Fisheries and Oceans Pêches et Océans
Pacific Region

DFO Science
Ocean Status Report 2000/01

1999 Pacific Region State of the Ocean

Background

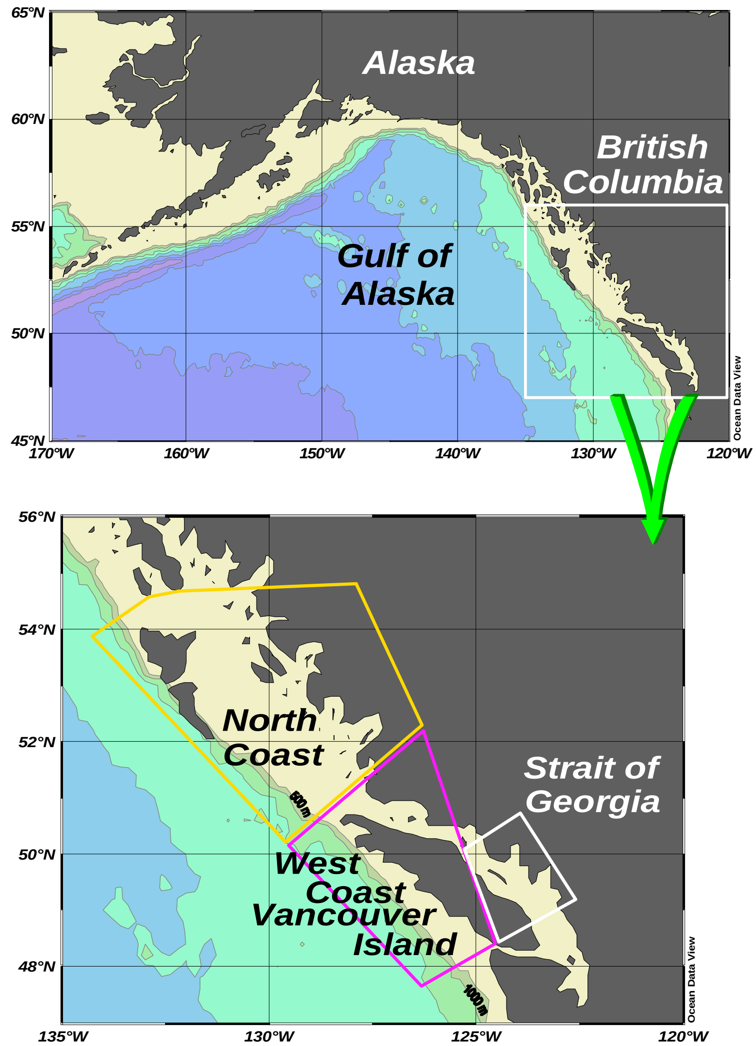
The physical, chemical and biological state of the marine environment impacts the yield (growth, reproduction, survival, distribution) of marine organisms as well as the operations of the fishing industry. Changes in the state of the ocean may contribute directly to variations in resource yield, reproductive 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 returned to near normal values in 1999 following several years of strongly "anomalous" conditions associated with El Niño warming events in the 1990s, highlighted by the major events of 1991/92 and 1997/98.



Canada

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Summary by Region

Gulf of Alaska

- Sea surface temperatures (SST) were approximately 1°C lower than normal (1956-1999 average) throughout most of the Gulf of Alaska.

- Anomalously low temperatures penetrated to about 100 metres depth.

- The mid-winter mixed layer was about 10 m deeper than normal (1956-1999 average) during the winter of 1998/99.

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

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

- Neon flying squid were distributed farther south in 1999, moving with the 16° C isotherm.

- Unusual deaths of Grey whales along the NE Pacific coast in 1999 may have been linked to inadequate feeding in the Bering Sea in the summer of 1998.

West Coast of Vancouver Island

- Continental shelf/slope SST was close to the 1990-1996 mean for January and February but 1 to 2° C below normal from March through August (south section) and March through September (north section). Temperatures were near normal from September through December (south section) and October through December (north section).

- Sea Surface Salinity (SSS) on the coast was near normal (1990-96 mean) until May, then above (below) normal in the south (north) coast through the summer and returned to near normal values in November.

- There were periods of strong southeasterly (downwelling-favourable) winds in winter and early spring and moderately strong periods of northwesterly (upwelling-favourable) winds from late spring (May) to late fall (November). Summer upwelling winds were weak on the south section during early August.

- The FNMOC Upwelling Index indicates normal to slightly above normal (1950-1999 mean) upwelling in summer (major events in late May and late July) and strong downwelling conditions from early February to early April.

- Subsurface temperatures to 400 m depth were near the 1990-1996 mean ("normal") at the beginning of the year and normal to slightly below normal during the summer (data series end at the beginning of October).

- Subsurface salinities to 400 m depth were near normal (1990-1996 mean) throughout the data series.

- Alongshore current velocity was stronger than normal (1990-1996 mean) during the winter and spring (peaking around 50 cm/s poleward in late February at 35 m depth) but returned to normal flow conditions by early April. Currents were poleward at all depths in winter and spring but mainly equatorward in summer at 35 and 100 m depths over the shelf break. Persistent poleward flow continued over the inner shelf.

- Concentrations of all major zooplankton taxa off Southern Vancouver Island swung sharply back to long term average (1980s) levels favouring boreal (cold water) species. California type species dominated during the late 1990's.

- Seabird (Tufted Puffin, Rhinoceros Auklet, Cassin's Auklet, Common Murre) breeding performance was uniformly high in 1999, particularly for the Tufted Puffin which failed to breed consistently from 1994-1998. In 1999, the nestlings grew rapidly, had high survival and fledged from the colony in high numbers.

- Survey indices of pre-recruitment shrimp abundances in May 1999 were the second highest since 1973 in the fishing ground north of Estevan Point, and the fifth highest off Tofino.

- Results from the La Perouse ecosystem model for southwest Vancouver Island suggest increased diatom production in 1999 due to enhanced upwelling.

- *Euphausia pacifica* 1999 abundance was the highest measured since 1991 in Barkley Sound.

- Ocean conditions were favorable for herring survival in 1999. All other factors being equal, this suggests improved recruitment to the stock in 2002.

- The abundance of Pacific sardine migrating to B.C. waters in the summer of 1999 seemed to be somewhat lower than 1997 and 1998.

- Sablefish recruitment, indicative of groundfish recruitment, was below average in the 1990s. There is some indication from larval surveys that year class success may improve.

- No resident (fish-eating) killer whales were observed in Johnstone Strait for 16 consecutive days in August, 1999, an unprecedented occurrence in over 25 years of monitoring. During this time, many of the whales normally seen in Johnstone Strait were spotted 55 miles SW of Cape Beale where Chinook salmon were concentrated.

North Coast

- SST out to 50 km west of the continental shelf was slightly cooler than the long term average with summer temperatures falling to 1°C below normal.

- In Dixon Entrance and Hecate Strait, SST declined to values that were typical of the 1980s and cooler than measured in the 1990s.

- Temperatures at 100 m depth in summer were close to the long term average. No data are available in other seasons.

- 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 near normal. Levels in February and March at Prince Rupert were 5 cm higher than normal due to storms but summer levels were 3 cm below normal.

- Offshore transport through coastal eddies diminished in 1999 after two large eddies formed and moved offshore in 1998.

- Hake continued to occupy northern B.C. waters where they were first observed in abundance in 1997.

Strait of Georgia

- SST was back to the long term average after a much warmer 1998. At mid depth, the anomalously warm temperatures returned to climatology near the end of the summer.

- Mean annual sea surface temperatures in Nanoose Bay cooled to values typical of 1977-1989, while bottom temperatures remained higher than the average for the

1990s.

- Bottom temperatures in the northern and southern portions of the strait were 1°C lower in 1999 (annual mean of 9.1°C) than in 1998 (annual mean of 10.1°C).

- Late summer salinities were substantially lower throughout the entire area compared to 1998.

- Total Fraser River discharge in 1999 was the third highest on record following exceedingly low discharge in 1998 and the second highest recorded of 1997.

- There was a return to a later beginning of the spring Fraser River freshet in 1998 that continued in 1999.

- The summer Fraser River freshet was much later than average, setting some record daily discharge values in August. This gave rise to exceptionally large negative sea surface salinity anomalies within the strait.

- Coho abundance continued to increase slightly in 1999 compared to 1997 and 1998. Chinook abundance in mid-summer was 20% higher in 1999 than 1998, but 30% lower than in 1997. Late-summer Chinook abundance was approximately half the estimates of abundance in 1997 and 1998. Chum abundance in mid-summer was 40% lower than in 1998 but was almost 4 times the estimated abundance in 1997. There was no large difference between chum abundance estimates for the late-summers of 1997, 1998 or 1999.

- The abundance of herring was similar to the 1998 abundance, about mid-range in the historically estimated levels.

- Major zooplankton groupings at COPRA station CPF1, south of Texada Island, experienced a 3.7 fold biomass increase over previous years. At station CPF2, west of Sisters Islets, the corresponding increase was 1.4 fold.

Prepared by:

Fisheries Oceanography Working Group

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R. G. Perkin (Rapporteur)

Gulf of Alaska

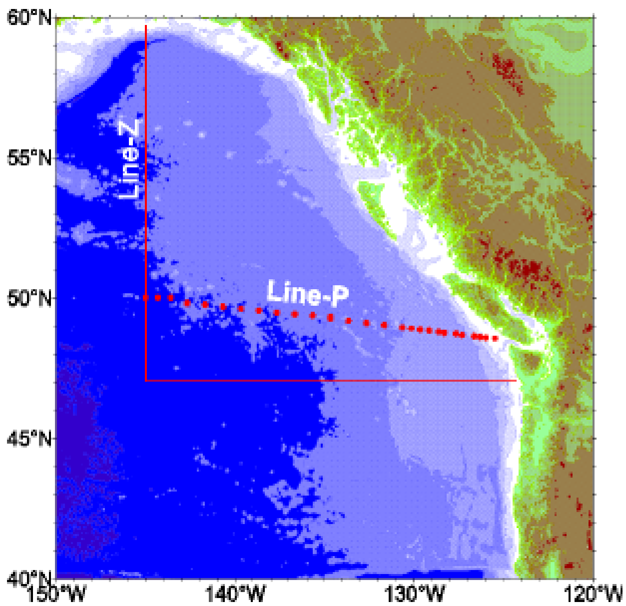


Figure 1. Map of the Gulf of Alaska showing the location of the sampling stations (red dots) comprising Line-P. Some other survey lines completed in recent years are also shown.

Physical Conditions

The El Niño event that dominated ocean conditions in the North Pacific between the spring of 1997 and the spring of 1998 was replaced by a La Niña event that began in the fall of 1998 and continued through most of 1999. As a result, the "warm" conditions of 1998 were replaced in 1999 by cool conditions throughout most of the Gulf of Alaska. (Fig. 1)

Figure 2 shows the distribution of sea-surface temperature in the Gulf of Alaska (the left column) for three 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. The right-hand column shows the temperature anomaly based on average (1956-1999) conditions along Line P.

The temperature plots demonstrate that the Gulf of Alaska was dominated from February through September by low temperatures at the surface. Along Line-P, these temperature deviations penetrated steadily deeper in the water column, and intensified through the year. At a depth of about 150 metres, was a region of the ocean that was warmer than normal. This warm sub-surface anomaly has been reported also by the Pacific Marine Environment Laboratory (Seattle) and appears to have been quite widespread in the Gulf of Alaska.

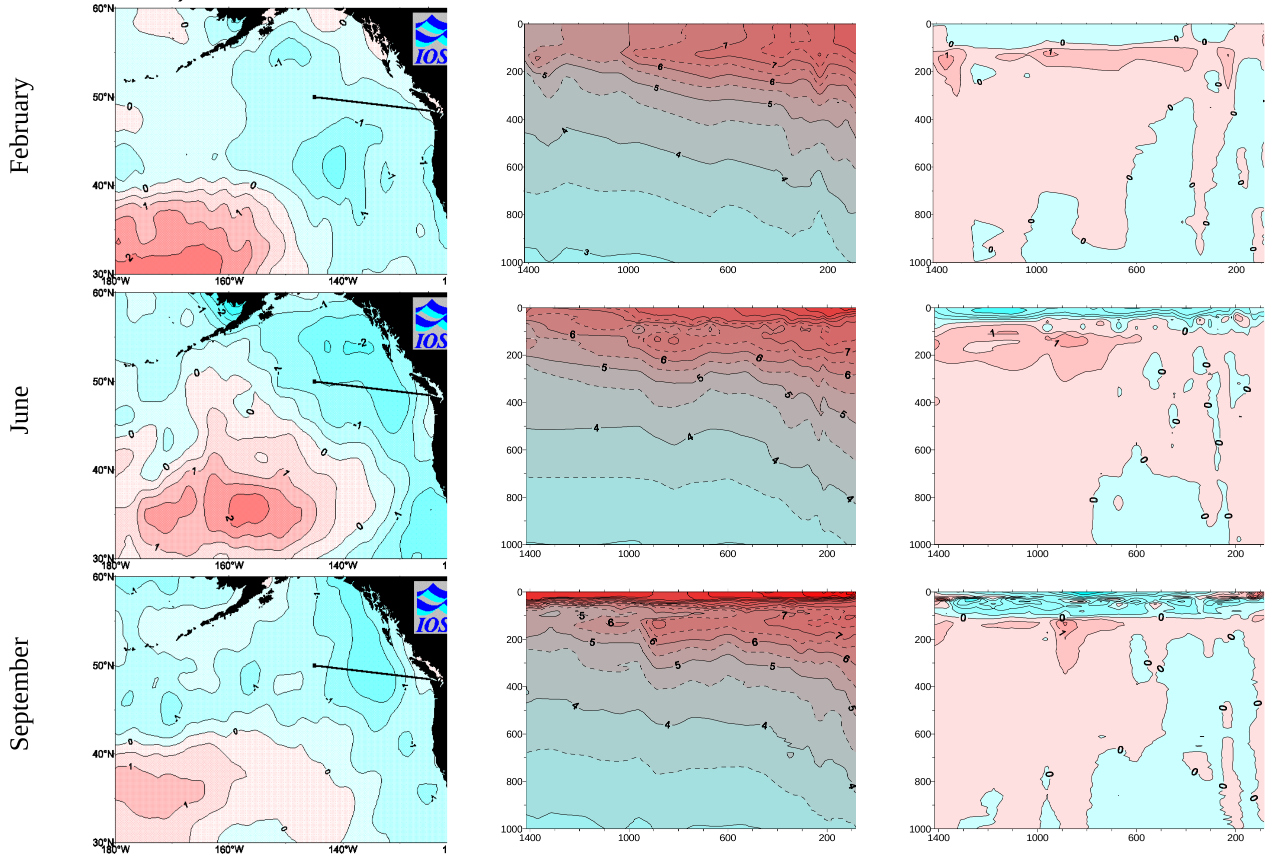
Maps of temperature in the Gulf of Alaska are prepared at the Institute of Ocean Sciences and an archive of maps from 1982 to the present time, can be viewed on the World Wide Web at:-

http://www.ios.bc.ca/ios/osap/projects/sst/archive/

Figure 3 shows sections of the salinity distribution along Line-P for the three surveys completed during 1999. These show that the Gulf of Alaska was dominated by higher than normal salinities extending from the surface to considerable depth.

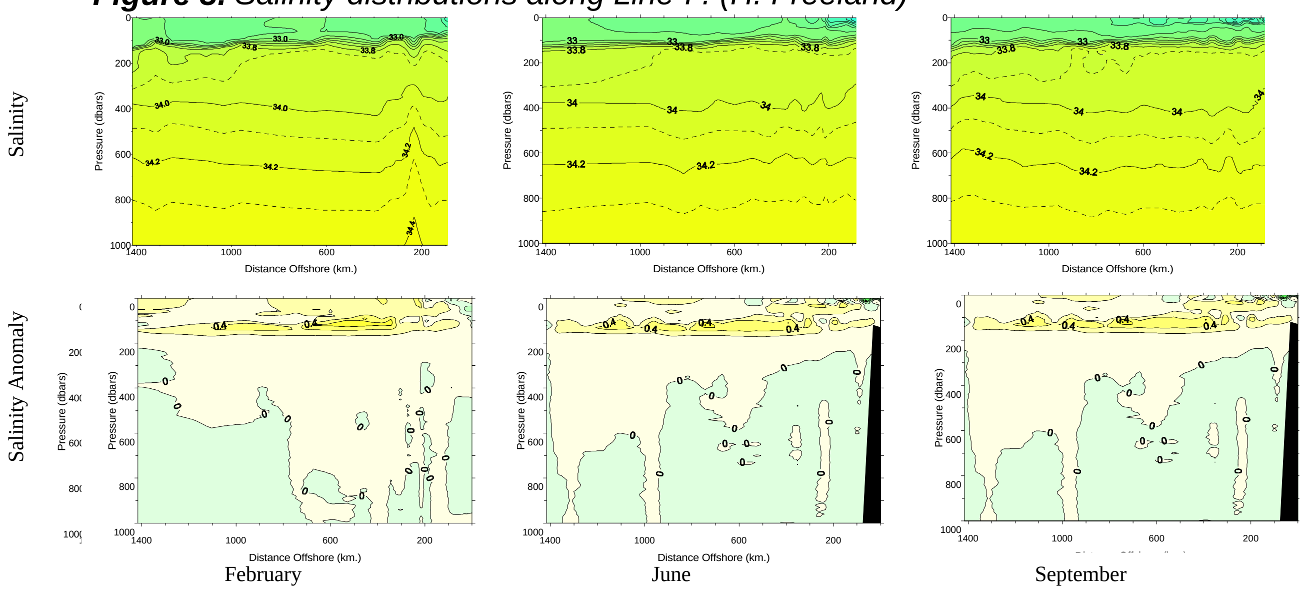
The combination of lower than normal temperatures and higher than normal salinity in the Gulf of Alaska has the effect of increasing the density of waters in the near-surface layer. This leads to a less stable water column and enhances mixing with deeper parts of the ocean. Figure 4 is a plot of "mixed layer depth". When this layer is thick, there presumably has been stronger than normal exchange between shallow and deep waters, enhancing the supply of nutrients from below. According to Figure 4, the mixed layer depth was much smaller than normal in the winter of 1997/98, but became slightly deeper than normal during the winter of 1998/99.

Figure 2. *Temperature distributions in the Gulf of Alaska during 1999. (H. Freeland)*



SST Anomalies in the NE Pacific | Temperature along Line-P | Temperature anomaly along Line-P

Figure 3. *Salinity distributions along Line-P. (H. Freeland)*



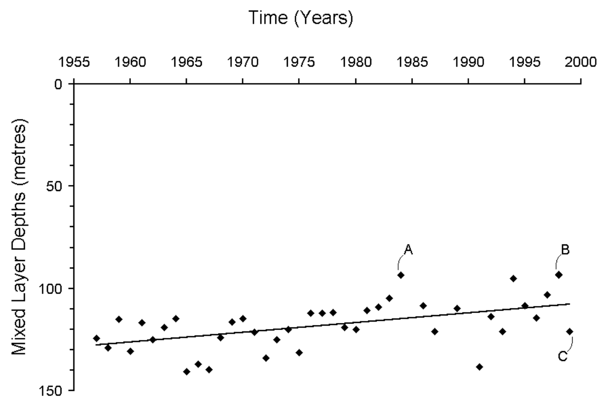


Figure 4. *Mid-winter mixed-layer depth at Ocean Station Papa. (H. Freeland)*

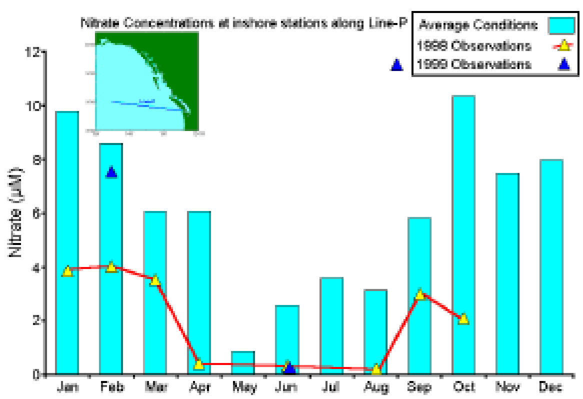


Figure 5. *The annual cycle of surface nutrients at inshore stations along Line-P. (H. Freeland)*

The result of changing mixed-layer depths is illustrated in Figure 5. The bars show the long-term average nitrate concentrations for the four inshore stations along Line-P. The open triangles and line give the nutrient concentration through 1998, a year that followed a winter with the thinnest recorded mid-winter mixed-layer. During the winter of 1998/99 the mid-winter mixed layer was relatively deep, coinciding with an abundant supply of nutrients to the surface layers of the ocean. Further, upwelling conditions near the coast (see the companion report on the West Coast of Vancouver Island) were such as to supply abundant nutrients during the summer of 1999, leading to the value of 11.5 mmol/L observed in August to September 1999. Unfortunately, ship-time was not available in February 2000 to examine conditions in the winter of 1999/2000, so alternative information had to be used to examine 1999 conditions.

Figure 6 shows a plot of water properties of seawater acquired from a profiling float drifting in the general vicinity of P16, one of the stations about half way along Line-P. The panel at top left shows the drift of the profiling float, and the other three panels show contour plots of temperature, salinity and the density of seawater along the float trajectory. In the section plots, the horizontal axis represents exactly one year.

Comparison of the beginning of each of the plots (February 1999) with the end of the plots (February 2000) reveals that conditions in February 2000 were very different from those experienced one year previously. In particular, the Gulf of Alaska near station P16 was notably warmer and less salty than it was one year ago. These effects both tend to reduce the density of surface waters so that the surface layer of the ocean is lighter and less stratified than it was in 1999.

Careful examination of the density plot in Figure 6 shows that the region of rapid density change is notably shallower than it was a year ago leading to the conclusion that the mixed layer was relatively shallow during the winter of 1999/2000. All other factors being equal, it is therefore unlikely that the abundant nutrient supply observed in 1999 will continue through 2000.

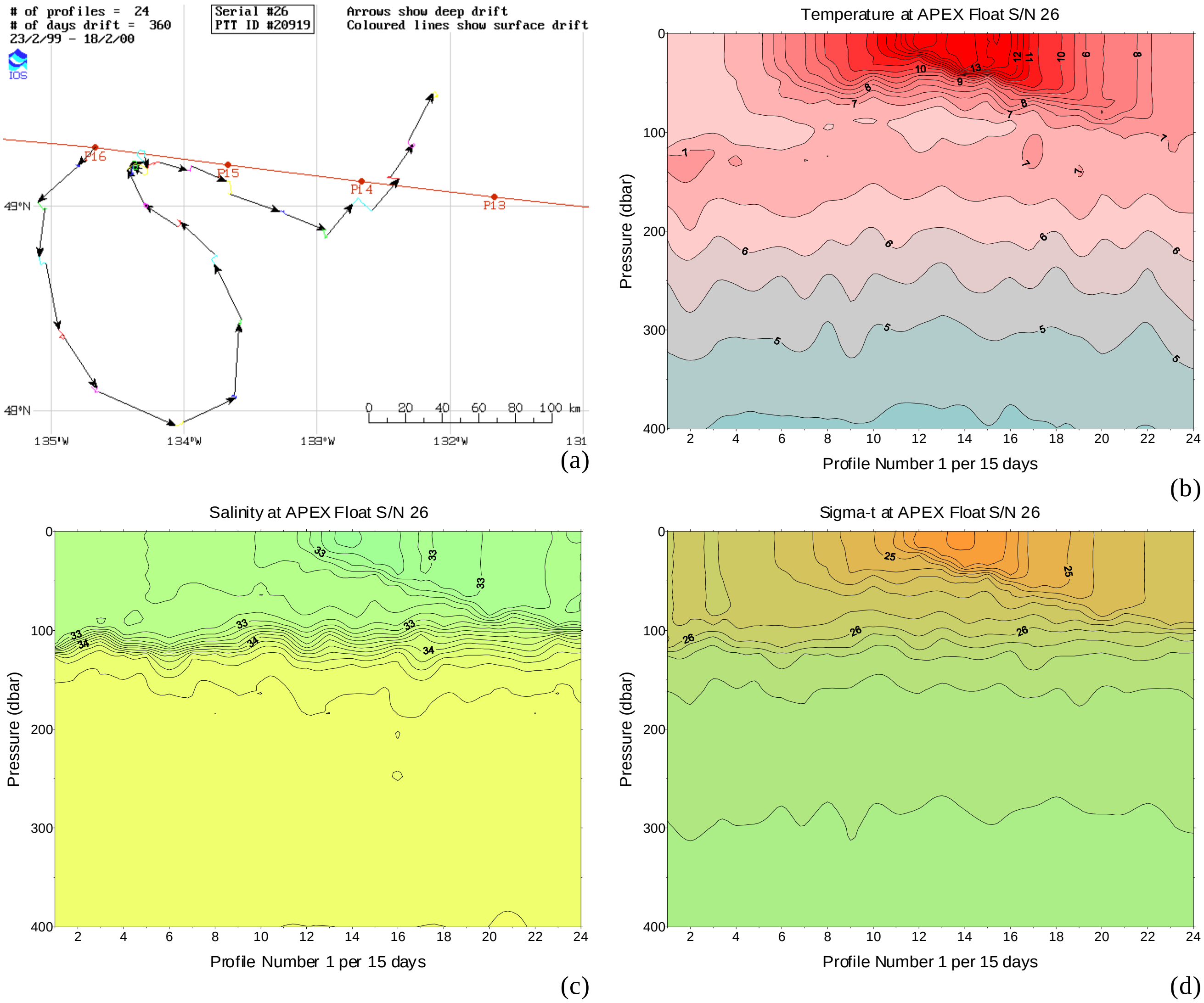


Figure 6. *(a) Drift of a float near Line-P over a 1-year interval (b) Temperature at that float (c) Salinity at that float (d) Density at that float. (H. Freeland)*

Phytoplankton

Figure 7 shows chlorophyll concentration at various stations along Line-P. The plot indicates that the biomass of phytoplankton (as chlorophyll concentration) along Line P in June and September of 1999 was between the range of values observed in previous years. The seasonal and interannual variability of phytoplankton biomass decreases with distance from shore. Thus, though there are large variations in the supply of nutrients, the direct link to plankton is weak.

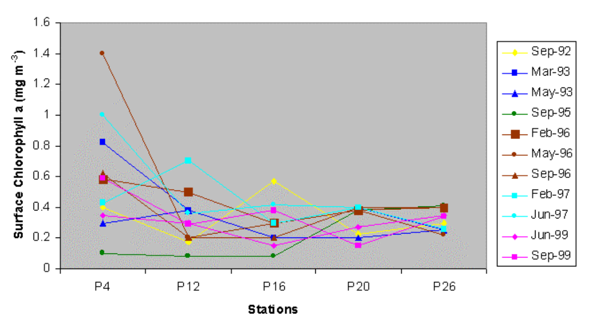


Figure 7. *Chlorophyll concentration along Line-P for various years and seasons. (A. Peña)*

Zooplankton

Net tows for upper water column (0-150 m) zooplankton have been conducted routinely in the Gulf of Alaska since the early 1990s at 5 locations along Line P, and opportunistically during other surveys (such as the summer research/training cruise of the Japanese vessel *Oshoro Maru*). Based on these data and earlier more frequent sampling during the weathership time series (1957-1980), the seasonal timing of the annual zooplankton peak is variable by more than a month, and is correlated with spring-season mixed layer temperature. The zooplankton peak is earlier when warmer, as was the case during most of the 1990s.

<u>Note</u>: Because seasonal coverage is not sufficient to reliably measure the strong and 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.

Squid Fishery

A commercial fishery for neon flying squid (*Ommastrephes bartrami*) was begun within the Canadian economic zone of the North Pacific in 1996. Consistent methods involving jigs and lights at depth were used during 1998 and 1999. Catch rates in 1998 [0.9 kg/(jig hour)] were twice those in 1999 [0.5 kg/(jig hour)]. Peak catch rates occurred at warmer sea surface temperatures in 1998 (16°C) than in 1999 (13-15°C). Figure 8 shows that the 16°C isotherm varies in latitude. It occurred furthest north in 1997, was farther south in 1998 and even farther south in 1999.

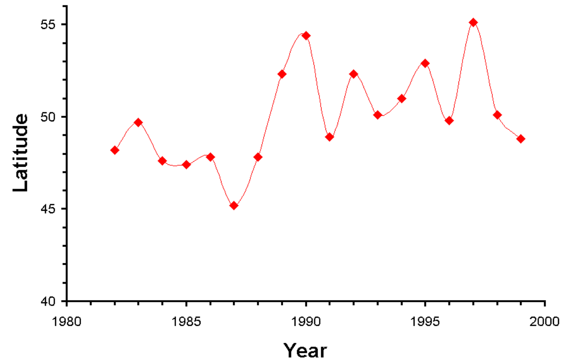


Figure 8.: *Latitude where the 16°C isotherm intersects the continental shelf edge in July of each year. (H. Freeland)*

Catches of squid were concentrated in the south-portion of the Canadian zone in 1999 compared with 1998 (Fig. 9), despite attempts to catch squid off the Queen Charlotte Islands in 1999. The implication is that squid did not migrate as far north in 1999 as in 1998 and were, therefore, less available to the Canadian fishery.

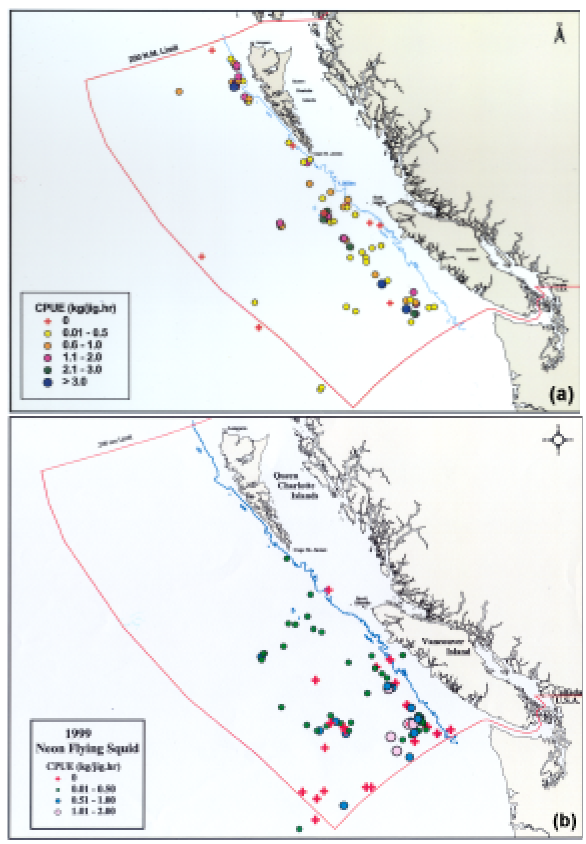


Figure 9.: Distribution of flying squid catches during 1998 (a) and 1999 (b). (G. Gillespie)

Grey Whales

Grey whales (*Eschrichthius robustus*) undertake seasonal migrations between Baja California, Mexico, and the northern Gulf of Alaska – Bering Sea. In 1999, almost 300 dead grey whales washed ashore along the coast between Baja California and the Bering Strait, which was four times the normal rate. These deaths occurred during the spring northward migrations, when the animals were moving between their over-wintering grounds and their northern feeding grounds. Analyses of the lipid content of the blubber indicate that these animals were likely emaciated, suggesting that they may not have obtained adequate food during their previous year (1998) on the feeding grounds in the northern Gulf of Alaska and the Bering Sea to carry them through the winter and into the 1999 northward migration season.

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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; while lighthouse stations (Fig. 2) provide long-term time series of daily sea surface temperature and sea surface salinity.

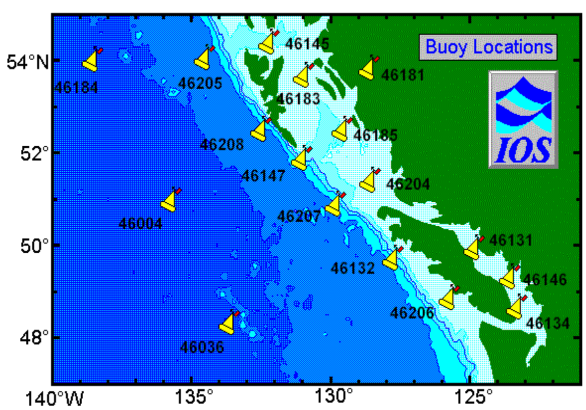

***Figure 1**. Weather buoys.*

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 transport, water temperature, and salinity at specified depths through the water column.

Oceanographic and meteorological conditions returned to near "normal" (1990-1996) values in 1999 following 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. Water temperatures were normal to slightly below normal and salinity was near normal to slightly above normal. Normal upwelling conditions prevailed along the coast in summer. Mean currents were stronger than normal in winter (January through February) but returned to near normal conditions in summer.

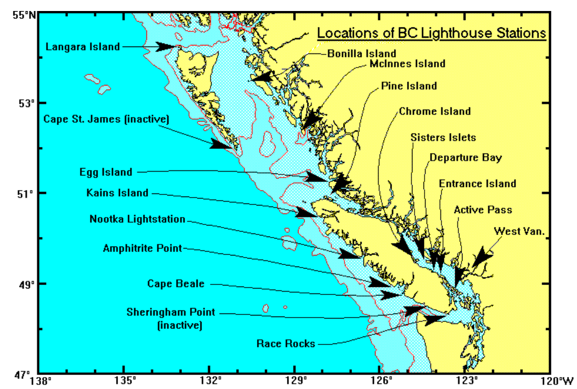

***Figure 2**. Lighthouse locations.*

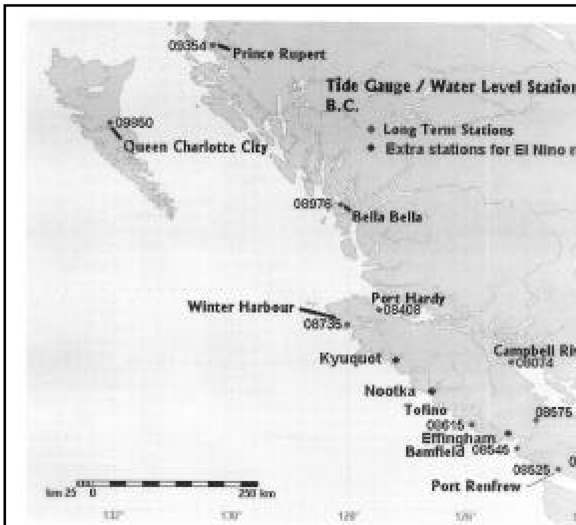

***Figure 3.** Tide Guage locations*

West Coast Meteorological Data

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

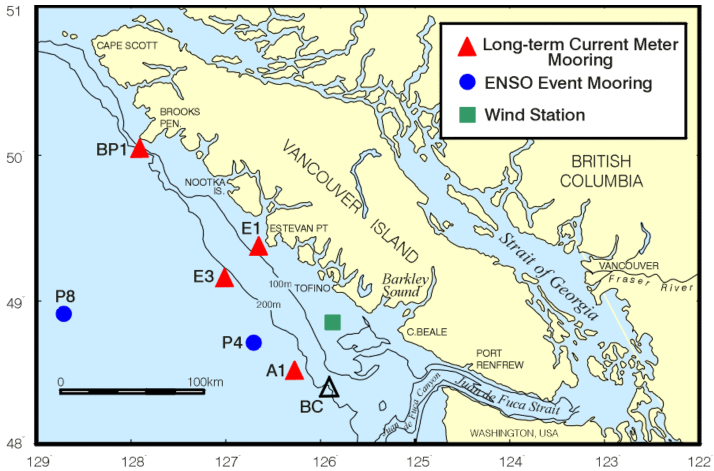

Figure 4. Current meter locations. (R. Thomson)

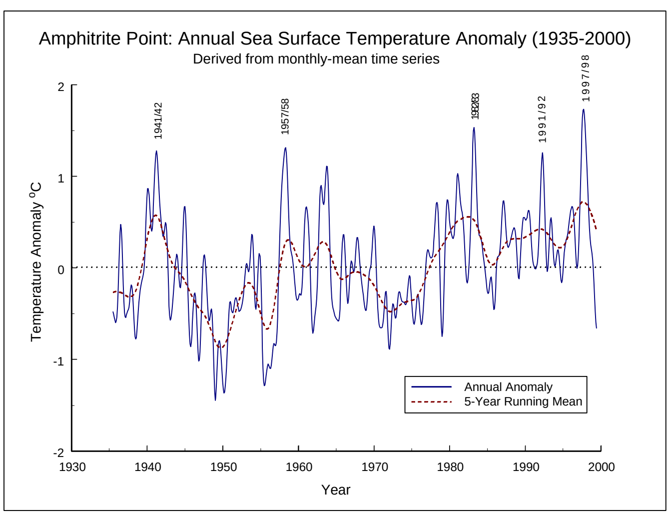

Figure 5. SST anomaly at Ampitrite Point. (R. Thomson, R. Hourston)

1. In 1999, there were periods of both strong southeasterly (downwelling-favourable) and strong northwesterly (upwelling-favourable) winds in winter and early spring and moderately strong periods of northwesterly (upwelling-favourable) winds beginning in late May to late fall (November) (Fig. 6). Upwelling winds were generally weak on the south coast from late July to early August.

2. Wave heights (Fig. 7) were typically higher-than-"normal" (1990-1996 mean) during winter and spring but decreased to lower-than-normal heights for the remainder of the year.

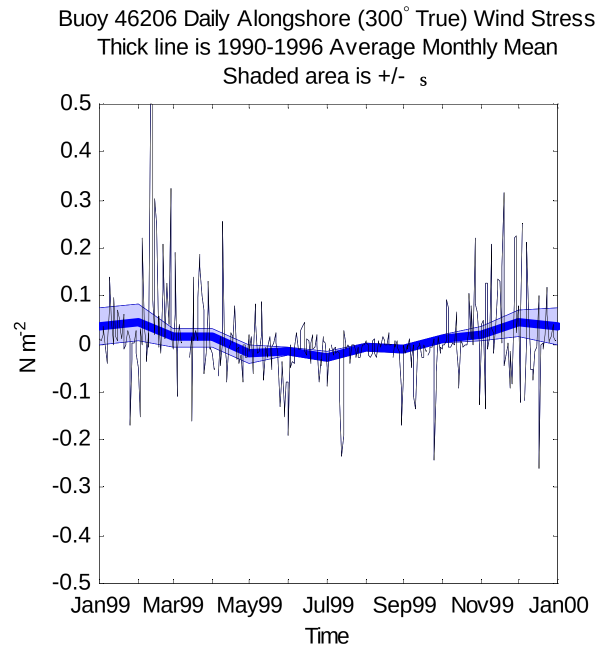

Figure 6. *Alongshore wind stress. (R. Thomson, R. Hourston)*

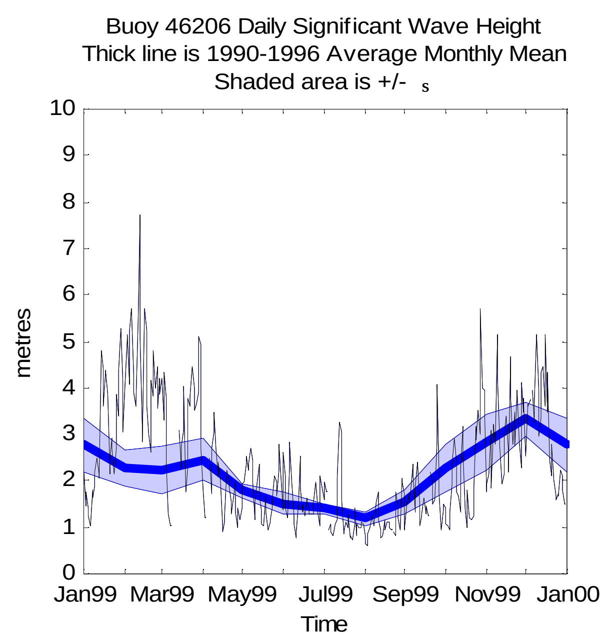

Figure 7. *Wave height. (R. Thomson, R. Hourston)*

West Coast Lighthouse Data

1 Sea surface temperature (SST) on the continental shelf was close to "normal" (1990-1996 mean) for January and February but 1 to 2º C below normal from March through September (north coast; Fig. 8a) and from March through August (south coast; Fig. 8b). Normal conditions prevailed from October through December (north coast) and from September through December (south coast). This change in SST was in marked contrast to the pronounced warming during the 1997/98 El Niño.

2 Sea surface salinity (SSS) on the central-north coast (Fig. 9a) was near normal until about May and significantly below normal from May through August. Salinities were normal to slightly below normal in the winter. SSS on the south coast (Fig. 9b) was near normal until May, slightly above normal through the summer and returned to near normal values in November.

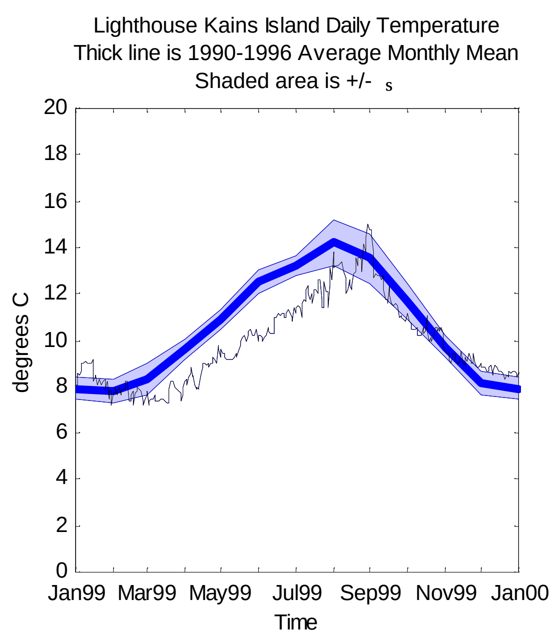

Figure 8a. *Northern SST. R. Thomson, R. Hourston*

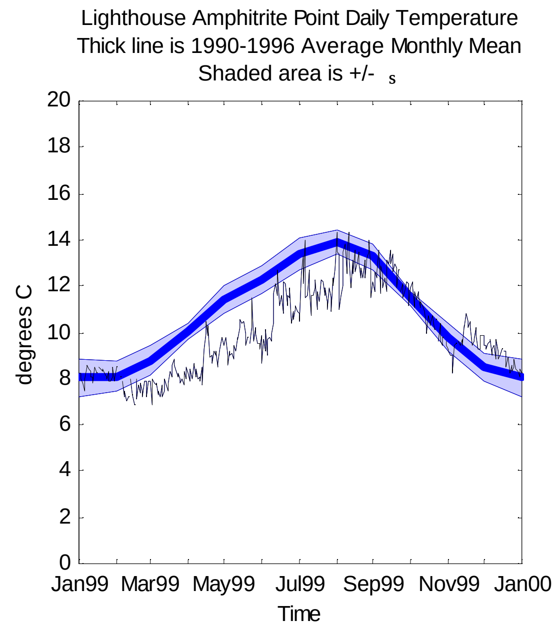

Figure 8b. *Southern SST. (R. Thomson, R Hourston*

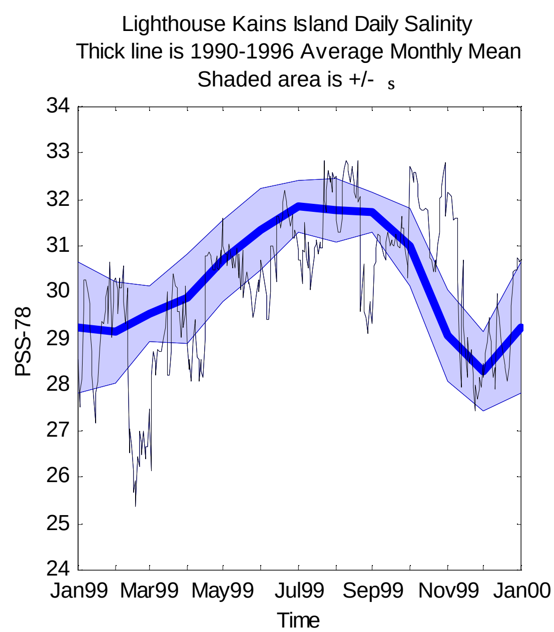

Figure 9a. *Northern SSS. (R. Thomson, R. Hourston)*

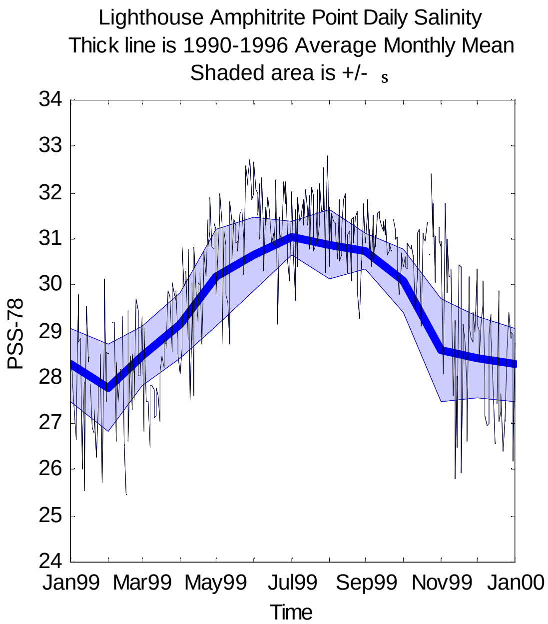

Figure 9b. *Southern SSS. (R. Thomson, R. Hourston)*

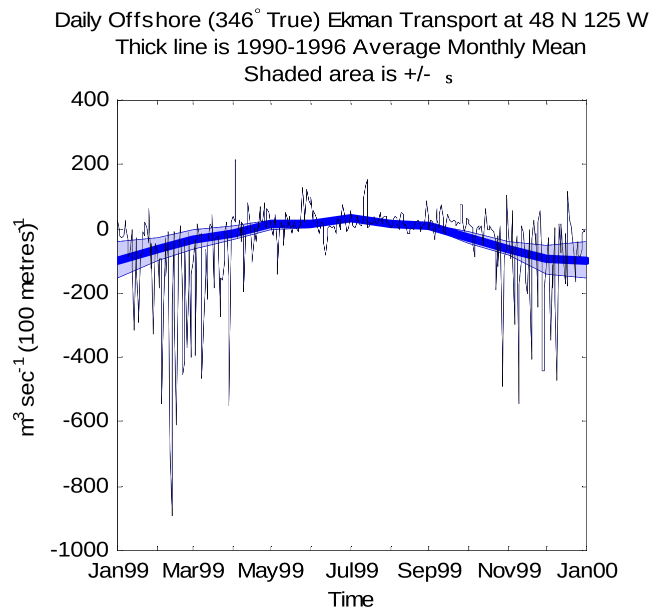

Figure 10a. *Ekman transport. (R. Thomson, R. Hourston*

Upwelling Indicies

1 The FNMOC (Fleet Numerical Meteorology and Oceanography Center) Upwelling Index (Fig. 10a), which is essentially the seaward flowing component of wind-induced Ekman transport, shows extensive periods of strong downwelling (negative values) during February to early April, and normal to slightly above normal upwelling conditions (positive values) in summer. Major summer upwelling events were recorded in late May and late July.

2 The Velocity Upwelling Index (Fig. 10b), which is a measure of the cross-shore, current-induced isopycnal tilt associated with upwelling (Thomson and Ware 1996), reveals major downwelling in February to early March and one major upwelling event in July.

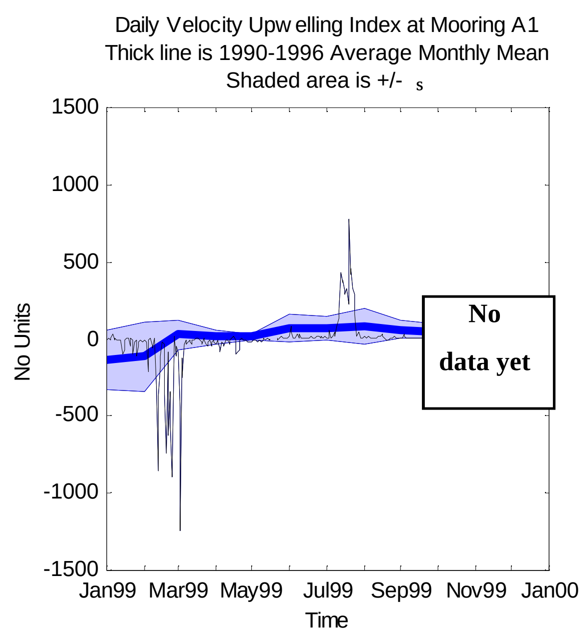

Figure 10b. *Upwelling index. (R. Thomson, R. Hourston)*

Southwest Vancouver Island Continental Slope (La Perouse Region)

1. Subsurface temperatures at 35, 100, 175 and 400 m depth over the continental slope were near "normal" (1990-1996 mean) at the beginning of the year and to slightly below normal during the summer (data series ends at the beginning of October).

2. Subsurface salinities at 35, 100, 175 and 400 m depth were near normal throughout the data series (data series ends at the beginning of October).

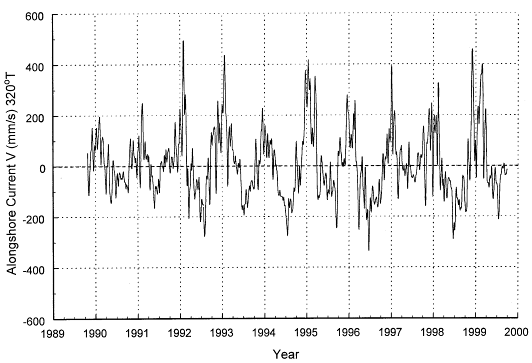

Figure 11. *Alongshore poleward current velocity at 35 m depth. (R. Thomson, R. Hourston)*

3. Alongshore current velocity was stronger than normal during the winter and spring (peaking around 50 cm/s poleward in late February at 35 m depth) but returned to normal transport conditions by early April (Fig. 11). Currents were poleward at all depth in winter and spring but mainly equatorward in summer at 35 and 100 m depth over the continental slope. Persistent poleward flow continued over the inner shelf region. 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 (Fig. 12).

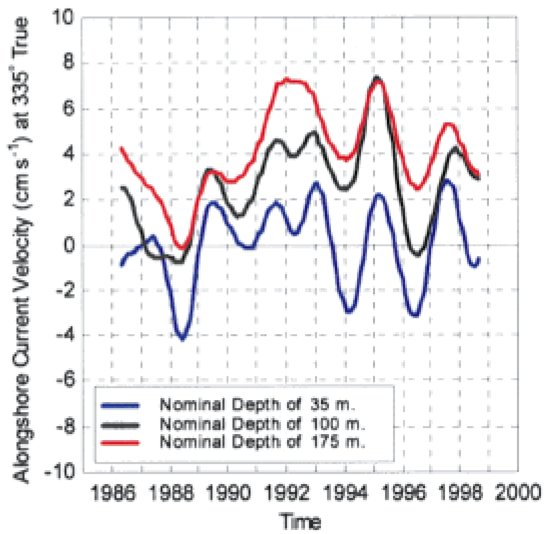

Figure 12. *Annual mean alongshore poleward current. (R. Thomson, R. Hourston)*

Central Vancouver Island Continental Shelf (Estevan Point Region)

Subsurface temperatures at 25 and 35 m depth were normal to slightly below normal during the year (data series ends at the beginning of October). No temperature data were recovered from 75 m depth due to failure of the instruments.

Subsurface salinities at 25 and 35 m depth were near normal throughout the data series (data series ends at the beginning of October). No data were recovered from the instrument at 75 m depth.

Alongshore current velocity was stronger than normal during the winter and spring (peaking around 100 cm/s poleward in late February) but returned to normal flow conditions by early April. 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.

Northern Vancouver Island Continental Shelf (Brooks Peninsula Region)

Subsurface temperatures at 35 and 75 m depth were "normal" (1990-1996 mean) during the year (data series ends at the beginning of October).

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).

Alongshore current velocity was stronger than normal during the winter and spring (peaking around 125 cm/s poleward in late February) but returned to normal flow conditions by early April. 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.

Zooplankton

Zooplankton sampling off southern Vancouver Island has been conducted frequently since 1979, and exists as a reasonably consistent time series since 1985 (sufficient to estimate annual anomalies of abundance and biomass for most of the major zooplankton species). The time period 1990-98 included strong changes in concentration (≈factor of ten) of the major species. Most of these shifts in the zooplankton community developed and persisted over time spans of several consecutive years. Examples (top to bottom in Fig. 13) included a cumulative shift to a more "southerly" copepod fauna (i.e. significant declines in several species of boreal copepods previously endemic to the NE Pacific continental shelf between 45°-60°N, and significant increases of several copepod species previously endemic to the California Current roughly between 35°-45°N). These changes roughly mirror-image broad peaks (minima) of biomass of the two major euphausiid species (three major subarctic oceanic copepod species) in the early-mid-1990s.

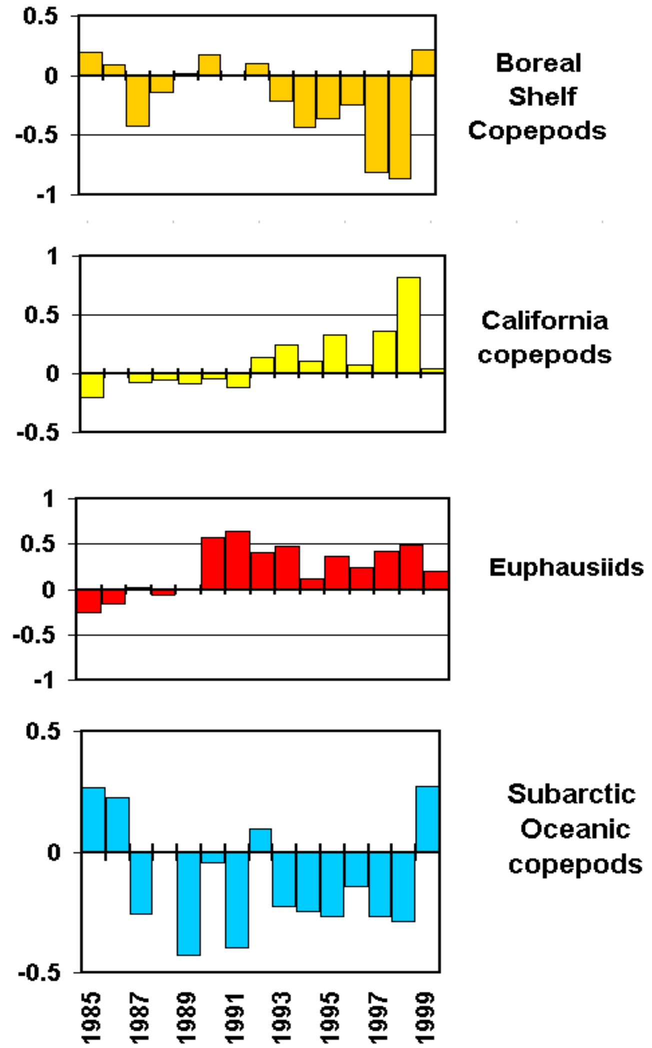

Figure 13. *Annual-average log-scale anomalies of biomass of the major southern Vancouver Island zooplankton taxa. Positive values are more than the 1979-1991 long term average, negative values less. (D. Mackas)*

The gradual evolution of the anomaly patterns noted above changed abruptly after 1998. In 1999, concentrations of all major zooplankton taxa had swung sharply back toward or past their long term average levels (i.e. to near-zero anomalies or of opposite sign; see final entries in the time series shown in Fig. 13).

The southern Vancouver Island zooplankton anomaly patterns were strongly and positively intercorrelated within groups of ecologically similar species, and between shelf and slope statistical regions extending roughly 150 km alongshore and 100 km cross-shore (averages within these species groups and regions are what is shown in Fig. 13). The direction and timing of the southern BC zooplankton interannual changes were also similar to changes observed independently off the central Oregon continental shelf (W. Peterson, 1999 and pers. comm.), 400 km to the south. This implies that environmental factors responsible for altering the zooplankton community have a large outer coast spatial extent, similar effects on similar species, and a dominant time scale of years to decades.

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

Greater along-line average abundance of the oceanic copepods (probably because of the progressive northward narrowing of the Vancouver Island continental shelf);

A superimposed meridional 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.

Results from a Lower Trophic Level Production Model

The La Perouse ecosystem model for the south-west 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 14 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, so primary production was probably higher in 1999 than it was in the two previous years.

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

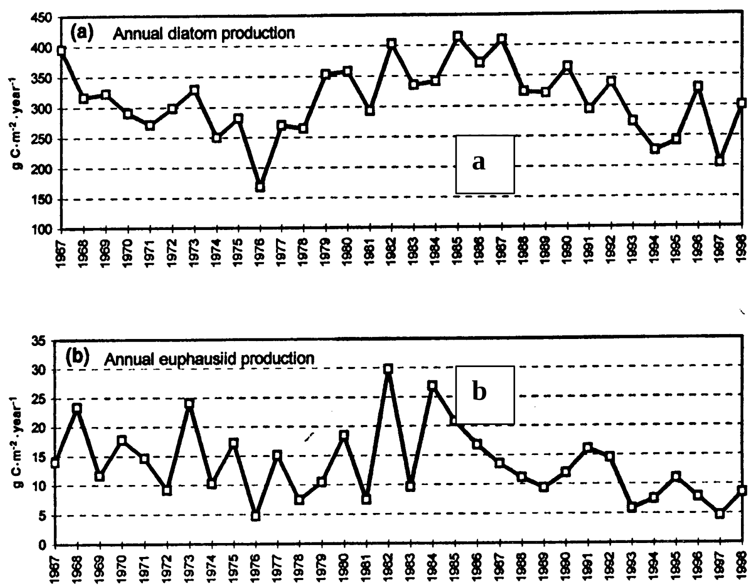

Figure 14. *Interannual variability and decadal trends in the lower trophic level production (diatoms and euphausiids) off the lower west coast of Vancouver Island, estimated by the La Perouse Ecosystem Model (Robinson and Ware)*

This modeled 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. 15). The adult biomass of this species declined in 1992, coincident with the strong 1991/92 El Niño event, and has remained low since then. It appears that this population in Barkley Sound has been suffering from a continuous recruitment failure during the 1990s. The second important euphausiid species, *Euphausia pacifica,* showed a similar declining trend in Barkley Sound with the exception of 1998 when there was a strong recruitment in this species. Upwelling conditions improved in 1998 (and 1999). *E. pacificia* in Barkley Sound may have responded positively to this increase since the abundance of this species was the highest measured to date.

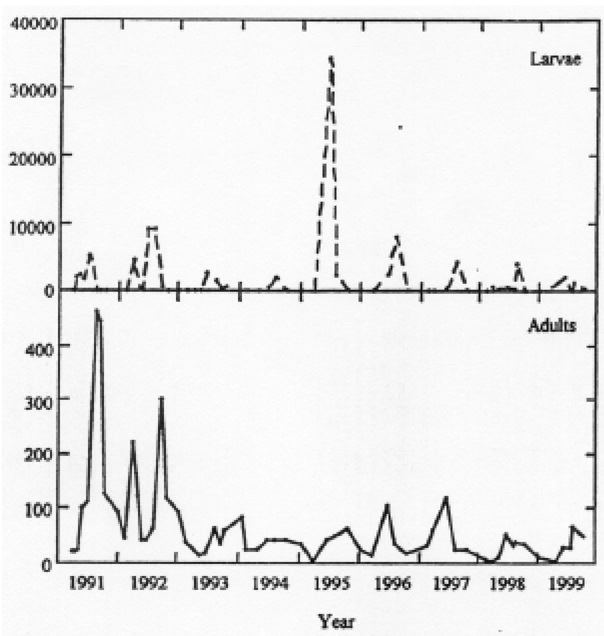

Figure 15. *Estimated Abundance (number*m^{-2}) of the euphausiid Thysanoessa spinifera in Barkley Sound. (R. Tanasichuk).*

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 Recruitment

Since about 1977, the recruitment of herring off the West Coast of Vancouver Island has been decreasing (Fig. 16). In 1999, the abundance (Fig. 17) was one of the lowest estimated since 1977.

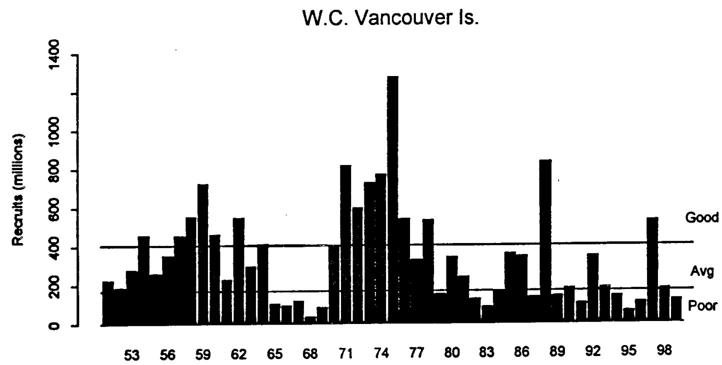

Figure 16. *Interannual variability and decadal trends in recruitment to the lower west coast of Vancouver Island herring stock. The boundaries for 'poor, 'average' and 'good' recruitment are shown. Note that 9 of the last 11 recruitments have been 'poor'. (Schweigert and Fort, 1999).*

The productivity of the west coast of Vancouver Island herring stock has been in a declining trend since 1989, primarily because recruitment to this stock has been poor for 9 of the last 11 years (Fig. 16). 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 recruitment to the stock in the year 2002.

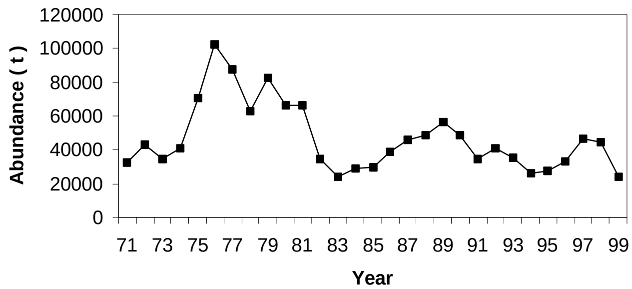

Figure 17. *West Coast Herring Abundance. (G. McFarlane)*

Pacific Sardine

acific 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 a combination of unfavourable environmental conditions and overfishing by the Canadian and U.S. fleets. The stock underwent a long decline to a low point in the mid-1970s. By the early 1980s the population off California was showing some signs of recovery. In fact, since the early 1990s, the California fishery has increased dramatically (Fig. 18). By July 1998, the estimated biomass of sardine was 1.6 million tonnes, and the stock was considered to be fully recovered by U.S. fishery scientists (Hill et al., 1999). Historically, an average of about 10% of the northern sardine stock migrated to B.C. in the summer. However, the actual percentage varied from year-to-year in response to changes in water temperature, and other factors. Large numbers of sardines were observed in B.C. in the summers of 1997 and 1998. The abundance appeared to be somewhat lower in 1999.

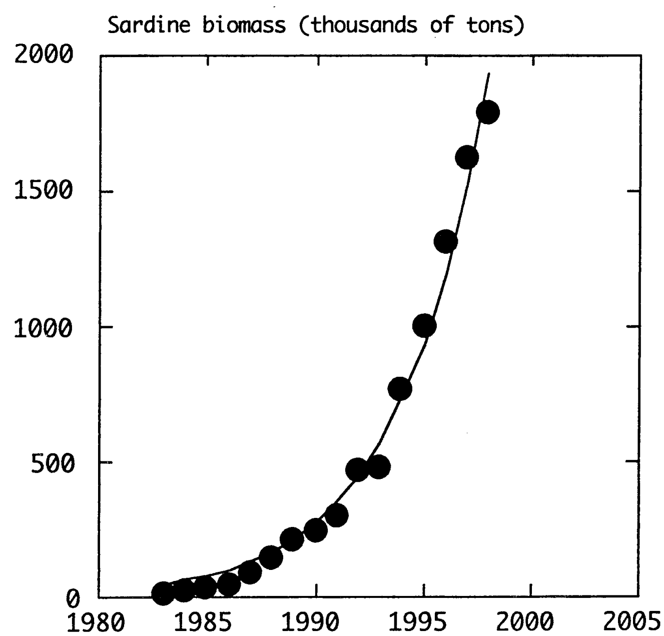

Figure 18. *Estimated biomass of Pacific sardine Age-1+ along the west coast of North America from California to British Columbia (Hill et al., 1999)***.**

After a 45 year absence from British Columbia waters, sardines reappeared off the west coast of Vancouver Island in 1992. From 1992-1996, their distribution was limited to the southern portion of Vancouver Island. In 1997, their distribution expanded northward to the southern portion of Queen Charlotte Sound and by 1998 sardines inhabited waters east of Queen Charlotte Island throughout Hecate Strait and up to Dixon Entrance. In 1999, sardine distribution retreated southward to the previous 1997 distribution range. Abundance estimates of sardines off the west coast of Vancouver Island are available only for 1997 and 1999. The abundance of sardines off the west coast of Vancouver Island in 1999 was lower (72,000 tonnes) than the abundance in 1997 (86,000 tonnes). In 1998, small young of year sardines appeared in survey trawls indicating likely spawning off the west coast of Vancouver Island (Fig. 19).

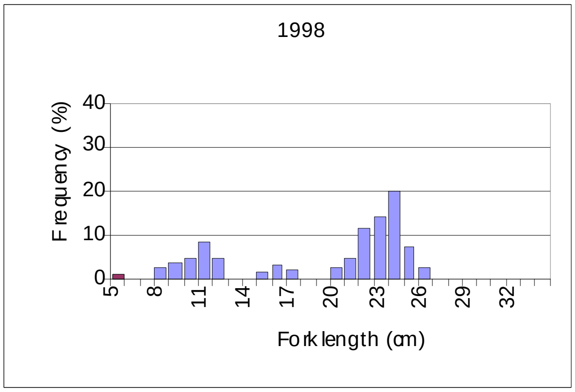

Figure 19. *Size distribution of sardines in survey trawls. (G. McFarlane)*

Hake

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 up towards Queen Charlotte Island. By 1997, hake were found along the southern portion of the Queen Charlottes and in 1998 were found as far north as Dixon Entrance. In 1999, hake continued to inhabit the waters from southern Vancouver Island to northern Queen Charlotte Island.

Larval Sablefish

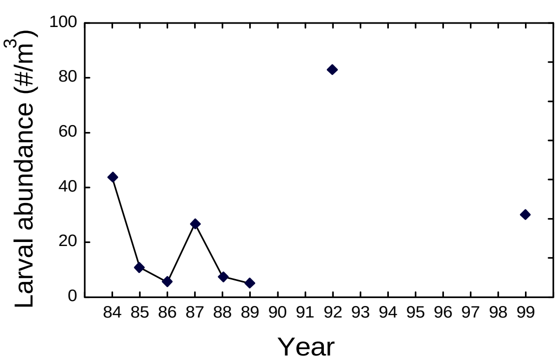

Figure 20. *Larval abundance of sablefish. (J. King)*

Abundance estimates of larval sablefish along the continental slope collected in surface tows conducted in April 1999 off the west coast of Vancouver Island were within the range of estimates from similar surveys conducted in 1984 through 1989 (Fig. 20), a period with periodic strong year classes. Though surveys were not generally conducted during the 1990s when strong year classes were infrequent, a survey conducted in 1992 produced an exceptionally high abundance estimate.

Killer Whales

Northern resident killer whales feed primarily on salmonids along the B.C. coast during the summer months. Typically in the month of August, many of the 16 northern resident pods can be found in the Johnstone Strait region. In 1999, there were no resident killer whales seen in this core area for 16 consecutive days. This was unprecedented in over 25 years of monitoring. Surprisingly, during this period an aggregation of more than half the northern resident population was found 55 miles southwest of Cape Beale off the southwest coast of Vancouver Island. In October a 2 week troll fishery took 55,000 chinook salmon from this area where the killer whales had been observed, suggesting that the whales may have been aggregating on the distribution of their preferred prey.

Seabird Reproductive Performance on Triangle Island

A joint seabird program on Triangle Island run by the Canadian Wildlife Service and the Center for Wildlife Ecology at Simon Fraser University completed it's sixth consecutive year of seabird population monitoring in 1999. Triangle Island is BC's largest seabird colony with the world's largest population of the Cassin's Auklet (CAAU) (*Ptychoramphus aleuticus*, a 200 g planktivore) and significant populations of Rhinoceros Auklet (RHAU) *(Cerorhinca monocerata*, a 500 g piscivore), Tufted Puffin (TUPU) (*Fratercula cirrhata*, 750 g piscivore), and Common Murre (*Uria aalgae*, a 900 g piscivore).

Nestling growth was measured in g/d during the linear portion of growth (5-25 d for CAAU; 10-40 d for RHAU and TUPU) and the anomalies were computed for the grand mean from 1994-

1999. For each species the anomaly was standardized to range from –1 to 1.

Breeding performance for all four species was uniformly high in 1999. The contrast was particularly marked for Tufted Puffin which failed to breed consistently from 1994-1998. For the Tufted Puffin, Rhinoceros Auklet and Cassin's Auklet nestling growth rates in 1999 demonstrated a positive anomaly when contrasted against the grand mean for 1994-1999 (Fig. 21). In 1999 the nestlings grew rapidly, had high survival, and fledged from the colony at high masses.

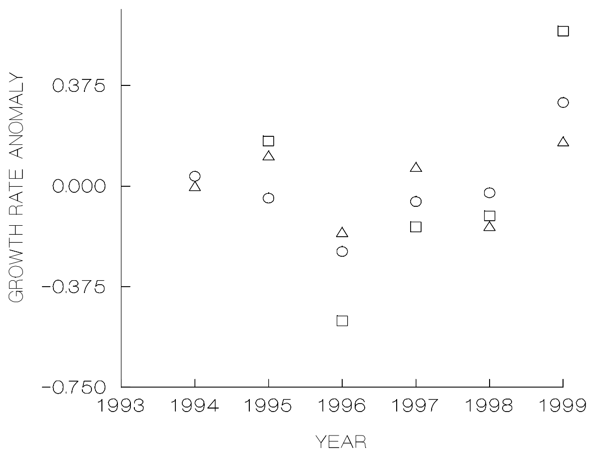

Figure 21. *Nestling growth rate anomalies for Cassin's Auklet (triangles), Rhinoceros Auklets (circles) and Tufted Puffin (sqaures) from 1994-1999. (D. Bertram)*

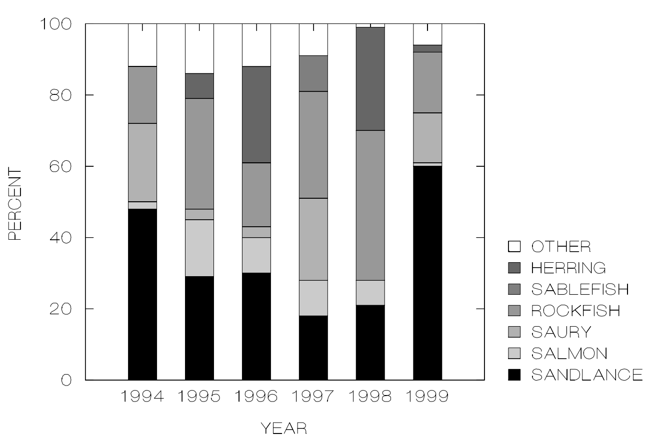

Figure 22. *Rhinoceros Auklet nestling diet collected at 10 weekly intervals from a sample of 10 – 12 incoming adults. The results for wet mass of prey are shown. (D. Bertram)*

The successful breeding for Tufted Puffin and Rhinoceros Auklet is likely linked to the dominance of Pacific sand lance (*Ammodytes hexapterus*) in the nestling diet in 1999 (> 60% of the overall diet mass; Fig. 22). Available time series data from Triangle Island (spanning 1975-1999) shows that rapid nestling growth is associated with higher proportions of sand lance in the nestling diet. The majority of sand lance captured by seabirds were 0+ fish, less than 100 mm, suggesting that 1999 may have been a strong year class for the local stock around Triangle Island.

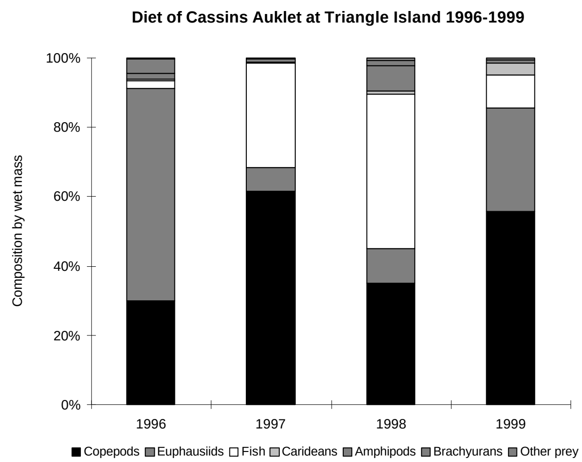

Figure 23. *Cassin's Auklet nestling diet samples collected from 10 incoming adults at 5 intervals separated by 10d throughout the chick rearing period. (D. Bertram)*

For Cassin's Auklet, the nestling diet (see Fig. 23) was composed primarily of copepods (*Neocalanus cristatus*) and euphausiids (*Thysanoessa inspinata*). The nestling diet composition itself does not readily explain the rapid growth of nestlings in 1999. Additional data on the frequency of feeding, however, indicates that nestlings were likely feeding at higher rates than in previous years with both parents delivering a meal each night. A telemetry study coupled with DFO ship sampling, conducted for the first time in 1999, also revealed that parent birds were foraging on zooplankton well off the shelf break, 40-75 km from the colony.

Contributors:

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North Coast

Surface temperatures throughout these 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 measurements revealed temperatures slightly cooler than average throughout the year, with temperatures in June and July as much as one degree Celsius 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 (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 in 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 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 one to two degrees below normal in spring and early summer, and close to normal for the remainder of the year.

Temperature at Bonilla Island

Figure 1a illustrates the temperature on the north coast in the 1990s. Temperatures in 1999 were slightly below normal, more so in summer, after a period of warm El Niño temperatures from the spring of 1997 to mid 1998. Summer temperatures declined in the mid 1990s, peaked during El Niño in 1997 to 1998, and then dropped in 1999. Winter temperatures in the 1990s were near normal, except for cooler temperatures during the El Niño winters of 1992 and 1998. The 1995 El Niño did not impact the North Coast temperatures as much as it did the South Coast.

Winter Sea Levels

Winter sea level elevations are mainly determined by storm-driven low air pressures and the accompanying northwestward component of the winds. In extreme El Niño winters, such as 1983, 1992 and 1997/98, advection of warm water from the south causes sea levels to increase due to thermal expansion of the water column.

Oceanographers often compute a pressure-adjusted sea level, in order to remove the direct effect of air pressure changes and determine the sub-surface pressure fields that drive ocean currents. Figure 1b above shows monthly average pressure adjusted sea level since 1990 for Prince Rupert. The main features of the sea level changes over the decade are still present, although at reduced magnitude, because at Prince Rupert the effects of air pressure and wind usually act together to raise or lower sea level.

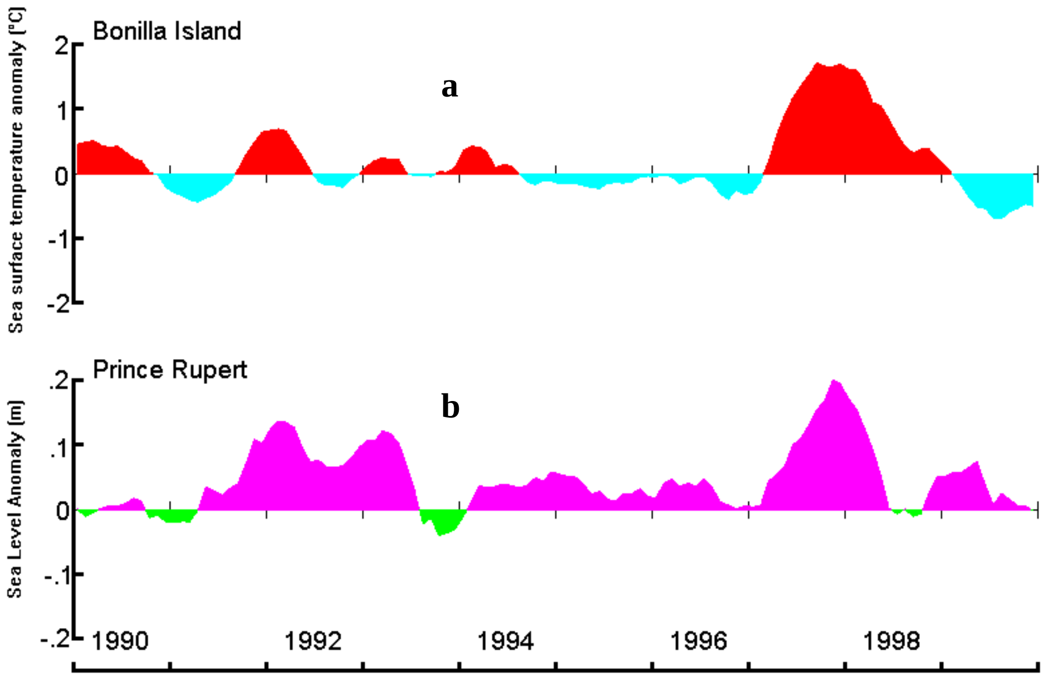

Figure 1. *Temperature anomalies at the Bonilla Island Lightstation (a) and sea-level anomalies at Prince Rupert in the 1990s(b). (H. Freeland)*

Missing Observations

Programs to observe currents and mid-basin salinity and temperature were discontinued in 1995 due to lack of funds. Aside from the lighthouse data, the only measurements available are temperatures from meteorological buoys, and occasional oceanographic sampling by DFO research vessels.

Trends over the Past Century

Monthly average sea levels are available since 1910 at several British Columbia ports. Annual average levels (Fig. 2) are available for the ports of Victoria, Tofino and Prince Rupert. The record at Victoria is almost continuous; other ports are missing data through the early years.

Elevations at each port are measured relative to benchmarks in nearby bedrock. A long-term rise or fall at each port can be attributed to both vertical bedrock motion and sea level rise.

Years denoted by large diamonds in Figure 2 represent major El Niño events that coincided with high sea levels at these ports. The annual average elevations for 1999 at all three ports were close to or slightly lower than normal values following the El Niño rise in 1997 to 1998.

Temperature and Salinity Trends

The trend in temperature over the period of 1940 to present (Fig. 3(a)) 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 1999 declined to values that were typical of the 1980s, and cooler than those measured in the 1990s.

Langara waters have freshened by 0.7 parts per thousand since the observations began in the early 1940s, but Bonilla salinity has remained about the same (Fig. 3(b)). In both 1998 and 1999, salinities at Langara and Bonilla were the same, whereas for most years the surface water at Bonilla is fresher. Prior to 1998 the salinities at these locations were similar only in 1978.

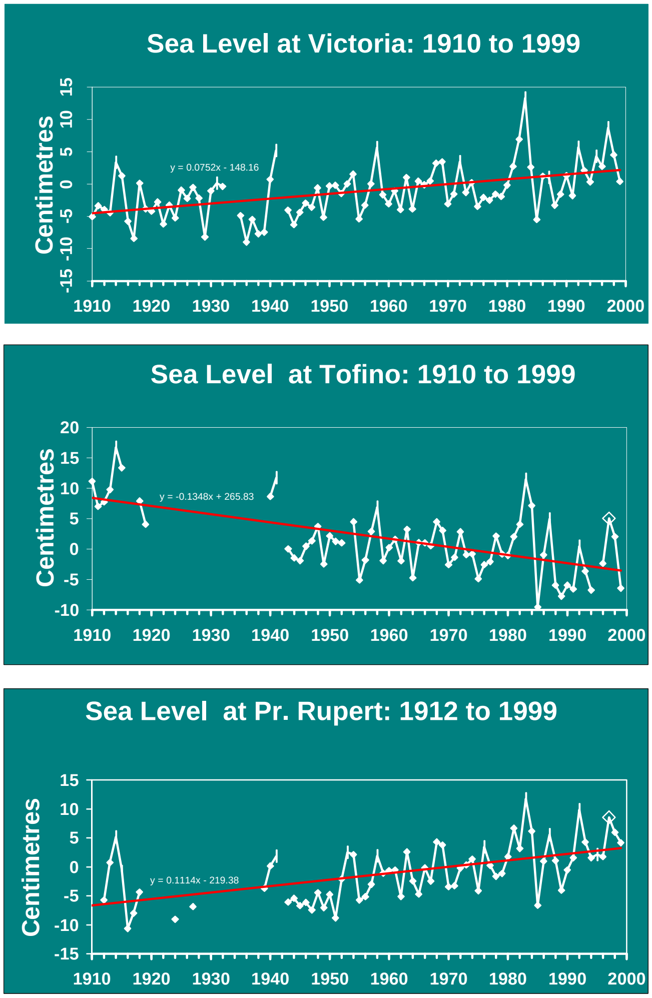

Figure 2. *Monthly average sea levels since 1910 at British Columbia ports. (W. Crawford)*

Set-up of Eddies West of the Queen Charlotte Islands

Sea level measurements from the TOPEX/ Poseidon and ERS-2 satellites are used to observe the set-up and movement of 200-km wide eddies off the West Coast of the Queen Charlotte Islands. These eddies have been observed earlier from thermal-imaging satellites, ship-based observations, and satellite-tracked drifters but their life history was unknown. It appears that these eddies are larger in El Niño winters, although one or two are formed during most winters. The eddies of 1995 and 1998 were the largest of the past decade, and the eddies formed

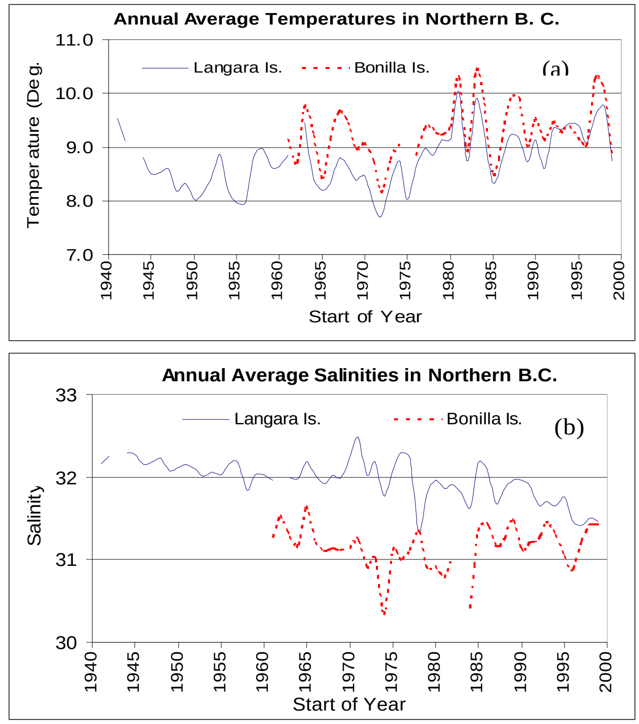

Figure 3. *North coast lighthouse temperatures (a) and salinities (b). (W. Crawford)*

in the winter of 1999 were close to normal size. Images of eddies in February of 1998 and 1999 are presented in Figure 4, with annotation showing their names assigned based on the location and year of origin along the coast.

TOPEX/Poseidon is a joint American-French program, and ERS-2 is owned by the European Space Program. Images were provided by the Colorado Centre for Astrodynamics Research. Eddies are named “Sitka” and “Haida” after local geographic features along the coast where they are formed.

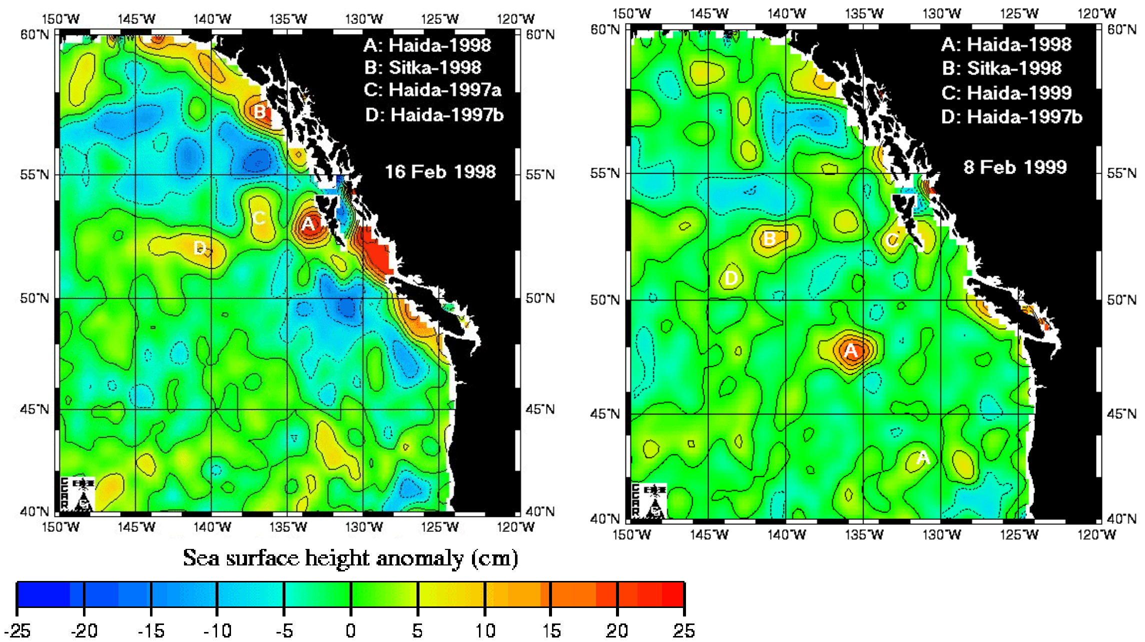

Figure 4. *Eddies. Water flows in a clockwise direction around the centres of these eddies, which are coloured red to denote their higher sea surface elevation. It is believed that such eddies carry coastal waters into the Gulf of Alaska. Eddies also carry coastal fish and plankton, along with nitrate and iron needed for plankton growth. (J. Cherniawsky, W. Crawford, and M. Foreman)*

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Strait of Georgia

Temperature and Salinity

Based on coastal lighthouse data and survey profiles taken throughout the strait in September (Fig.s 1 and 2), the surface temperatures in 1999 were within the range of temperatures measured in 1998 (15-16°C and 13-17°C respectively). The surface temperatures in the southern portion of the strait were similar in 1998 and 1999, but those measured in the northern portion were actually about 1°C warmer in 1999.

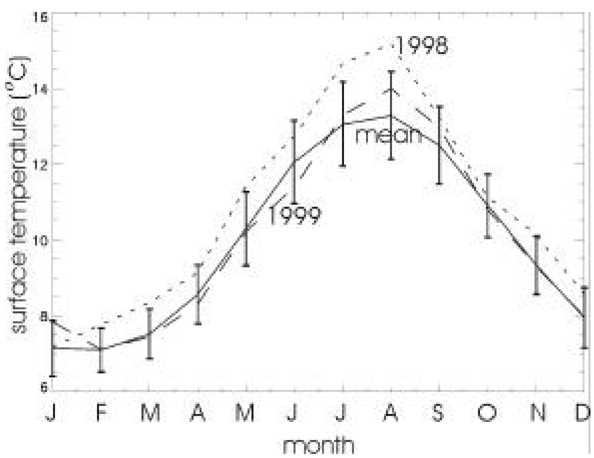

Figure 1. *Monthly mean surface temperature at Nanoose Bay. (D. Masson)*

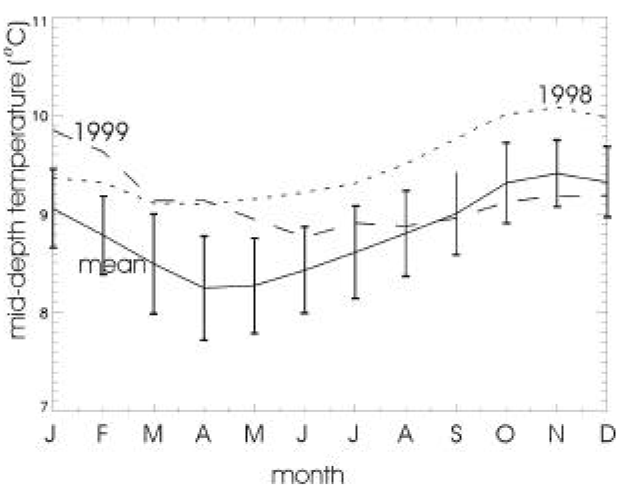

Figure 2. *Monthly mean 100m temperatures at Nanoose bay. (D. Masson)*

As with the surface waters, the anomalously warm temperatures measured at mid-depth, at the Nanoose Bay station, returned to climatology near the end of the summer (August).

Bottom temperatures in the northern and southern portions of the strait were similar to each other in 1999 (9.1°C), but were slightly cooler than in 1998 (10.1°C). At the Nanoose Bay monitoring site north of Nanaimo, the mean annual sea surface, 10 m depth and bottom temperatures cooled in 1999. Sea surface temperature was typical of the 1977 to 1989 conditions, while bottom temperatures remained at the higher than average conditions observed in the 1990s.

Late-summer (September) salinities in the Strait of Georgia were substantially lower throughout the entire area in 1999 compared to 1998. In 1998, the central strait and most of the northern strait were between 27 °/oo and 28 °/oo . In 1999, this same general area ranged between 21 °/oo and 24 °/oo, with the north averaging slightly higher salinities than the south. Bottom salinity was similar in 1999 to 1998 and there was no substantial difference throughout the Strait.

Fraser River

The 1999 Fraser River freshet was large and much later than usual (Fig. 3). The thick snow cover melted later than average in 1999 due to cold early summer temperature, setting some record daily discharge values for the river in August.

The large volume of fresh water entering the strait in late summer formed a much fresher upper layer than normal over the entire strait. This late freshet caused exceptionally high sea surface salinity anomalies within the strait, with record low values of August salinity in the northern strait. For example, a very large negative salinity anomaly was recorded at Entrance Island lighthouse station (Fig. 4).

Annual Fraser River flows continued the pattern of extreme fluctuations that started in 1997. The total discharge in 1999 was the third highest on record, following one of the lowest levels of discharge in 1998 and the second highest discharge level in 1997. The date at which the flow is double that of the average March flow is used as an indicator of the start of the spring freshet. The average start of the freshet during the 1980s was April 19th. During the 1990s, the freshet began earlier (average start date April 9th), but this pattern did not continue in 1998 (start date April 24th) or 1999 (start date of April 19th).

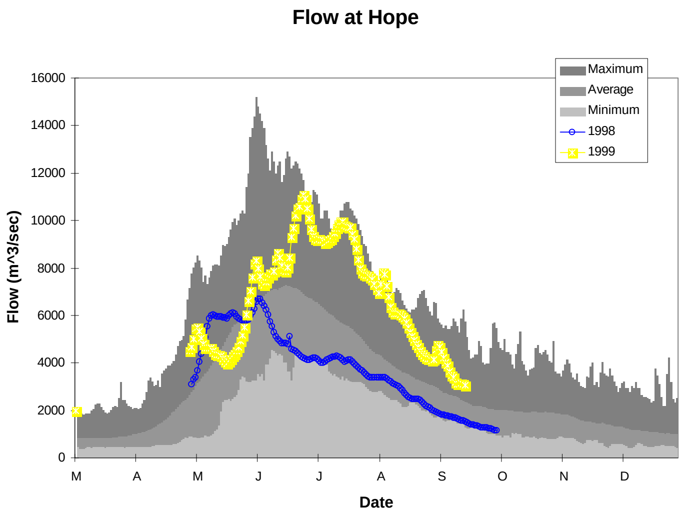

Figure 3. *Fraser river discharge at Hope. (M. Foreman and D. Masson)*

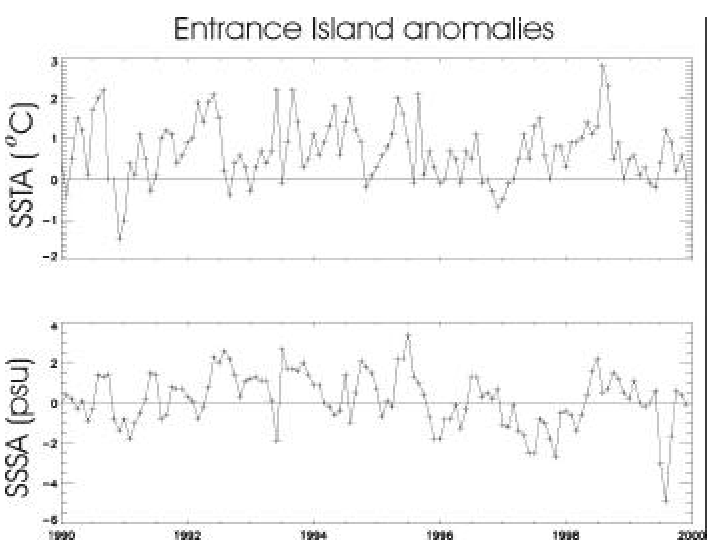

Figure 4. *SST anomalies and SSS anomalies at Entrance Island Lightstation. (D. Masson)*

Winds

During the 1990s the winter wind direction switched from a predominantly southeasterly direction to predominantly southwesterly. Southwesterly winter winds continued in 1999.

Zooplankton

The Cooperative Plankton Research Monitoring Program (COPRA) collects data from a series of 19 stations along the BC coast. This report is based solely on data from this program; other zooplankton data have been collected but not yet made available.

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 in a more stable water mass. However, CPF2 typically has higher zooplankton biomass (by about 15%) and abundance (by about 10%). *Pseudocalanus*, *Microcalanus*, euphausiids, and other miscellaneous groups of calanoid copepods dominate CPF1. *Calanus*, *Paracalanus*, euphausiids, and gastropods dominate CPF2.

Major zooplankton groupings experienced similar shifts in representation at both CPF stations in 1999. This included abundance reductions in Siphonophores (-76%) and *Pseudocalanus* (-11%), and abundance increases in gastropods (+56%), euphausiids (+32%), *Microcalanus* (+33%), and *Neocalanus* (+23%). *Paracalanus* was the exception with an increase of 36% at CPF1 and a decrease of 46% at CPF2 over averages taken since 1990.

Biomass values of major zooplankton groupings at COPRA stations (CPF1, CPF2) experienced an average 3.7 fold increase of biomass over previous years. CPF2's 1999 average biomass was 43.2 mg×m^{-3} or a 1.4 fold increase over previous years. Data from 1998 are similar to both biomass and abundance values for 1999, while years prior to 1998 are different.

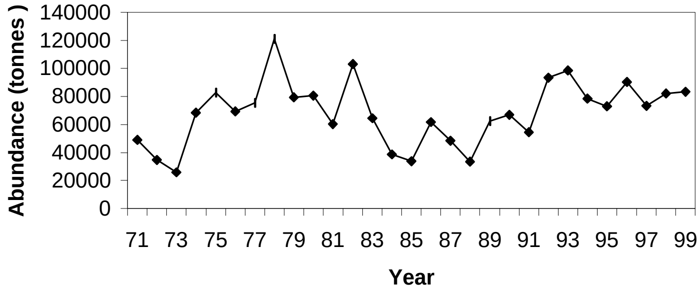

Figure 5. *Strait of Georgia herring abundance. (G. McFarlane)*

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Climate Indices

Global Air Temperature

Global air temperature is an important index of the state of the global climate. It rose dramatically during the 1990s with 1997 and 1998 setting records for sixteen consecutive months. The rate of change was 3°C per century since 1976, at the upper limit of predictions which range from 1.0 to 3.5°C per century.

La Niña brought some moderation of the global air temperature trend in 1999, especially to the eastern Pacific (Fig. 1). Coastal temperatures dipped below the 1961-1990 mean in many B.C. and Alaska locations. However, this was not generally the case: as seen in Fig. 2, north of latitude 20N, the world still experienced the second warmest year ever recorded (Karl et al., 2000).

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.

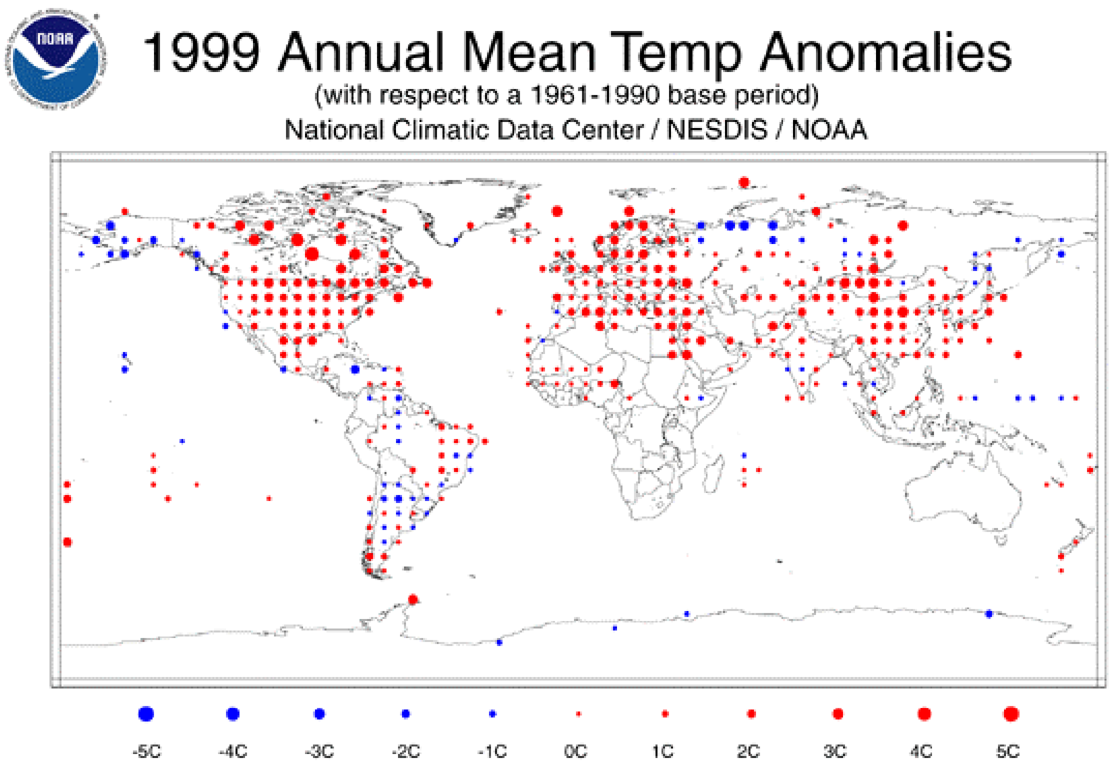

Figure 1. *The distribution of 1999 mean yearly temperature anomalies. (NOAA)*

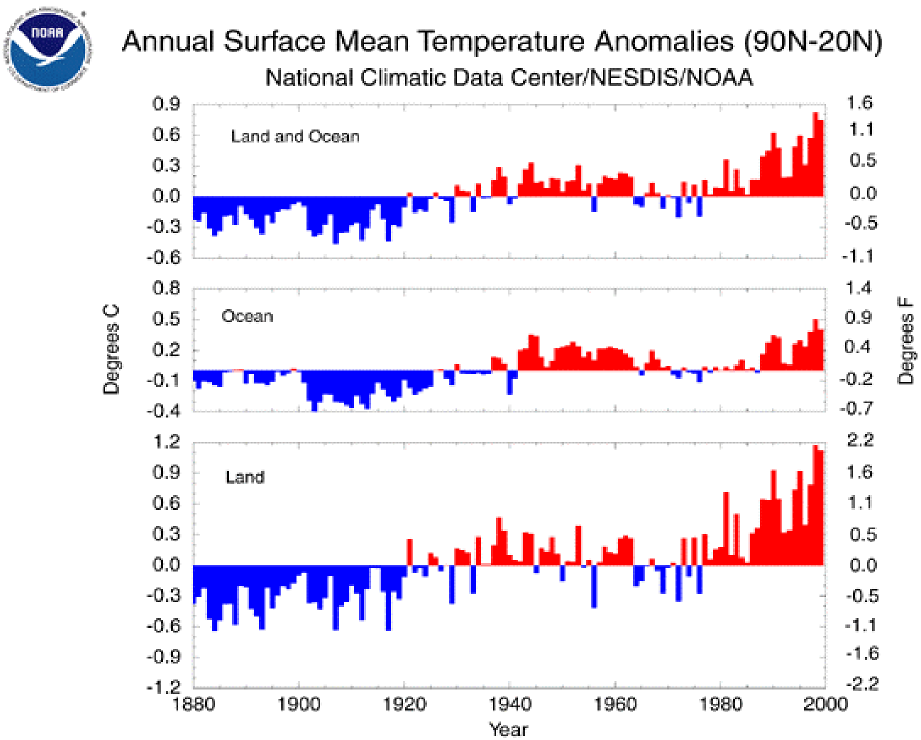

Figure 2. *North of 20 N, 1999 was still the second warmest year on record in spite of La Niña. (NOAA)*

Southern Oscillation

The Southern Oscillation Index (SOI) is used to measure 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. The last La Niña event occurred during the regime shift year of 1989.

http://www.cpc.ncep.noaa.gov/data/indices

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) Index 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 of offshore central surface waters; 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 but it is too early to know if these conditions will persist since year-to-year variations are large: negative values were also observed in 1990-92 and in 1995.

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

Because of La Niña conditions and a dip in the Pacific Decadal Oscillation Index, coastal British Columbia had near normal water temperatures in 1999. Ocean temperatures measured at lighthouses off British Columbia follow this trend with some recent moderation in evidence.

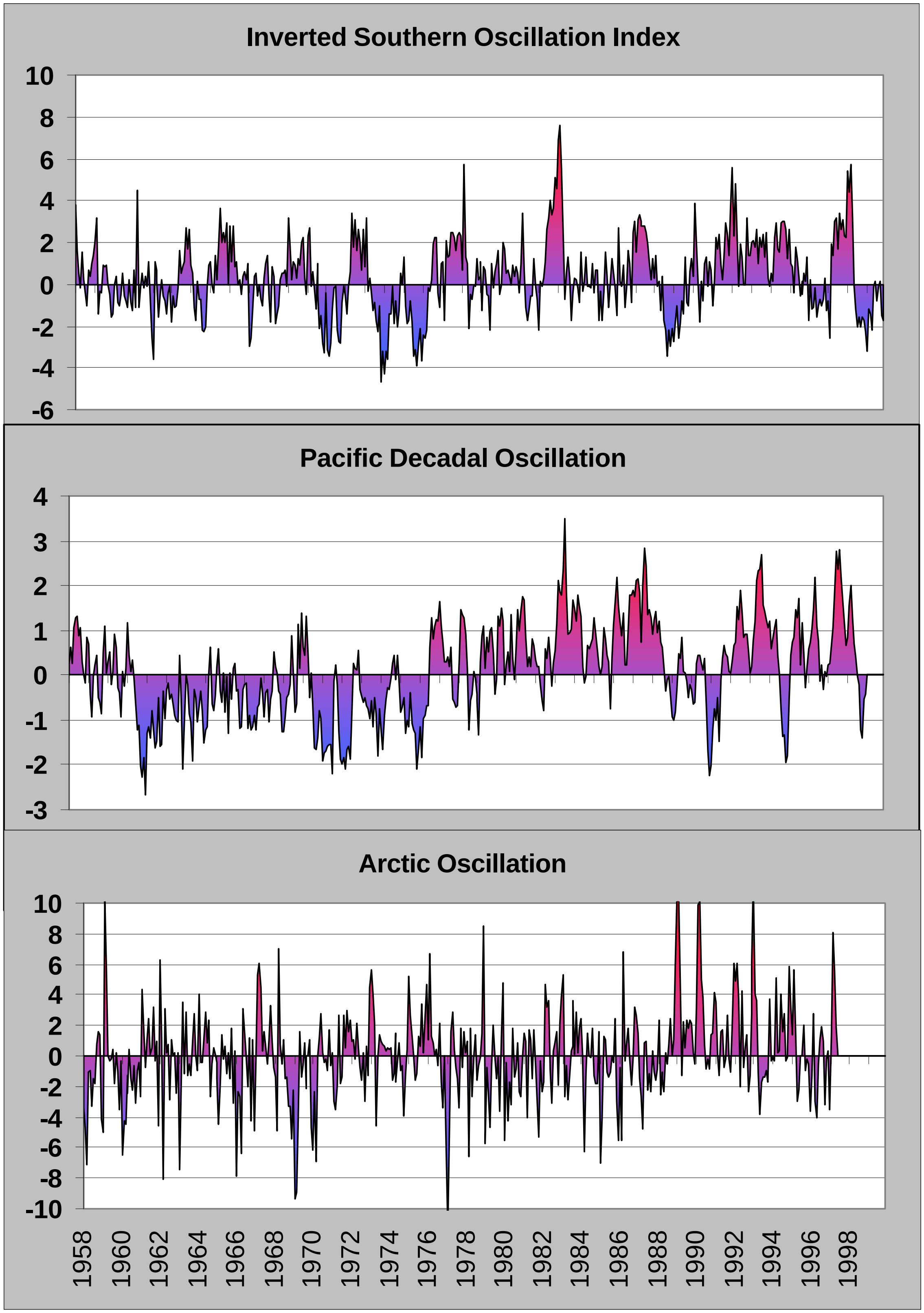

Fig. 3. *Variations in selected indices since 1958. The S.O.I. was inverted to reflect warmer coastal conditions with the negative phase. (R. Perkin)*

Arctic Oscillation

The Arctic Oscillation Index is the area weighted sea-level pressure anomaly poleward of 20N 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 Low Pressure

The Aleutian low pressure system is a semi-permanent feature of the North Pacific atmospheric circulation whose relative intensity has been linked to patterns in fish productivity. The Aleutian Low has exhibited decadal-scale variations in its relative intensity that correspond to well documented climate-ocean "regime shifts". Following a regime shift in 1989, the relative intensity of the Aleutian Low in the 1990s was moderate, as measured by the Aleutian Low Pressure Index (ALPI, Fig. 5). The Aleutian Low in 1998 was intense, corresponding to a high ALPI value, but the Aleutian Low intensity in 1999 was close to a long-term (1950-97) average. Preliminary results suggest that the Aleutian Low pressure system will be of low to moderate intensity for the winter of 1999/2000.

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

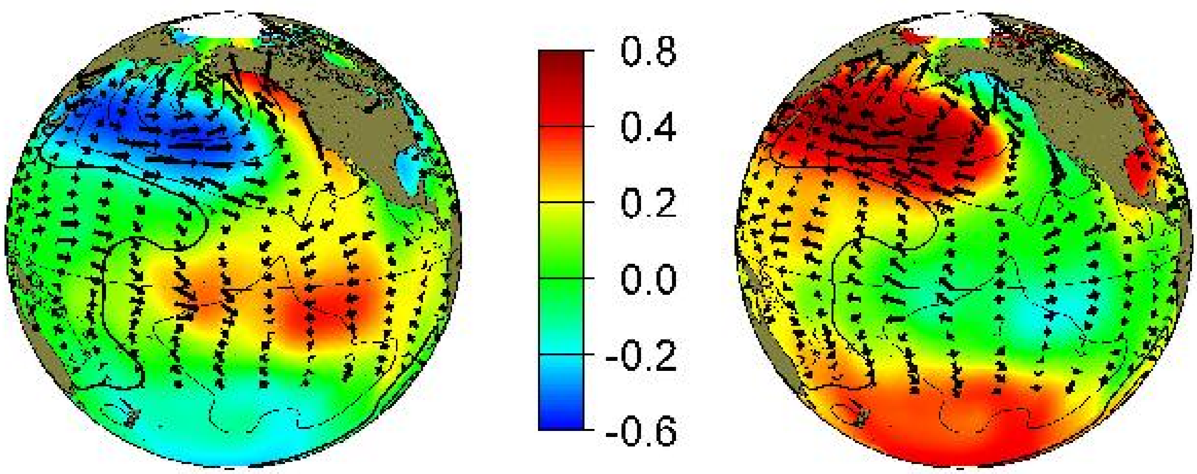

Fig. 4.*Typical wintertime Sea Surface Temperature (colors), Sea Level Pressure (contours) and surface wind stress (arrows) anomaly patterns during warm and cool phases of PDO*

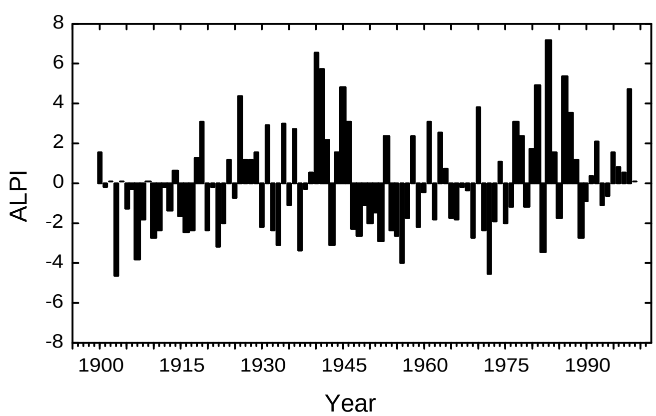

Figure 5. *The Aleutian Low Pressure Index. (J. King)*

Length of Day

The Length of Day is a measure of the rotational speed of the solid earth about its axis off rotation. It is measured as the annual mean difference (μ sec) between the astronomically and the atomically derived lengths of day. A period of decreasing Length of Day characterises a 'speeding up' of Earth's rotational speed. The last such speeding up period preceded the 1977 "regime shift" by several years. A slowing-down period preceded the 1989 regime shift. The Length of Day again decreased in 1996 and continued to decrease through 1999 denoting another speeding-up period(Fig. 6).

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

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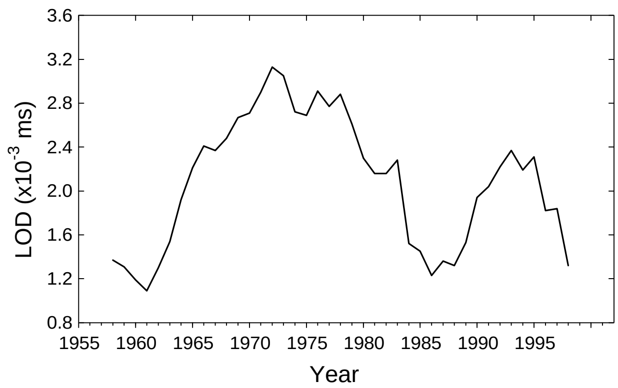

Figure 6. *Length Of Day Index*.

Fishery Interpretation and Speculative Results

As part of the mandate of the Fishery Oceanography Working Group, this section contains both factual and interpretative information for major fish stocks for the West Coast of Vancouver Island and the Strait of Georgia regions. Results are based on observation but might be subject to differing interpretation.

West Coast of Vancouver Island Major Fish Stocks

Numerous environmental factors effect ecosystem reorganization and the health of British Columbia's major commercial fish species. Water temperature, wind speed, ocean currents, 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.

Hake: The total biomass of hake will remain low on the west coast of North America. However, the present northern distribution will probably remain for the next few years, giving the appearance of more total abundance off British Columbia.

Herring: Herring in the Strait of Georgia will remain at high biomass while herring off the west coast will remain at current low biomass levels, hake being a major factor in low herring abundance.

Salmon: Growth of juvenile coho and chinook salmon in 1998 was significantly reduced off the west coast of Vancouver Island compared to Dixon Entrance and SE Alaska, possibly because of significant El Niño-induced nitrate depletion in the upper ocean (a depletion that was greater than previously observed at any time since the 1960s). As a result, poorer survival is anticipated for salmon stocks that either rear in the southern regions (some stocks of coho and chinook), or of stocks of salmon that migrate through these regions (all other stocks). In contrast, 1999 saw a sharp change in coastal ocean conditions, with many ocean variables, such as temperature and nitrate, returning to near normal distributions.

Coho and pink salmon spend only one full year rearing in the ocean before returning, so the juveniles entering the ocean in 1998 returned in 1999. Survival of southern BC stocks of these species (Fraser River pink salmon, Strait of Georgia coho) was poor, as expected given the extreme nutrient depletion and reduced growth that was observed. It might be anticipated that the improved juvenile growth of coho and chinook salmon observed in southern offshore regions of BC coastal waters in 1999 may lead to somewhat improved survival and this may be observed in calendar year 2000 for coho. However, sockeye, chum, and chinook salmon that entered the ocean in 1998 as juveniles will not return as adults until the calendar years 2001 and 2002 (primarily 2000 for Fraser River sockeye salmon). If the improved conditions observed in 1999 do improve juvenile salmon survival, this will not be observed until the return years 2002 and 2003 (primarily 2001 for Fraser River sockeye salmon). Adult escapements producing the smolts entering the ocean in these years are smaller than in the past so that higher ocean survival may not necessarily translate immediately into higher adult returns.

Total Pacific salmon catches will remain below the historic average of 60,000t, but total catches from all countries will remain high. For the next few years, abundances of all five species in the south will remain low, with Chinook and Coho juveniles in the Strait of Georgia continuing to have low survival, primarily from reduced food availability in the summer. Off the west coast, a combination of predation and food limitation through competition is expected to keep the abundance low. Pink, chum, and sockeye in the Fraser will respond as they did in the 1960's and abundances will be low, but unrelated to fishing removals. In the north, all species will be at or above historic averages as they benefit from more favourable oceanic conditions.

Strait of Georgia Ocean Age-0 Salmon

Mid-summer and late-summer surveys for juvenile salmon that had migrated in spring from freshwater into the Strait of Georgia indicated that coho abundance had continued to increase slightly in 1999 compared to 1997 and 1998. Chinook abundance in mid-summer was 20% higher in 1999 than 1998, but 30% lower than in 1997. However, by late-summer the chinook abundance in the Strait of Georgia was approximately half the estimates of abundance in 1997 and 1998. Chum abundance in mid-summer was 40% lower than in 1998 but was almost 4 times the estimated abundance in 1997. There was no large difference between chum abundance estimates for the late-summer of 1999, 1998 or 1997.

In September 1999, juvenile coho were approximately the same length as in September 1998 and 1997. However, the condition factor was lower in 1999 than in 1998 suggesting reduced growth in weight and possibly a lower marine survival in 2000, similar to the return of 1997 juveniles in 1998. Chum salmon juveniles were approximately the same size and condition in September 1999, 1998 and 1997. Chinook salmon were smaller in length in 1999 than in 1998, but the condition factors were similar.

In 1999, juvenile coho abundance was 20% higher and chum abundance about 40% higher than during the two previous years. Juvenile chinook abundance was approximately 50% lower, which suggests poor returns in several years. In 1999, more coho were in the top 15 m than in previous years (68% in 1999, 59% in 1998 and 56% in 1997). Almost all (99%) chum salmon were in the top 15 m, compared to 75% in 1998, and 89% in 1997. The percentage of chinook salmon in the surface layer was 55% in 1999, up from a value of 39% in 1998, but still and lower than a value of 63% in 1997.

Strait of Georgia 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 35 cm by the mid-1990s. This reduced growth continued into 1999.

Hake in the Strait of Georgia will continue to be of small individual size and large total biomass.

Strait of Georgia Herring

The abundance of herring was similar to the 1998 abundance, or just slightly more than 80,000 tonnes. This abundance is about mid-range in the historically estimated levels of the stock (1951-1999), with the lowest abundance estimated in 1968 (11,000 tonnes) and the highest abundance estimated in 1954 (155,000 tonnes). Since about the mid to late-1980s, the abundance of this stock has been increasing.

Strait of Georgia Salmon

The impact of the lower surface salinities in 1999 on coho and other species is not known but it may contribute to reduced survival.

Annual Fraser River flows continued the pattern of extreme fluctuations that started in 1997. The total discharge in 1999 was the third highest on record, following one of the lowest levels of discharge in 1998 and the second highest discharge level in 1997. Changes in flows from low to high have never been associated with above average marine survival of coho or chinook salmon.

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