulf for the last several years, which de-stabilise the upper part of the oceanic water column and effectively make it easier for wind systems to mix the upper part of the water column. The stability of the upper ocean in the Gulf of Alaska is dominated by salinity. When the surface mixed layer is deeper than normal we get low salinities deeper than normal, characterized by significant negative salinity anomalies near the base of the mixed layer.

A deeper mixed layer is important because it can increase the supply of nitrate, the critical macro-nutrient that during El Niño years can be in short supply.

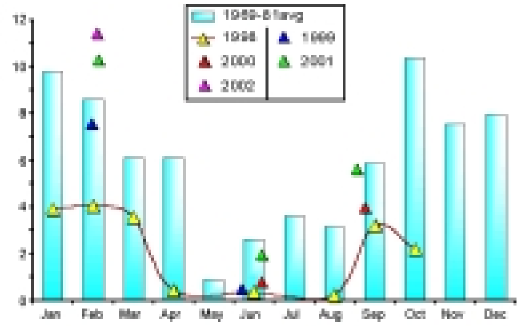


Figure 12. The annual cycle of surface nutrients at inshore stations along Line-P and observations in 1998, 1999, 2000 and 2001.

Figure 12 shows observations of nutrient concentrations averaged over a collection of inshore stations along Line-P, superimposed on a long-term (1969-1981) cycle for comparison. Winter nitrate levels have been increasing since 1998 when the last El Niño reduced southern BC coastal nutrients to the lowest levels seen in at least the last 15 years (older measurements are not as reliable as those since 1987 when nutrients started being measured onboard ship).

Since 1998 nitrate levels have been near or above long term average values. The most recent February measurements (2002) are higher than any winter measurement since the La Niña of 1989 when the average concentration was 13.0 μmol/l across the continental shelf at the southern end of Vancouver Island. The winter supply of nutrients largely regulates the strength of the spring bloom in oceanic waters, since this is a time of year when upwelling has not yet begun to supply nutrients to surface waters.

Maps of temperature in the Gulf of Alaska are prepared at the Institute of Ocean Sciences and an archive of maps from 1982 to the present time, can be viewed on the World Wide Web at: http://www-sci.pac.dfo-po.gc.ca/sci/osap/data/sstarchive.htm

Phytoplankton

The distribution and biomass of phytoplankton in the Gulf of Alaska during 2001, as observed by colour satellite data (SeaWIFS), were similar to those observed in previous years. In general, chlorophyll concentrations were high in the nearshore region during the spring-summer season and low and relatively constant offshore (Figure 13, left column). In contrast, the composition of phytoplankton seems considerably different from the previous year, with no evidence of coccolithophorid dominance in 2001 (Figure 13, right column).

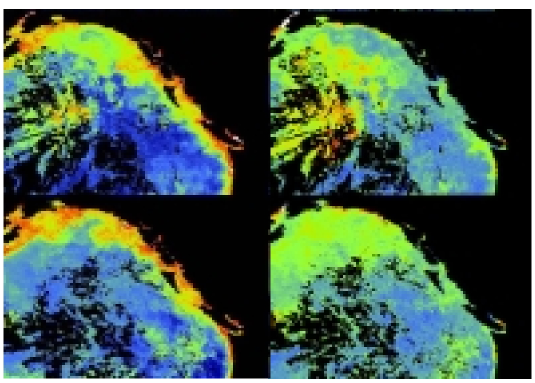


Figure 13. SeaWIFS composite image of the Gulf of Alaska in June of 2000 (top) and June of 2001 (bottom). Left column: chlorophyll concentration where red correspond to high concentrations. Right column: the L550 nm band where brighter regions (red) indicate high abundance of coccolithophorids.

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. Seasonal coverage of the more recent 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*). We are now evaluating alternate censusing methods based on summer sampling of the deep (400-1000m) dormant copepod population. We do know, based on this and earlier more frequent sampling during the weathership time series (1957-1980), that the seasonal timing of the annual *Neocalanus* biomass peak is variable by more than a month, and is correlated with spring-season mixed layer temperature. Seasonal timing of the Alaska Gyre *N. plumchrus* population was very early (late April-May) in the mid- 1990s, but has showed a return to long-term average timing (mid-late June) in 1999-2001.

In 2001, the major zooplankton research activity in the Alaska Gyre was a study of the oceanography and ecology of large anticyclonic eddies (‘Haida Eddies’). These eddies form in late winter near the outer coast of the Queen Charlotte Islands, then move westward into the open ocean. The eddies carry large initial loadings of coastal water, nutrients, plankton, and larval fish and invertebrates. The water and coastal biota gradually disperse from the eddy into the offshore water, over a time scale of about one year (Figure 14). We are finding that the eddies may be an important transfer mechanism from coast to offshore regions of the subarctic Pacific.

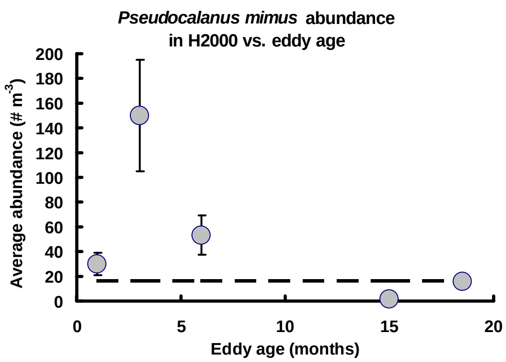


Figure 14. Abundance (log scale) in the Haida 2000 eddy of the continental margin copepod Pseudocalanus mimus, vs. age of the eddy (age zero is January 2000). Coastal taxa are abundant in the eddy during the first spring and summer after the eddy leaves the coast, but then decline toward average background levels in the Alaska Gyre (dashed line)

Humpback and Killer Whales

Sightings of Northern resident killer whales were similar in 2001 as for 2000, i.e. all pods were sighted in the Queen Charlotte Strait – Johnstone Strait area. This is similar to what occurred during the 1970's and 1980's, but different from the mid to late 1990's, when many Northern resident killer whale pods were not observed in the Queen Charlotte Strait region. There were several reports of large aggregations of humpback whales (and some fin whales) in Hecate Strait on the edge of Moresby Gully in May and June, and also near Langara Island at the northern tip of the Queen Charlotte Islands in late summer.

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 the Department of Fisheries and Oceans 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. 15) provide hourly time series information on winds, atmospheric pressure, wave height and period, and air/water temperature; lighthouse stations (Fig. 16) provide long-term time series of daily sea surface temperature and sea surface salinity. Tide gauge stations (Fig. 17) provide long-term series on hourly sea level variability and moored current meters (Fig. 18) yield hourly time series of current velocity, water temperature, and salinity at specified depths through the water column.

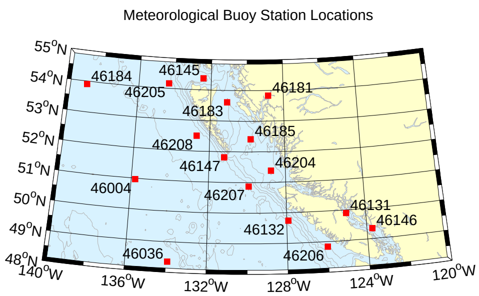


Figure 15. Weather Buoy locations.

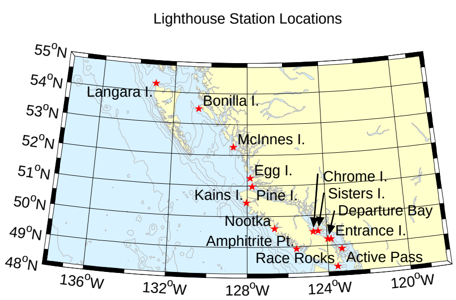


Figure 16. Lighthouse locations.

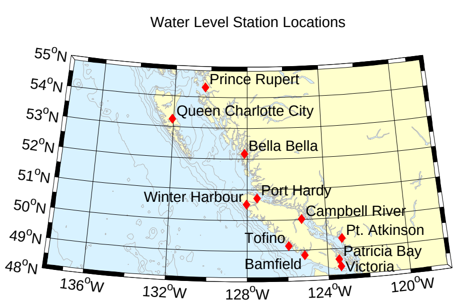


Figure 17. Tide Gauge locations.

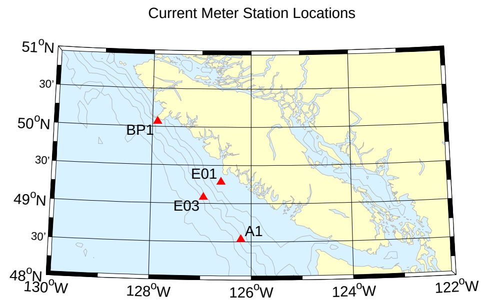


Figure 18. Current meter locations.

Although mean global air temperatures in 2001 were the second warmest on record next to 1998, oceanographic and meteorological conditions for the west coast at the start of 2001 reflected the continuation of moderate La Niña conditions that began in 1998, immediately following the major El Niño event of 1997-1998 (Fig. 19). By the spring of 2001 conditions in the tropical Pacific had returned to neutral (neither El Niño or La Niña). However, in the spring of 2001 the Pacific Decadal Oscillation (PDO) made a transition from near neutral to moderately strong negative values. A negative PDO is characterized by cool temperatures along the coast and these conditions persisted to the end of the year.

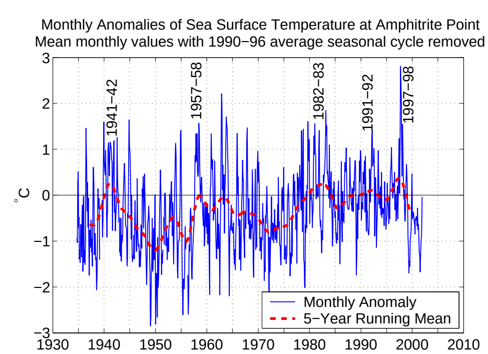


Figure 19. SST anomalies at Amphitrite Point from 1935 to 2001.

Surface oceanic conditions were similar for both the north and south coastal regions of offshore Vancouver Island. Throughout most of the year, upper ocean water temperatures were below normal while salinity was above normal. Upwelling was normal to above normal along the coast in summer. Water level was below normal until the spring, after which it returned to near normal. Mean currents over the slope and outer shelf were of normal poleward magnitude in winter (January through February) and in summer were weaker poleward or more strongly equatorward than normal.

West Coast Meteorological Data

Weather buoys have been maintained since 1989 off Vancouver Island by Environment Canada.

In 2001, there were periods of a few days of strong southeasterly winds in January, March, and October through December, with October-November completely dominated by these events (downwelling-favourable, positive values in Fig. 20). Moderately strong periods of northwesterly (upwelling-favourable) winds were recorded throughout the year, notably throughout the warm season, May-October, when upwelling moves nutrients up the water column at a time when nutrients and not light are possible limiting factors for biological productivity.

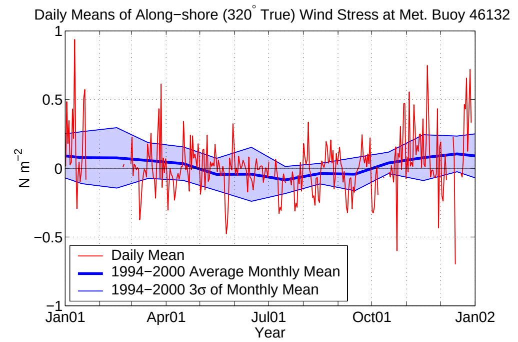


Figure 20. Alongshore wind stress for year 2001. Negative values favour upwelling.

Relative to previous years, the upwelling favourable winds of 2001 (negative along-shore wind stress anomalies in Fig. 21) were stronger than most years over the last decade, and similar in amplitude and duration to summer conditions in 1992 and 1990.

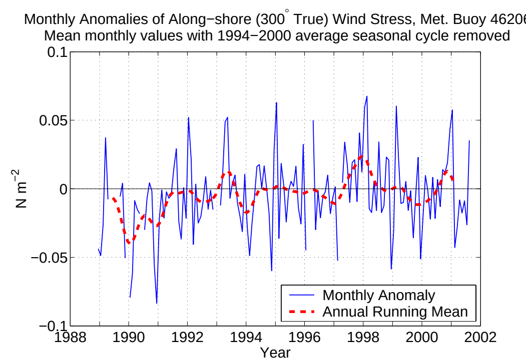


Figure 21. Alongshore wind stress anomalies from 1989 to 2001.

Wave heights were typically higher than the 1990-1996 mean over periods of a few days in mid-January, early March and May, and August-December (Fig. 22). Excluding these short-term events, wave heights were near-normal throughout the year, except during most of June when relatively low wave heights were recorded.

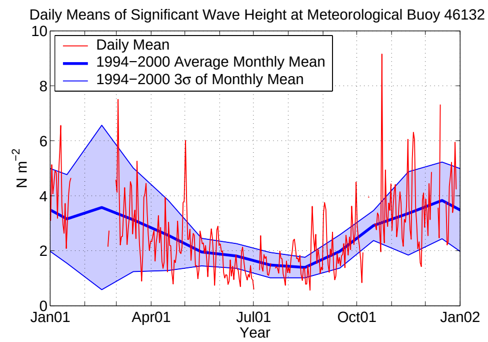


Figure 22. Significant wave height for year 2001.

Relative to previous years, wave heights appeared to be returning to mean levels in 2001 after the below-average years of 1999-2000 (Fig. 23).

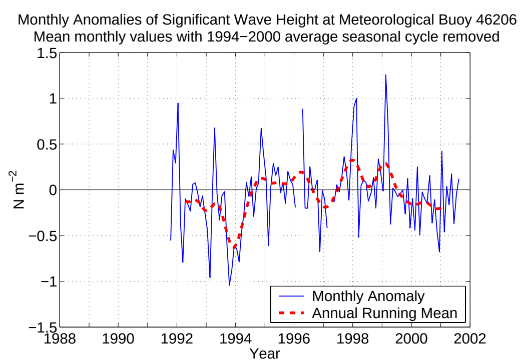


Figure 23. Significant wave height anomalies from 1991 to 2001.

West Coast Lighthouse Data

Sea surface temperature (SST) on the inner continental shelf was generally 1 to 2 °C below the 1990-1996 mean for most of the year (Figs. 24a,b). Only in January and December (and August at Kains Island) did SST values reach typical winter values. These colder SSTs were in marked contrast to the pronounced warming during the 1997-1998 El Niño. The cooling during 2001 was greater than recorded during the most recent La Niñas of 1988-1989 and 1984-1985, comparable to 1970-1971, and not as cold as the earlier La Niñas of 1975-1976, 1955-1956, 1950-1951, and 1938-1939 (Fig. 19).

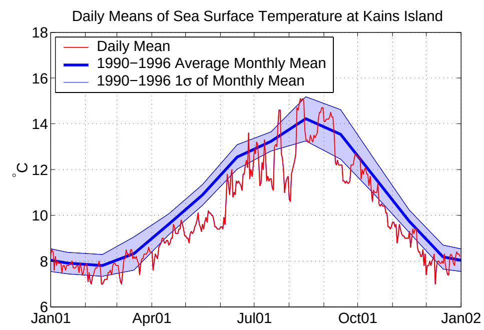


Figure 24a. Northern SST for year 2001.

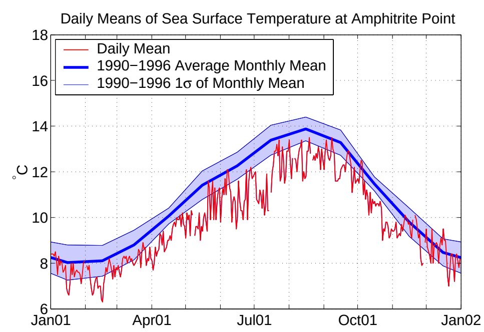


Figure 24b. Southern SST for year 2001.

Sea-surface salinity (SSS) at Kains Island was greater than the 1990-1996 mean by about 2 psu from January-April, before returning to near mean levels for the remainder of the year (Fig. 25a). At Amphitrite Point, SSS was well above the long term mean for most of the year (Fig. 25b).

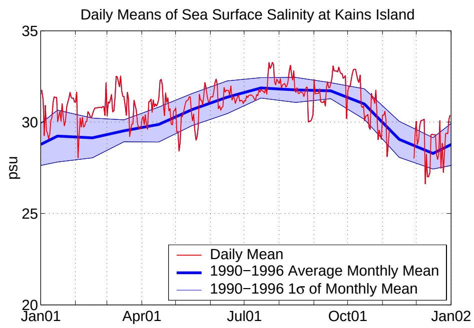


Figure 25a. Northern SSS for year 2001.

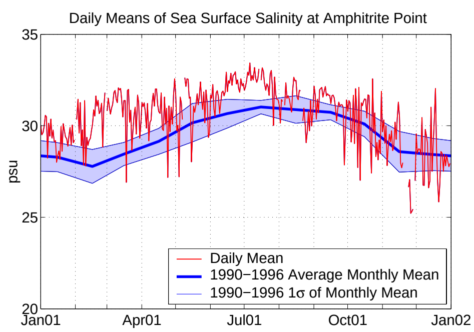


Figure 25b. Southern SSS for year 2001.

Relative to previous years, the higher surface salinities in 2001 are comparable to those recorded in the late 1970s, early 1950s, and from the late 1930s to early 1940s (Fig. 26).

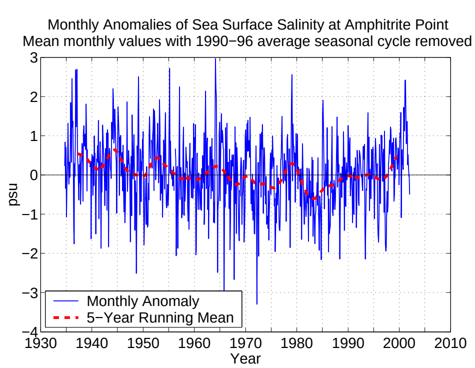


Figure 26. SSS anomalies at Amphitrite Point from 1935 to 2001.

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. 13 and 14. This index is essentially the seaward flowing component of wind-induced Ekman transport. The year 2001 had strong periods of downwelling (negative values) in the winter and spring months and August (Fig. 27). Moderately strong upwelling conditions occurred in February, May, July, and October-December. This agrees reasonably well with the occurrence of north-easterly (upwelling-favourable) winds recorded by the meteorological buoys.

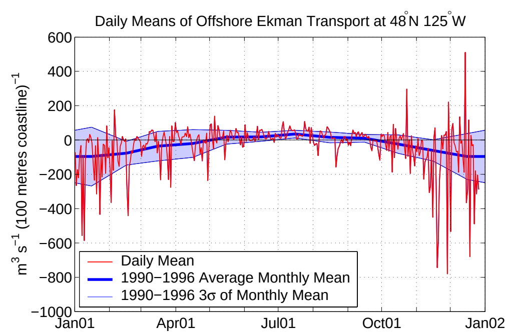


Figure 27. Upwelling index at 48° N, 125° W for year 2001. Wind driven seaward flowing transport is replaced by upwelling water from below.

Upwelling in 2001 appears to mark a return to mean values (relative to the 1990-1996 average) from below average upwelling since 1993 (Fig. 28).

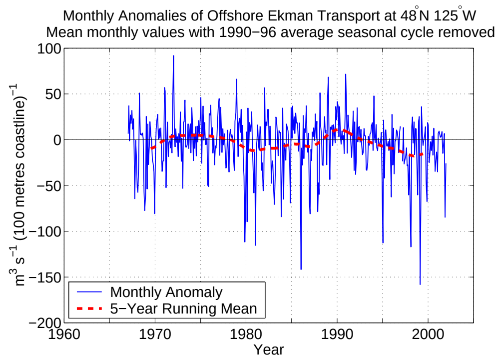


Figure 28. Upwelling index anomalies at 48° N, 125° W from 1967 to 2001.

Water Level

Water level was 10-20 cm lower than the 1990-1996 average from January through April, after which it returned to average levels for the remainder of the year (Fig. 29). The exception was during November when three episodes of a few days in duration pushed water levels 40 cm above normal. This was probably due to storm activity that was measured by the meteorological buoys (strong southerly winds generating storm surges and low air pressures with decreased depression of the sea surface through the inverse barometer effect).

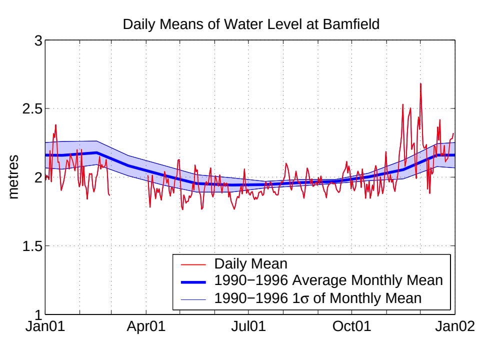


Figure 29. Water level at Bamfield for year 2001.

Lower water levels in 2001 are in marked contrast to the levels during the 1997-1998 El Niño (Fig. 30). 2001 levels are comparable to those recorded during the La Niñas of 1988-1989 and 1975-1976.

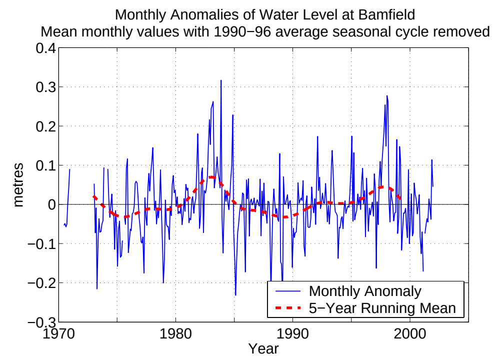


Figure 30. Water level anomalies at Bamfield from 1970 to 2001.

Southwest Vancouver Island Continental Slope (La Perouse Region)

Subsurface temperatures at 35, 100, 175, and 400 (not shown) m depth over the continental slope as measured at mooring A1 appear to have been near the 1990-1996 mean during 2001 (data series ends in early October) (Fig. 31). Because the mooring was 15 m deeper than the nominal depth during January-May, and 100 m deeper during August-October, observed temperatures over these months are offset to lower than expected for that nominal depth. Instrument failures at some depths resulted in significant data losses (e.g., June-September at 100 metres).

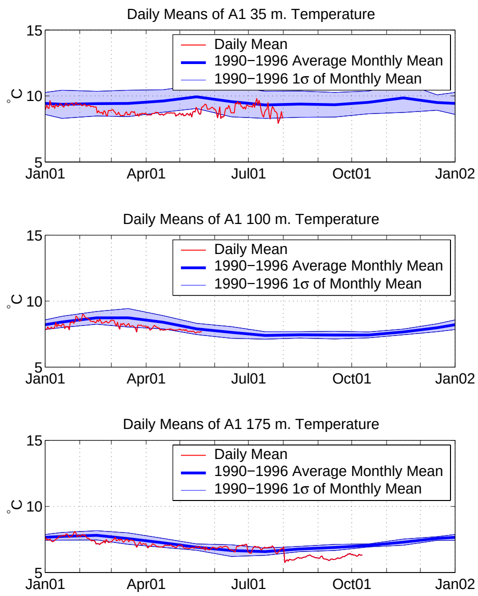


Figure 31. Temperature at 35, 100, and 175 metres depth at mooring A1 for year 2001.

Taking into consideration the changes in instrument depth over 2001 noted above, salinities measured at A1 appeared be below average at 100, 175, and 400 m until May. The data series ends at the beginning of October, and significant data losses shortened the data series even further.

Alongshore current velocity over the continental slope in 2001 as measured at A1 was poleward and of normal magnitude in winter and spring (peaking at around 40 cm s^{-1} in mid-January at 35 m depth), but reversed dramatically for about a week in mid-February (Fig. 32). Flow direction switched to equatorward during the normal March-April period, and became more strongly equatorward than normal in June-July before returning to near normal. The timing of the fall reversal back to poleward flow was also near normal, as was the magnitude of poleward flow in the fall.

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.

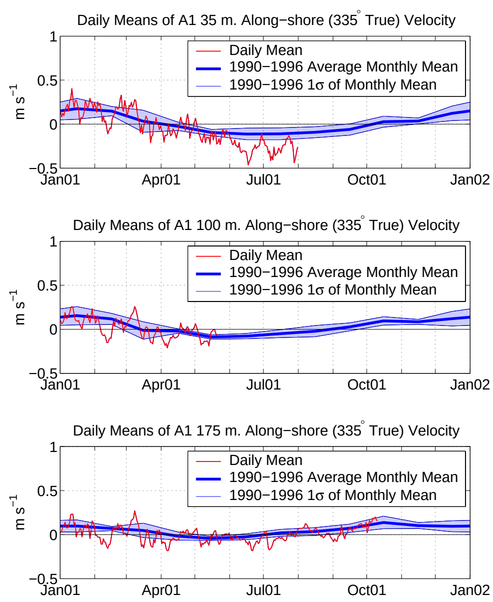


Figure 32. Alongshore (poleward) current velocity at 35, 100, and 175 metres depth at mooring A1 for year 2001.

Central Vancouver Island Continental Shelf (Estevan Point Region)

Subsurface temperatures at 25 m over the continental shelf near Estevan Point as measured at mooring E01 were near the 1990 to 1996 mean until May when they were much above average for the month (Fig. 33). In June-July there was a transition to below average temperatures, with a return to average until the beginning of October (end of data series), except for two spikes at the beginnings of September and October. At 35 m (not shown) and 75 m temperatures were near-to-below average until August-September, when spikes were recorded at the beginning of September and October.

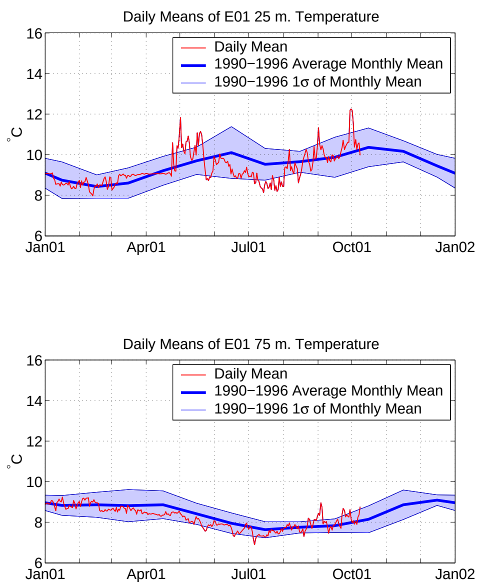


Figure 33. Temperature at 25 and 75 metres depth at mooring E01 for year 2001.

Subsurface salinities at E01 at 25 m were near-to-above the 1990-1996 mean through to the beginning of October (end of data series). Salinities at 35 and 75 m were below average in January, and average through to the beginning of October except for a strong below-average decrease in salinity at 75 m at the beginning of August.

Alongshore current velocity at E01 at 25, 35 (not shown), and 75 m was generally near average and poleward through the beginning of October (end of data series) (Fig. 34). Poleward flow reached a maximum of about 80 cm s-1 at 25 m in February, and short reversals of flow were common throughout the year. Under normal conditions, daily-average currents are persistently poleward off Estevan Point (driven by runoff from the Fraser River and the west coast of Vancouver Island) up to a distance of 20-30 km offshore except for reversals caused by strong northwest winds in summer. Typical wind-induced reversals last for several days to a week.

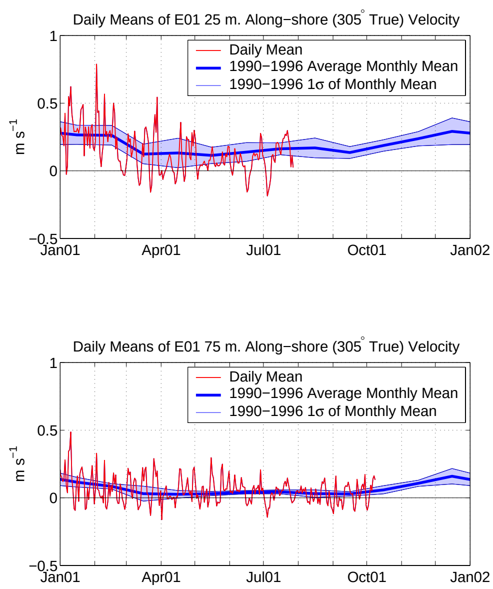


Figure 34. Alongshore (poleward) current velocity at 25 and 75 metres depth at mooring E01 for year 2001.

Northern Vancouver Island Continental Shelf (Brooks Peninsula Region)

Subsurface temperatures at 35 m over the continental shelf near Brooks Peninsula as measured at mooring BP1 were near the 1990-1996 mean during May-July, 2001, and generally above the mean by 2-3 degrees C in August-September (Fig. 35). There were no data after October due to it being the end of the data series, and no data January-May due to instrument failures. Temperatures at 75 m were near-to-below the mean through July, then about average through September except for three spikes in August-September of about 1 degree C.

Salinity at 25 m at BP1 was near-to-above average June-July, below average in August, and near average in September. Before July there was no data. At 75 m salinity was average in January, above average by about 1 psu February-April, near average May-July, and below average August-September.

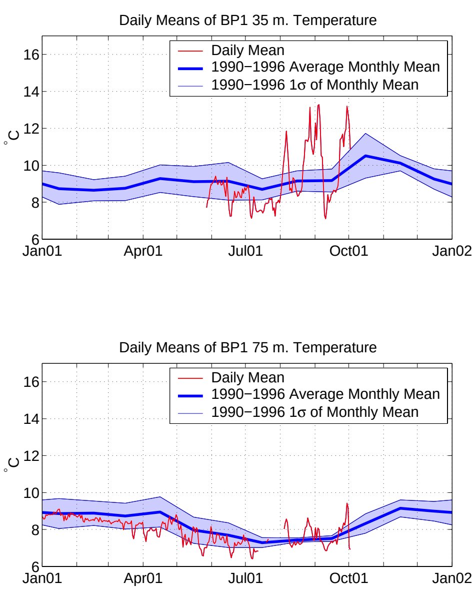


Figure 35. Temperature at 35 and 75 metres depth at mooring BP1 for year 2001.

Alongshore current velocity at BP1 was near-to-below the 1990-1996 mean in January-May (peaking at about 60 cm s-1 in early February), and near average May-September, with many short current reversals throughout the year (Fig. 36). Under normal conditions, daily-average currents over the narrow 5 km shelf off Brooks Peninsula are persistently poleward except for reversals caused by strong northwest winds in summer. Typical reversals last for several days.

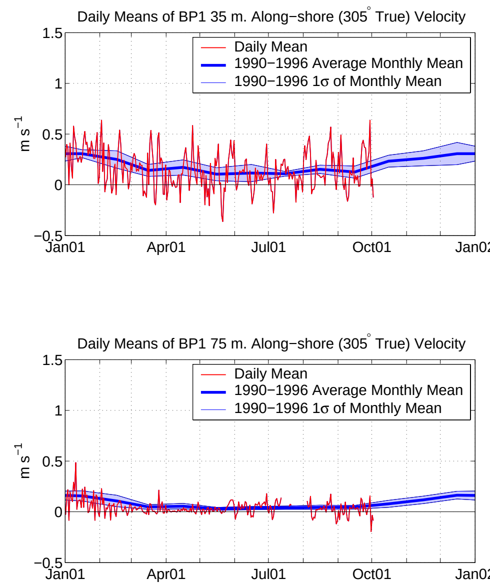


Figure 36. Alongshore (poleward) current velocity at 35 and 75 metres depth at mooring BP1 for year 2001.

Phytoplankton

In the West coast of Vancouver Island, monthly composite of colour satellite data (SeaWIFS) show that in 2001 the spring bloom of phytoplankton started in March rather than in April, as observed in the three previous years where SeaWIFS data are available (Fig. 37). Otherwise, the distribution and concentrations of chlorophyll was similar to those observed in previous years. The most likely cause of the early

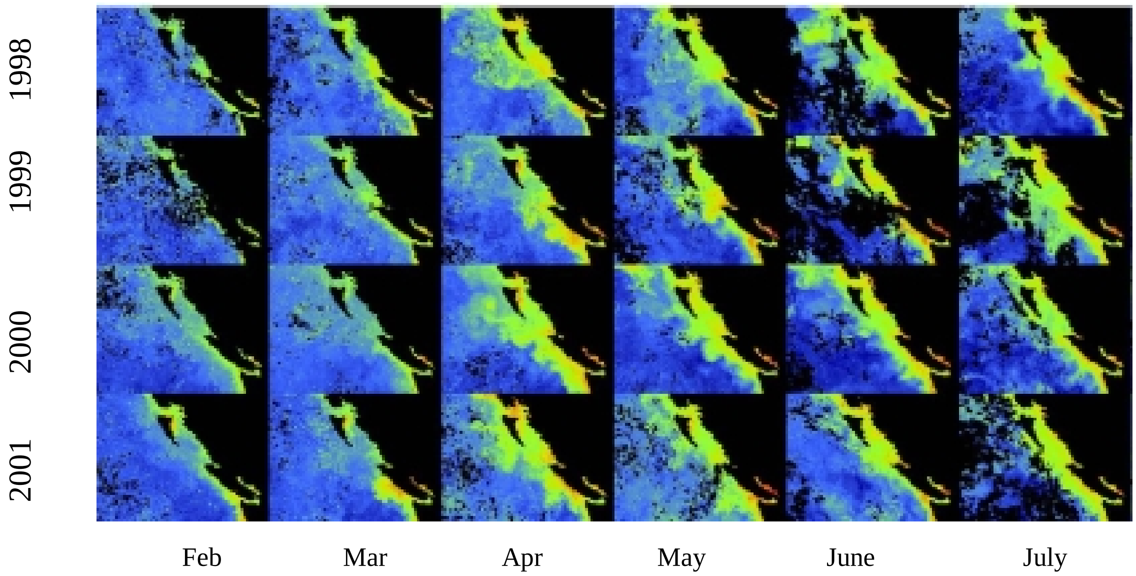


Figure 37. Monthly composite of SeaWIFS chlorophyll concentrations of the West Coast of Vancouver Island from Feb to May of 1998 to 2001.

spring bloom in 2001 is early seasonal increase in solar radiation and water-column stratification. Unfortunately, field observations are lacking at this time of the year so we cannot corroborate chlorophyll satellite observations with *in situ* measurements nor to identify factors responsible for variations in the timing of the spring bloom.

Numerous studies have shown that the timing of the spring phytoplankton bloom can significantly impact food web production and in particular the growth and survival of copepods and fish larvae. However, we do not know how this might affect fish production in the coming years. A study of the dynamics of phytoplankton in coastal waters of Vancouver Island is underway aimed at developing a quantitative understanding of the factors controlling, temporally and geographically, the magnitude of plankton production.

Zooplankton

Time series of zooplankton samples collected since 1985 off southern Vancouver Island (48°-49°N) allow us to estimate annual anomalies of most of the major zooplankton species (relative to a 1979-1991 long term baseline average annual seasonal cycle). For detailed description of sampling and analysis methods, see Mackas, Thomson and Galbraith (2001). The west coast sampling has been continued, and the anomaly time series updated, through 2001.

Year-to-year biomass variations for several of the major taxonomic groups are summarised in Figure 38, along with the corresponding time series for the 'Northern Oscillation Index' (Schwing et al., in press). 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;

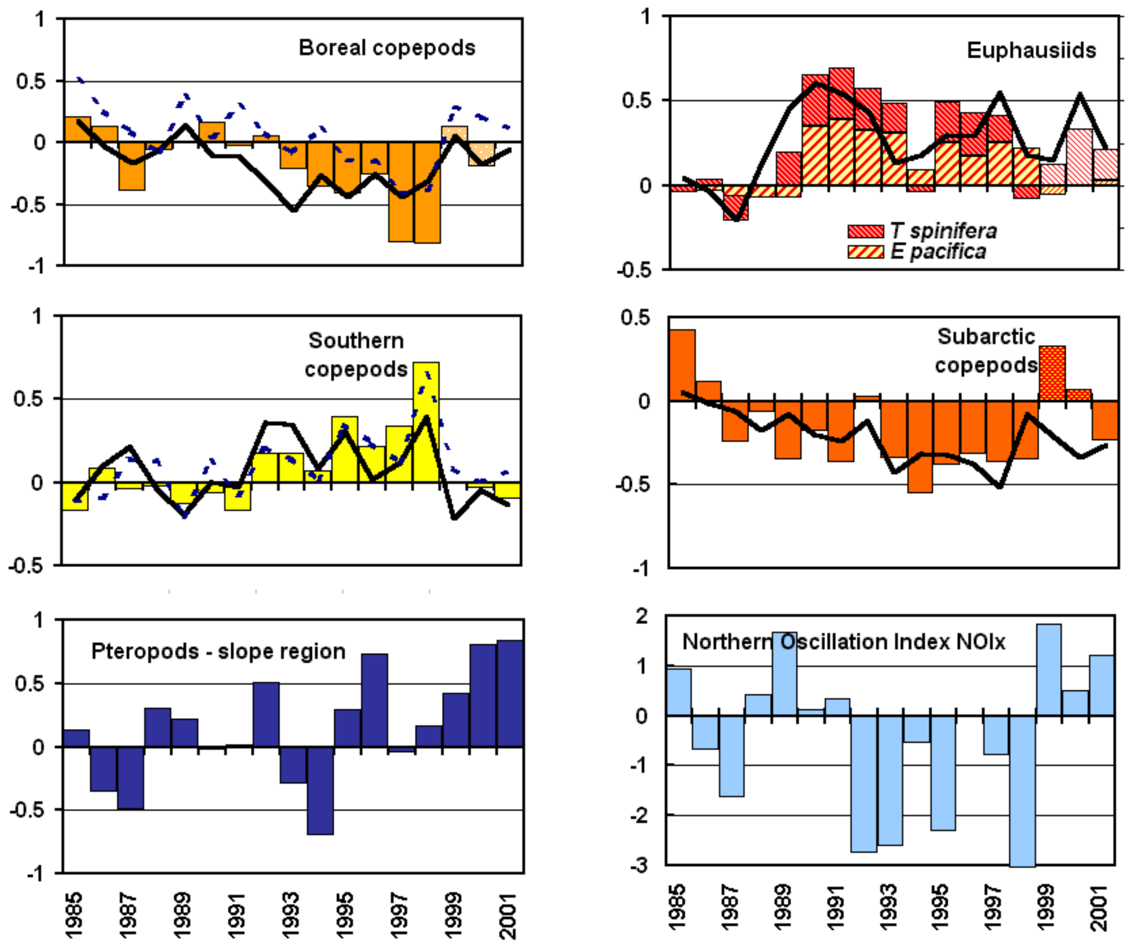


Figure 38. Time series of annual zooplankton anomalies averaged across southern Vancouver Island statistical areas and within groups of ecologically similar species (colored columns), and of the PFEL Northern Oscillation Index. Lines show fits to the zooplankton anomaly time series from stepwise regressions on 1985-1998 time series of environmental indices: large-scale (solid lines) and local water properties (dashed lines). Note the continuing 'predictive' fit 1999- 2001.

an anomaly of –1 means that they were one tenth as common.

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 Nino-La Nina 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 1999-2001 zooplankton anomalies (not included in the fitting operation) have continued to track the environmental regressions.

Comparable time series are being developed for more northerly WCVI sampling lines off Estevan Point (49°20'N), off Esperanza Inlet (49°50'N), off Brooks Peninsula (50°N), and off Cape Scott (51°N). These time series are still too brief to provide statistically reliable estimates of local zooplankton abundance "climatologies", but their trends in recent years have also been generally similar to those from southern Vancouver Island continental margin. 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.

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

Sampling of euphausiids in Barkley Sound continued in 2001. Figure 39 shows the time series of median dry biomass of adult *T. spinifera* (>9 mm) for 1991-2001. The median annual biomasses for 2000 and 2001 were comparable to those for 1991 and 1992 which, in turn, were about six times greater than the median annual biomass for 1993-1999.

Growth in herring continues to be reduced. Tanasichuk (2002) reported that size-at-age of recruit herring for the 1993-95 year-classes was unusually low, possibly related to low euphausiid biomass during the pre-recruit phase, which disrupted compensatory density-dependent growth. The current state of recruit size-at-age is shown in Figure 40. The biomass of euphausiids that herring feed on has increased somewhat in 2001 although it remains much lower than for 1991-92. The reduction in size-at-age has implications for the growth of adult fish of the same year-class as growth rates of adult fish are determined mainly by size at the beginning of the growth season.

The investigation of the effect of euphausiid availability on marine survival of salmon which was presented in last year’s report has been extended. First, the relationship for coho was expressed in a more biologically realistic way. Rather than expressing survival as a simple function of euphausiid availability, the test was restated as evaluating the effect of smolt and euphausiid abundances on returning adults. The measure of euphausiid abundance tested was for 9-12 mm *T. spinifera*, the species and size composition of prey that Petersen et al. (1982) reported for Oregon Coast coho smolts. Results showed that smolt and euphausiid abundances collectively explain 97% of the variation in number of adults returning to Carnation Creek (Fig. 41). The relatively low abundance in 9-12 mm *T. spinifera* for the 2001 smolt year suggests that wild coho survival will be relatively poor. Second, a similar type of relationship was developed for Barkley Sound (Great Central and Sproat Lakes) sockeye. 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 and both lakes. Variations in sockeye prey, and an example of the fit of the relationships to the observed values, are presented in Figure 42. 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.

Finally, it appears that the feeding biology and distribution of sockeye and coho salmon, herring and hake are related to the population biology of *T. spinifera*. *T. spinifera* begins spawning in February-March (Tanasichuk 1998). Most of the annual production results from spawns early in the year. The size fraction of euphausiid consumed by coho and sockeye, and their timing of migration, reflect spawning periodicity and the growth of euphausiids from the dominant *T. spinifera* cohorts. Sockeye feed on euphausiids early in the year (April-June) when many new animals are in the 3-5 mm size range. Coho, in turn, feed later on larger members of the same cohorts, after the euphausiids have grown to between 9 and 12 mm in length. The growth period for herring is between August and October, when the new production of euphausiids would be >17 mm. Finally, Pacific hake arrive on the SWCVI in June-July when the euphausiids produced by the early spawns would be at least 17 mm long, the size range that Pacific hake select. It is especially interesting to consider fish species-specific food availability. For example, euphausiid (*T. spinifera*) availability was relatively good for herring and sockeye in 2001 but was exceptionally poor for coho. This is interpreted as reflecting the match of euphausiid production and fish feeding as a consequence of variations in the timing and intensity of euphausiid spawns, euphausiid cohort-specific mortality, and fish distribution in time and space along the SWCVI.

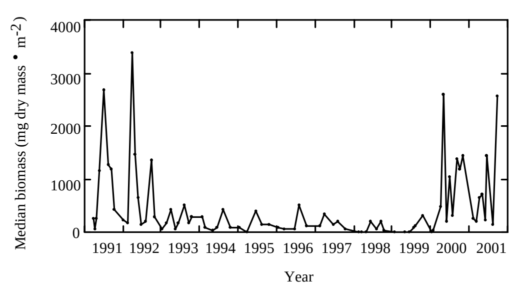


Figure 39. Median biomass of adult *Thysanoessa spinifera*.

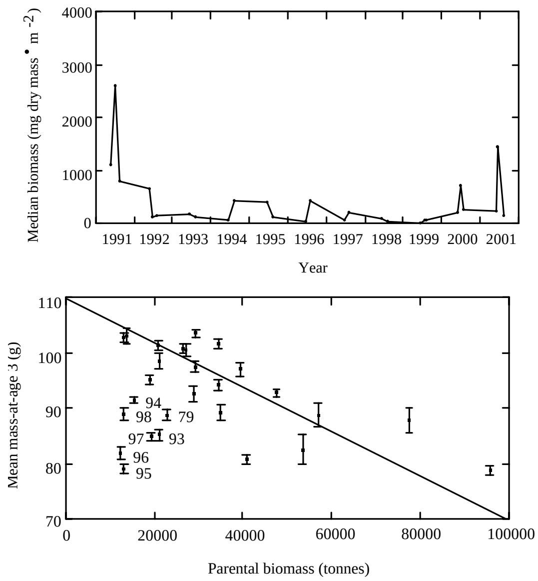


Figure 40. Upper panel: interannual variations in the biomass of herring prey (*T. spinifera*, > 17mm long) over the feeding season. Lower panel: relationship between parental biomass and mean size-of recruit herring; line is shows the density-dependent effect on growth; labels are year-class and identify outliers to the relationship.

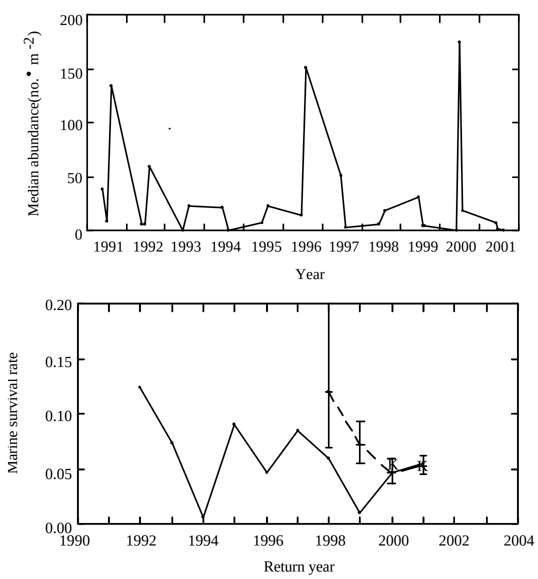


Figure 41. Upper panel: interannual variations in the abundance of 9-12 mm *T. spinifera* over June-August. Lower panel: results of retrospective analysis of forecasting accuracy of smolt-euphausiid regression for Carnation Creek coho. Solid circles – observed survival rate. Open circles – predicted 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.

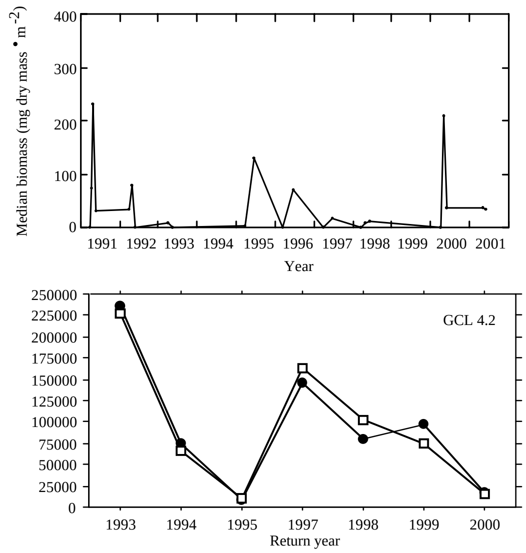


Figure 42. Upper panel: interannual variations in the biomass of 3-5 mm *T. spinifera* over April-June. Lower panel: plots of observed (solid circles) and fitted estimates (open squares) of number of returning sockeye by lake and age. GCL – Great Central Lake.

Shrimp

Results from fishery-independent small-mesh trawl surveys conducted off the west coast of Vancouver Island in May 2001 indicated that stocks of smooth pink shrimp (*Pandalus jordani*) continued to build on the southern part of the continental shelf, with the composition (age structure) of the catches being more similar to that during 2000 than during most of the 1990's (i.e. many young shrimp). In addition, a resurgence of walleye pollock was noted in these southerly areas, along with good catches of juvenile sablefish (300-350 g), and eulachons (ages 1 and older). If present oceanographic and hydrographic conditions continue, the expectation is for a good build-up of shrimp northward along the west coast of Vancouver Island over the next 6-8 years.

Herring and Herring Recruitment

Since about 1977, the recruitment of herring off the West Coast of Vancouver Island has been decreasing (Fig. 43). In 2001, the abundance (Fig. 44) remained the low levels observed during the stock collapse in the late 1960s. The productivity of the west coast of Vancouver Island herring stock (Fig. 44) has been declining since 1989, primarily because recruitment to this stock has been poor for 6 of the last 10 years (Fig. 43). A long-term research program has shown that herring recruitment in this region tends to be associated with warm ocean temperatures (opposite to the Strait of Georgia stock) 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 1999 and 2000 and should result in improved recruitment to the stock in the year 2002 and 2003.

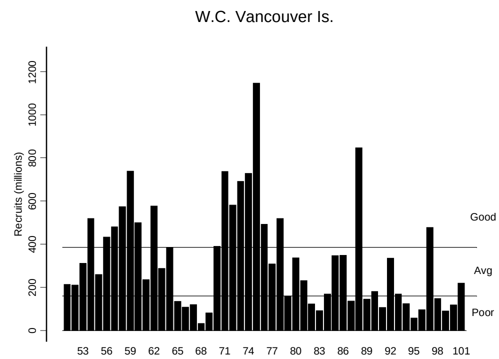


Figure 43. Interannual variability and decadal trends in recruitment to the west coast of Vancouver Island herring stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown. Note that 6 of the last 10 recruitments have been ‘poor’.

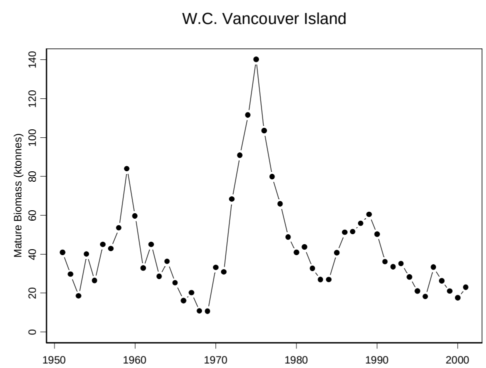


Figure 44. West Coast Vancouver Island Herring Abundance.

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 without warning in 1947 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, sardine distribution again contracted southward. During 2000, sardines did not appear in Canadian waters until late-July, early-August and were confined to coastal inlets along Vancouver Island. The most recent U.S. assessment indicates a continuing exponential increase in sardine abundance (Fig. 45). However, the 2001 trawl survey off Vancouver Island (Fig. 46) indicated that fewer sardines were present than in 1999 or 1997. The average abundance of sardines off the west coast of Vancouver Island since 1997 is approximately 75,000 tonnes.

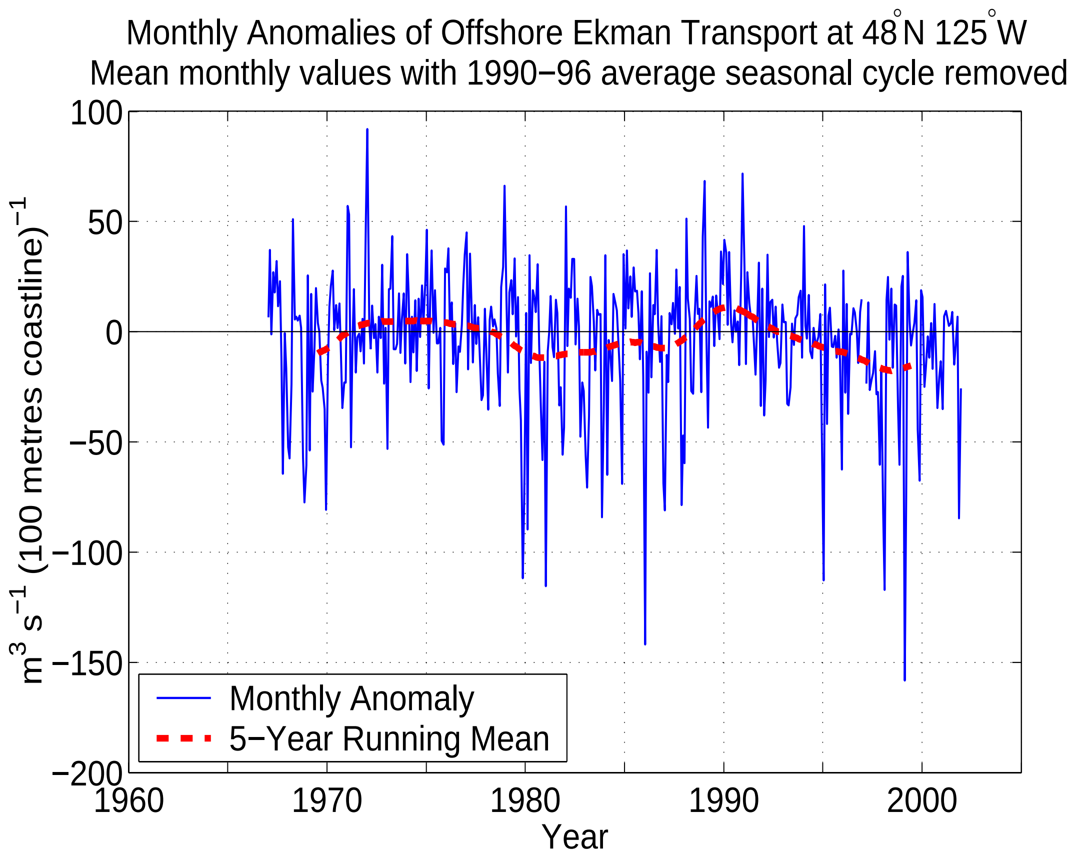


Figure 46. The distribution of Pacific Sardine was concentrated in southern offshore areas and coastal inlets in 2001. X = stations where no sardines wre captured.

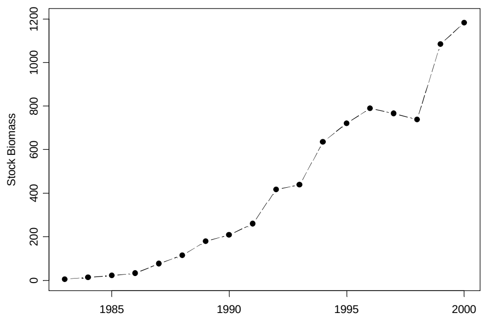


Figure 45. Time series of Pacific sardine stock biomass (x1,000 mt) of age 1 and older fish, estimated from an age-structured stock assessment model (data from Conser et al. 2001).

Hake

Pacific hake range throughout the California Current System from Baja California to the Gulf of Alaska. Their distribution and abundance are closely linked to oceanographic conditions in the NE Pacific. The biomass that is typically over 1 million mt supports large domestic fisheries in both Canada and the U.S. They have been assessed triennially since 1977 using hydro-acoustic survey techniques.

The most recent joint Canada/U.S. survey was conducted in 2001. The total biomass declined to 738 thousand mt from 1.2 million mt in 1998. This is the lowest observed biomass in the survey time series (Fig. 47). A stock assessment was conducted in early 2002 that models the population using survey biomass estimates and age compositions from the survey and the fishery. The analysis indicated that abundance has been declining since the mid-1980's when stock abundance increased to close to 6M mt due to three successive very strong year-classes (1977, 1980 and 1984) (Fig. 48). The analysis suggests that the survey underestimated the size of the population in the earlier years.

The distribution of biomass changed considerably in the 1990's with changing ocean conditions that resulted in over half of the biomass being present in Canadian and Alaskan waters in 1998. This northward push appears to have reversed dramatically in 2000 and 2001. In 2000, there were negligible amounts of hake available in the traditional fishing grounds of LaPerouse. In 2001, only 10 percent (75.3 thousand mt) of the stock biomass present in the triennial zone and the fishery was unable to take all of the available yield. In the U.S. portion of the survey there were few hake north of the Oregon border.

On a positive note there is some indication of moderate recruitment with the 1999 year-class (age 2's) accounting for 400 thousand mt of 738 thousand mt of total biomass. The two-year olds were present from California to Washington but did not show in the Canadian portion of the survey. The assessment estimates the year-class to be of only slightly above average strength but larger than others observed during the 1990's (Fig. 48).

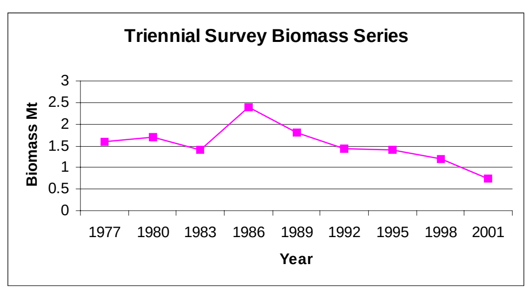


Figure 47. Triennial survey estimates of total offshore Pacific Hake biomass from 1997-2001.

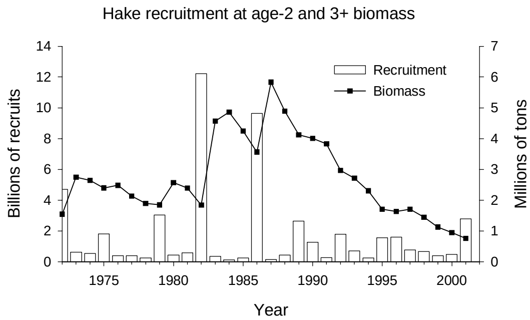


Figure 48. Estimated time series of offshore Pacific hake recruitment (at age 2) adult (age 3+) abundance.

Growth & Energetic Status of Pacific Salmon

Surveys initiated in 1998 showed that the juvenile coho salmon remaining off the West Coast of Vancouver Island in October 1998 were less than half the size of the animals sampled in northern British Columbia and SE Alaska (Fig. 49). This difference in growth is sufficient to explain much of the marine survival difference seen in many stocks of coho, chinook, and steelhead, if they remain in the regions of poor ocean conditions.

Coho collected in October were much smaller in the south in 1998 (~200g) compared to those collected in the north (~400 g). With the change in ocean conditions in 1999, coho size in October 1999 was essentially identical between southern and northern regions (~300 g), but then showed some slight evidence for smaller size to the south in 2000 and 2001. Generally, the results for 2001 suggest similar growth to that observed in 1999 and 2000. Adult salmon returns in 2001 were the survivors of the juvenile salmon entering the ocean in 1999 (chinook, chum, and sockeye) and

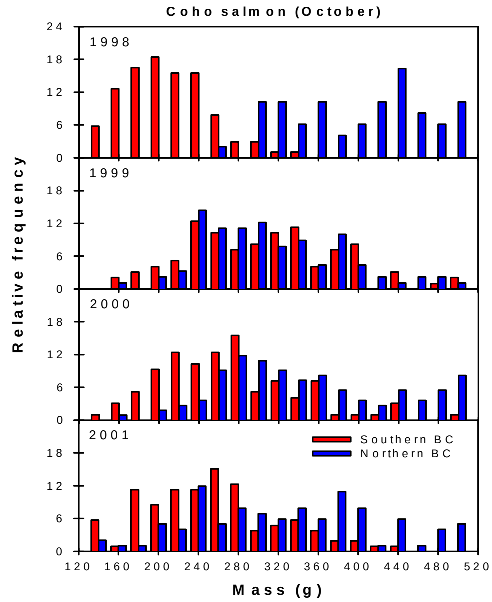


Figure 49. Size frequency distributions of coho collected off the west coast in October for southern British Columbia (west coast of Vancouver Island and Hecate Strait) versus northern British Columbia (Dixon Entrance and SE Alaska). The coho results show a major difference in size, apparently as a result of reduced feeding success

2000 (coho and pink salmon). In general, the adult returns of these species were very good in 2001, suggesting that the continued good juvenile salmon growth seen in 2001 may translate into continued improved salmon returns in subsequent years.

Proximate analysis indicates that coho found off southern BC in 1998 had lower stored energy in October than animals foraging farther north (Fig. 50), and that in 1999 and 2000 not only were animals in different regions able to grow to the same size, but that they also had roughly equal amounts of stored energy when animals of equivalent size are compared. Although measurement of the stored energy reserves of the coho collected in 2001 is not yet complete, it appears that these animals were also in good condition with high energy reserves. This also suggest that ocean conditions has improved since 1998.

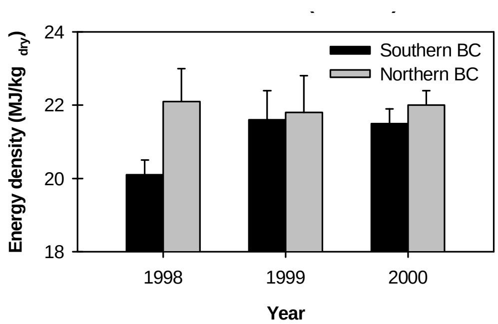


Figure 50. Energy density of juvenile coho salmon collected off the west coast of British Columbia during the month of October. Caloric content was lower for coho collected in Southern BC in 1998. The error bars represent 2 x SE.

The differences in mean size attained by the autumn indicate that growth rates vary greatly between regions. To evaluate the cause of these differences in growth, a mass balance model of cesium accumulation to estimate food consumption rates of salmon was used (Forseth et al. 1992, 1994; Rowan and Rasmussen 1996). Cesium accumulates in fish tissue as a result of ingestion, and provides an integrated measure of food consumption that has been used to derive consumption rates for a number of salmonids in freshwater systems.

Consumption rates of juvenile coho salmon were similar across regions and years (range: 7-10% of their body weight per day) (Fig. 51). Thus, differences in growth rates observed for juvenile coho salmon could not be attributed to differences in consumption rates. Rather, it suggests that metabolic costs or prey quality varied between years and areas. The size differences seen in 2001 suggest that growth conditions favourable to good salmon returns have continued.

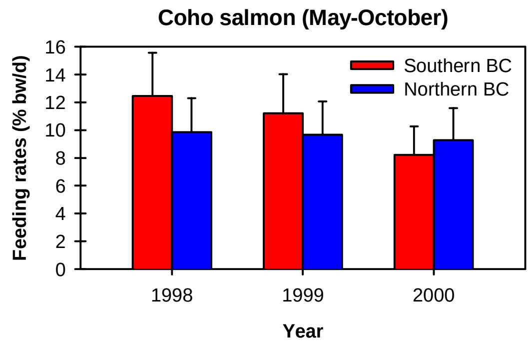


Figure 51. Summer feeding rates of juvenile coho salmon collected during the shelf surveys. Error bars represent 2 x SE.

Seabird Reproductive Performance on Triangle Island and in Laskeek Bay (Queen Charlotte Islands)

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, fledgling success, adult survival and population trends.

Year 2001 Performance on Triangle Island

Timing of Breeding and Nestling Growth

In 2001 the timing of breeding for the fish eating Rhinoceros Auklet, Tufted Puffin and Common Murre was very similar to the previous two years (Figure 52). In contrast to the other species timing of breeding for the planktivorous Cassin’s Auklet has advanced dramatically over the last two years. Year 2001 was, in fact, the earliest hatch date on record from the Triangle Island time series.

Nestling Growth

Nestling growth rates in 2001 were improved for the Rhinoceros auklet compared to the value reported for 2000. Tufted Puffin growth was below average, much lower than observed over the past two years, but not as poor as most of the 1990s. Tufted Puffin nestlings grew well early in the season but growth was retarded in late July at the same time that Pacific Saury (*Cololabis saira)* began to appear as the dominant prey in the diet of the Rhinoceros Auklet. The Cassin's Auklet nestlings grew at below average levels, much lower than in the previous 2 years perhaps due to changes in the availability of key prey species.

Nestling Diet

The food delivered to Rhinoceros Auklet nestlings in 2001 consisted primarily of Pacific sand lance (*Ammodytes hexapterus* 47 % by wet mass) and Pacific Saury (*Cololabis saira* 40 %) in addition to juvenile salmonids (*Onchorynchus spp:* 7 %) Interestingly, juvenile rockfish (*Sebastes spp,* 1 %) was scarce, far lower than observed in the last seven years.

In 2001 a third year of radio telemetry revealed that breeding Cassin's Auklet were foraging significantly further north than in the previous two years. Concurrent sampling by DFO revealed that Pteropods (salps) dominated the area near Triangle Island when the seabird marine distributions were recorded. The influence of the salps on the distribution of seabirds and their prey (e.g., the copepod *Neocalanus cristatus),* and the impact on reproductive performance are currently under investigation.

Reproductive performance and ocean climate variation

For Cassin's Auklet and Rhinoceros Auklet on Triangle Island our conclusion from last year that warm waters in spring are associated with poor nestling growth was supported when the 2001 data were added to the analysis (Figure 53). The poor performance of the Cassin's Auklet during warm spring years likely reflects (at least in part) a temporal mismatch between the timing of availability of their main prey (*Neocalanus cristatus*) and the timing of breeding. In warm spring years when SSTs were high (e.g., 1996 and 1998) the zooplankton peak is early and poor nestling growth and large scale nestling mortality are observed for Cassin's Auklet. The fact that the 2001 growth value was lower than expected may be related to the large number of salps in the area of the colony in that year (see above). The mechanism linking poor nestling growth and warm SST is less clear for the piscivorous Rhinoceros Auklet but may be related to temperature dependent recruitment to fish prey populations such as Pacific sand lance. The relationship between April SST and nestling growth rate indicate that that growth rate declines significantly as SST increases (> 7.5°C), demonstrating a strong response of seabirds to variation in ocean climate (Figure 54).

Laskeek Bay Background and Species Natural History

From 1984-1989, the Canadian Wildlife Service (Tony Gaston) studied the breeding biology of Ancient Murrelets on Reef Island (53°52' N, 131°31'W), Queen Charlotte Island. In 1990, the Laskeek Bay Conservation Society began a long-term research and visitor interpretation program on nearby East Limestone Island (52°54.4' N; 130°37.5'W).

Each year, researchers visit East Limestone Island and collect time series information on burrow occupancy, breeding success, adult mass at departure, chick mass at departure, adult survival, and median date of chick departure. Approximately every five years, the Canadian Wildlife Service conducts colony surveys in the Queen Charlotte Islands to assess population trends.

Year 2001 Performance in Laskeek Bay

Timing of breeding

In 2001, Ancient Murrelet chick departures (and hence egg laying) were later than the previous 14 years. From 1984 to 1994, the median date of chick departure became progressively earlier. Since 1995, median chick departure dates have been highly variable.

Breeding Success

Since 1984, there has been no statistical change in breeding success at the colonies on East Limestone Island and Reef Island. However, an examination of the breeding success anomalies reveals that three of the last four years are lower than the long term colony average (1.38 chicks per pair, Figure 55). The greatest drop occurred in 1998 and the next year, when sea surface temperatures cooled and breeding success returned to pre-ENSO levels. In 2001, breeding success was similar to 2000.

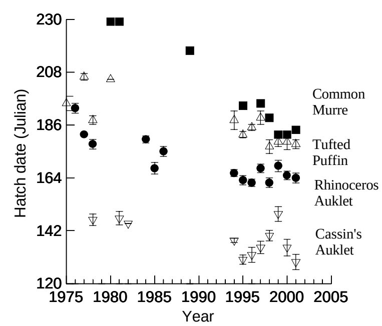


Figure 52. Timing of breeding for seabirds on Triangle Island, British Columbia, Canada (1975-2001). Values are mean hatch dates (with 95 % confidence intervals) for Cassin's Auklet, Rhinoceros Auklet and Tufted Puffin. Values for Common Murre are dates when nestlings were first observed.

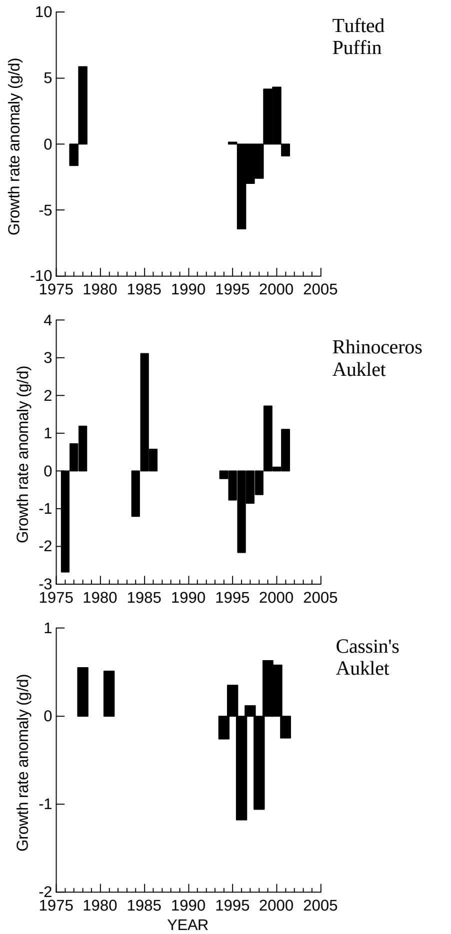


Figure 53. Nestling growth rate anomalies (g/d) for Tufted Puffin, Rhinoceros Auklet and Cassin's Auklet on Triangle Island, British Columbia, Canada (1976-2001). Note that in 1976 breeding failure was observed for the Tufted Puffins because most eggs failed to hatch.

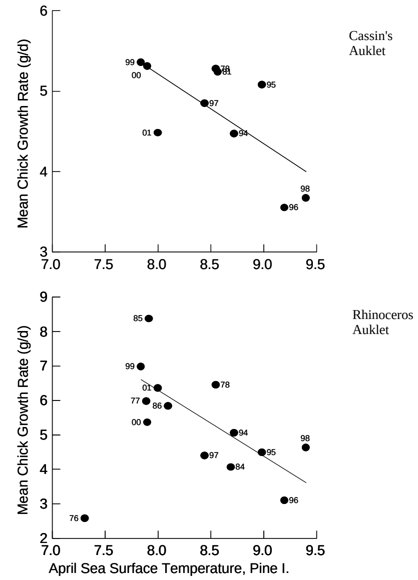


Figure 54. Consequences of interannual variation in spring SST for Cassin's Auklet and Rhinoceros Auklet reproductive performance on Triangle Island, British Columbia, Canada (1976-2001). Growth rates of nestling Cassin's Auklet and Rhinoceros Auklets are generally lower when spring is early and sea surface temperatures are warm. Mortality from starvation is much more frequent when chick growth rates are low. The slopes of the lines are statistically significant for both the Cassin's Auklet ($y = 12.1 - 0.87x$; $F_{1,8} = 7.3$, $P = 0.03$) and the Rhinoceros Auklet (excluding 1976, $y = 21.6 - 1.9x$; $F_{1,11} = 13.2$; $P = 0.004$). Shown are mean annual population estimates of nestling growth rate in relation to the average SST in April at Pine Island (50°35'N 127°26') Lightstation.

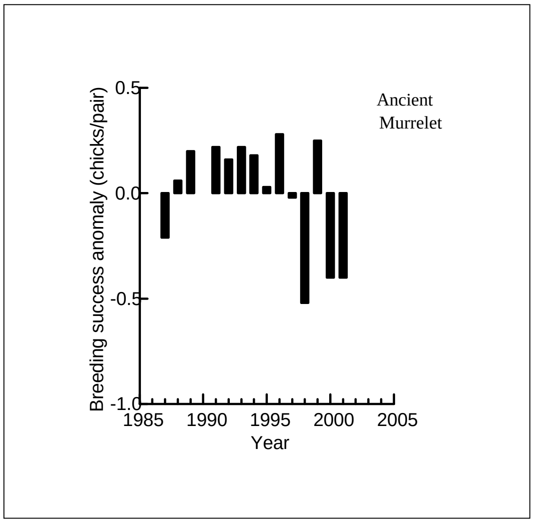


Figure 55. Breeding success anomalies for Ancient Murrelets at East Limestone Island (1991 –2001) and Reef Island (1986-1989) in Laskeek Bay, Queen Charlotte Islands, British Columbia, Canada.

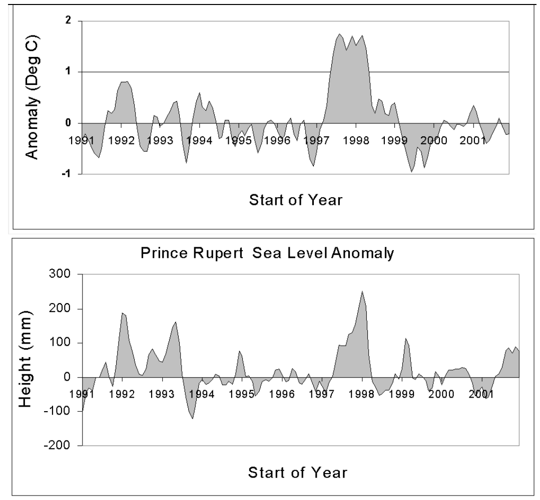


Figure 56. Top panel: monthly anomalies of temperature at Bonilla Island Lighthouse. Bottom panel: monthly anomalies of sea level at Prince Rupert, for the time period 1991 to 2001.

North Coast

Figure 56 displays monthly anomalies of temperature at Bonilla Island Lighthouse and sea level at Prince Rupert, for the period 1991 to 2001. Both anomalies were large and positive during the 1991/92 and 1997/98 El Niño winters. However, in 1999 temperature dropped while sea level rose. In the year 2001 temperatures were generally cooler than the long term average. Sea level was lower than average in winter and early spring, higher than average from late spring to year-end. These fluctuations are normal for non-El Niño years.

Winter sea level and temperature

Water temperature at Bonilla Island and pressure-adjusted winter sea level at Prince Rupert (Fig. 57) 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 have strong currents through Hecate Strait and are poor recruitment years. “Winter” is the three month period of January to March inclusive.

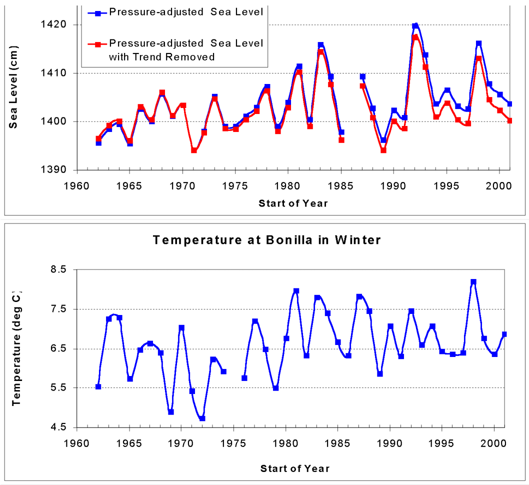


Figure 57. Top panel: winter pressure-adjusted sea level at Prince Rupert relative to chart datum. Bottom panel: temperature at Bonilla in winter.

Two curves in Figure 57 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 for 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 inter-annual variability in winter sea level relevant to ocean currents in Hecate Strait and possibly Dixon Entrance.

Pressure-adjusted sea level at Prince Rupert in winter, 2001, continued its decline following the high in the El Niño winter of 1998. The level of 1400 centimetres at Prince Rupert in 2001 winter was about as low as observed since 1990. The winter of 2001 was one of six winters in the period 1990 to 2001 whose pressure-adjusted sea level dropped to such levels. Prior to 1990 even lower values were common.

The annual average temperature at Bonilla is also plotted in Figure 57 back to the start of observations at this Lighthouse in 1962. The annual average temperature was a few tenths of a degree warmer than observed in 2000, but a few tenths of a degree cooler than average for the period 1981 to 2001. Except for the extreme high temperature in the El Niño winter of 1998, the past seven years were cooler than the average of 1981 to 1994, but warmer than the average found in the mid-1960s to mid-1970s.

Set-up of Eddies West of the Queen Charlotte Islands

Eddies are named Sitka and Haida after local geographic features along the coast where they are formed. One or two Haida Eddies form in Canadian waters during most winters. Sitka Eddies form west of Alaska. Eddies were larger in winters of very strong El Niño events, such as 1982-1983 and 1997-1998. The 1998 eddy was the largest of the past decade, whereas the eddies formed in 1999-2001 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 2001 supports the reverse side of this trend.

Much, if not most, of the source waters 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 58 displays images of these eddies in the Eastern Gulf of

Alaska for four seasons in 2001. Most eddies decayed severely during autumn storms between September and December.

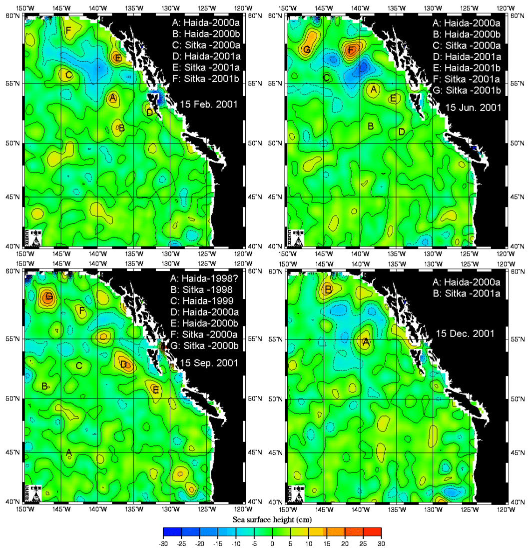


Figure 58. Satellite images of Haida eddies west of Alaska, for four seasons in 2001.

The two eddies formed in the 2001 winter rate as two of the weakest observed to date. The eddy denoted Haida-2001a drifted toward the southwest through spring and summer, but decayed during autumn storms. By December it could not be clearly identified in these images. The second eddy to form, Haida-2001b, merged into an eddy formed the previous year and ceased to be a separate feature.

Sea Level Trends

Monthly average sea levels are available since 1910 or so at several British Columbia ports. Annual average levels are presented in figure 59 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.

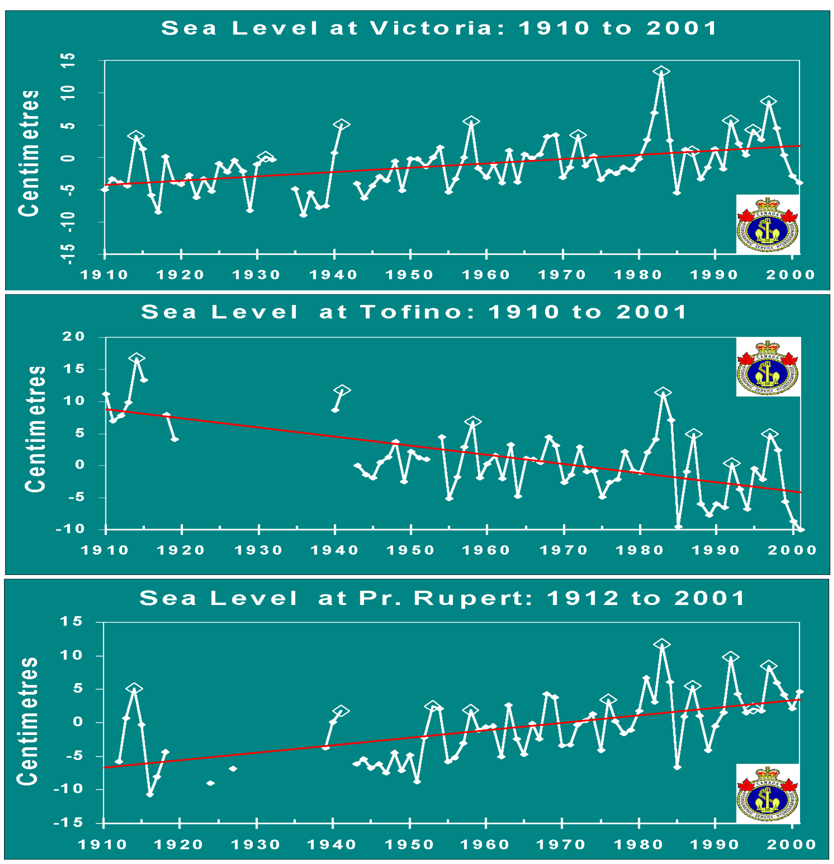


Figure 59. Annual average sea levels: top panel: Victoria, middle panel: Tofino, bottom panel, Prince Rupert, from 1910 to 2000.

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 7 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 denoted by large diamonds denote major El Niño events that coincided with high sea levels at these ports. Elevations at Tofino and Victoria have declined steadily since the latest El Niño in 1997/98. Sea level at Prince Rupert rose a few centimetres from 2000 to 2001. At both Tofino and Victoria the annual average sea level fell well below the trend line, indicating values between 5 and 10 cm below normal. At Prince Rupert the annual average sea level was close to normal.

Global sea level rise has been 10 to 20 centimetres/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.

Temperature and Salinity Trends

The trend in temperature over the period of 1940 to present matches that of many records in the northern hemisphere (Fig. 60). Warm temperatures in the early 1940s were followed by a cooling until mid 1960s and early 1970s, followed by warming. At Langara Island and Bonilla Island the temperatures in 2000 stayed within a few tenths of a degree of the values in 2000, but were lower than typical values observed during the 1990s. Historically, the temperature at Bonilla is a few tenths of a degree warmer than temperature at Langara. This held true for 2001.

The salinity at Langara freshened by 0.7 since the observations began in the early 1940s, mostly during the period 1971 to present (Fig. 60). Bonilla surface waters did not experience the same trend. Only one year, 1978, saw annual average salinity at Langara as fresh as observed from 1996 to 2001. At Bonilla, the reverse trend held. Annual average salinity from 1998 to 2001 was saltier than typically observed. The period 1998 to 2001 marks the only time in the 40-year record of Langara and Bonilla salinity that values at these two ports were within 0.3 for more than a single year.

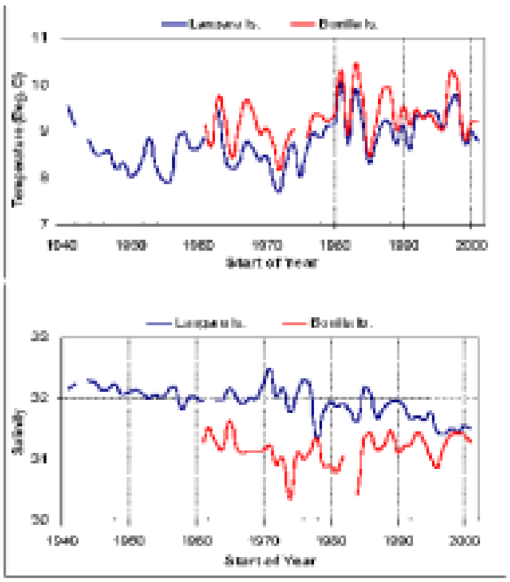


Figure 60. Annual average temperatures (upper panel) and salinities (lower panel) in northern British Columbia from 1940 to 2000.

Flatfish in Hecate Strait

Catch age analysis has been updated through 2001 for Rock sole and English sole in Hecate Strait. The decline in recruitment observed for both species in the 1990s has leveled off. Rock sole biomass shows little trend between 1998 and 2001 while English sole biomass increased slightly over the same period.

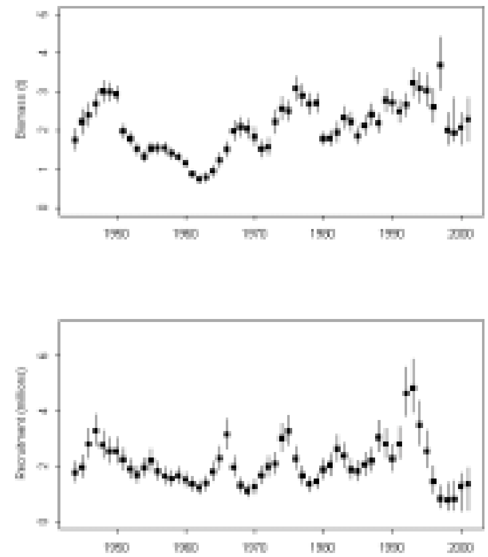


Figure 61. Biomass (upper panel) and recruitment (lower panel) for Hecate Strait English sole, 1945-2000.

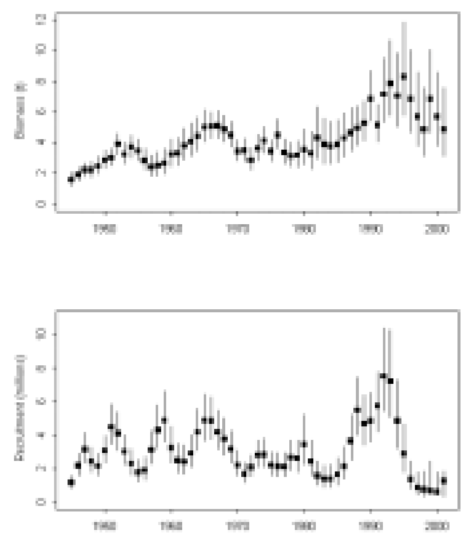


Figure 62. Biomass (upper panel) and recruitment (lower panel) for Hecate Strait Rock sole, 1945-2000.

Incorporating an environmental index in the assessment of Pacific Cod

Tyler and Crawford (1991) tested several possible environmental stock recruitment functions for the Pacific cod stock in Hecate Strait including transport, temperature, herring as prey for young cod, and herring as prey for spawners. They concluded that the transport hypothesis was the most effective in explaining recruitment anomalies for the stock. Sea level at Prince Rupert during the spawning period (January-March) was used as an index of transport. High sea levels indicated high transport through Hecate Strait and this resulted in low recruitment success due to removal of cod eggs and larvae from the area.

Their analysis of alternative hypotheses was repeated using data from the original time period along with new data for the late 1980s and 1990s. The original conclusions held and the transport hypothesis continues to be the best predictor of recruitment anomalies. Based on these results, an index of sea level height in Prince Rupert was incorporated as an environmental 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 have been unfavourable for recruitment through most of the 1990s, however, sea levels have declined in the past 2 years and recruitment may be improving.

Herring in Hecate Strait

The exploitable biomass of herring in the Hecate Strait area is an amalgamation of 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. 63,65,67). Levels of recruitment to the Queen Charlotte Islands have been depressed (Fig. 64) with 5 of the past 10 year-classes being 'poor' while the Prince Rupert stock (Fig. 66) has experienced a good recruitment at least every 4 years since 1980. Recruitment to the Central Coast stock (Fig. 68) 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 and Prince Rupert District have been getting stronger while those in the Central Coast have been getting weaker suggesting poorer survival conditions in the latter area. Abundance in the Queen Charlotte Islands and Prince Rupert are expected to increase in 2002 while the Central Coast will most likely decline from the levels of 2001.

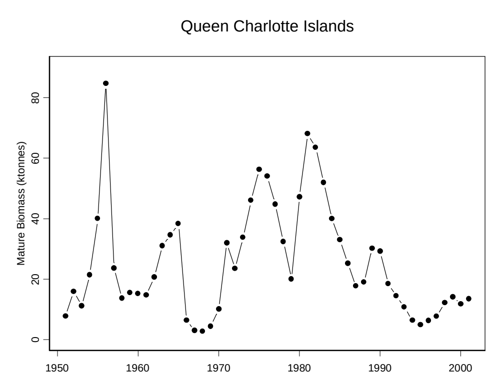


Figure 63. Queen Charlotte Islands herring abundance.

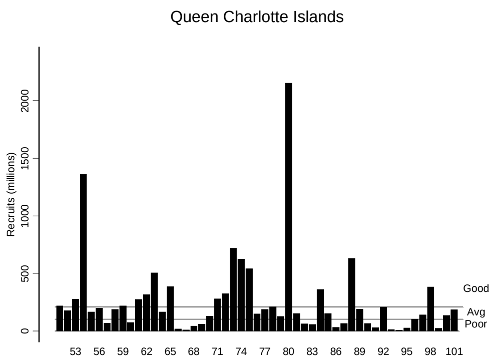


Figure 64. Interannual variability and decadal trends in recruitment to the Queen Charlotte Islands herring stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown. Note that 5 of the last 10 recruitments have been ‘poor’.

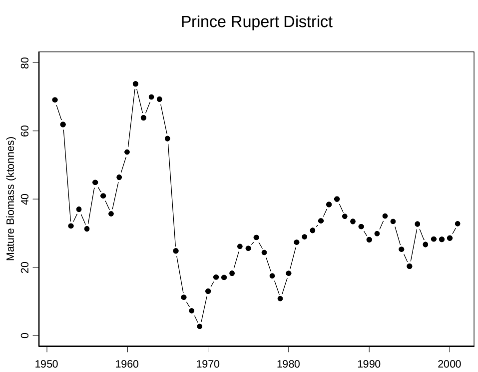


Figure 65. Prince Rupert District herring abundance.

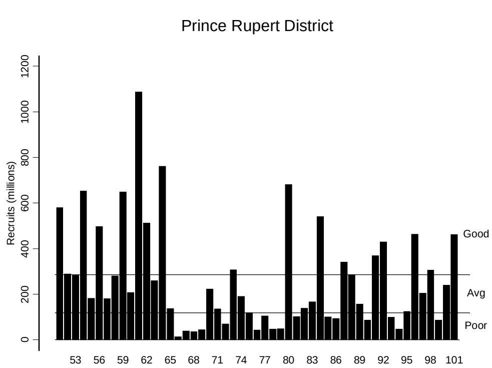


Figure 66. Interannual variability and decadal trends in recruitment to the Prince Rupert District stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown. Note that ‘good’ recruitments have occurred almost every four years since 1980.

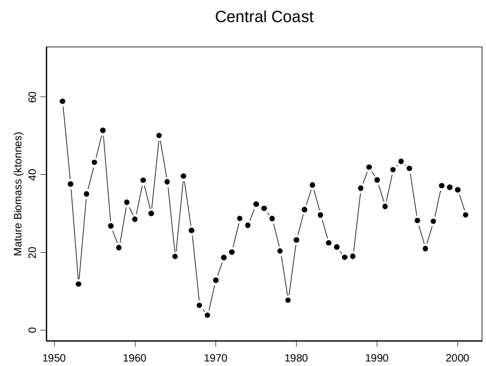


Figure 67. Central Coast herring abundance.

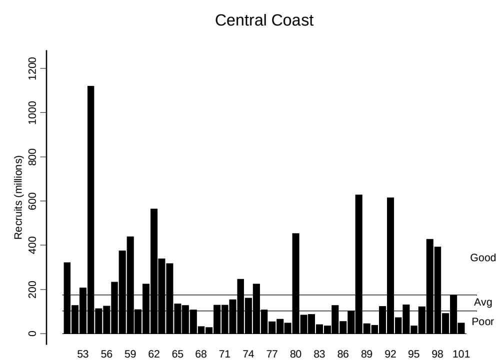


Figure 68. Interannual variability and decadal trends in recruitment to the Central Coast stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown.

Strait of Georgia

Temperature and salinity

The sea surface temperature in the strait remained slightly above the long-term average in 2001, with sea surface temperature anomaly of about 0.5^{o} C for most of the year (Fig. 69). Sea surface salinity remained higher than average for the whole year, with SSSA values varying from about 1 to 2 psu. The results of Figure 69 are monthly values measured at Entrance Island. Similar conditions were recorded at other lighthouse stations as well as at the Nanoose Bay station.

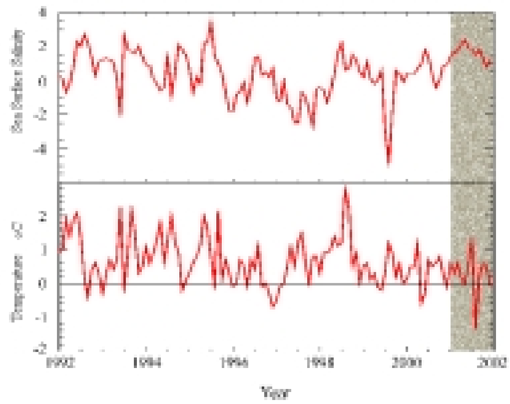


Figure 69. Monthly sea surface salinity and temperature anomalies measured at Entrance Island.

Fraser River Influence

Due to lower than normal snow pack levels throughout its watershed, the discharge rate for the Fraser River in 2001 was lower than the long term average during the most of the year. The freshet peaked in early summer with maximum discharge reaching moderate values of about 7000 m3 s-1 followed by an unusual late second peak in late July (Fig. 70) due to important rainfall at the time.

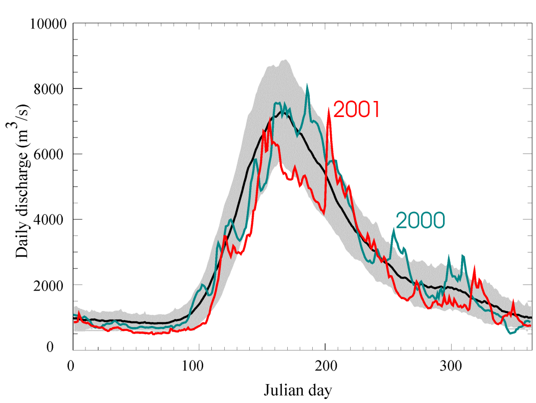


Figure 70. Fraser River discharge at Hope. The black line indicates the long term average discharge rate, and the shaded area the standard deviation about the mean.

The mean annual daily discharge of 2320m3/s was lower in 2001 than the long term average of 2720 m3/s (Fig. 71). Figure 71 also gives the day of the year for which half of the total yearly discharge was reached. The time series indicate a long-term tendency towards earlier freshet. However, in the last three years (including 2001), there seems to be a reversal of this trend, with more fresh water coming later in the year.

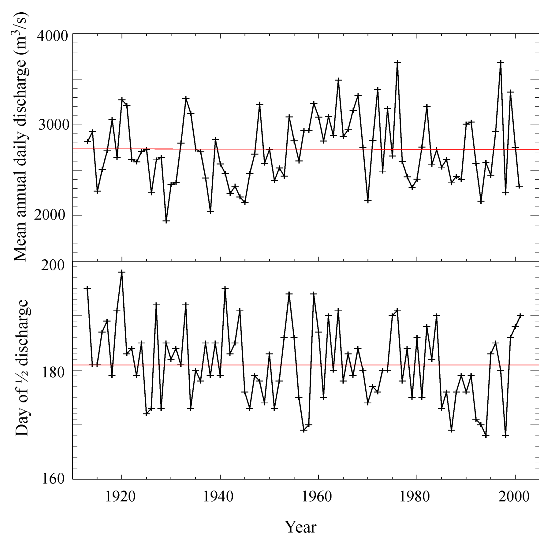


Figure 71. Mean annual discharge and day of the year for which half of the total yearly discharge is reached, for the Fraser River at Hope.

Figure 72 gives contours of salinity measured at Nanoose Bay, located in central deep basin of the Strait, during the last two years. It is evident that, in 2001, the surface fresh layer was much thinner than in the previous year because of the reduced freshwater discharge in 2001.

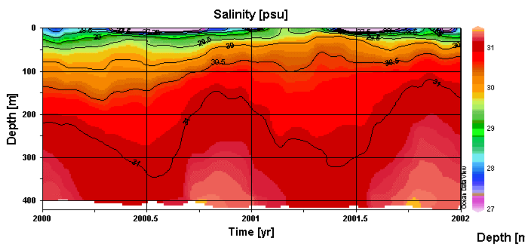


Figure 72. Contours of salinity measured at the Nanoose Bay station.

Zooplankton

The Cooperative Plankton Research Monitoring Program (COPRA) collects physical (CTD) and zooplankton data from a series of 19 stations in five unique oceanographic regions along the British Columbia coast (Fig. 73) including all historical COPRA samples (http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/plankton/zooplanktondatabase.htm).

The two Strait of Georgia stations, CPF1 and CPF2, are sampled the most frequently of all COPRA stations (samples collected about bimonthly). During 2001, both of these stations have had similar biomass and abundance values; however, CPF1 is more influenced by southern Strait currents and zooplankton distributions are similar to other southern Strait zooplankton stations. CPF1 is located between the southern and central Strait and shows a mix of zooplankton from both areas.

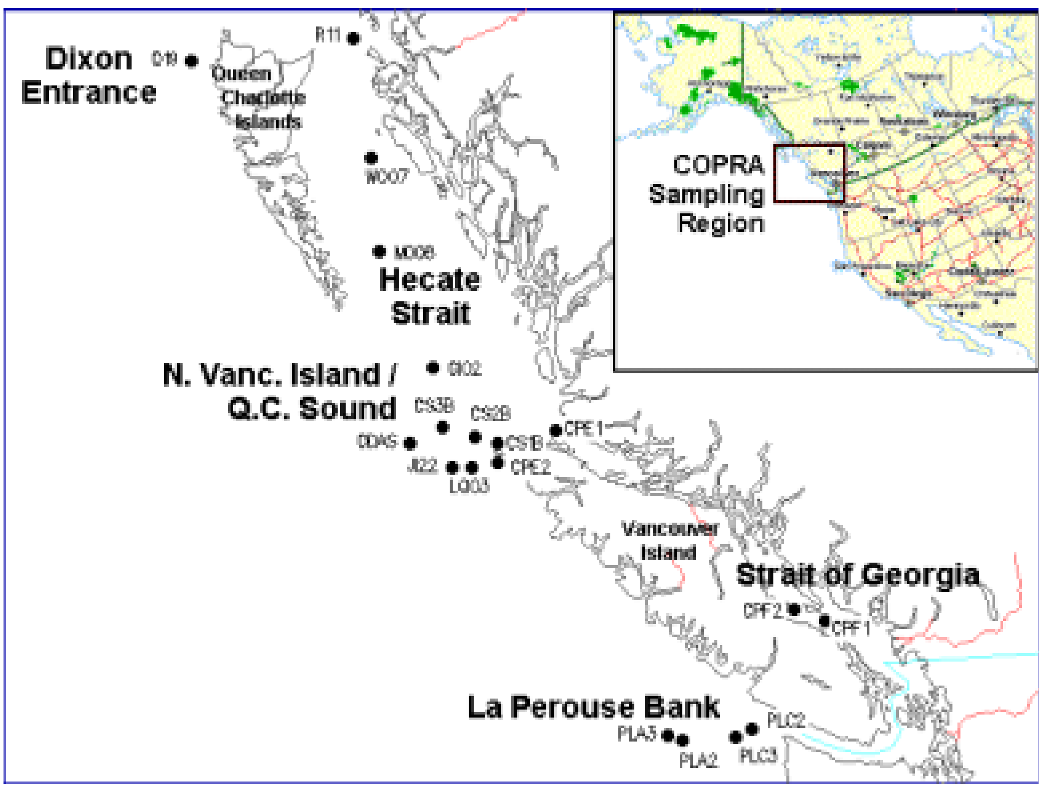


Figure 73. Standard COPRA CTD and zooplankton sampling stations.

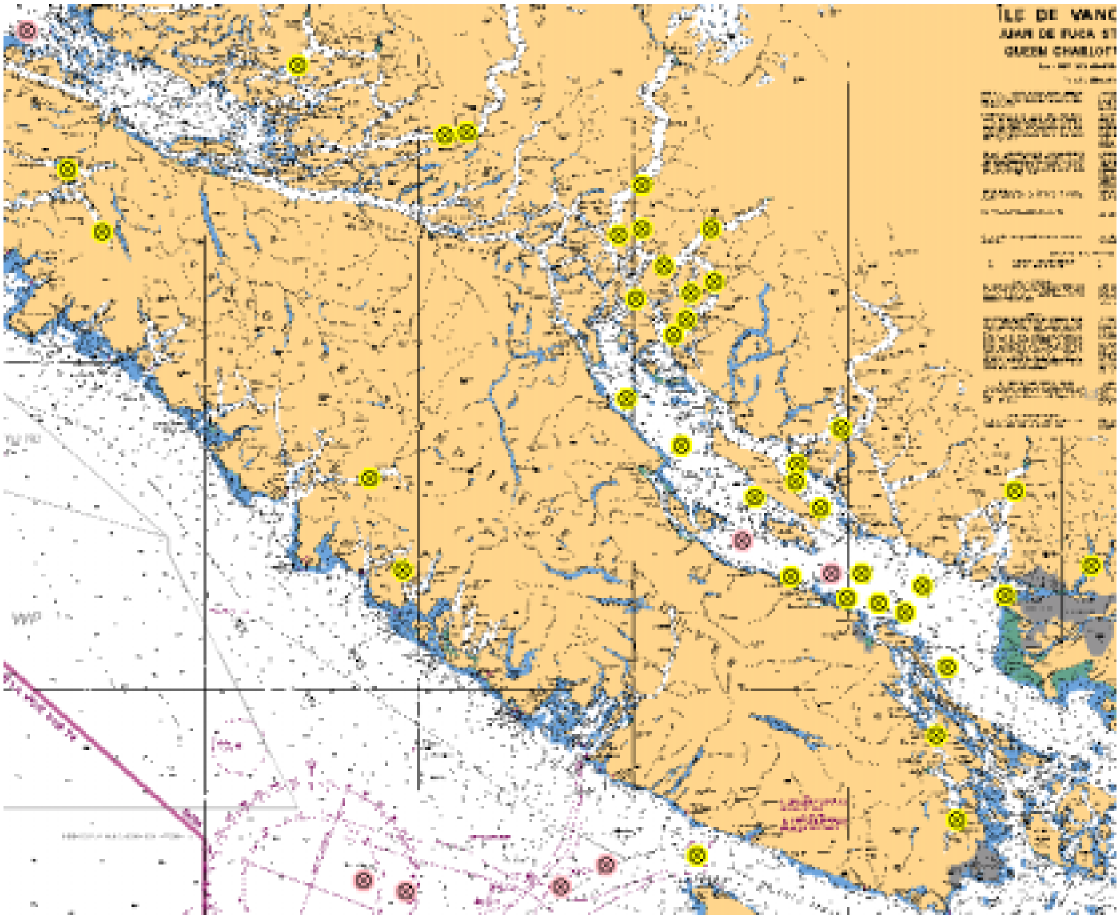


Figure 74. Zooplankton sampling stations collected from 2000-2002 in the Strait of Georgia and its adjacent inlets. Yellow dots denote stations that were part of the SSF covariability project, including the monitoring of inlets for NIS and euphausiid acoustic assessments. Pink dots are standard COPRA sampling stations, including four stations on La Pérouse Bank.

Euphausiids

An acoustic time series monitoring program for euphausiids has been conducted within the Strait of Georgia and adjacent inlets for the last 12 years.

The dominant euphausiid found in the Strait of Georgia is *Euphausia pacifica*, with an average body length of 16mm and average life span of 12-14 months. Euphausiids are one of the most abundant plankton in the Strait of Georgia and form the primary food source for many commercially important fish species (e.g. salmon, herring, and hake). Euphausiid species composition varies in the adjacent inlets. Saanich and Jervis Inlets are also both dominated by *E. pacifica*, whereas Knight and Toba Inlets contain significant amounts of *Thysanoessa spinifera*. Changes in dominant euphausiids in inlets may contribute to the distribution and health of hake and other fish that prefer euphausiid-based diets.

Acoustic data collected in 2000 also noted a ‘ramping-up’ of the euphausiid biomass within the Strait of Georgia by at least 2-4x above historical values over the last decade (see 2000 Pacific Region State of the Ocean report and Romaine et al. 2002). In addition, there was an increase in individual size of Euphausiids in 2000. This increased size persisted in 2001.

Salmon

Juvenile salmon surveys conducted in July 2001 indicated that the improved productivity observed in the Strait of Georgia in 2000 has continued. In 2001, the abundance of ocean age 0 coho, chinook, and chum salmon remained high relative to the period from 1997 to 1999 although slightly lower than in 2000. The estimated abundance of ocean age 0 coho in July 2000 was 9.5 million compared to the estimated 11.2 million observed in 2000 (7.9 million) but exceeding the combined abundance from 1997-1999. Similarly, ocean age 0 chinook abundance was 5.9 million, which was lower than 2000 but 1.3 to 2.5 times higher than the 1997 to 1999 period. Ocean age 0 chum salmon abundance had greater variability between years with an abundance of 14.2 million in 2001 compared to the estimated abundance of 27 million in 2000. The 2001 estimated abundance ranged from 1.3 to 7.1 times higher than the years 1997 to 1999.

In addition to the continued increase in abundance of ocean age 0 salmon in the Strait of Georgia, the individual size and condition of coho were significantly greater than the 1997 to 1999 years. Average size of chinook and chum salmon was more variable among years, however, the condition of these species in 2001 was the highest for the 1997 to 2001 period.

The distribution of the ocean age 0 salmon within the Strait of Georgia remained consistent with previous years. In 2001 98% of the coho were in the top 45m, 99% of chinook were in the top 60m, and 98% of chum were in the top 30m.

In addition to the observed increases in size and/or condition of juvenile salmon in 2000 and 2001, there were changes in the incidence of empty guts and in the average gut volume. For all three species the incidence of empty guts decreased in 2000 and 2001 and the average gut volume increased.

The results of improved ocean survival of ocean age 0 salmon in 2000 were observed in the returns of adult coho and pink salmon in 2001. As forecast last year, coho did return to the Strait of Georgia and did have increased marine survival. The marine survival of coho increased to 4.5% and returning fish were larger. In addition, there was a record escapement of 22 million pink salmon to the Fraser River. This record escapement came from one of the weakest brood years on record.

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. This good recruitment is linked to a reduction in size at age of Pacific hake, a major predator of herring. Abundance of herring in the Strait of Georgia reached a recent high level in 2001 at just over 100,000 tonnes (Fig. 75) 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. 76). Juvenile rearing conditions within the Strait of Georgia appears 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 1999 and 2000 corresponding to the 2002 and 2003 recruitments suggest that 2002 will be an 'average-good' recruitment while 2003 could be another 'good' year. The recent strong recruitment should maintain the stock at very healthy levels for the next few years.

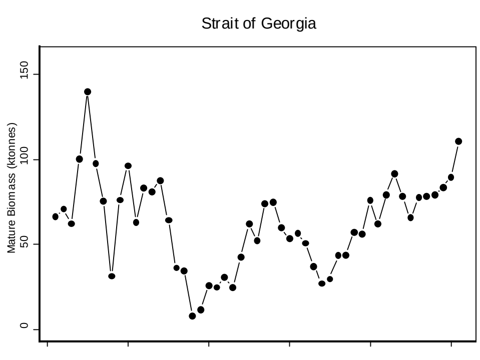


Figure 75. Strait of Georgia herring abundance.

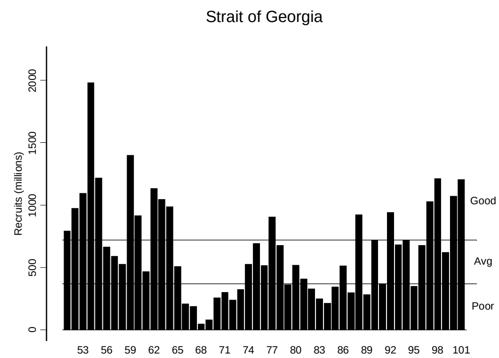


Figure 76. Interannual variability and decadal trends in recruitment to the Strait of Georgia stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 6 of the last 10 year-classes have been 'good'.

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/

meteorological factors, we can only speculate on the impacts.

West Coast of Vancouver Island Major Fish Stocks

Hake: The total biomass of hake will remain low on the west coast of North America. The dramatic change in distribution in 2000 and 2001 resulted in a large decrease in total abundance off British Columbia. It is not known if the distribution of hake observed in 2000 and 2001 will persist into 2002. The 2001 assessment for hake off the west coast indicates stocks are now at historical low levels as a result of poor recruitment during the 1990s coupled with high exploitation rates. The recent (2001) acoustic survey indicates the 1999 year class is the strongest since 1987.

Salmon: Total Canadian 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 recorded in 1996. In 1999 and 2000 the total catches of Pacific salmon in Canada were the lowest on record (starting in 1925). Although catches in 2001 are expected to remain low, 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 stocks. 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.

Herring: Herring on the west coast of Vancouver Island are likely show some trend to increasing abundance given the reduction in the abundance of predators in the area. Since ocean conditions were more favourable for herring survival in 1999 and 2000, we expect an improvement in recruitment to the stock, beginning in 2002.

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 2000 and 2001, the distribution of sardines in B.C. was again reduced and limited to areas around western and northern Vancouver Island.

Groundfish: The recent climate/ocean regime shift (1999) may result in improved year class success and subsequent recruitment of many groundfish stocks. During the 1990s several groundfish species experienced reduced year class success (McFarlane et al. 2000). If the 1999 regime shift does improve year class success, the improved recruitment will not be evident until the cohort enters the fishery. For example, sablefish recruitment might improve in 2004, halibut in 2007, and Pacific ocean perch in 2009.

North Coast Major Fish Stocks

Flatfish: The decline in recruitment seen in Rock sole and English sole in the 1990s has levelled off. Since 1998 English sole biomass has increased slightly while no trend is evident for Rock sole.

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 in the last two years and recruitment may be improving.

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 Major Fish Stocks

Euphausiids: The abundance of euphausiids in the Strait of Georgia doubled in September 2000 compared to October 1999. This increased biomass is important, as euphausiids are a major prey item for many predators such as coho salmon. In addition, in 2000 and 2001 the individual size of the euphausiids increased significantly. We expect to see an increase in the abundance of predators in the improved productivity continues.

Salmon: The behaviour of Strait of Georgia coho salmon changed in the mid-1990s when virtually all the coho left the Strait of Georgia and did not return until the spawning migration. During these years there was also a dramatic decrease in the marine survival of coho salmon. These changes in coho behaviour and survival were associated with changes in climate and oceanography.

In 2000, we observed a dramatic increase in the abundance of juvenile coho, chinook and chum salmon in the Strait of Georgia. The abundance of salmon juveniles in the Strait of Georgia in 2001 remained high. Juvenile coho abundance in 2001 was slightly lower than 2000 but still exceeded the combined estimates from 1997 to 1999.

The individual size and condition of juvenile coho in 2001 remained significantly greater than coho from 1997 to 1999. Although the average size of juvenile chinook and chum salmon was more variable, the condition of these species in 2001 was the highest for the 1997 to 2001 period. In 2000 and 2001 there was a decrease in the incidence of empty stomachs and an increase in the average stomach volume of juvenile coho, chinook and chum salmon in the Strait of Georgia.

As forecast in the 2000, State of the Ocean Report, coho salmon did return to the Strait of Georgia in 2001 for the first time since 1994. The marine survival of Strait of Georgia coho also increased to 4.4% from 1.9% with some stocks increasing as high as 7.1% (Black Creek, Simpson et al 2002). We expect to see a similar behaviour in 2002 and marine survivals similar to 2000.

In addition to increased marine survival of coho, there was an increase in the marine survival of pink salmon. As a result of the improved marine survival and to no fishing on these stocks, Fraser River pink salmon escapement was 2x the highest recorded with an estimated 22 million fish returning to the Fraser River. If average freshwater production and survival rates are applied, the number of juvenile pink salmon entering the Strait of Georgia in 2002 could exceed one billion. How these juveniles will impact other salmon and other species in the Strait of Georgia is unknown but should be studied consistent with our emphasis on ecosystem management.

Hake: The mean length of age 4 females is used as an indicator of change in the mean size of hake. The mean length of age 4 female hake in the Strait of Georgia decreased from approximately 40cm in the 1980s to 35cm by the mid-1990s, and remained small until 1999. Since 2000, size at age increased slightly. Hake in the Strait of Georgia will continue to be of small individual size and average total biomass at least until 2004.

Herring*:* The abundance of herring in 2001 is stronger even than recent years at just 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 1951-2001. The abundance of this stock has been increasing steadily since the recent low of the mid-1980s. Juvenile surveys in 1999 and 2000 suggest the trend of recent strong recruitment is likely to continue at least over the next few years.

Contributors

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