2000 Pacific Region State of the Ocean

Background

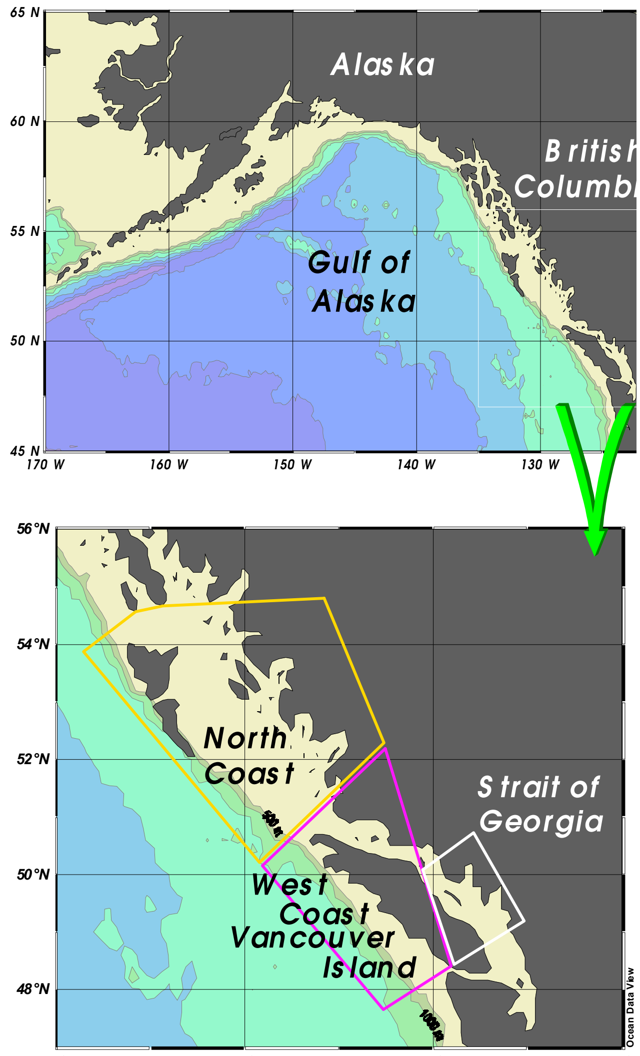
This report documents the state of the ocean for the year 2000. The physical, chemical and biological state of the marine environment impacts the yield (growth, reproduction, survival, distribution) of marine organisms as well as the operations of the fishing industry. Changes in the state of the ocean 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 2000 reflected the moderate La Niña conditions in the equatorial Pacific, and followed near-normal conditions in 1999 and several previous years of strongly "anomalous" conditions associated with El Niño warming (highlighted by the major events of 1991/92 and 1997/98).



Canada

Table of Contents

Summary by Region

Gulf of Alaska

- Except for a persistent pool of warm surface water centered near 35° N, 160° W in the western northeast Pacific, sea surface temperatures (SST) in 2000 were approximately 1°C lower than normal (1961-1990 average) throughout most of the Gulf of Alaska.

- Anomalously low temperatures penetrated to about 100 metres depth.

- Concentrations of nitrate, a macro-nutrient, returned to near background levels.

- Phytoplankton concentrations were variable but not dissimilar to previous years.

- Unusual deaths of Grey whales along the NE Pacific coast in 2000 may have been linked to inadequate feeding in the Bering Sea in the summer of 1999. In contrast, Humpback whales were relatively abundant off the B. C. coast relative to other years.

West Coast of Vancouver Island

- Coastal and continental shelf/slope SST varied from near normal to roughly 0.5 to 1.0 ºC below the 1990-1996 mean during the year. Within inshore protected waters, surface temperatures often exceeded normal values in summer but returned to near normal conditions in the fall. In the offshore region, maximum departures from mean conditions occurred through the winter to late spring (May).

- There were few periods of strong (> 0.2 N/m^2) southeasterly (downwelling-favourable) winds in winter and spring and only one major upwelling period (mid June) in summer. The strongest upwelling favourable winds occurred in early November and mid December when the magnitude of the daily-mean southeastward wind stress exceeded 0.35 N/m^2. Summer upwelling winds were weak over the south section from mid-June to late August.

- The Fisheries National Marine Oceanographic Center (FNMOC) Upwelling Index indicates normal (1990-1996 mean) upwelling in summer with a single major event in mid June and persistent downwelling conditions during the winter of 1999/00 and the fall of 2000.

- Subsurface temperatures to 400 m depth at mooring site A1 were near to slightly below the 1990-1996 mean (“normal”) while those at coastal mooring sites E1 and BP1 were normal to near-normal until mid summer but much higher than normal off Estevan point in later summer (record ends in October). (Note: Changes in mean temperature levels at slope location, A1 may occur from one deployment period to the next due to slightly different mooring depths.)

- Subsurface salinities to 400 m depth at site A1 were near normal (1990-1996 mean) throughout the data series. At sites E1 and BP1, salinities were near normal but with periods of much lower (1 psu) salinity pulses in spring and early summer. (Note: Changes in mean salinity levels at slope location, A1 may occur from one deployment period to the next due to slightly different mooring depths and sensor response.)

- Alongshore current velocity was near normal (1990-1996 mean) during the winter and early spring with daily mean speeds peaking around 40 cm/s poleward in late February at 35 m depth at site A1, 70 cms/ poleward at 25 m depth at site E1 and 80 cm/s at 35 m depth at BP1. Near-surface currents were generally more strongly equatorward than normal in spring but less strongly poleward than normal in summer.

Mean currents were poleward at all depths in winter but mainly equatorward in summer at 35 m depth over the shelf break. As usual, mean currents were persistently poleward over the inner shelf.

- There was a substantial increase in the zooplankton prey species for herring, hake and coho salmon. Improved food availabiltiy for these fish removes this constraint on growth and marine survival which has characterized recent years.

North Coast

- As in 1999, SST out to 50 km west of the continental shelf was slightly cooler than the long-term average.
- As in 1999, in Dixon entrance and Hecate Strait, SST remained at values typical of the 1980s and cooler than measured in the 1990s.
- Surface salinities at Bonilla Island in Hecate Strait were close to or slightly above the long term average while Langara Island in Dixon Entrance continued to show a decreasing salinity trend. Few other data are available for the North Coast.
- Annual average sea levels (adjusted for changes in atmospheric pressure) were lower than the long-term trend.
- Offshore transport through coastal eddies diminished in 2000 and only remnants of previous eddies were present in the offshore offshore region.
- Hake abundance dropped dramatically in 2000. Hake were found in only small aggregates off the north coast of Vancouver Island.

Strait of Georgia

- SST was close to the long-term average in 2000. At mid depth, the water temperatures remained near climatology throughout the year.
- Mean annual sea surface temperatures in Nanoose Bay were typical of those for the averaging period of 1977-1989.
- Surface salinities closely followed climatology throughout the year.
- Total Fraser River discharge in 2000 was near the long-term average with periods of slightly enhanced discharge near the end of the year.
- There was a trend toward a later beginning of the spring Fraser River freshet that began in 1998 and continued through 2000.
- The summer Fraser River freshet was slightly later than average.
- Along with reduced rainfall, there was an indication of rising salinity anomalies at the end of 2000, and continuing into 2001.
- Coho abundance significantly increased in 2000 compared to previous years and was almost a factor of two greater than in 1999.
- The abundance of coho, chinook and chum all increased significantly in 2000.
- The abundance of herring was similar to that of the last several years, slightly above the historically estimated levels.
- There was a significant increase in euphausiid size and biomass abundance in 2000 over 1999.

Prepared by:

Fisheries Oceanography Working Group

R. E. Thomson (Chair)
R. G. Perkin (Rapporteur)

Gulf of Alaska

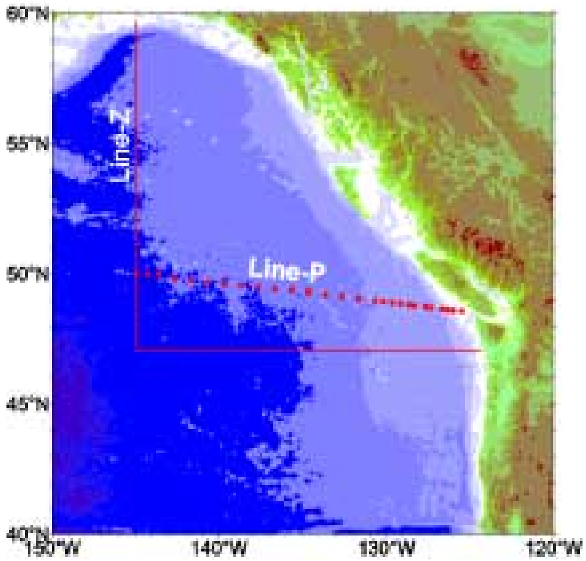


Figure 1. Map of the Gulf of Alaska showing the location of the sampling stations (red dots) comprising Line P. Some other survey lines completed in recent years are also shown.

Physical Conditions

El Niño dominated ocean conditions in the North Pacific between the spring of 1997 and the spring of 1998. This was quickly followed by a La Niña event that began in the fall of 1998 and continued through most of 1999. Since that time, the La Niña event has shown signs of disappearing, and then returning. The result was that, though not as severe as in the winter of 1998/99, the winter of 1999/00 and the subsequent seasons have been dominated by ocean temperatures that remained significantly below normal.

Figure 2 shows a plot of an index called "the southen oscillation index" which is a rough measure of the tendency towards or away from El Niño/La Niña conditions (see also "Climate Indices", this report). This 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 ever since.

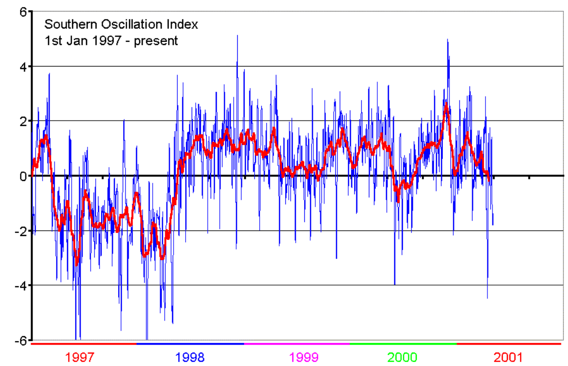


Figure 2. The southern oscillation index for the years 1997 to present. Positive values indicate a tendency towards La Niña conditions, and negative numbers a tendency towards El Niño conditions.

At the moment (Spring, 2001), this index, and other indicators suggest that the Pacific ocean is near normal on the equator, where El Niños and La Niñas are formed, and there are some indications that a "Pacific Warm Event" (code for some kind of El Niño event) could develop by the end of calendar 2001. If this happens (and the forecast is extremely speculative), this event could give rise to anomalously warm conditions in the Gulf of Alaska during the winter of 2001/02.

Figure 3 shows the distribution of sea-surface temperature in the Gulf of Alaska (the left column) for two months for which there were surveys along Line P. The centre 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 1 for location).

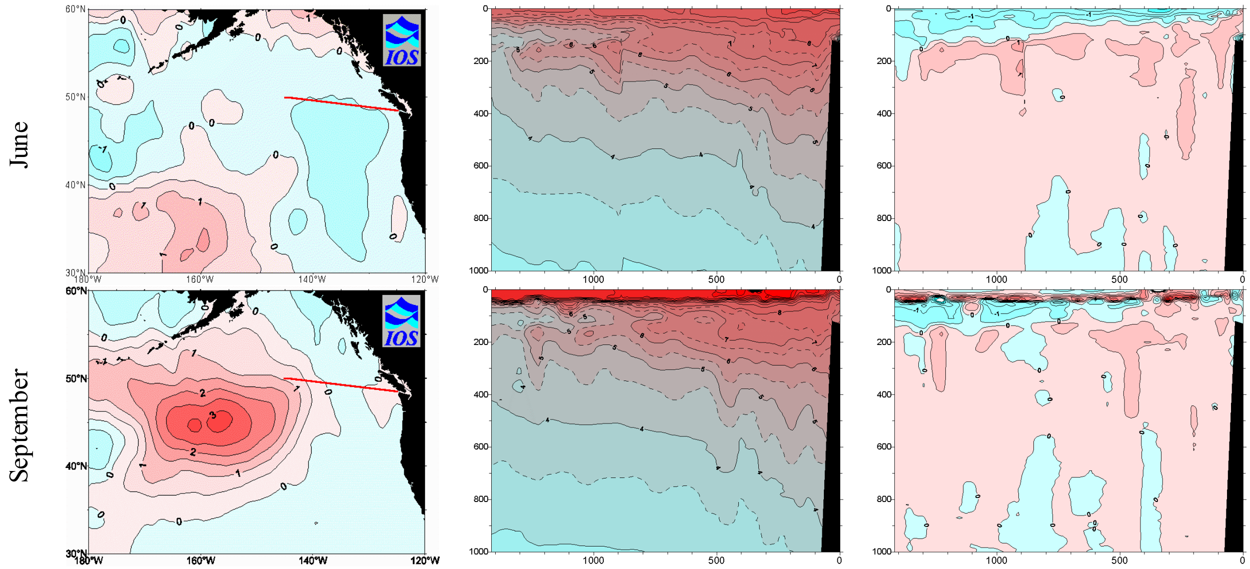


Figure 3. Temperature variations in the Gulf of Alaska during June and September, 2000.

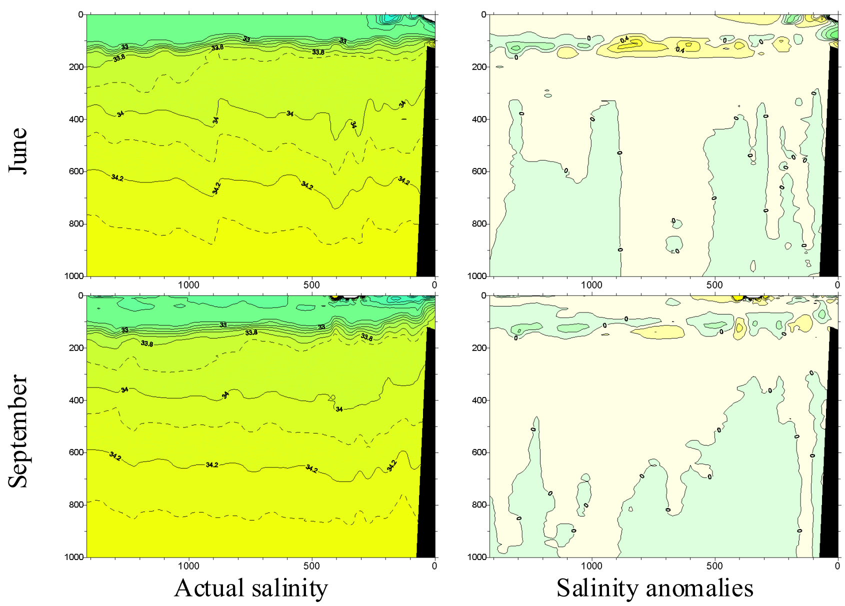


Figure 4. Salinity variations in the Gulf of Alaska during June and September, 2000

The right-hand column shows the temperature anomaly based on average (1956-1999) conditions along Line P. The left column shows the surface distribution of temperature anomaly for the whole Gulf of Alaska. The location of the Line P section is indicated on these maps, for reference. Normally, we expect to be able to present distributions representative of the winter immediately prior to the biologically active period. Unfortunately, fiscal restraint did not permit the usual survey to be completed in February 2000.

The temperature plots demonstrate that the Gulf of Alaska in June was clearly below normal temperature at the surface, though not greatly so, and that this low-temperature effect penetrated to a depth of about 50 metres inshore, and to about 200 metres in the centre of the Gulf. In September conditions remained very similar. 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/osap/projects/sst/archive/

Figure 4 shows sections of the salinity distribution along Line P for the two surveys completed during 2000. Salinity in the Gulf of Alaska was, unlike 1999, very close to the long-term climate normal. This implies that there were no unusual flows of tropical or sub-arctic waters into the regions of interest to B.C. during 2000.

One year ago we were able to report on the state of the ocean surface mixed layer at the end of winter. This is important because changes in this parameter, largely controlled by mid-winter climate conditions in the Gulf cause it sometimes to be either significantly deeper or shallower than normal. This affects the nutrients that are supplied into the surface layer to drive the biologically productive periods of spring and summer. However, in the absence of a February Line P survey, we have no information available this year.

We speculate that with ocean surface temperatures and salinities near normal at the surface in September 1999 and June 2000 (if anything, temperatures were a little below normal), we would expect that the water column might be a little less stable than the long-term average. This should lead to a slightly increased supply of nutrients.

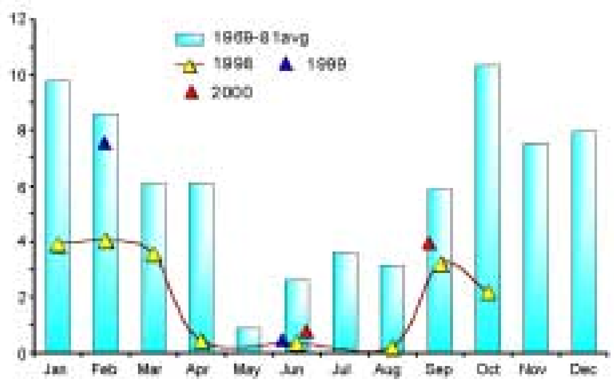


Figure 5. The annual cycle of surface nutrients at inshore stations along Line P and observations in 1998, 1999 and 2000.

Figure 5 shows observations of nutrient distributions averaged over a collection of inshore stations along Line P, superimposed on a long-term average cycle for comparison. This shows that in mid-June and September 2000 the concentration of dissolved nitrate was a little higher than in recent years. Unfortunately, we were not able to observe behaviour during the critical pre-spring period.

During 2001, the first deployments will be made towards implementation of the Argo array. This is a major international effort to deploy a global ocean-climate observatory. The result is that from 2001 onwards there will be comprehensive sampling of the climatic state of the ocean (temperature, salinity and derived quantities, note that this does not include dissolved nutrients). The results of this endeavour will be presented in the 2001 State of the Ocean Report (http://www.pac.dfo-mpo.gc.ca/sci/psarc/OSRs/Ocean%20Status%20Reports.htm).

Northern Gulf of Alaska

In response to the 1997-98 El Niño and the recognized need for broad areal coverage of this global phenomenon, oceanographic sections were established to monitor coastal oceanographic conditions in the northern Gulf of Alaska. Data were obtained aboard the *CCGS Sir Wilfrid Laurier* during its annual mission to (July) and from (October) the Western Arctic. Locations of the standard sections are shown in Figure 6.

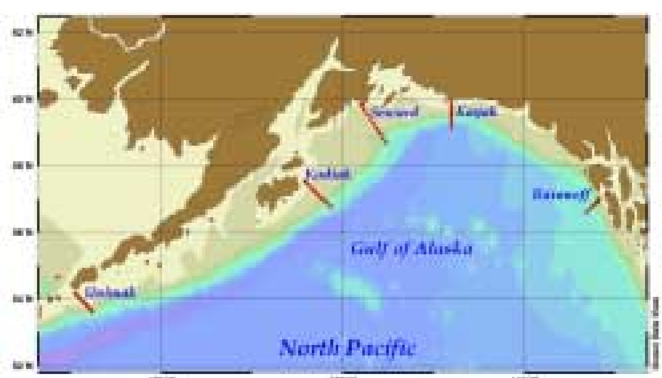


Figure 6. Standard oceanographic sections for profiles of temperature and salinity.

A synthesis of data collected 1997 to 2000 is in progress; however, selected sections for Kayak and Kodiak islands from July 2000 illustrate basic oceanographic conditions in the coastal northern Gulf of Alaska.

At this time the Kayak Section (Figure 7) is dominated by a freshened layer (S ~ 32.0) derived from continental runoff that is about 20 – 30 m thick and that extends about 20 - 30 km offshore.

A sharp front is evident immediately inshore of the shelf break. This freshened layer is associated with a north-flowing buoyancy-boundary current that likely plays a key role in the dispersal and migration of marine animals.

The main halocline (32.4 < S < 33.8) extends from about 50 – 200 m, roughly aligns with a 6 °C thermostad, and exhibits both a subsurface temperature minimum (near S = 33.0) and a subsurface maximum (near S= 33.6).

The Kodiak Island section (Figure 8) is similar, but with notable differences. The freshened layer of coastal water is slightly more saline and extends deeper into the water column, especially adjacent to the coast.

A near-surface front occurs near the shelf break, and a more pronounced front is associated with the deepening of isohalines 20 km offshore.

Water within the main halocline is similar to that of the upstream Kayak Island section, including the presence of the temperature minima and maxima features. Here, however, halocline waters are roughly associated with thermostad conditions near 4.5 °C.

At this time the Kayak Section (Figure 7) is dominated by a freshened layer (S ~ 32.0) derived from continental runoff that is about 20 – 30 m thick and that extends about 20 - 30 km offshore.

A sharp front is evident immediately inshore of the shelf break. This freshened layer is associated with a north-flowing buoyancy-boundary current that likely plays a key role in the dispersal and migration of marine animals.

The main halocline (32.4 < S < 33.8) extends from about 50 – 200 m, roughly aligns with a 6 °C thermostad, and exhibits both a subsurface temperature minimum (near S = 33.0) and a subsurface maximum (near S= 33.6).

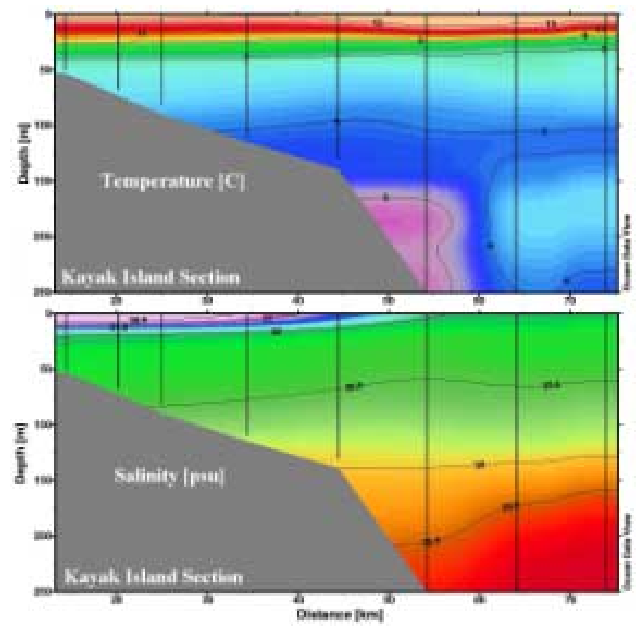


Figure 7. **Kayak Island section - 2000**

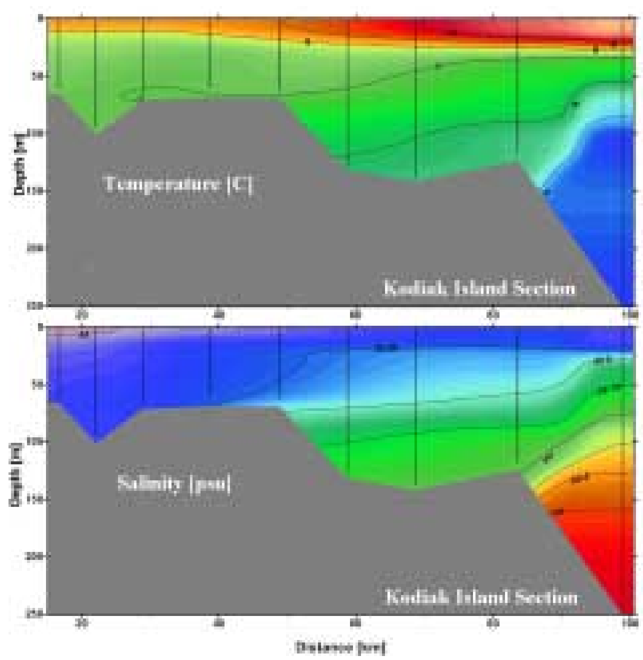


Figure 8. Kodiak Island section - 2000

Phytoplankton

In the northeast subarctic Pacific, there are significant inshore and offshore gradients in phytoplankton biomass and production. Based on observations from the two end-members of Line P transect, one in the open ocean (Ocean Station P) and one in the shelf region (Station P4), the biomass of phytoplankton (as chlorophyll concentration) in 2000 was between the range of values observed in previous years (Figure 9). Ocean Station Papa is characterized by lack of nutrient depletion and of seasonal variability in phytoplankton biomass. Model results in this region indicate that phytoplankton production (which is only occasionally measured) is a better indicator of changes in the planktonic ecosystem than phytoplankton biomass (Denman and Peña, 2001). At the inshore site (Station P4) seasonal variability is important. Because seasonal coverage in the data set is not sufficient to measure the narrow phytoplankton spring bloom, alternate methods based on moored sensors are being proposed.

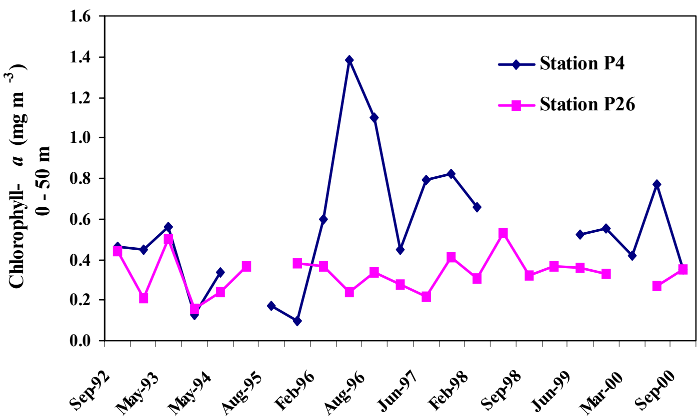


Figure 9. **Chlorophyll concentration at the two end-members of Line P transect, Station P26 (50º N, 145º W) and P4 (48º 39' N, 126º 40' W).**

The composition of phytoplankton in the NE subarctic Pacific is generally dominated by autotrophic flagellates such as *Phaeocystis pouchetti*. In contrast to the previous year (June, 2000) the most abundant nanoflagellate was the coccolithophorid *Emiliana huxleyi* which contributed to more than 50% of phytoplankton biomass (in carbon units). This increase in coccolithophorids abundance in the spring/ summer of 2000 was also observed in colour satellite data (SeaWIFS) and appears to have been quite widespread in the Gulf of Alaska (Fig. 10). High abundances of coccolithophorids have been previously observed in this region and the cause of this is unknown. Coccolithophorids are an important component of the marine carbon cycle being responsible for reducing the removal of CO_2 from the surface ocean.

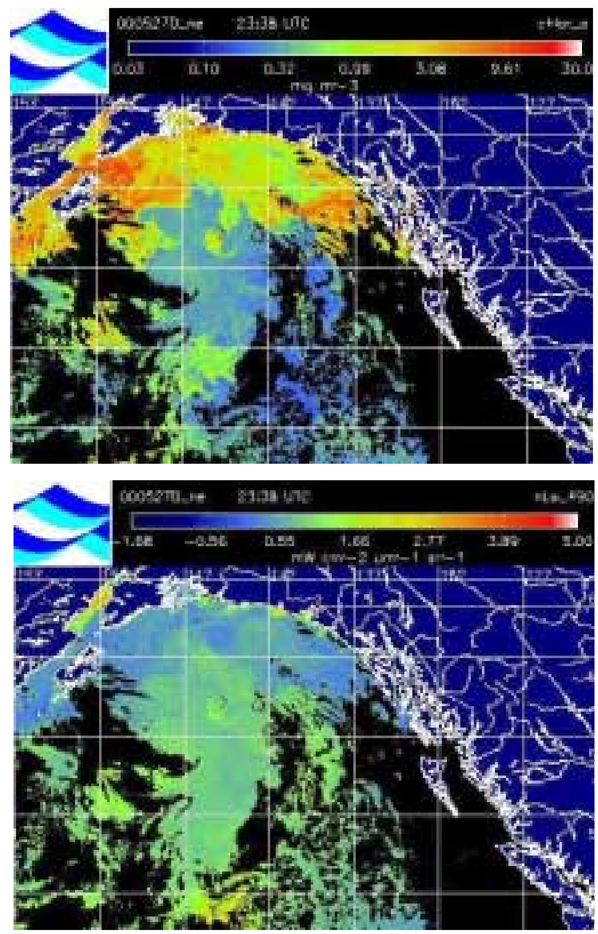


Figure 10. **SeaWIFS image of the NE Pacific on 27 May, 2000. Top: chlorophyll concentration; bottom: the 490 nm band where brighter regions indicate high abundance of coccolithorphorids.**

Zooplankton

Upper water column (0-150 m) zooplankton net tows in the Gulf of Alaska have been conducted routinely since the early 1990s at five locations along Line P, and opportunistically during other surveys (such as the summer research/training cruise of the Japanese vessel *Oshoro Maru*). Seasonal coverage 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 (400-1000 m) 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 early (late April-May) in the mid-1990s, but has showed a return to long-term average timing (mid-late June) in both 1999 and 2000.

Note: Because seasonal coverage is not sufficient to reliably measure the strong and temporally narrow late spring annual peak in upper ocean zooplankton biomass, alternate methods based on summer sampling of the deep (400-1000m) dormant copepod population are being proposed.

Humpback and Grey Whales

The situation with grey whales along the B.C. coast in 2000 was similar to that in 1999, in that a number of grey whales were found washed up dead along the coast, apparently emaciated and having run out of food reserves. In contrast, Humpback whales were particularly abundant (relative to previous years). The vicinity of the Scott Islands was a “hot spot” starting in early April 2000, with in excess of 100 humpbacks observed feeding around Cox Island. These sightings continued through the spring and into the summer. Sightings of humpback whales were also common along the Queen Charlotte Islands off Langara Island and southern Moresby Island. Over 70 humpback whales were still being reported off Rose Spit, northern Hecate Strait, in early December, 2000.

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 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. 1) provide hourly time series information on winds, atmospheric pressure, wave height and period, and air/water temperature; lighthouse stations (Fig. 2) provide long-term time series of daily sea surface temperature and sea surface salinity.

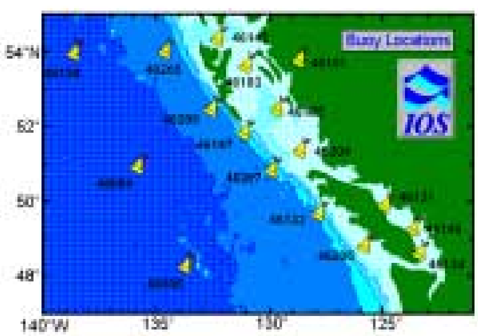


Figure 1. – Weather Buoys

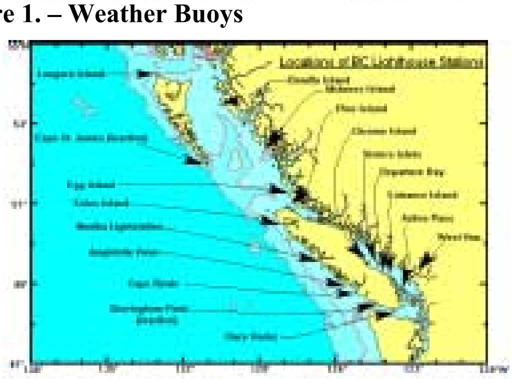


Figure 2. Lighthouse locations

Tide gauge stations (Fig. 3) provide long-term series on hourly sea level variability and moored current meters (Fig. 4) yield hourly time series of current velocity, water temperature, and salinity at specified depths through the water column.

Oceanographic and meteorological conditions for the west coast were characteristic of moderate La Niña conditions in 2000 following near-normal conditions in 1999 which, in turn, came after roughly a decade of "anomalous" conditions punctuated by the major El Niño events of 1991/92 and 1997/98 (Fig. 5). Changes in oceanic conditions were similar for both the north and south coastal regions of offshore Vancouver Island. Upper ocean water temperatures were normal to below normal and salinity was near normal to slightly above normal. Upwelling was normal to below normal along the coast in summer. Mean currents over the slope and outer shelf were stronger poleward than normal in winter (January through February) but less strongly equatorward than normal in summer.

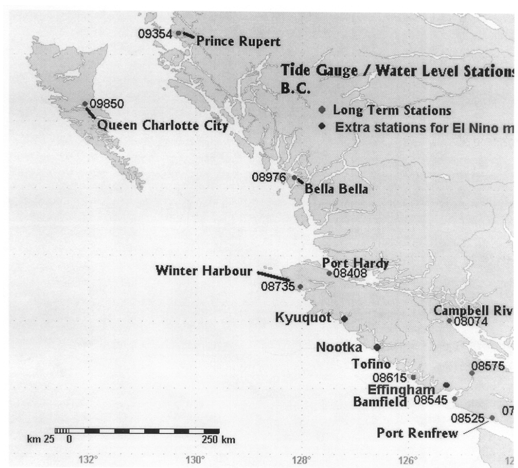


Figure 3. **Tide gauge locations.**

West Coast Meteorological Data

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

1. In 2000, there were periods of strong southeasterly (downwelling-favourable) winds in the winter of 1999/00 and a few periods of strong northwesterly (upwelling-favourable) winds in mid-winter of 1999/00 and spring (late March

early April). Moderately strong periods of northwesterly (upwelling-favourable) winds were recorded from late May to early fall (November) (Fig. 6). Upwelling winds were generally weak on the south coast from late July to late August. The most significant upwelling events occurred in mid June and late August.

2. Wave heights (Fig. 7) were typically higher-than-“normal” (1990-1996 mean) during early February and from late February to late March but decreased to near-normal heights until late October. Relatively low wave heights were recorded during most of April.

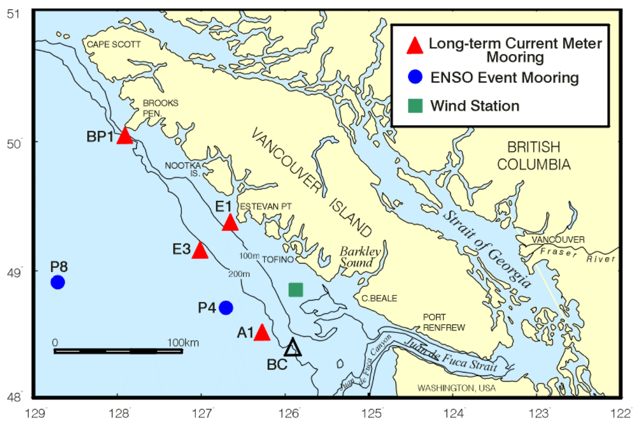


Figure 4. Current meter locations.

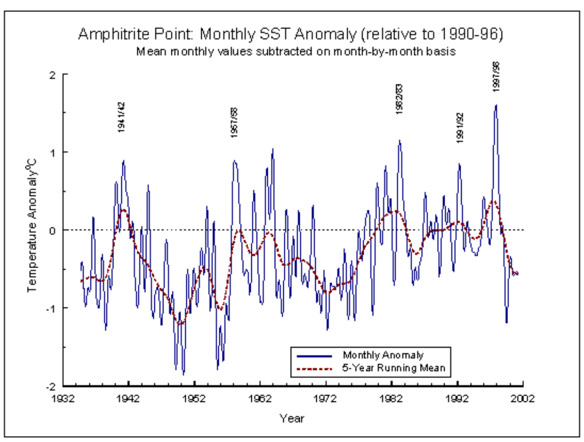


Figure 5. SST anomaly at Amphitrite Point.

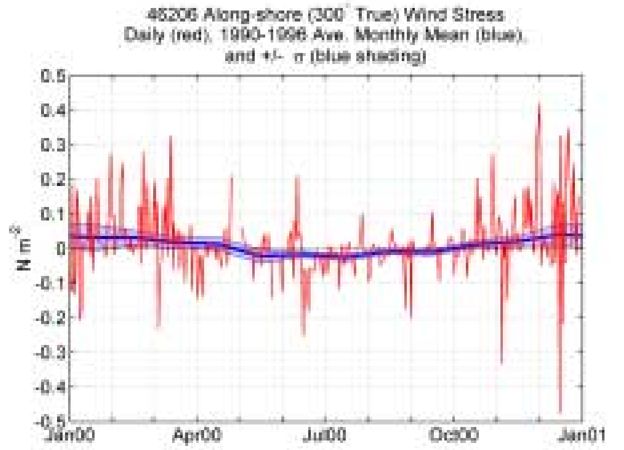


Figure 6. Alongshore wind stress. Negative values favour upwelling.

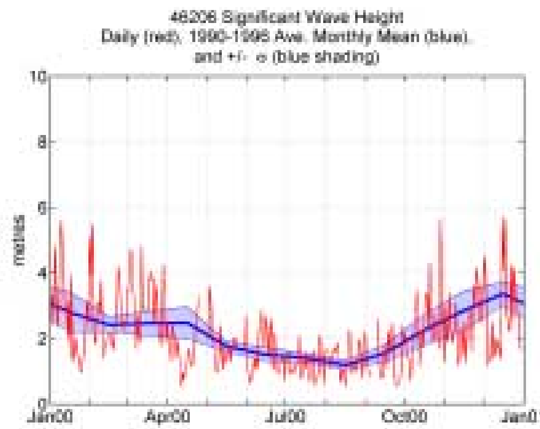


Figure 7. Significant wave height.

West Coast Lighthouse Data

Sea surface temperature (SST) on the inner continental shelf was generally 0.5 to 1.0 ºC below “normal” (1990-1996 mean) for most of the year (Figure 8a,b). Only in late summer (late July to late August) did SST values reach typical summer values. This change in SST was in marked contrast to the pronounced warming during the 1997/98 El Niño.

Surface salinities were generally near normal (1990-1996 mean) throughout the data series but with large positive and negative departures in early spring and fall (Figs. 9a,b). The large (greater than 2 psu) increases in the fall of 2000 mirror the large increases in late winter 2000 salinity in the Strait of Georgia.

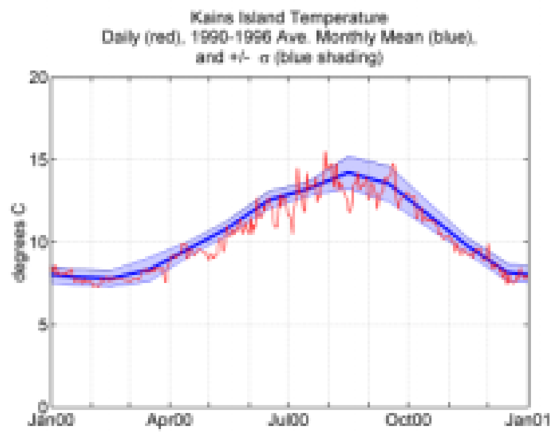


Figure 8a. Northern SST.

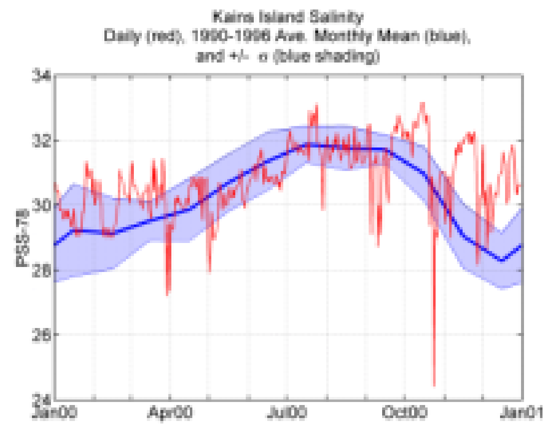


Figure 9a. Northern SSS.

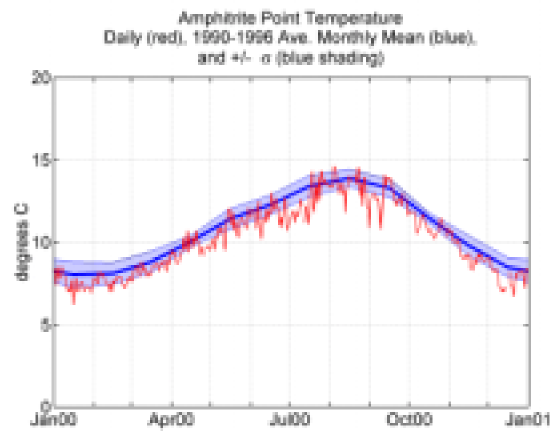


Figure 8b. Southern SST.

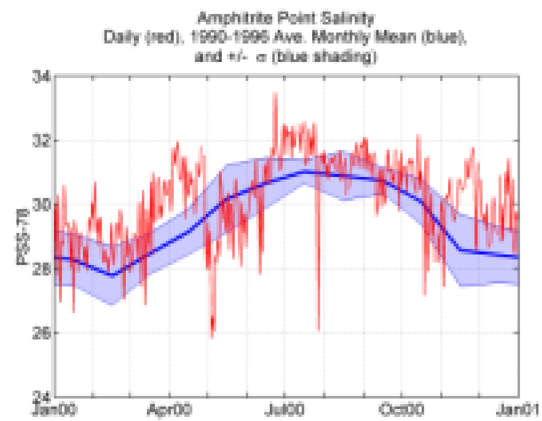


Figure 9b. Southern SSS.

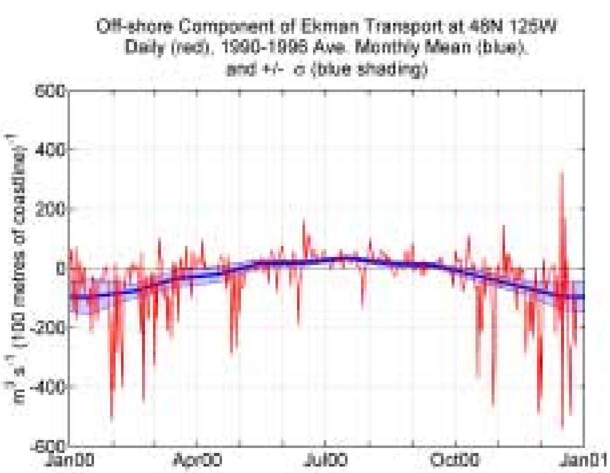


Figure 10. Upwelling Index. Wind driven, seaward flowing transport is replaced by upwelling water from below.

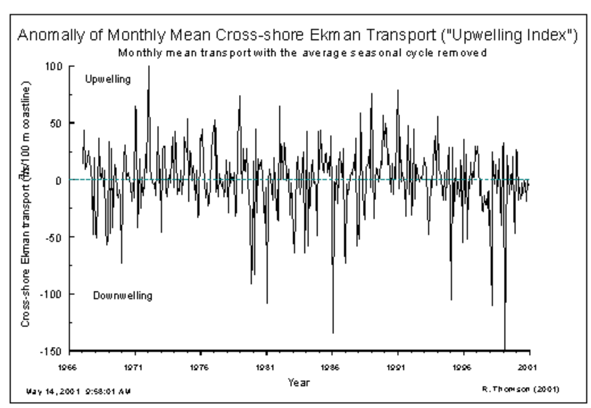


Figure 11. B.C./Northern Washington upwelling anomalies from 1966 to 2001

p elling Indicies

The FNMOC (Fisheries National Marine Oceanographic Center) Upwelling Index for the west coast of Vancouver Island and northwest Washington State is shown in Figures 10 and 11 along with the normal seasonal cycle. This index is essentially the seaward flowing component of wind-induced Ekman transport. Year 2000 had extensive periods of strong downwelling (negative values) during February to mid March, and from late April to early May. Normal to slightly above normal upwelling conditions (positive values) occurred in summer, with one major upwelling event in June.

South est Vancouver Island Continental Slope La Perouse egion

Subsurface temperatures at 35, 100, 175 and 400 m depth over the continental slope appear to have been near-to-below "normal" (1990-1996 mean) during the year (data series ends at the beginning of October). Because the mooring was 35 m deeper than the nominal depth during the May to October deployment, the observed temperatures (especially those at the upper instrument, nominally at 35 m depth) will be offset to lower than normal values.

Because the mooring was 35 m deeper than the nominal depth during the May to October deployment, it is difficult to characterize the salinities for 2000. Taking into consideration the change in instrument depth, it would appear that salinities were near normal at 35, 100 and 175 m depth but below normal at 400 m depth (data series ends at the beginning of October).

Alongshore current velocity over the continental slope was generally stronger poleward than normal during the winter and spring (peaking around 40 cm/s poleward in late February at 35 m depth) but then became more equatorward than normal during April and May (Fig. 12). Currents were poleward at all depths in winter but mainly equatorward in spring. Weak but persistent equatorward currents prevailed through the summer at 35 m depth while persistent poleward flow occurred at 100 and 175 m depth. 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.

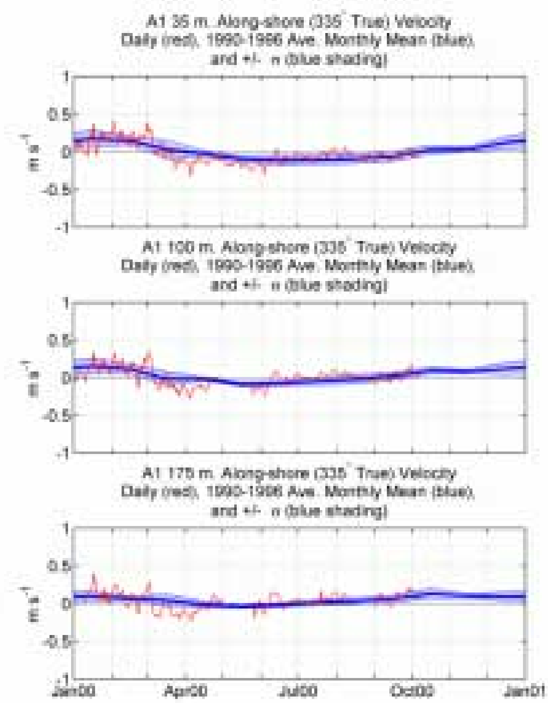


Figure 12. Daily mean alongshore poleward current velocity at 35, 100 and 175 m depth at mooring A1 for year 2000.

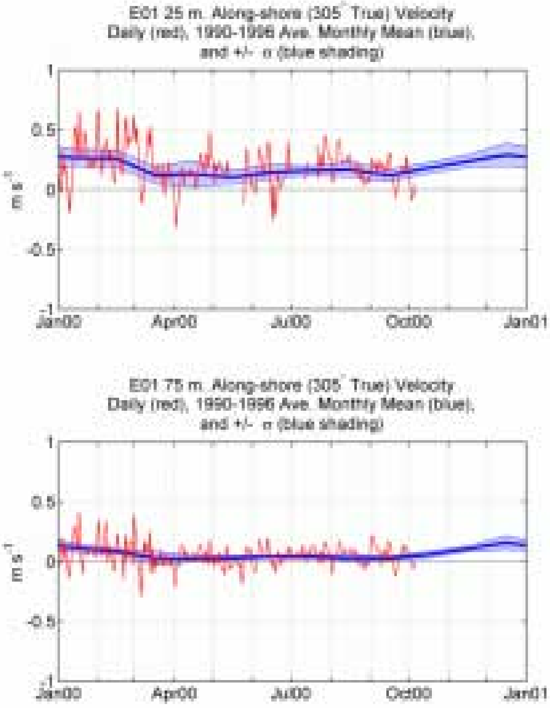


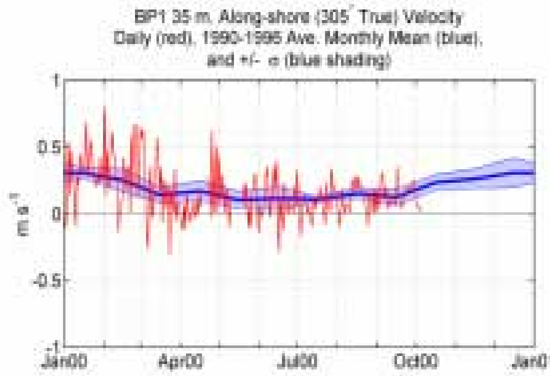
Figure 13. Daily mean alongshore current at mooring E01 for year 2000.

Central Vancouver Island Continental Shelf Estevan Point egion

1. Subsurface temperatures at 25 and 35 m depth were normal to slightly below normal from winter through spring, became below normal in early summer and above normal in late summer to early fall (data series ends at the beginning of October). Temperatures at 75 m depth dipped sharply below normal in April but otherwise were near normal.

2. Subsurface salinities at 25 were slightly above normal while those at 35 m depth were normal to well below normal for prolonged periods in spring. Salinities at 75 m depth were well below normal with a major salinity decrease of about 4 psu from April to May (data series ends at the beginning of October).

3. Alongshore daily mean current velocity was stronger than normal during the winter and early spring (peaking around 70 cm/s poleward at 25m depth), returning to normal flow conditions by early March (Figure 13). 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.



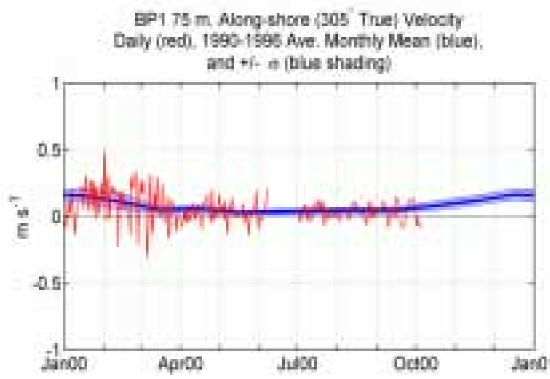


Figure 14. (top) Daily mean alongshore current at 35 m depth at mooring BP01 and Figure 15. (bottom) Same as Figure 14 but at 75 m depth.

Northern Vancouver Island Continental Shelf Brooks Peninsula egion

1. Subsurface temperatures at 35 and 75 m depth were near or below “normal” (1990-1996 mean) during the year (data series ends at the beginning of October).

2. Subsurface salinities at 35 and 75 m depth were slightly below normal during the winter and spring but returned to normal conditions in the

summer (data series ends at the beginning of October).

3. Alongshore daily mean current velocity (Figures 14 and 15) was near normal during most of the year, except for an extended period of strong (60-70 cm/s at 35 m depth and 30-40 cm/s at 75 m depth) poleward flow through February and an extended period of equatorward flow in March and April (the record ends in early October). 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.

West Coast of Vancouver Island Mixed Layer Depth

A newly formulated "split-and-merge" (S&M) algorithm was used to examine the climatology and variability in mixed layer depth off the west coast of Vancouver Island. The method improves the reliability of mixed layer depth estimates compared to conventional threshold, integral, and least-squares regression methods and makes it possible to determine other aspects of the upper ocean structure such as the depth and gradient of the permanent pycnocline. Based on profile data collected systematically off the west coast of Vancouver Island from May 1979 to May 2000, the mixed layer depth undergoes small (»2 m) summer diurnal variations due to a combination of surface radiative heating and tidal flow normal to the continental slope. Maximum depths occur around 09:00±1 h and minimum depths around 15:00±1 h, local time. Wind mixing generates detectable mixed layer depth variations of O(1 m), with wind stress leading layer depth by about six hours. In the offshore sector of the continental margin, mean-monthly mixed layer depths range from 20 m in summer to 60 m in winter (Figure 16). Corresponding depths for the inner shelf region are 10 to 20 m shallower because of the greater vertical stability provided by year-round coastal runoff. The annual cycle, daily-averaged wind mixing, and diurnal cycle account for 46, 5 and 2%, respectively, of the observed variance in mixed layer depth. An additional 2% of the variance is linked to interannual variability. The remaining variance is presumably associated with advection, high-frequency "noise", and unresolved wind-mixing. There is no significant trend in the regionally averaged mixed layer depth for either the full 21-year data record or the highly sampled summer-only record. The significant trend of $-0.11\pm0.07 m\times yr^{-1}$ in the integral depth-scale (effectively the depth of the permanent pycnocline) may be indicative of decreased winter downwelling and/or increased summer upwelling in the eastern boundary current regime off the central coast of North America.

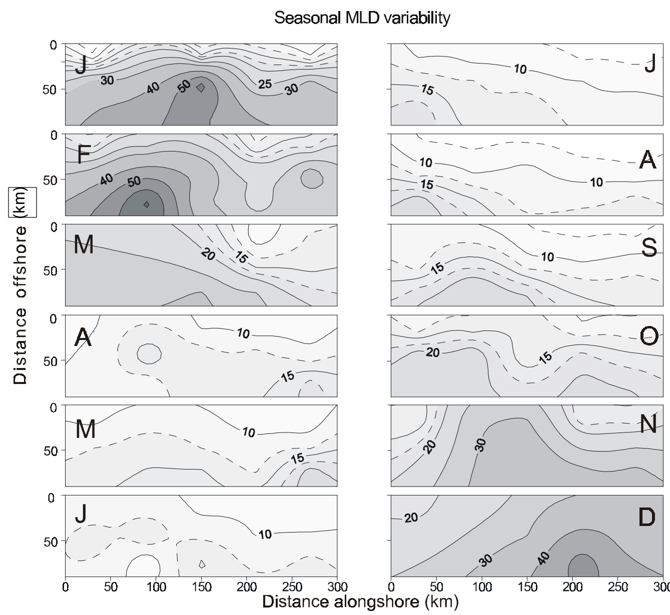


Figure 16. Mean monthly mixed layer depths in metres off the west coast of Vancouver Island. The origin is at the northwest corner of Brooks Peninsula. Distances are alongshore to the southeast and offshore to the southwest from the corner of Brooks Peninsula.

Zooplankton

West Coast Vancouver Island

Zooplankton sampling off southern Vancouver Island (48°-49°N) has been conducted frequently since 1979, and on a reasonably consistent monitoring grid since 1985. Coverage is sufficient to estimate annual anomalies of abundance and biomass for most of the major zooplankton species (column graphs in Figure 17; for additional taxa and more detailed discussion see Mackas, Thomson and Galbraith 2001). The time period 1990-2000 included some very strong (factor of ten or larger) variations in concentration of the major species groups. The zooplankton anomaly patterns were strongly and positively intercorrelated within groups of ecologically similar species, and between shelf and slope statistical regions extending 150 km alongshore and 100 km cross-shore (averages within these species groups and regions are what is shown in Figure 17). The direction and timing of the southern B.C. zooplankton interannual changes were also very similar to changes observed independently 400 km to the south off the central Oregon continental shelf (W. Peterson, 1999 and pers. comm.).

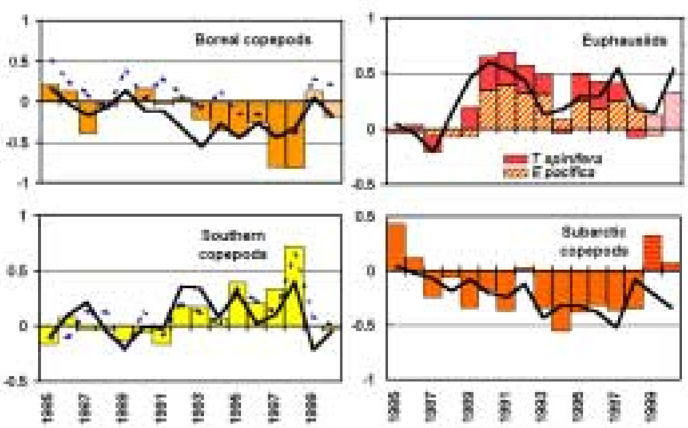


Figure 17. Time series of annual zooplankton anomalies (colored columns) averaged across southern Vancouver Island statistical areas and within groups of ecologically similar species. Lines show fits to the time series from stepwise regressions on 1985-1999 time series of environmental indices: large-scale (solid lines) and local water properties (dashed lines). Note the continuing 'predictive' fit in 1999 and 2000.

Many of post-1985 changes in the zooplankton community developed and persisted over time spans of several adjoining years, but 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 change included major declines in several species of 'boreal' copepods (*Calanus marshallae*, *Pseudocalanus mimus*, *Acartia longiremis*) previously endemic to the NE Pacific continental shelf between 45°-60°N, and major increases of several 'southern' copepod species previously endemic to the California Current roughly between 35°-45°N (*Clausocalanus* spp., *Ctenocalanus vanus*, *Mesocalanus tenuicornis*, *Paracalanus parvus*). The early-mid 1990s also showed to have broad maxima of biomass for the two regionally-dominant euphausiid species *Euphausia pacifica* and *Thysanoessa spinifera*.

In 1999, following the strong La Niña that began in late 1998 in the equatorial Pacific, the concentrations of all of the major zooplankton taxa swung sharply back toward or past their long term average levels (i.e. to near-zero anomalies or of opposite sign). Zooplankton concentrations for 2000 have remained close to the long-term average (near-zero anomalies), but differences from the preceding decade are less striking than in 1999.

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 lines in Figure 16. Note that for most taxa, the 1999 and 2000 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), Esperanza Inlet (49°50'N), Brooks Peninsula (50°N), and 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.

COPRA Zooplankton Monitoring – N.E. Pacific Coast

The Cooperative Plankton Research Monitoring Program (COPRA) collects both CTD and plankton data from a series of 19 stations along the B.C. coast (Figure 18). The objective of this monitoring program is the establishment of salinity, temperature, and plankton structures along the coast. Samples are collected opportunistically by researchers passing near COPRA stations. Samples are processed by IOS and zooplankton data are made publicly available through the IOS Zooplankton Database.

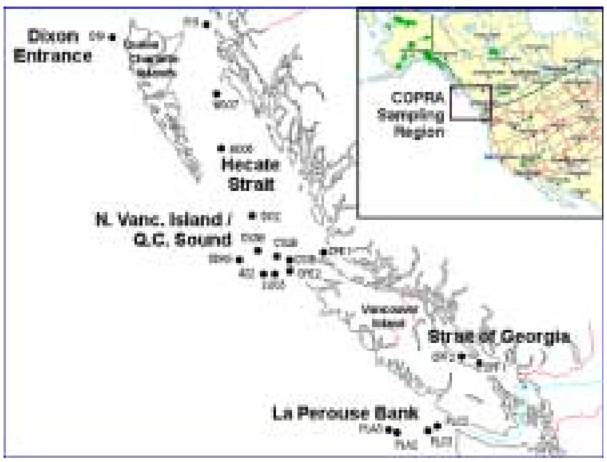


Figure 18. Standard COPRA monitoring stations

COPRA data, when combined with other planktonic data collected off the B. C. coast, forms a comprehensive data set that can be used to monitor changes in both geographic and temporal community structures. The IOS Zooplankton Database contains several data extraction and analysis routines, including the annual interpolated zooplankton abundance plots.

Figure 19 shows the annual abundances of the Californian chaetognath, *Sagitta euneritica*, between 1997-2000. Pushed north by the 1998 ENSO event, this animal was not detected between 1991 and 1996 but had retreated to typical concentrations along the B.C. coast by late 2000 (see Mackas, Thomson and Galbraith, 2001). Other local zooplankton, such as *Pseudocalanus* sp., *Calanus marshallae*, *Paracalanus* sp., *Clausocalanus* sp., and salps showed trends of moving northward between 1997-1998 from the presence of warmer waters entering the B.C. coast during the ENSO event.

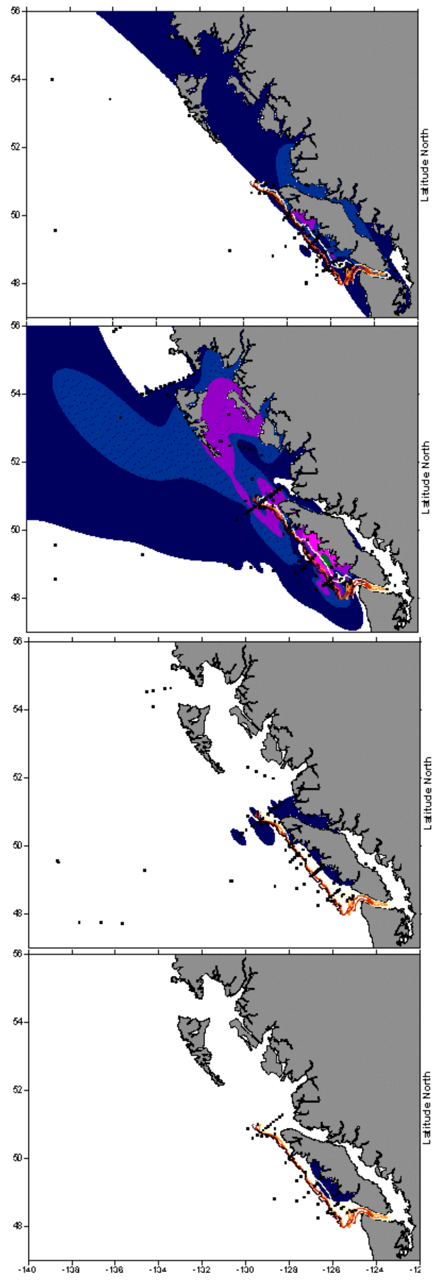


Figure 19. ***Sagitta euneritica*** **abundance between 1997 (top plate) and 2000 (bottom plate). Note the higher concentrations (blue <2 animals/m^2 and purple 2-5 animals/m^2) during the 1998 ENSO event, followed by the decline in 1999-2000. This Californian chaetognath was not detected in any concentrations along the B.C. coast between 1991-1996.**

Influence of euphausiid biomass on the productivity of Pacific herring and coho salmon along the south-west coast of Vancouver Island

Results of zooplankton sampling in Barkley Sound showed that the biomass of one major euphausiid species (*Thysanoessa spinifera*) along the southwest coast of Vancouver Island increased in 2000 but the biomass of the other species (*Euphausia pacifica*) did not (Figs. 20 and 21). The increased biomass of *T. spinifera* reflected greater food availability for Pacific herring (*Clupea pallasi*), Pacific hake (*Merluccius productus*) and coho salmon (*Oncorhynchus kisutch*) (Fig.22) because these fish prefer this euphausiid species (Petersen et al. 1982, Tanasichuk 1999, Tanasichuk *In press*).

Improved food availability could mean that the West Coast Vancouver Island herring stock may recover from the recent depression of growth and reproductive potential that is coincidental with low food availability (*T. spinifera* >17 mm). Fig. 23 shows an update of the relationship between year-class strength (parental biomass) and size of recruit (age 3) herring that Tanasichuk (1997) presented. He reported that recruit size for the 1993 year-class was an outlier to the density-dependent relationship because it was exceptionally small. Tanasichuk noted that this year-class was the first to experience exceptionally low food availability throughout the pre-recruit phase (the first three years of life). All later year-classes showed the same response which supports the suggestion that the low *T. spinifera* biomass was suppressing growth and disrupting compensatory density-dependent growth. Tanasichuk (*In press*) reported that the reduction in *T. spinifera* biomass influenced adult growth because initial size mostly determined adult growth rates. Smaller recruit size and adult growth suppression reduced reproductive potential (population fecundity) by 20% (Fig. 24). This means that the population is less resilient than it "should" have been because of depressed egg production. This observation also has implications for the precautionary approach to fisheries management. Target and limit reference points assume that fish population productivity does not vary. The suppression of growth and reproductive potential shows that the assumption is invalid.

The increased food availability for coho salmon suggests that marine survival rates should be high for fish returning in 2001. Tanasichuk (*In press*) reported a relationship between the biomass of euphausiids (*T. spinifera* 9 -12 mm) consumed by coho smolts (Peterson et al. 1982) and marine survival rates of Carnation Creek salmon (Fig. 25). Marine survival rates are forecasted to be the highest in 10 years (Simpson et al. 2001). Analysis also suggested that the highest marine survival rates for coho would have occurred at biomasses about three times greater than observed in 2000.

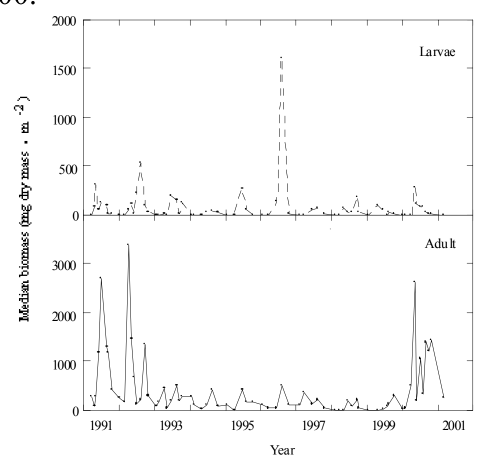


Fig. 20. Median biomass (mg dry mass • m^{-2}) of *T. spinifera*.

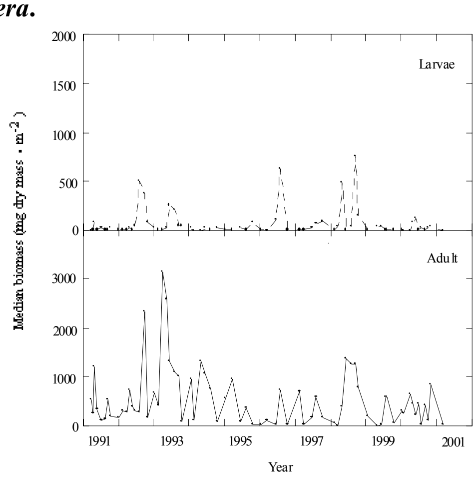


Fig. 21. Median biomass (mg dry mass • m^{-2}) of *E. pacifica*.

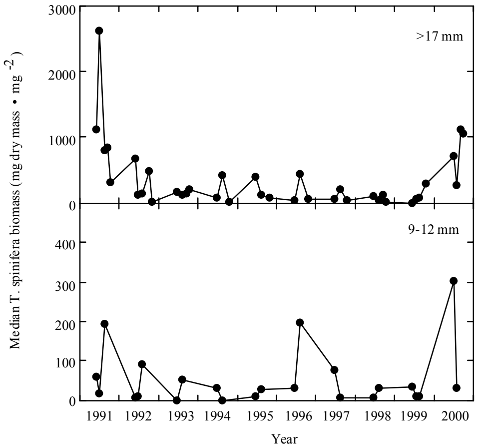


Fig. 22. Median biomass (mg dry mass • mg^{-2}) of key prey for Pacific herring and Pacific hake (>17 mm *T. spinifera*) and coho salmon (9-12 mm *T. spinifera*).

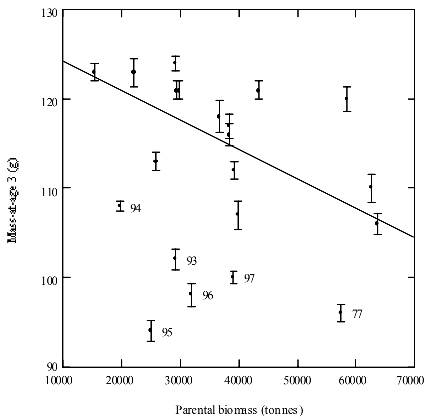


Fig. 23. Relationship between total mass of recruit herring and parental biomass, 1980-2000. Plotting values are year-class. Error bars are + 2 S. E.

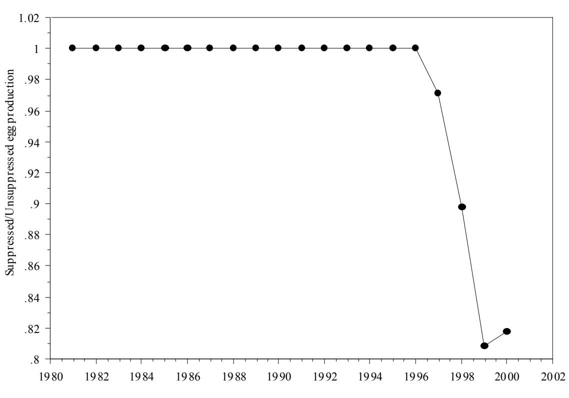


Fig. 24. Influence of growth suppression on the reproductive potential of the WCVI herring population.

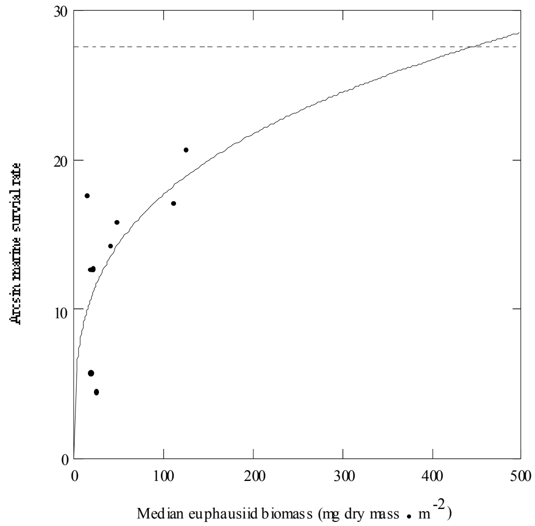


Fig. 25. Relationship between food availability and marine survival rate for coho salmon from Carnation Creek, WCVI, 1991-2000. Dotted line shows the arc sin of the maximum observed survival rate.

Results from a Lower Trophic Level Production Model

The La Perouse ecosystem model for the southwest Vancouver Island region has been applied retrospectively to estimate how interannual and decadal time scale changes in climate forcing at the bottom of the food web, and top-down forcing impacts caused by variations in predator biomass at the top of the food web, jointly affect lower trophic level production in this region (Robinson and Ware 1999). Figure 26 shows that annual diatom (phytoplankton) production probably peaked around 1986 and declined to a minimum around 1997. This decline was primarily caused by a large reduction in upwelling intensity, particularly during the 1997/98 El Niño. Upwelling increased in 1999 and was near normal in 2000, so primary production was probably higher in 1999 than it was in the two previous years and near normal in 2000.

In the model, the productivity of euphausiids declined from a peak in 1984.

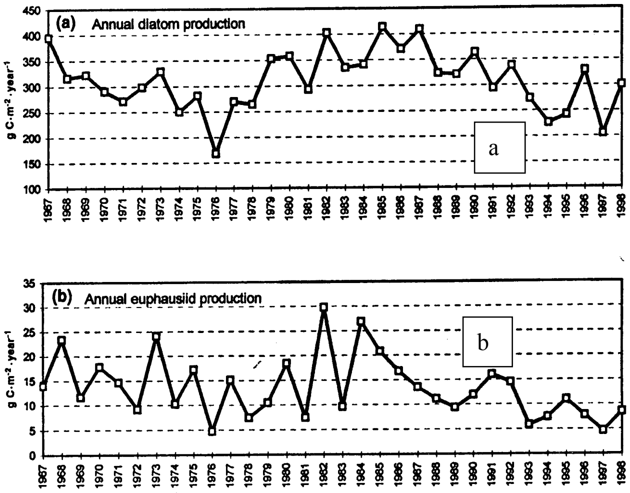


Figure 26. Interannual variability and decadal trends in the lower trophic level production (diatoms and euphausiids) off the lower west coast of Vancouver Island, estimated by the La Perouse Ecosystem Model (Robinson and Ware; 1999)

This modelled decreasing trend is consistent with field measurements of the abundance of the dominant euphausiid in the Barkley Sound region, *Thysanoessa spiniferia* during the 1990s (Fig. 20) but not with the observed euphasiid abundance on the outer shelf.

Shrimp

Smooth pink shrimp (*Pandalus jordani*) are caught in three fishing grounds off the west coast of Vancouver Island. Research vessel surveys are conducted annually in May to estimate abundances and to monitor changes in distributions. Estimates of the abundances of age 1 *P. jordani* in May 1999 were the second highest since 1973 in the fishing ground north of Estevan Point, and the fifth highest since 1973 in the fishing ground off Tofino. A preliminary recruitment relationship for smooth pink shrimp indicates that advection of larval shrimp from populations to the south are important contributions to these populations. These animals recruit to the fishery at age 2, and therefore confirmation of the strength and recruitment success of this 1998 year class (sampled in 1999) will be available after the May 2000 research survey.

Herring and Herring ecruitment

Since about 1977, the recruitment of herring off the West Coast of Vancouver Island has been decreasing (Figure 27). In 2000, the abundance (Figure 28) was one of the lowest estimated since the stock collapse in the late 1960s.

The productivity of the west coast of Vancouver Island herring stock (Figure 27) has been declining since 1989, primarily because recruitment to this stock has been poor for 7 of the last 10 years (Figure 28). A long-term research program has shown that herring recruitment in this region tends to be below average when ocean temperatures are warm and the summer biomass of migratory predators (primarily hake and mackerel) is high. The negative correlation between herring recruitment and temperature probably reflects: 1) poor feeding conditions for herring larvae and juveniles during their first growing season; and 2) a general increase in the mortality rate of the larvae and juveniles, due to an increase in the intensity of invertebrate and fish predation in the rearing area in warm years. Several field studies designed to measure the predation rate have confirmed that the negative correlation between herring recruitment and hake biomass could be caused by predation. Apart from predation by hake and other predators, ocean conditions were more favourable for herring survival in 1999 and 2000 and should result in improved recruitment to the stock in the year 2002.

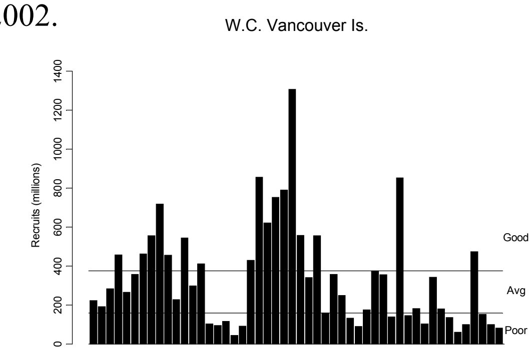


Figure 27. Interannual variability and decadal trends in recruitment to the lower west coast of Vancouver Island herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 7 of the last 10 recruitments have been 'poor'.

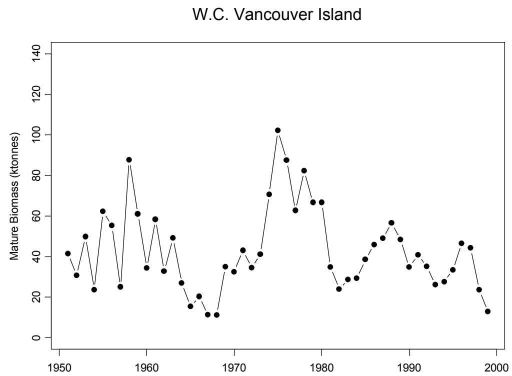


Figure 28. West Coast Herring Abundance.

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 (Figure 29). In 1997, their distribution expanded northward and by 1998 sardines inhabited waters east of Queen Charlotte Island 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 (Figure 29). The average abundance of sardines off the west coast of Vancouver Island since 1997 is 80,000 tonnes.

Figure 29. The distribution of Pacific Sardine was confined to coastal inlets in year 2000.

Hake

Pacific hake have historically spawned off the coast of California in winter and migrated to the west coast of Vancouver Island in summer. During the 1990s, the northward distribution expanded towards Queen Charlotte Island (Figure 30). By 1997, hake were found along the southern portion of the Queen Charlottes and in 1998 were found as far north as Dixon Entrance. During 2000, hake distribution changed dramatically. Hake were not found in traditional fishing grounds, but were found in small aggregates off the north coast of Vancouver Island. During the 1990s, hake abundance averaged 400,000-500,000 tonnes. In 2000 the abundance dropped dramatically.

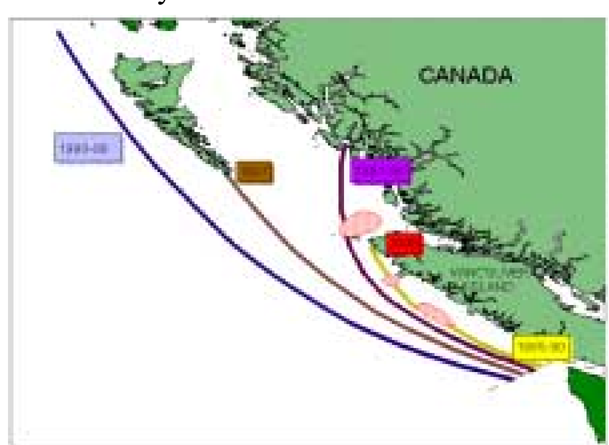


Figure 30. Yearly changes in the distribution of Pacific Hake.

Seabird eproductive Performance on Triangle Island ith notes on Frederick Island

Background and Natural History

Triangle Island (5052'N 12905'W) supports the world's largest population of Cassin's Auklet (*Ptychoramphus aleuticus*; 1.1 million breeders) and a large population of Rhinoceros Auklet (*Cerorhinca monocerata*; 82,000 breeders) in addition to significant populations of Tufted Puffin (*Fratercula cirrhata* 52,000 breeders) and Common Murre (*Uria aalge;* 8,200). All species lay a single egg per breeding attempt. The Cassin's Auklet is a small (190g) planktivorous, burrow nesting seabird which visits the colony only at night. The Rhinoceros Auklet (*Cerorhinca monocerata)* is a 550 g piscivorous, burrow nesting species which also visits the colony only at night. The Tufted Puffin is a 750 g, piscivorous, burrow nester which visits the colony at multiple times throughout the day when feeding young. The Common Murre is a large (950g), piscivorous, cliff nesting, diurnal species.

Since 1994 researchers from Canadian Wildlife Service (CWS) and Simon Fraser University have been visiting Triangle Island colony annually (April – August) to collect time series information on seabird breeding propensity, timing of breeding, hatch success, nestling growth and development, nestling diet, fledging success, adult survival and population trends. Figure 33 couples available historical information with time series for timing of breeding, growth rate variation, Rhinoceros Auklet nestling diet, and the relationship between spring SST and nestling growth rate.

Year 2000 Performance
Triangle Island

In 2000, the seabirds breeding on Triangle Island generally performed well, similar to the 1999 season. The timing of breeding (Figure 31) was considerably earlier than 1999 for the planktivorous Cassin's Auklet, but was similar to 1999 for the fish eating Rhinoceros Auklet, Tufted Puffin and Common Murre. Nestling growth rates (Figure 33) were strikingly similar to the high levels observed in 1999 for the Tufted Puffin and Cassin's Auklet. Rhinoceros Auklet nestling growth rates were similar to long term average.

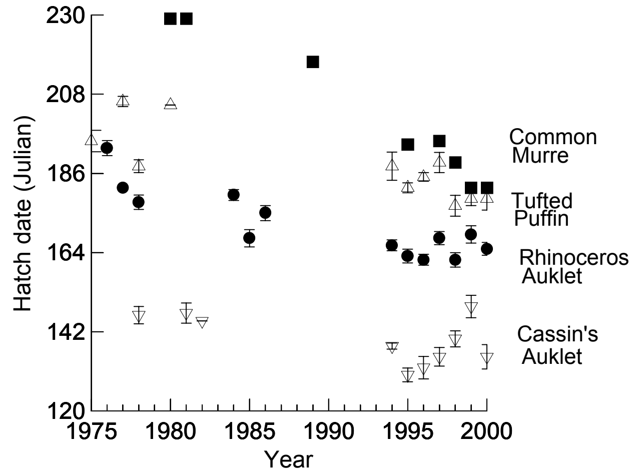


Figure 31. Timing of breeding for seabirds on Triangle Island, British Columbia. Values are mean hatch dates (with 95 % confidence intervals) for Cassin's Auklet, Rhinoceros Auklet, and Tufted Puffin. Values for Common Murre are dates when nestlings were first observed.

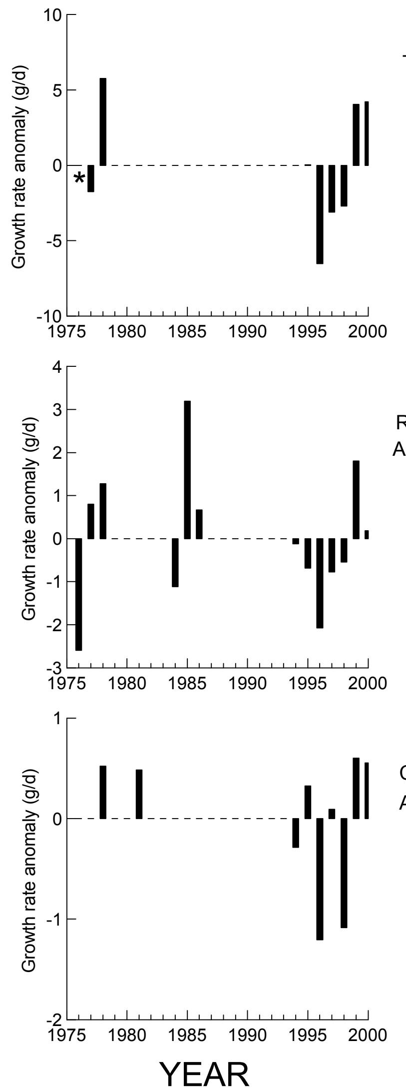


Figure 32. Nestling growth rate anomalies (g/d) for Tufted Puffin (TUPU), Rhinoceros Auklet (RHAU) and Cassin's Auklet (CAAU) on Triangle Island, British Columbia. Note that in 1976 breeding failure was observed for the Tufted Puffins because most eggs failed to hatch (*).

The food delivered to Rhinoceros Auklet nestlings in 2000 consisted primarily of Pacific sand lance (52%: *Ammodytes hexapterus* by wet mass) in addition to juvenile salmonids (*Onchorynchus spp:*15%) juvenile rockfish (*Sebastes spp,* 26%) and Pacific Saury (*Cololabis saira* 4%: Figure 33). For Cassin's Auklet the nestling diet throughout the chick rearing period was dominated by *Neocalanus cristatus* and *Thysanoessa spinifera.*

A radio telemetry study conducted in conjunction with sampling by DFO on the Cape Scott (also, Triangle Island) line revealed that breeding Cassin's Auklet were foraging 50-60 km SW of the colony, overlapping significantly with the core foraging distribution identified in 1999.

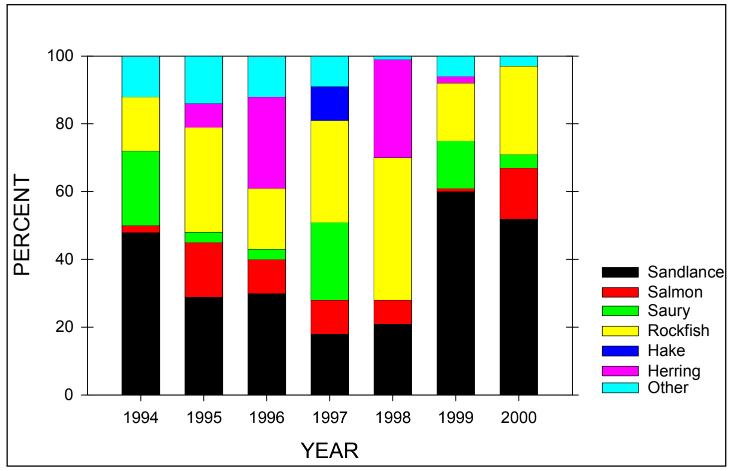


Figure 33. Rhinoceros Auklet nestling diet collected at 9-10 weekly intervals from a sample of 10 – 12 parents coming to the colony on Triangle Island, British Columbia, at night. The results for wet mass of prey are shown.

Frederick Island

From 1994-1998, in contrast to the population on Triangle Island, the Cassin's Auklet on Frederick Island (53°56' N, 133°11' W) to the north in the coastal downwelling domain exhibited uniformly high reproductive success (e.g., chick growth rates, fledging mass and fledging success). In 2000, the growth rate of nestlings was 5.1 ± 0.9 g/d (between 5 and 25 days old, mean ± S.D.) similar to previous values from the 1990s and also similar to the value observed on Triangle Island in 2000 (5.3 ± 0.96 g/d). Nestling diet in 2000 on Frederick Island was similar to that for Triangle Island, with Euphausiids (*Thysanoessa spp)* and *N. cristatus* dominating the food load delivered to the colony.

Seabird eproductive Performance and Ocean Climate Variation

For Cassin's Auklet and Rhinoceros Auklet on Triangle Island, warm sea surface temperature (SST) in spring is associated with poor nestling growth (Figure 34). The poor performance of the Cassin's Auklet during warm spring years likely reflects 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 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 growth rate declines significantly as SST increases (> 7.5°C), demonstrating a strong response of seabirds to variation in ocean climate (Figure 34).

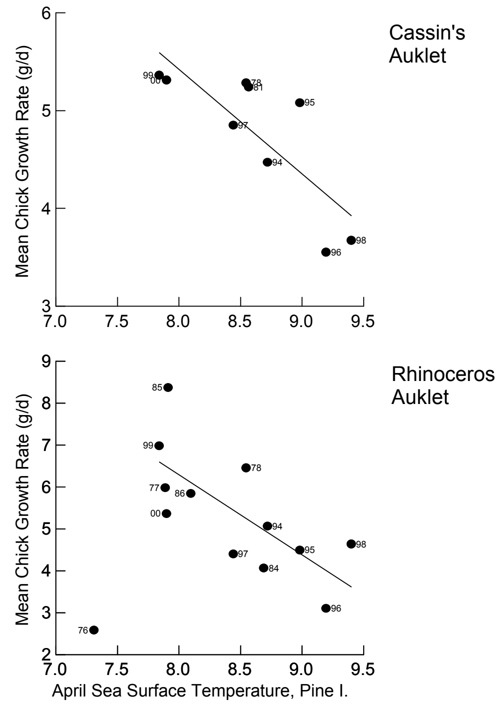


Figure 34. Consequences of interannual variation in spring SST for Cassin's Auklet and Rhinoceros Auklet reproductive performance on Triangle Island, British Columbia. Growth rates of nestling Cassin's Auklet and Rhinoceros Auklets are generally lower when spring is early and sea surface temperature is high. 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 13.97 – 1.07x; $F_{1,7}$ 12.5; P 0.009) and the Rhinoceros Auklet (excluding 1976, y 21.53 – 1.91x; $F_{1,10}$ 11.2; P 0.007). Shown are mean annual population estimates of nestling growth rate in relation to the average SST in April at the Pine Island Lightstation (50 35'N, 127 26'W).

North Coast

Surface temperatures throughout North Coast waters, out to 50 km west of the continental shelf, were slightly cooler than normal; with summer temperatures falling the most below normal. At Bonilla Island in Hecate Strait, daily temperatures were slightly cooler than average throughout the year, with temperatures in June and July as much as 1°C below normal (Fig. 1a). At Langara Island on the north tip of the Queen Charlotte Islands, daily temperatures were slightly above normal in January and December, and almost a degree below normal in June and July.

At 100 m depth temperatures in summer were close to normal. Too few measurements are available in other seasons.

Surface salinities at Bonilla Island were close to normal, whereas salinities at Langara Island were about 0.5 parts per thousand above normal. Too few measurements were available to determine anomalies with confidence in waters of Queen Charlotte Sound, Hecate Strait, Dixon Entrance or west of the Queen Charlotte Islands either at surface or at 100 m depth.

Annual average sea levels for 2000 (adjusted for changes in atmospheric pressures) were near the 1975 to 1995 average, and lower than observed during the 1997/98 El Niño. However, levels in February and March at Prince Rupert were 5 cm higher than normal (1975-1995) due to storms. Summer levels (July to October) were about 3 cm below normal.

Meteorological Buoy Data

Extreme storms hit the North Coast region, mainly Queen Charlotte Sound and southern Hecate Strait, in February, and continued into March in Queen Charlotte Sound. These storms raised sea levels as noted above. Autumn storms were more severe than normal, with stronger than average

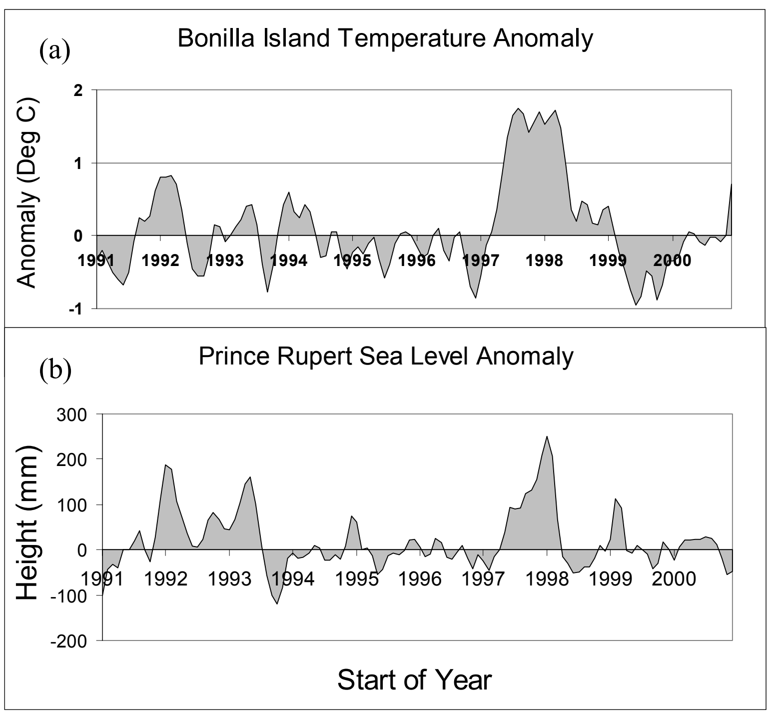


Figure 1. Monthly anomalies of temperature at Bonilla Island (a) **and sea level at Prince Rupert** (b) **for the past ten years. Surface ocean temperatures at Bonilla Island are recorded by Lighthouse staff daily, and sea levels at Prince Rupert are measured continuously by the Canadian Hydrographic water level gauge. The El Niño event of 1997 to early 1998 stands out clearly, with warmer waters and higher sea levels. Temperatures at Bonilla dropped below normal in 1999 and returned to near normal in 2000.**

winds toward the northwest, but did not match the winds of February

Winds in Queen Charlotte Sound in spring and summer were close to normal, whereas winds were downwelling favourable (northwestward) in spring in Hecate Strait.

Sea surface temperature was 1-2°C below normal in spring and early summer, and close to normal for the remainder of the year.

Winter Sea Level and Temperature

Water temperature at Bonilla Island (Figure 2a) and Pressure-adjusted winter sea level at Prince Rupert (Figure 2b) have been used as indicators of recruitment strength of Pacific cod. Generally, winters with high pressure-adjusted sea levels are poor recruitment years. The term "pressure-adjusted sea level" denotes a time series of sea level in centimetres added to the time series of local air pressure in millibars, and represents the total pressure on the ocean. The graph for Prince Rupert (Figure 2b) presents the levels in centimeters. Horizontal variations in these levels drive ocean currents. Two series are presented below. The blue line in Figure 2b denotes the variation from year to year in the average pressure-adjusted sea level at Prince Rupert from 1 January to 31 March in each winter. This line includes both the variations due to changes in local weather and currents, and also the long-term trend due to global sea level rise. The red line shows the pressure-adjusted sea level with a long-term sea level rise removed, using the slope of the 89-year times series above.

In general, warm winters and high sea levels in winter go together. Surface waters at Bonilla Lighthouse are generally warmer and higher after 1976, and most of the high temperatures and sea levels fall in El Niño winters. Temperatures

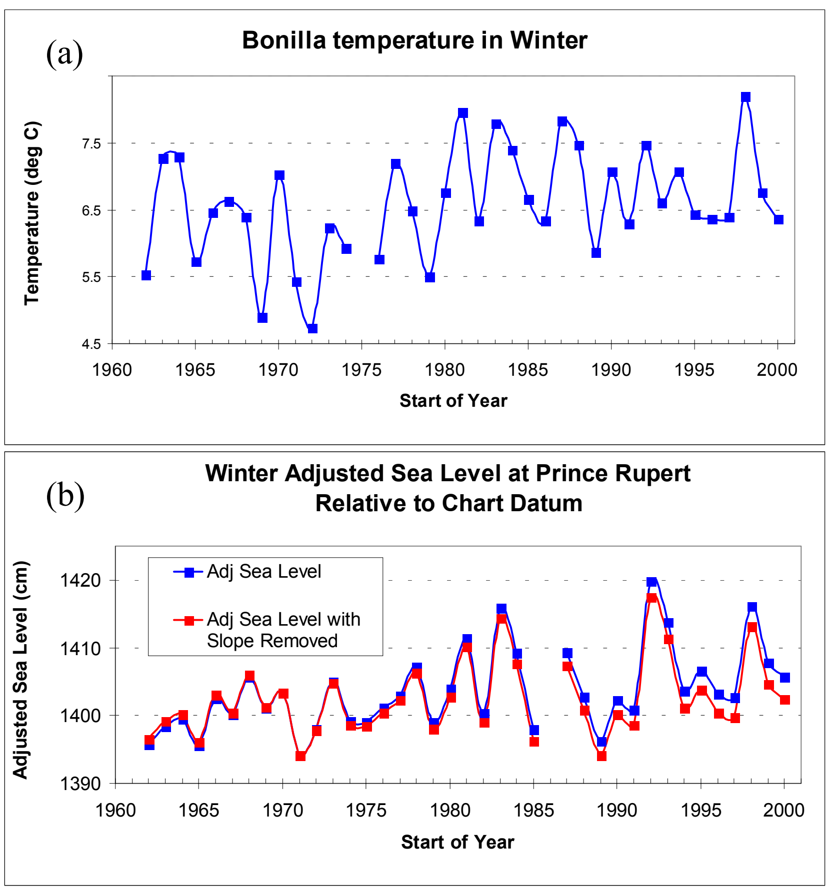


Figure 2. Water temperature at Bonilla Island (a) and ad usted sea level at Prince Rupert.

during the winters of 1999 and 2000 returned to cooler values, generally representing the non-El Niño winters of the previous two decades.

Sea Level Trends

Monthly average sea levels are available since the early 1990s at several British Columbia ports. Annual average levels are presented for the ports of Victoria, Tofino and Prince Rupert (Figure 3). The record at Victoria is almost continuous since 1910, other ports are missing data through the early years.

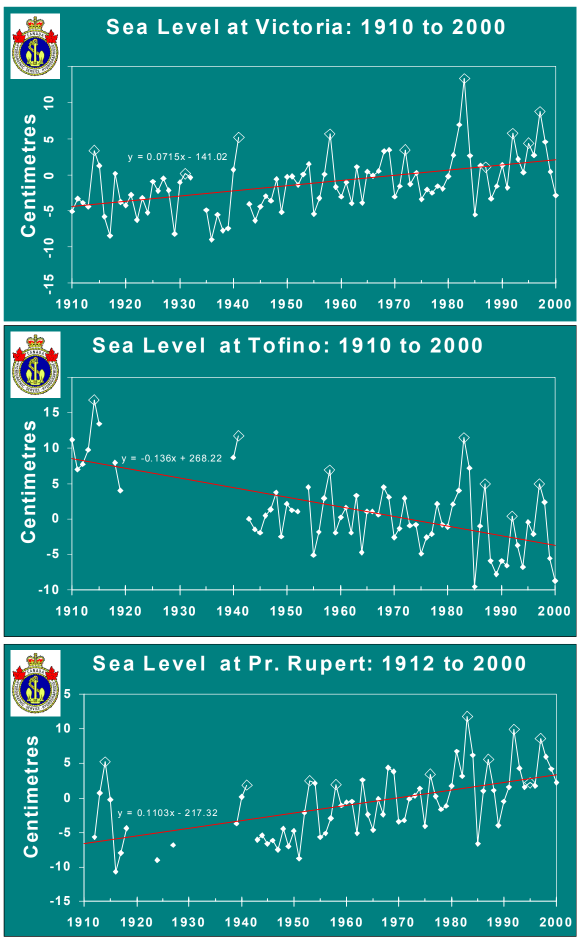


Figure 3. Sea level trends at B. C. coastal locations.

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 Victoria and Prince Rupert the local sea level is rising. 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 all three ports have declined steadily since the latest El Niño in 1997/98.

Temperature and Salinity Trends

The trend in temperature over the period 1940 to present (Figure 4a) matches that of many records in the northern hemisphere. 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 rose only a few tenths of a degree from values in 1999, but were lower than typical values observed during the 1990s.

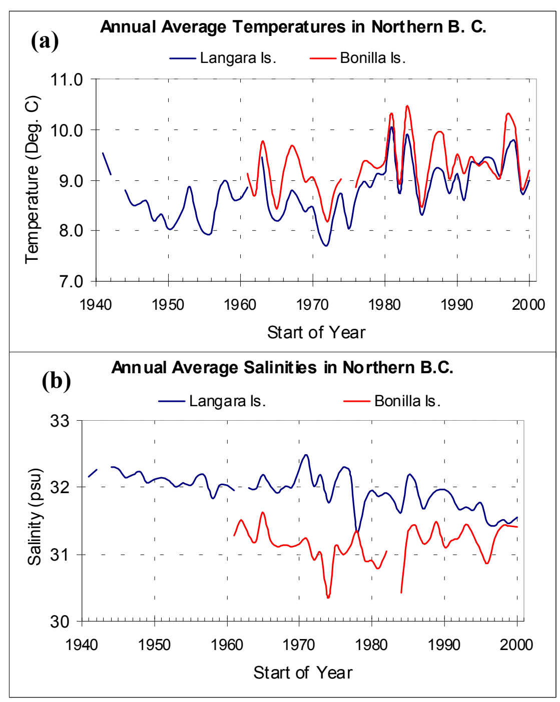


Figure 4. Temperature and salinity trends in Northern B.C.

Langara waters have freshened by 0.7 since the observations began in the early 1940s (Figure 4b). Bonilla surface waters have not experienced the same trend. In both 1998,1999, and 2000 salinities at Langara and Bonilla were almost the same, whereas for almost all previous years back to the beginning of the record in 1962, the surface waters at Bonilla were fresher.

Set-up of Eddies West of the ueen Charlotte Islands

Two satellites presently provide continuous measurements of sea level height: **TOPE /POSEIDON** operated by the United States and France, and **ERS-2**, operated by the European Space Agency. Data from these satellites have been processed by Brian Beckley of Goddard Space Flight Center with additional tidal processing by Fisheries and Oceans scientists at the Institute of Ocean Sciences in Sidney, B.C. Images are prepared at the Institute of Ocean Sciences. The images in Figures 5 and 6 show the winter height anomalies in three successive winters, relative to a sea surface averaged over the years 1992 to 1993 and 1995 to 2000. These anomalies have been adjusted for atmospheric pressure effects.

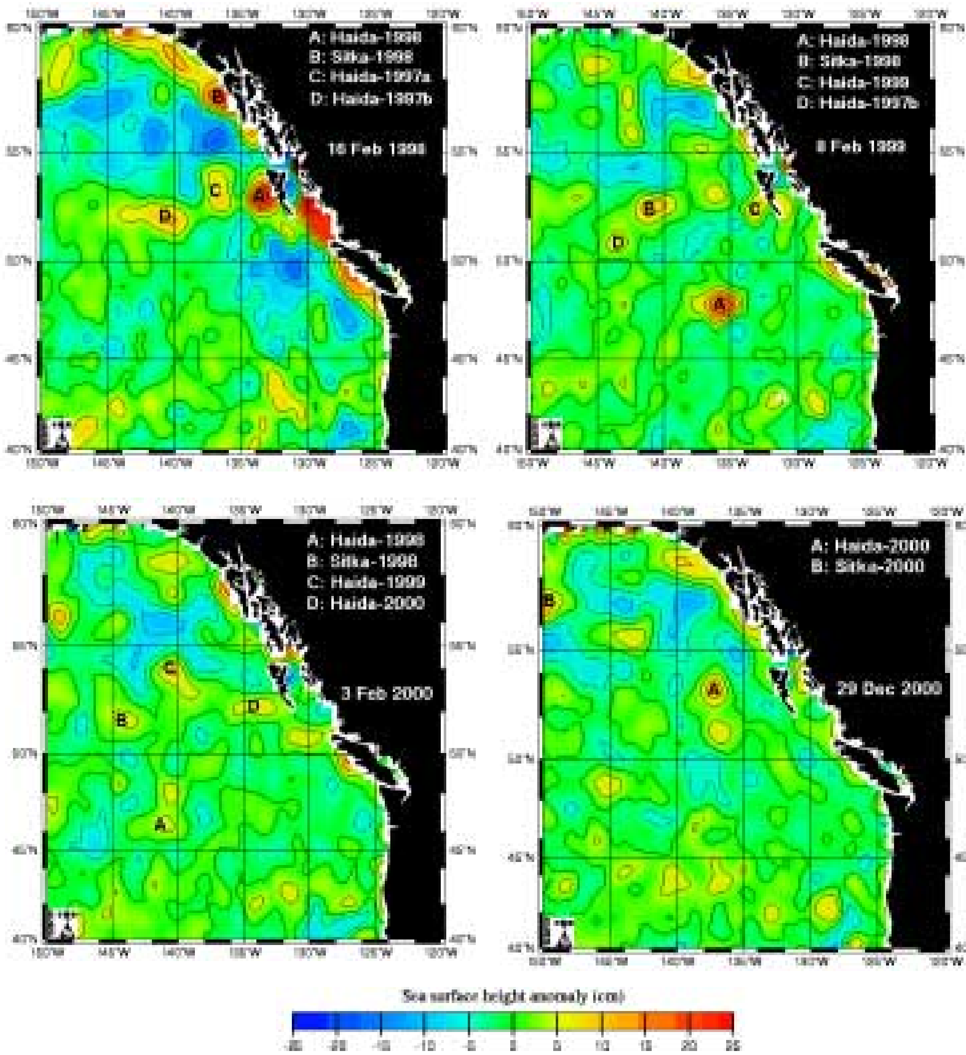


Figure 5. TOPE /Poseidon images of recent eddies in the NE Pacific. Water flows in a clockwise direction around the centres of these eddies, which are coloured orange and red to denote their higher sea surface elevation. It is believed that such eddies carry coastal waters into the Gulf of Alaska. Eddies also carry coastal fish and plankton, along with nitrate and iron needed for plankton growth.

One or two eddies of the kind shown in Figure 5 form in the NE Pacific during most winters. Eddies are generally larger in winters of 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 the winter of 1999 and 2000 were close to normal size. Images of these eddies are presented below for February 1998 to 2000 and a final one for December 2000, with annotation showing their names assigned based on the location and year of origin along the coast.

Figure 6 is a close-up of the eddy region along the west coast of North America. Red regions denote higher-than-average sea surface heights, with extreme highs of more than 40 cm along the West Coast of the Queen Charlotte Islands in the winter of 1997 to 1998. Blue denotes lower than normal sea surface heights, with extreme lows of almost 40 cm off southern California in the winter of 1999 to 2000.

High sea levels along the coast indicate warm water flowing northward, a normal occurrence in west coast winters. The extreme highs in the winter of 1997 to 1998 show water warmer than normal flowing faster than normal, as part of the global El Niño event in that winter. The graphs of 1998 to 1999, and 1999 to 2000 show conditions typical of non-El Niño or La Niña years.

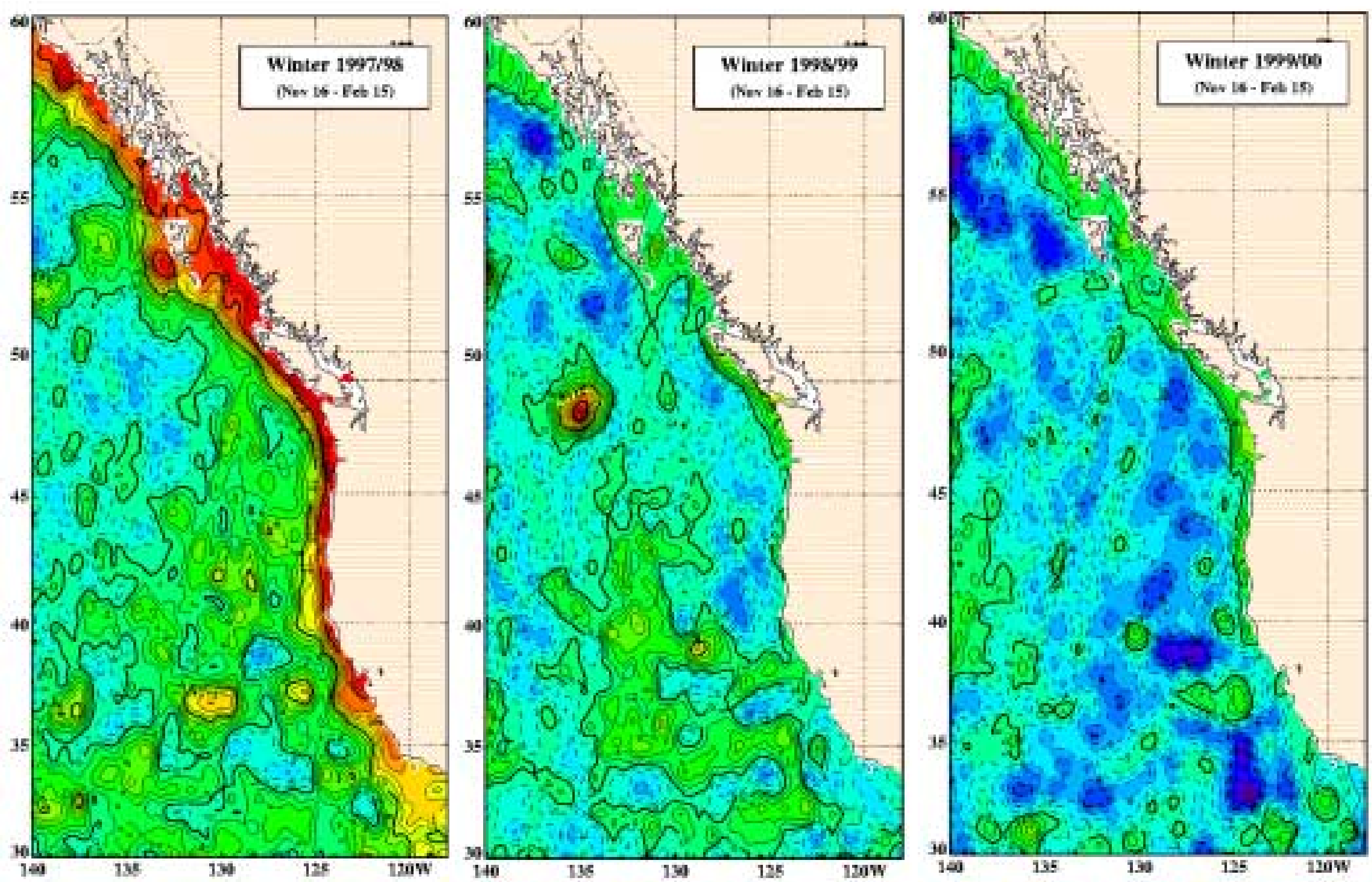


Figure 6. **Sea level changes through the transition from El Niño (1997/98) to La Niña (1999/00)**

Flatfish in Hecate Strait

The exploitable biomass of Hecate Strait rock sole and English sole was low in the late 1940s and fluctuated without an overall trend between that time and 1980. Between 1980 and 1995 the exploitable biomass for this stock increased to the highest level recorded in the last 50 years (Figure 7). By 1999 biomass for both species declined to a level near the long-term average for the last 50 years (Figure 5). The fluctuations in abundance for both of these species appears to be due mainly to the influence of the environment on year class success. If 1999 and 2000 conditions result in improved year class success for these flatfish species, the increase in abundance will not be evident until the recruited 4 year olds enter the fishery in 2003/04. Ocean temperature and transport at the time of the egg and larval stages are important determinants of recruitment (Fargo et al. 2000).

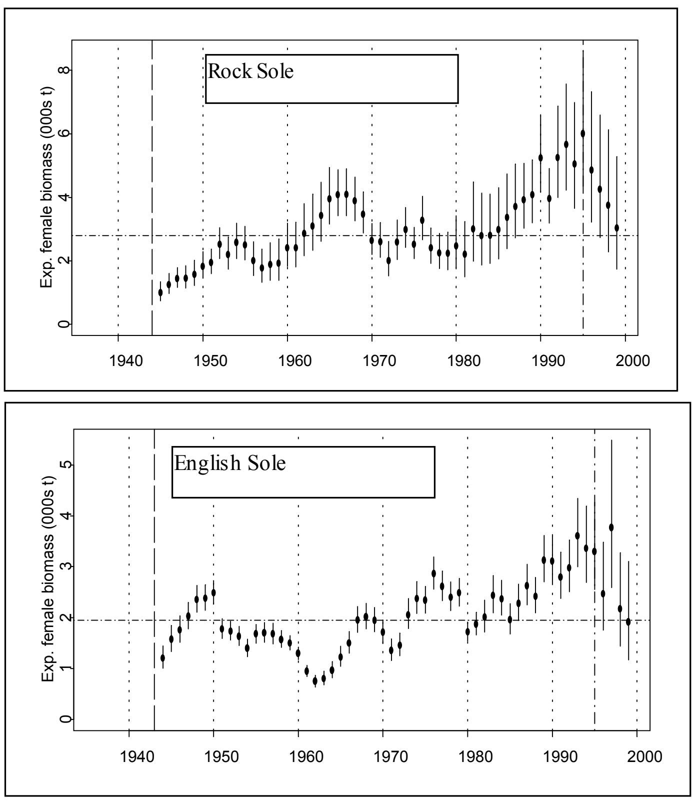


Figure 7. Expoitable biomass of flatfish in the Hecate Strait.

Strait of Georgia

Temperature and Salinity

The sea surface temperature in the strait remained slightly above normal in 2000, with sea surface temperature anomaly of about 0.5 °C for most of the year (Fig. 1). The sea surface salinity also closely followed the long term seasonal cycle with small positive (less than 1 psu) anomalies for most months. Similar conditions to those at Entrance Island were recorded at other lighthouse stations as well as at the Nanoose Bay station at the surface and through the water column, with small positive temperature anomalies over most of the year.

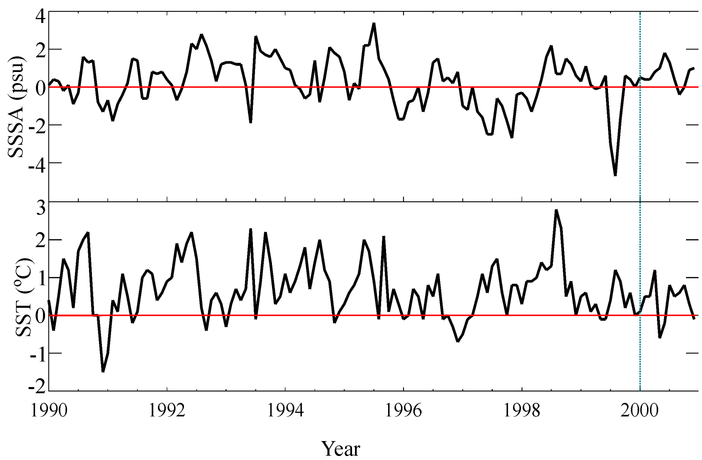


Figure 1. Monthly sea surface salinity (SSSA) and temperature (SST) anomalies measured at Entrance Island.

Fraser River:

The discharge rate for the Fraser River in 2000 was very close to the long-term average during the entire year. In contrast to the large 1999 freshet, this year's freshet peaked in early summer with maximum discharge reaching moderate values of about 8000 $m^3 s^{-1}$ (Fig. 2).

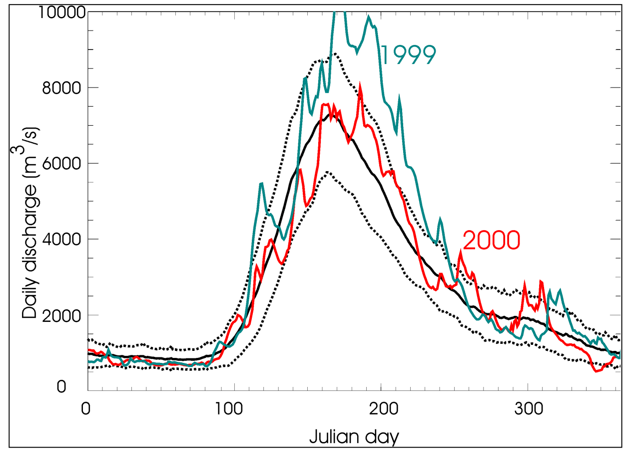


Figure 2. Fraser River discharge at Hope. The black line indicates the long term average discharge rate, and the dotted lines the standard deviation about the mean.

For the year 2000, the mean annual daily discharge of 2749 m^3/s was very close to the long-term average of 2724 m^3/s (Fig. 3). However, the extreme variation between 1997 and 2000 was unique to the time series. Figure 3 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 few years (including years 1999 and 2000), there seems to be a reversal of this trend, with more fresh water coming later in the year.

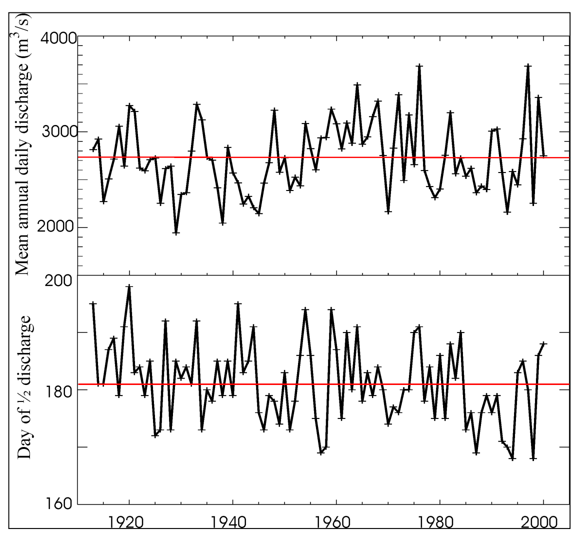


Figure 3. Mean annual discharge and day *of the year for hich half of the total yearly discharge is reached for the Fraser iver at Hope.*

Zooplankton

The Cooperative Plankton Research Monitoring Program (COPRA) collects data from a series of 19 stations along the B. C. coast. Outer coast results are included in the section for the West Coast Vancouver Island. The Strait of Georgia has two COPRA stations: CPF1 (south of Texada Is.) and CPF2 (west of Sisters Is.). CPF1 experiences a higher current flow and more variable physical and chemical conditions than CPF2, which is located to the north and in a more stable water mass. However, CPF2 typically has higher zooplankton biomass (by about 15%) and abundance (about 10%) over CPF1.

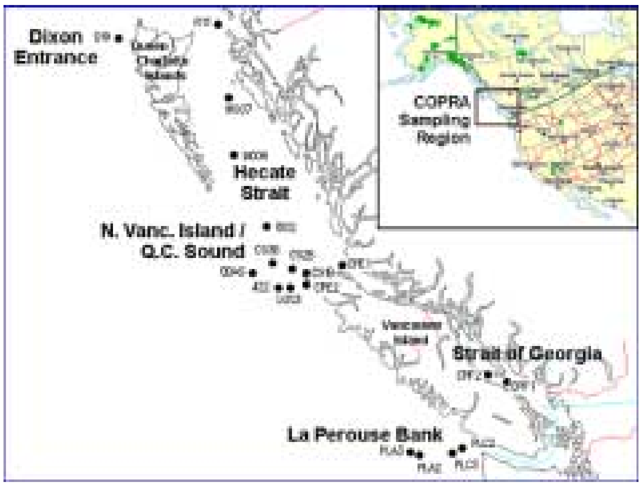


Figure 4. Standard COPRA monitoring stations.

Euphausiids

The dominant euphausiid found in the Strait of Georgia is *Euphausia pacifica*, with an average body length of 16 mm and an average life span of 12-14 months. Euphausiids are one of the most abundant plankton in the Strait and form the primary food source for many commercially important fish species (e.g., salmon, herring, and hake).

Hydroacoustic surveys of Euphausiids were conducted in the Strait of Georgia in July and October of 1999 and September 2000. There was more than a doubling of the Euphausiid biomass from 371 Kt in October 1999 to 821 Kt in September 2000. Additional surveys in April and August 2000 estimated at 914200 ±51500 t and 1162400 ±11200 t (wet weight), respectively. Figure 5 displays the August 2000 euphausiid distributions for the central Strait. Euphausiid values during 2000 were among the highest recorded concentrations over the last decade (Figure 6). The individual size of the Euphausiids was also significantly larger in 2000. The average adults *Euphausia pacifica* in July 1999 was 9.0 mm compared to 10.5 mm in July 2000 ($p < 0.05$). This increased size was also observed in September with an average size of 12.6 mm and 14.9 mm in 1999 and 2000, respectively.

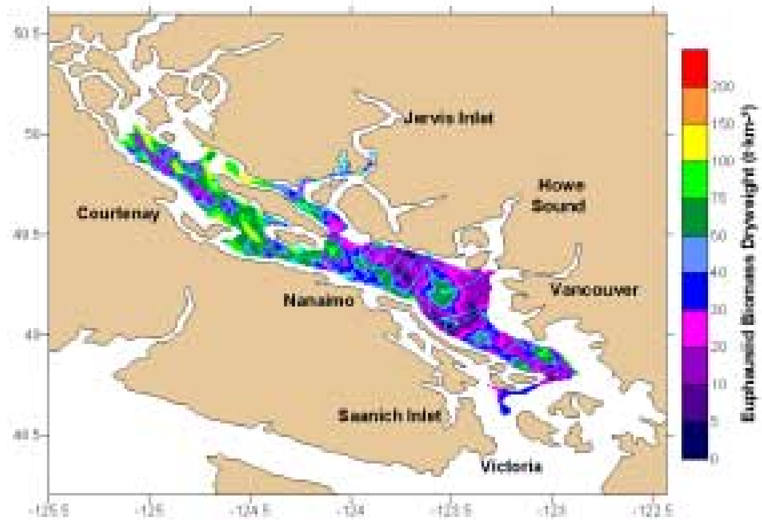


Figure 5. Central Strait of Georgia euphausiid distributions for August 2000. Total biomass was estimated at 1 162 400 ±112 000 t wet weight (for dry weight calculations divide by 6).

Ocean Age-0 Salmon

Surveys conducted in July 2000 indicated that there was a substantial increase in the early marine survival of ocean age 0 coho, chinook, chum and possibly pink salmon. Although the numbers of hatchery salmon entering the Strait of Georgia was consistent with previous years and the clipped fin recoveries from surveys indicated that the proportion of hatchery to wild smolts had increased only marginally (2.5%), the abundance of the total salmon smolts had increased by a factor of 2 to 4.

The estimated abundance of ocean age 0 coho in July 2000 was 11.2 million, or 3.3 times higher than in 1999, and exceeded the abundance of coho in 1997-1999 combined (Beamish et al. 2000). Chinook abundance was 7.9 million or 1.8 times higher than in 1999 and 3.3 and 1.7 times higher than in 1998 and 1997, respectively. Chum abundance was 27 million or 3.6 times the abundance in 1999 and more than 13 times the abundance in 1997. Pink salmon abundance was 1.3 times greater than in 1998 and, because of the odd/even cycle of this species, cannot be compared to 1997 or 1999.

In addition to the increased abundance, the individual size and condition of coho were significantly greater than in previous years. Chum salmon were larger than in 1998 and 1997. The size of the chinook salmon smolts did not increase from the previous three years and although pink salmon were larger than the even year cycle, they were the same size as the odd year fish caught in 1998. The condition factor of pink, chinook and chum did not change from the 1997 to 1999 years.

The distribution of the ocean age 0 salmon within the Strait of Georgia remained consistent with previous years. In 2000, 96% of the coho were in the top 45 m, 95% of chinook were in the top 60 m, and 98% of chum and 97% of pink were in the top 30 m.

The abundance and condition of the ocean age-0 salmon caught in the September, 2000 survey were consistent with 1999. However, during this survey Strait of Georgia, coho tags were recovered in Queen Charlotte Strait and off the West Coast of Vancouver Island suggesting that the movement of coho out of the Strait of Georgia may have started earlier than in previous years.

Hake

Pacific hake is the dominant resident species in the Strait of Georgia. The Pacific Biological Station (Nanaimo) has been running surveys at least once per year since 1995 and these surveys are often conducted in the early spring during the spawning season when mature hake are aggregated in the deep basins of the Strait. In the 1990s, the recruitment of hake improved, however individual growth rates decreased dramatically resulting in smaller size at age. As a consequence of these two opposing responses to environmental conditions, the abundance of hake in the Strait of Georgia has remained relatively stable in the 1990s at approximately 60 000 tonnes. In 2000, size at age increased slightly but recruitment estimates are yet unknown.

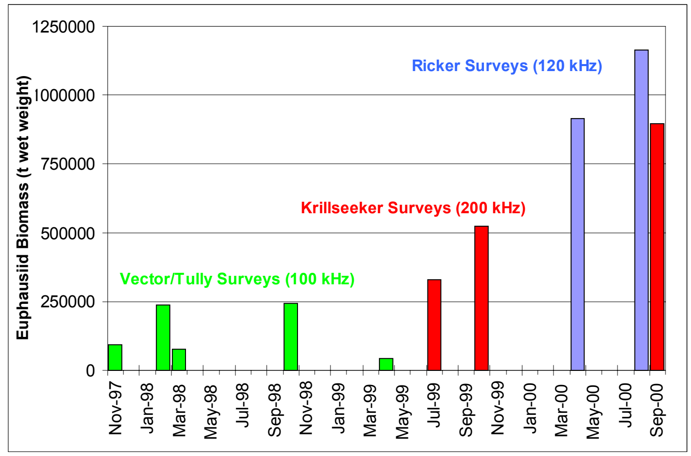


Figure 6. Euphausiid biomass estimates for the central Strait from 1997-2000. Different platforms and equipment were used to collect data and these have been standardized to compare biomass estimates.

Killer Whales

Sighting and distributions of Killer whales were more "normal" in 2000 (i.e. they were typical of sightings during the 1970s and 1980s). The year 2000 was the first time in several years that (almost) all northern resident pods were encountered (including one that had not been seen since 1989). The year 2000 also experienced several days with a "superpod" in excess of 100 whales in Johnstone Strait, and three weeks in late August when ~60 whales occurred in the northern Strait of Georgia, which were then observed to travel past Nanaimo to the mouth of the Fraser River, then out past Victoria. This was the first time in 26 years of observations that such a "transect" of the Strait of Georgia by northern residents had been observed. There is speculation that this behaviour may have been due to a low diversion rate of salmon entering through Johnstone Strait, such that the resident whales had to "go looking" for their food.

British Columbia Inlets

B. C. Inlets are partially isolated from annual and higher frequency variations present in the near surface waters. As a consequence, the deep waters of many B. C. inlets (i.e. those waters trapped behind the inlet's sill) provide a good location for monitoring the long term changes in water properties (temperature, salinity and dissolved oxygen). The deep waters record the temperature, salinity and dissolved oxygen properties of the outside waters between renewal events. The almost 50 year long time series of water properties from some inlets, more than 60 years in the case of Saanich Inlet, provide a record of our coastal environment and how it has changed in the last half century.

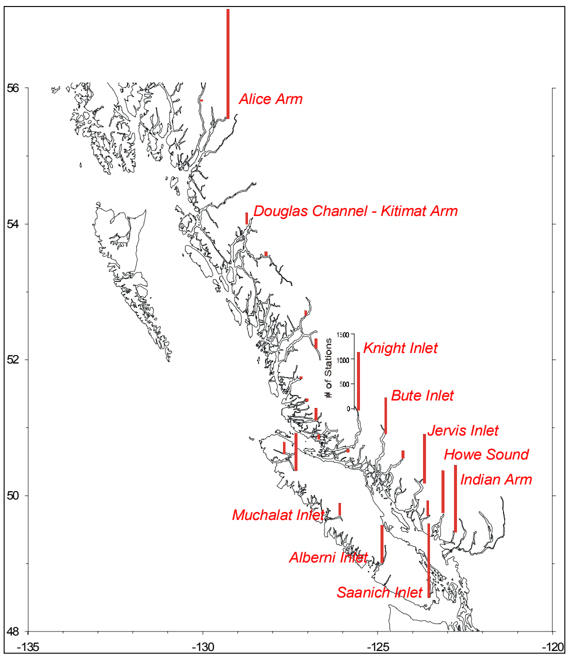


Figure 1. Number of stations sampled in the main inlets of the B. C. coast.

The best sampled B. C. inlets are mainly from the south coast; several Georgia Basin inlets (Saanich, Indian Arm, Howe Sound, Jervis, Bute), Muchalat Inlet on the west coast of Vancouver Island, and Knight Inlet on the central coast. In the central (excepting Knight Inlet) and north coasts sampling is sparse.

The time series of deep water temperature anomalies from all of the better sampled inlets show an overall increase of about 0.5 to 1 C° since the mid 70s. The rise in temperature is more consistent in the last 20 to 25 years than in the first half of the time series. In the first half of the time series there are temperature variations of ~0.5 °C on time scales of 5 to 10 years but the overall trend is not clear. The shallower silled inlets like Indian Arm and Howe Sound exhibit larger amplitude variation in their deep water properties reflecting the higher variability of the shallower renewal waters.

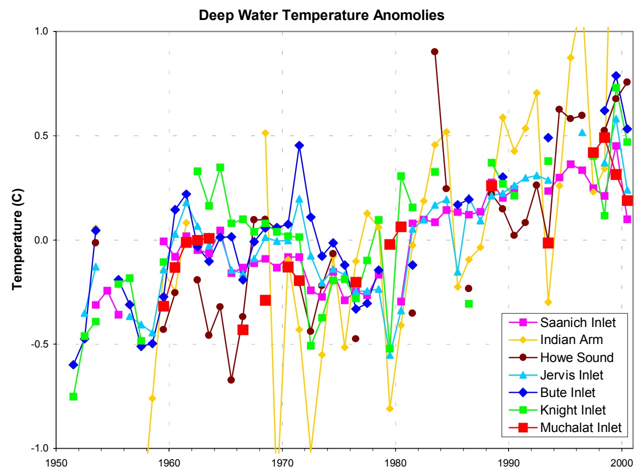


Figure 2. Annual averaged deepwater temperature anomalies from the better sampled B. C. inlets.

In 2000, the deep water temperatures generally decreased except in Howe Sound. Deep water temperatures increased in Howe Sound because there was effectively no renewal between the times of sampling in 1999 and in 2000. For Bute and Jervis inlets deep water temperatures returned to levels not seen since the late 80s and early 90s.

Unlike temperature, the time series of deep water salinity anomalies do not show any overall trend over the almost 50 year time span. The shallower silled inlets like Indian Arm and Howe Sound exhibit much larger amplitude variation in their deep water properties

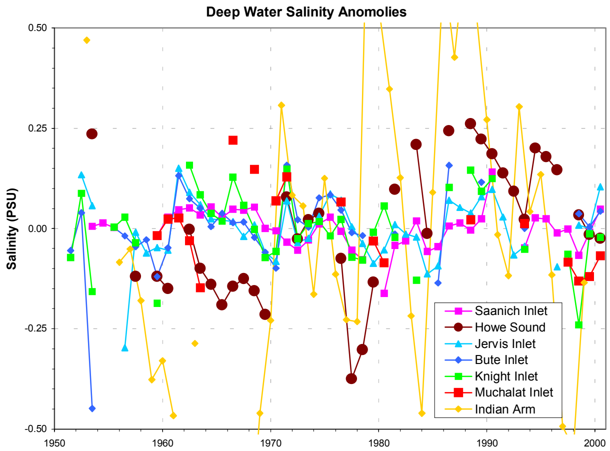


Figure 3. Annual averaged deep water salinity anomalies from the better sampled B. C. inlets.

In 2000, deep water salinity generally increased indicating that renewal had occurred between the sampling dates in 1999 and 2000. In Howe Sound there was effectively no deep water renewal as the salinity decreased slightly.

Climate Indices

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 3°C per century from 1976 to 1998, but only 2°C per century if taken between 1976 and 2000. Global climate model predictions range from 1.5°C to 4.5°C in the next century.

In 1999, La Niña brought some moderation of the upward trend in B. C. coastal air temperatures, and has continued to do so with mild La Niña conditions throughout 2000 and early 2001. Coastal temperatures dipped to normal or below normal in many B.C. locations. However, this was not generally the case as seen in Fig. 1, with North America and Europe continuing with temperatures significantly higher than the 1961 to 1990 average. The continued warming of Alaska and the Canadian Arctic is evident in average anomalies of 2°C and in extreme events such as the January, 2001 temperature anomaly in Whitehorse, over 13°C above normal. 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 2000 with land areas more affected than the oceans.

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.

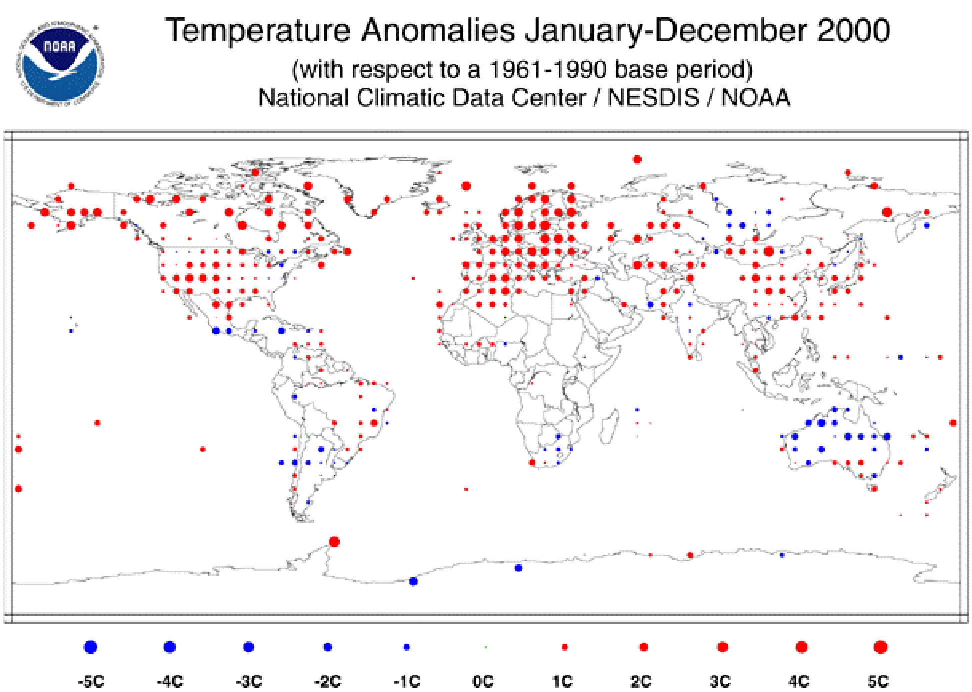


Figure 1. The distribution of year 2000 mean yearly temperature anomalies. (NOAA)

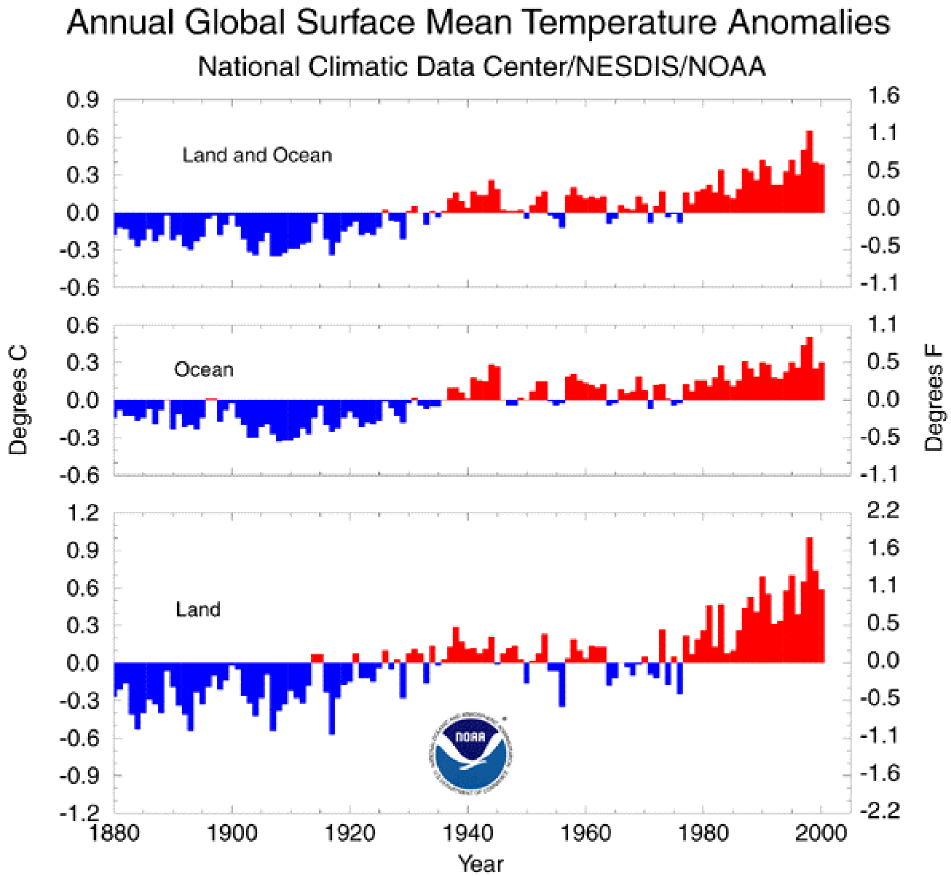


Figure 2. Although cooler than recent years, 2000 was still warmer than normal

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 Niña event of 1998/99 which has also turned out to be a persistent occurrence lasting through 2000. The last La Niña event occurred during the regime shift year of 1989.

http://www.cgd.ucar.edu/cas/climind/soi.html

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 2000 and into 2001. Short-lived negative phases were also observed in 1990-92 and in 1995. The patterns of wind and temperature associated with the PDO are shown in Figure 4.

http://tao.atmos.washington.edu/pdo/

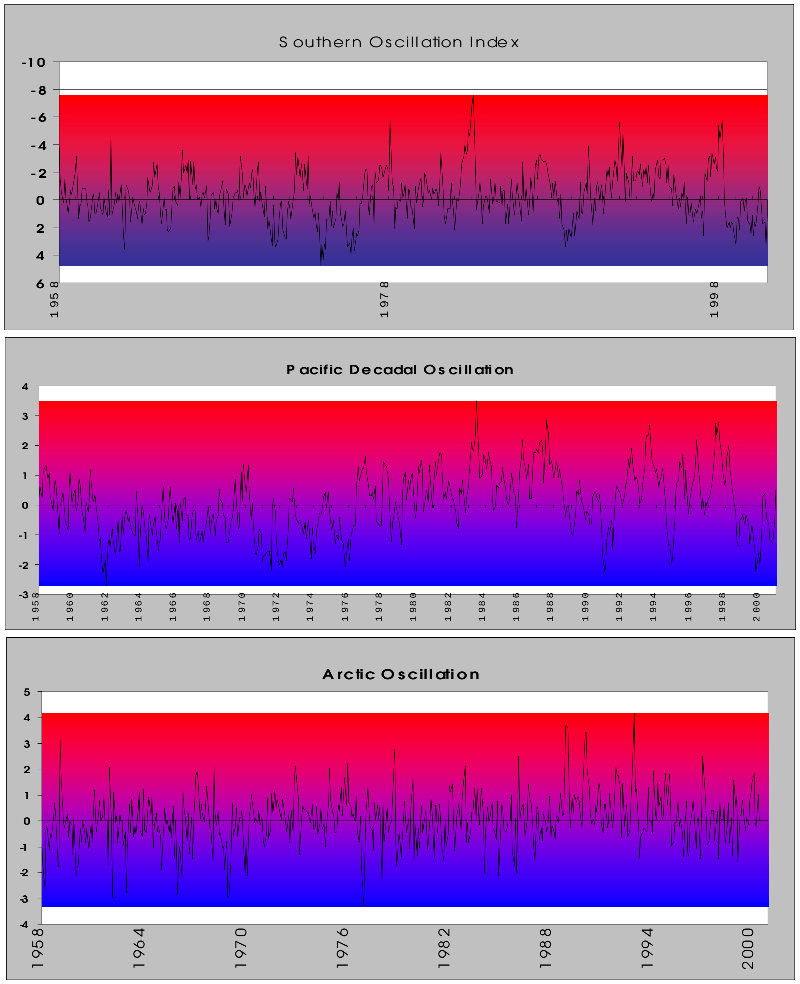


Figure 3. Variations in selected indices since 1958. The scale in the top panel was inverted to reflect warmer coastal conditions with negative index.

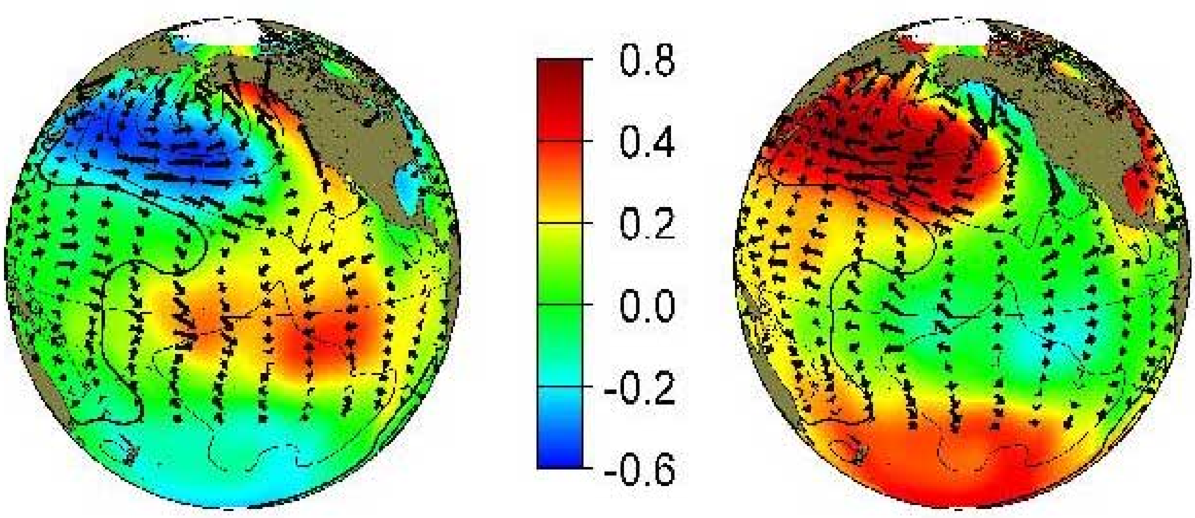


Figure 4. Typical wintertime sea surface temperature (colors), sea level pressure (contours) and surface wind stress (arrows) anomaly patterns during warm (left) and cool (right) phases of PDO.

Associated with La Niña conditions and a dip in the Pacific Decadal Oscillation Index, coastal British Columbia had near normal water temperatures in 2000. Ocean temperatures measured at lighthouses off British Columbia followed this trend.

Arctic Oscillation

The Arctic Oscillation Index (Figure 3) is the area weighted sea-level pressure anomaly poleward of 20°N and, so, is related to the PDO (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 Lo 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, (Figure 5).

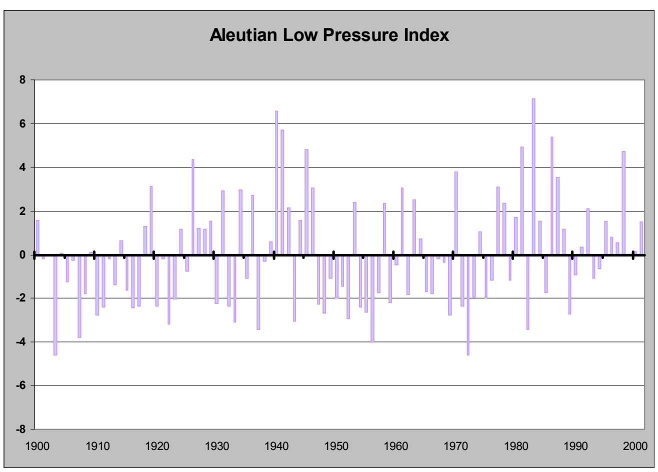


Figure 5. Aleutian Low Pressure Index.

http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/english/Clm_Indx_ALPI.htm

Length of Day

The Length of Day is a measure of the rotational speed of the solid earth. It is measured as the annual mean difference (milliseconds) between the astronomically derived and the atomically derived lengths of day. A period of decreasing Length of Day values represents a 'speeding up' of the Earth's rotational speed. The last such speeding up period preceded the 1977 regime shift by several years (Figure 6). A slowing down period preceded the 1989 regime shift by several years (Figure 6). The 1998 regime shift was preceded by a speeding up period (Figure 6). In 2000, the Length of Day continued to decrease indicating a continuation of the present regime conditions.

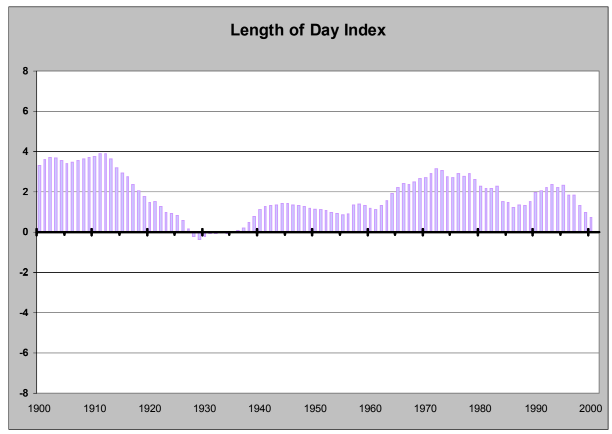


Figure 6. Length of Day Index.

http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/english/Clm_Indx_LOD.htm

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. Positive values represent intense Aleutian lows, above average frequency of westerly and southwesterly winds, cooling of sea surface temperatures in the central North

Pacific, and warming within North American coastal waters. While an extreme positive value represented 1998, the AFI values for 1999 and 2000 were near long-term average conditions (Figure 7)

http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/english/downloads/afi.txt

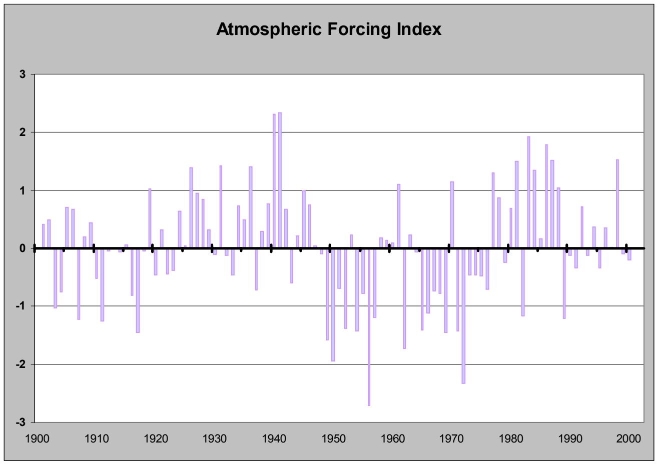


Figure 7. Atmospheric Forcing Index

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 Ma or 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 resulted in a large decrease in total abundance off British Columbia. It is not known if the distribution of hake observed in 2000 will persist into 2001.

Herring: Herring on the west coast of Vancouver Island are likely to remain at their current depressed levels given the abundance of predators in the area. However, because ocean conditions were more favourable for herring survival in 1999 and 2000, we should see an improved recruitment to the stock, starting 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, the distribution of sardines in B.C. was again reduced and was limited to areas around western and northern Vancouver Island.

Salmon: Total Pacific salmon catches will remain below the historic average of 60,000 tonnes but total catches from all countries will remain high. In 1999 and 2000 the total catches of Pacific salmon in Canada were the lowest on record (starting in 1925). Catches in 2001 are expected to remain low, but there are indications that the productivity of Pacific salmon will improve in future years in the southern range of their distribution. For example, the returns to the Columbia River in 2001 appear to be the largest on record. The total Pacific catch of all species is declining from historic high levels and is expected to continue to decline in conjunction with changes in large-scale climate indicators that appear to have changed trends in 1998.

Strait of Georgia Ma or Fish Stocks

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

Ocean Age-0 Salmon: The behaviour of Strait of Georgia coho salmon changed in the mid-1990s with large percentages of juveniles moving from the strait to regions outside of the strait. During this period, the marine survival of Strait of Georgia coho also declined. These changes appear to have been associated with physical changes. It appears that the new physical regime in the strait continued through 2000. Ocean age 1 coho will be back in the Strait in 2001 and their survival may be larger.

Surveys in July, 2000 for juvenile salmon that had entered the Strait of Georgia from freshwater in 2000 indicated that coho abundance increased dramatically with more coho in 2000 than in 1997, 1998 and 1999 combined. Chinook abundance in July was 1.8 times higher in 2000 than in 1999. Chum abundance in July was 3.6 times higher than in 1999 and 13 times higher than in 1997.

In addition to the increased abundance, the individual size and condition factor of coho increased in 2000. The individual size of chum in 2000 increased but chinook and pink remained the same size as previous years.

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 40 cm in the 1980s to 35cm by the mid-1900s. In 2000, size at age increased slightly. Hake in the Strait of Georgia will continue to be of small individual size and large total biomass.

Herring: The abundance of herring in 2000 was similar to the two previous years at just over 80,000 tonnes. Current abundance is about mid-range in the historical time series from 1951-2000, with the lowest abundance estimated in 1968 (11,000 tonnes) and the highest abundance estimated in 1954 (154,000 tonnes). The abundance of this stock has been increasing since the mid- to late 1980s.

Contributors

Richard Beamish
Doug Bertram
Bill Crawford
Graham Ellis
Jeff Fargo
Jackie King
Sandy McFarlane
Skip McKinnell
Dave Mackas
Diane Masson
Angelica Peña
Ron Perkin
Ian Perry
Steve Romaine
Jake Schweigert
Dario Stucchi
Ron Tanasichuk
Rick Thomson
David Welch

References

Beamish, R., K.L. Poier, R.M. Sweeting, and C.M. Neville. 2000. An abrupt increase in the abundance of juvenile salmon in the Strait of Georgia. (NPAFC Doc. 473) Pacific Biological Station, Nanaimo, B.C.

Denman, K.L. and M.A. Peña, 2001: The Response of Two Coupled 1-D Mixed Layer / Planktonic Ecosystem Models to Climate Change in the NE Subarctic Pacific Ocean. Deep Sea Research II, (submitted)

Fargo, J, A.R. Kronlund, J.T. Schnute and R. Haigh. 2000. Stock assessment of rock sole and English sole in Hecate Strait for 2000/2001. Canadian Stock Assessment Secretariat Research Document 2000/166.

Foreman, M.G.G., R.E. Thomson, and C.L. Smith. 2000. Seasonal current simulations for the western continental margin of Vancouver Island. *J. Geophys.Res*., 105 (C8), 19,665-19,698.

Karl T. R.,Knight R. W., Baker B., 2000. The record breaking global temperatures of 1997 and 1998: Evidence for an increase in the rate of global warming. Geophys. Res. Lett. Vol. 27, No. 5, p. 719.

Kieser, R., K. Cooke., W.T. Andrews, G.A. McFarlane, and M.S. Smith. 1998. A hydroacoustic survey of Pacific hake in the Strait of Georgia, British Columbia, Canada, February 20-March 5, 1996. Can. Man. Rep. Fish. Aquat. Sci. 2456:57 pp.

McFarlane, G.A., J.R. King and R.J. Beamish. 2000. Have there been recent changes in climate? Ask the fish. Progr. Oceangr. 47 (2000): 147-169.

Mackas, D.L. and M. Galbraith. *in press*. Zooplankton community composition along the inner portion of Line P during the 1997-98 El Niño event. Progr. Oceanogr.

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

Patterson, R.T., J.-P. Guilbault, and R.E. Thomson. 2000. Foraminiferal distribution in a suboxic anoxic inlet on Vancouver Island, west coast of Canada. *J. Foraminiferal Res*., 30 (4), 321-335.

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

Robinson, C.L.K. and D.M. Ware. 1999. Simulated and observed response of the southwest Vancouver Island pelagic ecosystem to ocean conditions in the 1990s. Can. J. Fish. Aquat. Sci. 56:2433-2443.

Romaine, S.J. 1997. Estimation of krill

(*Euphausia pacifica* Hansen) biomass within semi-enclosed bodies of water. M.Sc. Thesis, Univ. Victoria. 144 pp.

Romaine, S.J., K. Cooke, R. Keiser, G.A. McFarlane, M. Saunders. *In Press.* Hake and Euphausiid Acoustic Studies in the Strait of Georgia. Puget Sound Research 2001.

Schweigert and Fort, 1999. Stock Assessment for British Columbia herring in 1999 and forecasts of the potential catch in 2000. Canadian Stock Assessment Secretariat Research Document 99/178.

Simpson, K., Dobson, D., Irvine, J. R., Holtby, L. B. and Tanasichuk, R. W. 2001. Forecast forsouthern British Columbia coho salmon in 2001. PSARC Salmon Subcommittee Working Paper. S01-04. 51p.

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

Tanasichuk, R.W. 2000. Interannual variability in euphausiid population biology and its implications for fish production along the southwest coast of Vancouver Island. Can. J. Fish. Aquat. Sci. 57: (in press).

Tanasichuk, R. W. In press. Implications of interannual variability in euphausiid population biology for fish production along the southwest coast of Vancouver Island: a synthesis. Fish. Oceano

Thompson, David W. J. and John. M. Wallace, 1998: The Arctic Oscillation signature in the wintertime geopotential height and temperature fields. *Geophys. Res. Lett.,* **25,** No. 9,1297-1300.

Thomson, R.E. and D.M. Ware. 1996. A current velocity index of ocean variability. J. Geophys.Res., 101, 14,297-14,310.

Thomson, R.E., and S.E. Allen. 2000. Time series acoustic observations of macro-zooplankton diel migration and associated pelagic fish abundance. *Can. J. Fish. Aquatic Sci*., 57 (9), 1919-1931.

Ware, D.M. and G.A. McFarlane. 1995. Climate-induced changes in Pacific hake (*Merluccius productus*) abundance and pelagic community interactions in the Vancouver Island upwelling system. Can. Spec. Publ. Fish. Aquat. Sci. 121: 509-521.

Ware, D.M., and R.E. Thomson. 2000. Interannual to multidecadal timescale climate variations in the northeast Pacific. *J. Climate*, 13 (18), 3209-3220.

This report is available:

PSARC Secretariat
Pacific Biological Station
Nanaimo, BC V9R 5K6
Phone: (250) 756-7208
Fax: (250) 756-7209
E-Mail: psarc@pac.dfo-mpo.gc.ca
Internet Address: (www.dfo-mpo.gc.ca/csas)

ISSN 1480-4913 (for English series)
ISSN 1480-4921 (for French series)

La version française est disponible à l'adresse ci-dessus.

Correct citation for this publication

DFO, 2001. 2000 Pacific Region State of the Ocean. DFO Science Stock Status Report 2001-01 (2001).