2003 Pacific Region State of the Ocean

Background

This report documents the state of the ocean for the year 2003, and into 2004. 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 light stations, moored subsurface current meters, coastal tide gauge stations, autonomous ocean profilers, and 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. Fisheries data are maintained in archives at the Pacific Biological Station in Nanaimo.

Executive Summary

The weak El Nino and Southern Oscillation of 2002 to 2003 set up anomalously warm sea surface temperatures and anomalous downwelling-favourable cyclonic winds in the Canadian region of the Gulf of Alaska from October 2002 to early 2003. By mid 2003 the ocean surface waters cooled somewhat, returning to more "average" temperatures until early 2004. In May 2004 the coastal ocean waters off British Columbia were above average in temperature, perhaps associated with the exceptionally warm, sunny, April weather, and it is unclear if this warming will persist. Winter winds of 2003/04 revealed none of the persistent anomalies that set up previous regimes. Perhaps mid 2003 to early 2004 was a transition year, where it is unclear what regime we are headed into. Perhaps we may see an "average" regime continue. Despite the unclear future, effects of past regimes will persist.

This temperature change during 2003 was much weaker than experienced during the abrupt regime shift in late 1998, or during the 1976/77 and 1989 regime shifts. Decadal-scale variability in regimes is increasingly being recognized as causing sudden shifts in marine production trends, especially for ground fish and Pacific salmon. Even longer modes (70-90 years) of variability may be important for longer-lived species.

Much of the variability of the coastal waters and biota of British Columbia since 1970 can be related to changes in prevailing winds in winter. The years of 1970 to 2002 experienced significant, persistent, decadal regimes separated by surprisingly strong regime shifts. The strongest shifts appear to have been in 1976/77 and 1998/99, with another, perhaps weaker shift in 1989. Many of the oceanic and biological changes during one regime remained in place well into the following one. For example the cool sub-surface waters formed at 120 metres depth during the 1999 to 2002 cool regime remained in place until early 2004. Some changes occurred with no apparent lag. An example of this are coho salmon indicators in the Strait of Georgia, which have oscillated in phase with temperature regimes, as noted by Simpson *et* *al.* (2004): "All wild and hatchery indicators [of coho] in the Georgia Basin have followed the same trend: minimum survivals in about 1998 after a relatively steady decadal decline followed by a slight improvement until 2001 and a decrease since."

In general, warmer regimes are associated with stronger winds from the south along the coast, lower surface nutrient levels, stronger coastal flow to the north, increasing numbers and percentage of southern species of plankton, and of fish such as sardines and hake, and lower marine survival for Pacific salmon at the southern limit of their range. Cooler winds reverse these trends. Exceptions exist, of course, and there are variations within these "warm" and "cool" regimes, as noted within the report, but trends do emerge in a multi-year perspective.

The figures below reveal winters during which persistent wind directions were observed along the West Coast, as described by Bond *et al.* (2003) and Jim Overland (personal communication).

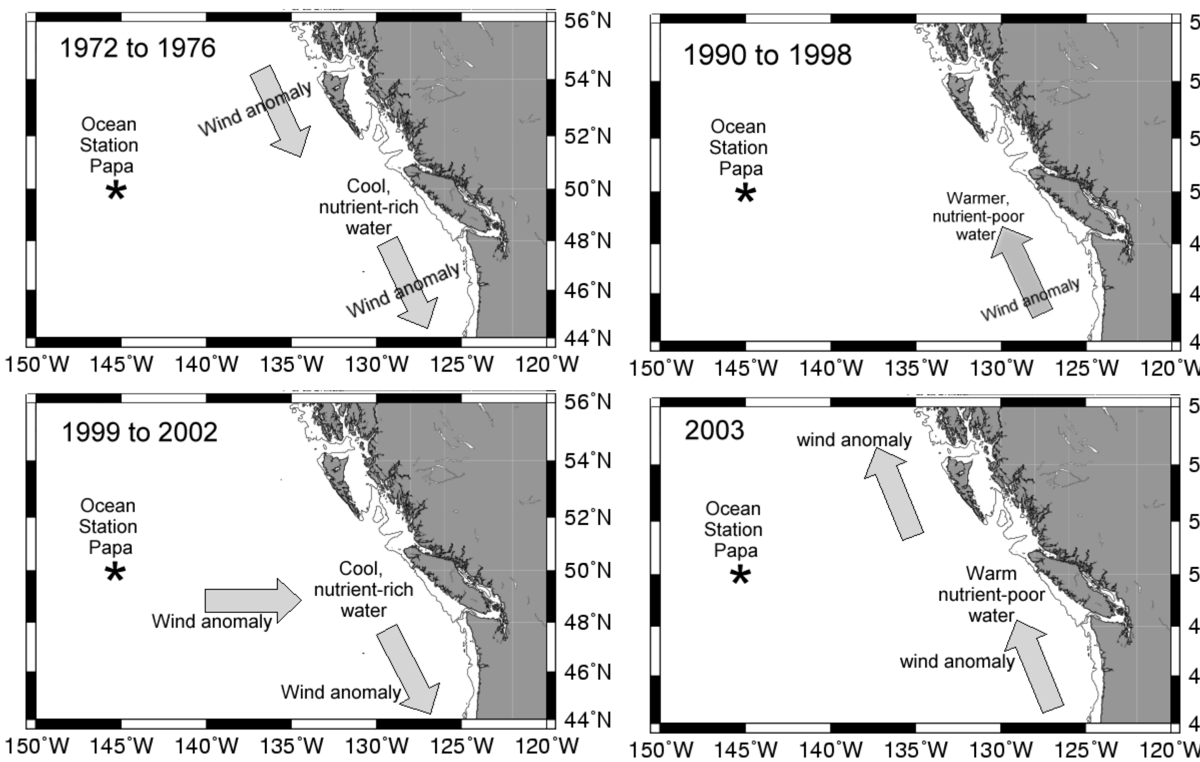

Figure 1. Persistent wind anomalies in winter along the West Coast. "Winter" included the months of November to March, labelled by the year of January to March observations.

The cool regime of 1972 to 1976 experienced anomalously strong winds from the north in winter, (actually weaker winds from the south) and cooler ocean surface waters off British Columbia. Immediately following the end of this regime, wind anomalies reversed, persisting for the next 12 years or so (not plotted), warming the coastal waters. The top right panel shows persistent wind anomalies for the period 1990 to 1998, which carried southern waters and species northward along the coast. This regime also reversed abruptly in 1998 to a cool regime for the years 1999 to 2002. The weak El Nino of 2002 to early 2003 (bottom right panel) ended the cool years, or perhaps interrupted them.

Many oceanic features and biological species responded in 2003 to these past changes in winter winds and surface ocean temperatures in the Canadian waters. Specific examples of responding features and species are listed below.

Coastal water levels were well above normal in the warm 1990s, lower than normal in 1999 to 2002, and a bit higher again in 2003.

The **North Pacific Current** flowed more toward the north in late 2002 and early 2003, coinciding with the weak El Niño. It normally flows eastward along 40°N toward North America. By early 2003, perhaps when El Niño-like winds abated in the Gulf of Alaska, it returned to a more normal course.

Coastal temperatures sampled at light stations were above normal during the 2002-2003 winter along the west coast of Vancouver Island, and normal during the rest of 2003. Strait of Georgia and northern BC temperatures were warmer in 2003 than during the previous 4 cool years.

Ocean surface waters of the Canadian Exclusive Economic Zone (200-mile limit) were also warmer in 2003 than in previous three to four years. However, subsurface waters from 100 to 200 metres depth carried cooler temperatures from the 1999 to 2002 cold regime because the ocean surface heating requires more than one year to penetrate below 100 metres.

Alongshore current in 2003 on the Vancouver Island continental shelf saw a return to near 1990-96 average northward flow since a gradual but dramatic shift to a more equator-ward component that began in 2000. Both shifts are likely due to winter wind patterns noted above.

Phytoplankton growth in spring of 2003 along the southwest coast of Vancouver Island was lower than observed by satellite in the preceding four cool years, and closer to the low growth observed in the spring of 1998, the previous warm year.

Deep-sea zooplankton biomass during spring (May-June) was lower in 2003 than in the previous two colder years by about a factor of 2, based on preliminary analysis of a few samples. (When surface waters are cool, nutrient levels are often higher.) For June to August 2003 it appears that subtropical species extended further north *and* boreal species were still doing well throughout the region.

West Coast Vancouver Island zooplankton showed effects of the 2002/2003 El Niño. Southern species increased in biomass, following an increase in northern species during the 1999-2002 years of cool coastal waters. For most species, the strongest anomalies were in spring and early summer of 2003, and had returned to near-zero by early autumn.

Barkley Sound euphausiid (*T. spinifera*) larvae and adults biomasses in 2003 were the lowest in the time series; adult biomass was at least 10 times lower than in most other years and 100 times less than in 2000.

Pacific hake were also found farther north in 2003, due perhaps to warmer waters in the continental shelf than 1999 to 2002, and perhaps to the continued, normal, northward spread of an individual year-class of hake. Hake biomass increased in 2003 due to the growth of individuals in the 1999 year-class that dominates the population along the West Coast.

California tonguefish (*Symphurus atricauda*) were observed in May 2003 in Barkley Sound, the most northerly occurrence ever reported for this species. This is consistent with warmer waters and weak El Niño in 2002-2003.

West Coast Vancouver Island eulachon index increased during the 1999-2002 cool years, but declined slightly in warmer 2003.

Herring year classes of the cool years of 2000 and 2001 are large on the west coast of Vancouver Island, and should result in improved recruitment to the stock in the year 2003 and 2004. The warmer waters of 2003 might impact herring stocks by bringing in more predatory hake.

Sardines were scarce in the 2003 trawl survey off Vancouver Island except in the south and some concentrations at the mouth of the inlets. Their numbers had increased during warm years of the late 1990s, but decreased during the 1999-2002 cool period. The 2003 warming was likely too short duration and too recent to abate this decline.

Juvenile Coho growth conditions off south-western British Columbia were lower in 2002 to 2003 than in 2001 to 2002, but similar to conditions seen during the three preceding cool years. Generally, coho juveniles in this region are healthier in colder years, and their poorer conditions following the warmer 2002-2003 winter support this hypothesis.

Pink salmon returned in record high numbers to the Fraser River in 2001 and estimated high numbers in 2003. (They entered the ocean in 2000 and 2002.)

Sockeye salmon returns to the Fraser River were slightly above average in 2002 and near average in 2003. Survival was slightly below average in both years.

Pacific herring had the largest biomass in 2003 in the Strait of Georgia since 1955. These three adult stocks likely responded well to the cool regime that began in 1999. The warm winter of 2002-2003 was too recent to impact present adult stocks.

Cassin's auklets fledgling production was higher in 2003 than during the warm years in the 1990s on Triangle Island off northern Vancouver Island, but lower than during the cool years of 1999-2002. This production likely varies as the supply of prey, mainly **Pacific sandlance**, which itself varies in biomass with changes in local temperatures, nutrients and plankton biomass.

> **Some oceanic features and biological species did not seem to respond in an expected or consistent way to the ocean temperature changes in the past years. Specific examples of non-responding oceanic features and biological species are listed below.**

Mixed layer depth in mid-Gulf of Alaska in winter is usually shallowest in winters of El Niño-like weather. However, the 2003-2004 non-El Niño winter produced the second-shallowest mixed layer depth observed in almost 50 years.

Salinity at Langara Island of north-western Queen Charlotte Islands declined in each year since 2000, as part of a general 30-year trend toward fresher water there. Other BC shore stations do not reveal this 30-year trend.

Haida Eddies are often larger and more numerous following warm winters with higher sea levels. One therefore would expect the 2003 eddies to be large. Instead, the 2003 eddies were small.

Common Murres bred successfully on Triangle Island (76% of pairs raised chicks to depart the colony) even as other bird species did not.

The poor ocean conditions for **juvenile salmon** observed in the Strait of Georgia in 2002 continued in 2003, evidenced by low catches and low average size of juvenile salmon. Oceanographic and climatic conditions did not show any clear trend to explain this decline from 2000-2001, and we continue to investigate the underlying causes for this variability within the current regime.

Juvenile sockeye salmon may also be exhibiting a change in behaviour, in that they appear to be spending much more time in the Strait of Georgia than either the literature or our previous experience suggest.

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Summary by Region

Global Climate

Global temperatures continued to be well above the average conditions found in 1960 to 1991, and 2003 tied 2002 for the second warmest on record. 1998 was the warmest.

The multi-decadal trend to warmer temperatures has continued, with greatest increases over land in the Northern Hemisphere.

Southern Oscillation Index (SOI) values for 2002/2003 indicated that a weak El Niño developed in the last half of 2002 and persisted into early 2003. It was followed later in 2003 by generally normal conditions of neither El Niño nor La Niña.

The **Pacific Decadal Oscillation** (PDO) increased in magnitude through the 2002-2003, perhaps due to changes in atmospheric circulation that coincided with the weak 2002/2003 El Niño. The PDO then declined to low values later in 2003.

The **Victoria Mode** of the PDO had been strongly positive since 1999, but declined to weak positive values in 2003 and early 2004. This decline may have been due to the weak 2002/2003 El Niño. Calculations of this mode in early 2004 are based on February observations only, in a reduce oceanic region compared to the standard Victoria Mode.

The **Arctic Oscillation** index was weakly positive in early 2003, then declined to low values later in the year.

Aleutian Low Pressure Index (ALPI) was extremely high in 2002, indicating a strong Aleutian Low. While the ALPI value in 2003 was not as high as 2002, it still reflected a strong Aleutian Low.

Gulf of Alaska

The **Aleutian Low Pressure Atmospheric System** was extremely strong in 1998, and of moderate intensity from 1999 to 2001 and farther north. The shift to the north in 1999-2001 brought cooler waters to southern BC regions. In the 2002 to 2003 winter, the centre of this low pressure system moved southward and increased to a strong intensity due to El Niño-like weather. Strong Aleutian Lows are associated with increased upwelling and increased productivity in mid-Gulf of Alaska, and decreased upwelling along Canadian west coast waters. (Downwelling takes place when warm, nutrient-depleted, surface water flows into a region, pushing cool, nutrient-rich water far below the surface. In upwelling conditions the warm surface waters are pushed away by the winds, to be replaced at ocean surface by cool, nutrient-rich water from the depths.)

A re-analysis of atmospheric air pressures and winds revealed that winters of the northeast Pacific in 1999 to 2002 were dominated by a weather pattern that had been relatively weak in previous decades. This pattern, labelled the **Victoria Mode** of the Pacific Decadal Oscillation, coincided with the northward movement of the Aleutian Low Pressure System noted above. It brought cool water to coastal regions of British Columbia, as well as to Washington State and Oregon coasts in 1999-2002.

This **cool subsurface water** near the coast extended to depths of about 200 metres below surface, with record cold anomalies at 100 to 200 metres in 2002. These cold subsurface waters persisted into early 2004, then abated.

Land temperatures were warmer along the Pacific Coast of Canada in 2003 than in 2002.

Winter winds cool the ocean surface, and mix the surface waters with deeper ocean waters, bringing deep, nutrient rich water to the surface. Much of the middle of the Gulf of Alaska relies on this winter input of nutrients to supply surface life with nutrients. The depth of this **surface mixed layer** in late winter is therefore an indicator of nutrient supply for spring and summer growth. The depth of this winter mixed layer in mid-gulf was less in the 2002/2003 and 2003/2004 winters than in any of the previous winters since monitoring began in 1956, due to the warm surface and cool deep anomalies noted above, and also due to relatively weak winds. These two shallowest mixed layer depths are part of a 45-year trend toward shallower mixed layers in mid-gulf in winter.

The **ocean nutrient levels** responded to this decrease in mixed layer depth. Nitrate is one of the main nutrients in the ocean that has been monitored over the past decades. Nitrate concentrations in mid-gulf were low in surface waters in the winters of 2002/2003 and 2003/2004, but higher at 100 metres depth, just below the mixed layer. In contrast, nitrate levels through the 1980s and early 1990s were the same at surface and 100 m depth. Interestingly, the surface nitrate levels are close to the long term average, and the 100-m-deep nitrate levels are very high compared to previous years.

A five-year-old sampling program for **deep-sea zooplankton** found that their biomass in surface, open-ocean waters during spring (May-June) was lower in 2003 than in the previous two colder years by about a factor of 2, although similar to levels observed in 2000 and so not unusual (at least as far as 'usual' can be determined from this short time series). This sampling program maps out the north-to-south spatial distribution of zooplankton, and found that in summer 2003 the southern species increased their relative concentrations in northern portions of the gulf and the northern (boreal) species of zooplankton also survived well. In other words, these species thrived in the same regions more than in the previous decade, perhaps due to the warm-surface, cool-sub-surface temperatures.

Pacific hake were found farther north along the Canadian continental margin in 2003 than in the previous survey in 2001, although none were observed north of mid-Queen Charlotte Sound. The increased northern extent might be due to warmer surface waters in 2003. Their population is still dominated by the 1999 year class.

West Coast of Vancouver Island

The record of coastal ocean currents and subsurface temperatures began in 1990, and the 1990 to 1996 period is used as reference for normal conditions in the following discussion.

Year 2003 marked a return to more normal **sea surface temperature** (SST) and **sea surface salinity** (SSS) after a prolonged cool and salty period that began during La Niña of 1998/1999. **Alongshore wind stress** and **wave heights** continued to be normal in 2003. The **upwelling index** returned normal in 2003 after below-average values since the mid-1990s. The low-frequency variability in **sea level** has mirrored that of SST since the 1970s, and like SST, **sea level** returned to normal after below-average values since mid-1998.

Subsurface ocean temperatures at 35, 100, 175 and 400 metres depth over the continental slope were warmer than normal over January-February 2003 then cooled to below-normal through to the fall (data series ends in late September 2003).

Alongshore current on the continental slope in 2003 marked a return to normal conditions following a shift to a more southward flow that began in 2000 and continued to 2002.

Satellite observations of **chlorophyll** concentrations along the **southwest** coast of Vancouver Island show that in 2003 the spring bloom of phytoplankton started in March as in the two previous years (2001-2) rather than in April as observed in previous years where SeaWiFS data are available (1998-2000). The magnitude of the 2003 spring bloom in inshore waters was weaker than during the 1999-2002 cool years. Chlorophyll concentrations seldom indicated a spring bloom of phytoplankton along the **northwest** coast of Vancouver Island between 1998 and 2003, and a spring bloom was observed there in 2001 only. In general, higher concentrations are observed at the end of the summer along the **northwest** coast of the island. Higher concentrations of chlorophyll were observed in both **southwest** and **northwest** coasts of Vancouver Island in July-September 2003 and were closer to shore in 2003 than in 2002.

Zooplankton observations, which require ship-based measurements, continued through 2003 along the west coast of Vancouver Island, although with a smaller-than-average number of sampling periods due to shortfalls in funding and ship availability. The southwest Vancouver Island zooplankton in 2003 showed effects of the weak El Niño that took place in late 2002 and early 2003. This response can be interpreted as a partial (and probably temporary) return toward the zooplankton community of the mid and late 1990s. Southern species were significantly more abundant than average throughout 2003. By autumn 2003 anomalies in zooplankton populations were near zero.

Euphausiid sampling in Barkley Sound continued in 2003, estimating annual biomass for larvae (<10 mm) and adults (>9 mm) of the two predominant species (*Thysanoessa spinifera*, *Euphausia pacifica*). Specific size ranges of *T. spinifera* adults are preferred food for Pacific herring (*Clupea pallasi*), Pacific hake, eulachon (*Thaliechthys pacificus*) and coho salmon (*Oncorhynchus kisutch*) smolts, whereas sockeye (*O. nerka*) and chum (*O. keta*) smolts prefer different sizes of *T. spinifera* larvae. Biomasses of *T. spinifera* larvae and adults in 2003 were the lowest in the time series; adult biomass was at least 10 times lower than in most other years and 100 times less than in 2000.

Abundances of **smooth pink shrimp** and several species of **flatfishes** are sampled with small-mesh bottom trawl nets in May of each year. Their numbers increased after 2000, peaked in 2002, but then declined in 2003.

An unusual occurrence of **California tonguefish** (*Symphurus atricauda*) was observed on these surveys in May 2003 in Barkley Sound, which is the first reported occurrence of this species in British Columbia (previous most northerly occurrence along the west coast of North America was in Yaquinna Bay, Oregon). This is consistent with warmer waters of 2002/2003 winter, and with a moderate El Niño that persisted into early 2003.

Catches of **eulachon** during shrimp surveys off Vancouver Island in May of each year have been used to form an index of the stock abundances of eulachon in rivers of southern B.C. This index suggests that a significant increase in eulachon has occurred since 1999 in southern British Columbia, reaching levels not seen in the past decade; however, the index showed a slight decline in 2003.

The productivity of the west coast of Vancouver Island **herring** stock has been declining since 1989, primarily because recruitment to this stock has been poor for 6 of the last 10 years although there are recent signs of some recovery in the past two to three years. In 2003, the spawning biomass increased to the average for the past two decades.

Ocean conditions were more favourable for **herring** survival in 2000 and 2001 and should result in improved recruitment to the stock in the year 2004.

Sardines returned to Canadian west coast waters in 1992 and reached their highest biomass in 1998. However, sardines did not appear in Canadian waters in 2003 until late-July and were confined to coastal inlets along Vancouver Island and parts of the Central Coast. The 2003 trawl survey off Vancouver Island found virtually no sardines in the offshore waters except in the south and some concentrations at the mouth of the inlets.

The 2003 survey found that **coho** salmon growth conditions off southern British Columbia were lower than in 2002, but similar to conditions seen in other post-1998 years. Coho salmon growth was low in the Strait of Georgia and high in the Bering Sea (Bristol Bay) relative to the west coast of Vancouver Island.

Scientists of the Centre For Wildlife Ecology have examined **seabird** populations in Triangle Island off north-western Vancouver Island every year since 1994. In general, breeding date of several of the alcids family of seabirds (auks, auklets, puffins, guillemots, murres, murrelets) was late at Triangle Island in 2003 compared to previous years, and breeding success was low, suggesting that females were in poor condition early in the season, likely due to lower-than-normal concentrations of prey in the nearby ocean.

North Coast

Sea surface temperatures (SST) were warmer in 2003 at Langara and Bonilla Islands than in 1999-2002, reaching high levels typical of El Niño years of the 1980s and 1990s. This warming is likely due to the impact of the 2002/2003 El Niño.

Sea surface salinity (SSS) at Bonilla Island was similar to the levels found in the previous two years, but the salinity at Langara Island continued its long-term decline that began in the early 1970s. This trend in salinity is not found at other stations in British Columbia and its cause is not known.

A transport hypothesis based on pressure-adjusted sea level at Prince Rupert was used to explain recruitment anomalies for the **Pacific cod** stock in Hecate Strait. High sea levels reflect high seawater transport through the strait, which is suspected to remove more larvae from Hecate Strait in winter, resulting in poor recruitment. Throughout the 1990s sea levels were considerably high and unfavourable for recruitment. Sea levels (transport) decreased after 1998, and from 2000 to 2002 were sufficiently low to indicate reasonably good levels of Hecate Strait cod recruitment. Higher pressure-adjusted sea levels in 2003 suggest future recruitment will be closer to normal.

Offshore transport by **Haida Eddies** was low. The 1998 eddy was the largest ever observed, while eddies formed from 1999 to 2003 were much smaller. However, a single large eddy that formed west of the Queen Charlotte Islands in the winter of 2004 is the largest observed since 1998.

Indications are that recent year-classes of **herring** in the Queen Charlotte Islands region of Hecate Strait have remained weak, except in 2003, while those in the Prince Rupert District and Central Coast have been getting stronger suggesting better survival conditions in the latter areas. Abundance in the Queen Charlotte Islands and Prince Rupert is expected in 2004 to remain similar to recent levels while the Central Coast could decline slightly from the level of 2003.

Strait of Georgia and Adjacent Channels

Snow pack in spring 2003 in the Fraser River basin was considerably below normal, leading to the lower-than-normal **Fraser River** runoff in 2003. Snow pack in spring 2004 was closer to normal. The freshet peaked in early June 2003 with maximum discharge values of about 7500 $m^3 s^{-1}$. After the peak discharge, the flow rate remained below seasonal means for the rest of the year except for a short period in late October when heavy rain increased it significantly.

Sea surface salinity remained higher than average for most of the year, with anomalies varying from about 1 to 3 psu. However, in the months of October and November 2003, the surface salinity significantly decreased due to strong Fraser River discharge.

Sea surface temperature in the Strait of Georgia remained above normal for all of 2003, with anomalies at Entrance Island reaching a maximum of almost 2 deg C in August.

Sub-surface temperatures in the Strait of Georgia were cool in 1999 to 2002, following the warm year of 1998. However, the cool episode was interrupted by significantly warmer conditions in the Strait during 2003, perhaps due to the weak El Niño conditions of late 2002 and early 2003.

Survival conditions for juvenile herring in the Strait of Georgia have been unusually good during the last decade. Abundance of **herring** in the Strait of Georgia reached a record high level in 2003 at just over 150,000 tonnes, exceeding the 1955 historical high.

A climate regime shift occurred in late 1998 and was apparent in shifts in climate indicators in the Strait of Georgia, including sea surface temperatures and the dominant winter wind direction. The impacts of the regime change on the productivity of the Strait of Georgia were first observed in 2000 and have persisted through 2003. There were record returns of **pink salmon** to the Fraser River in 2001 (entered the ocean in 2000). Returns of pink salmon in 2003 (entered the ocean in 2002) were estimated to be high based on imprecise test fish information and anecdotal reports from test fisheries. There were average returns of **sockeye salmon** to the Fraser River in 2002 and near average returns in 2003. Fraser sockeye survival was lower than average in both years. The largest biomass of **Pacific herring** since 1955 was observed in 2003.

The September 2003 and 2002 surveys found that **juvenile coho salmon** were again smaller than observed in the September 2000 and 2001 surveys. The **coho CPUE** in September was low, similar to 2002. This reduced size and CPUE are indications of reduced marine survival for the coho salmon that entered the Strait of Georgia in 2003. Therefore, reduced abundances resulting from reduced marine survival could be expected when these brood years return in 2004.

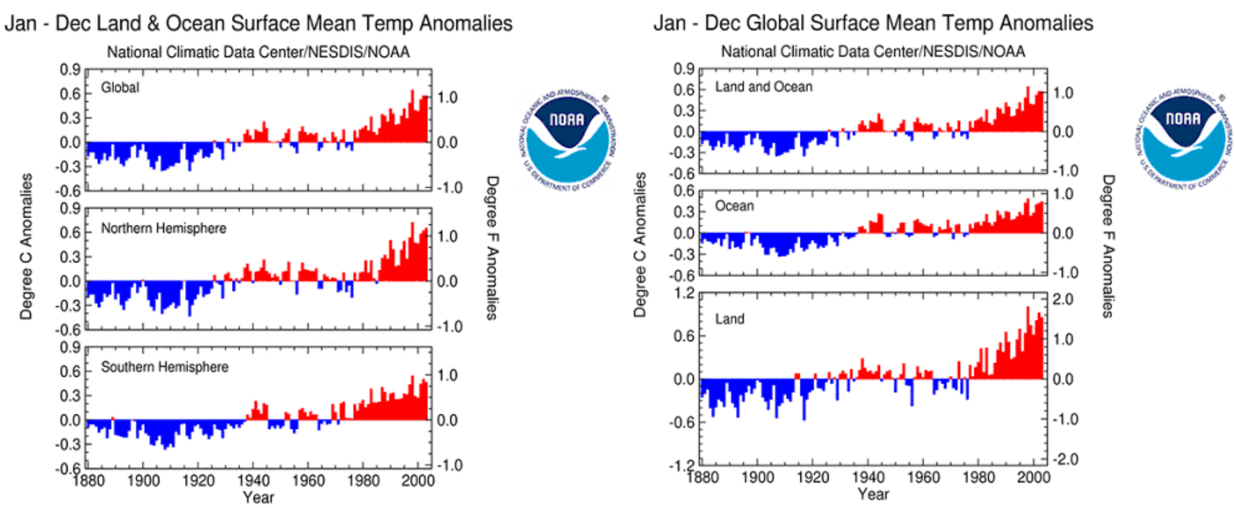
Year 2002 saw a three-fold increase in **river lamprey wounds on juvenile salmon** in the Strait of Georgia compared to the rates observed from 1997-2001. Unfortunately, the lack of a July 2003 juvenile salmon survey in the Strait of Georgia precludes an estimate for 2003.

The average size of **juvenile chinook salmon** was larger in 2003 than in 2002, but still smaller than values observed in 2000 and 2001. Juvenile chum salmon in September of 2003 were larger than in the 2002 survey.

Global Climate

Global air temperature rose dramatically after 1976, with 1997 and 1998 setting records for high temperature for sixteen consecutive months. Since 1998 the global temperature rise has moderated but still remains significantly above pre-1976 levels. Figure 2 shows that even though the global anomaly has decreased from the record levels of 1998, the warmer conditions which characterized the 1990s have continued in 2003 with air temperatures over land areas more affected than those over the oceans.

Mean global surface air temperatures in 2003 were tied with 2002 as the second warmest on record next to 1998, the warmest year on record since 1880 (Sources: U.S. National Climatic Data Center, and U.S. National Oceanic & Atmospheric Administration). Regionally, land-based records showed the Pacific Coast of Canada in 2003 was the ninth warmest and 12th driest since 1948 (Source: Meteorological Service of Canada).



(a) (b)

Figure 2 (a) Time series of global temperatures, showing differences between Northern and Southern Hemispheres. The northern hemisphere has warmed more than the southern hemisphere in the past decade. (b) Time series of global temperatures, showing differences between land and ocean. Land temperatures have risen about twice as much as ocean temperatures in the past two decades. (Source: U.S. National Oceanic and Atmospheric Administration.)

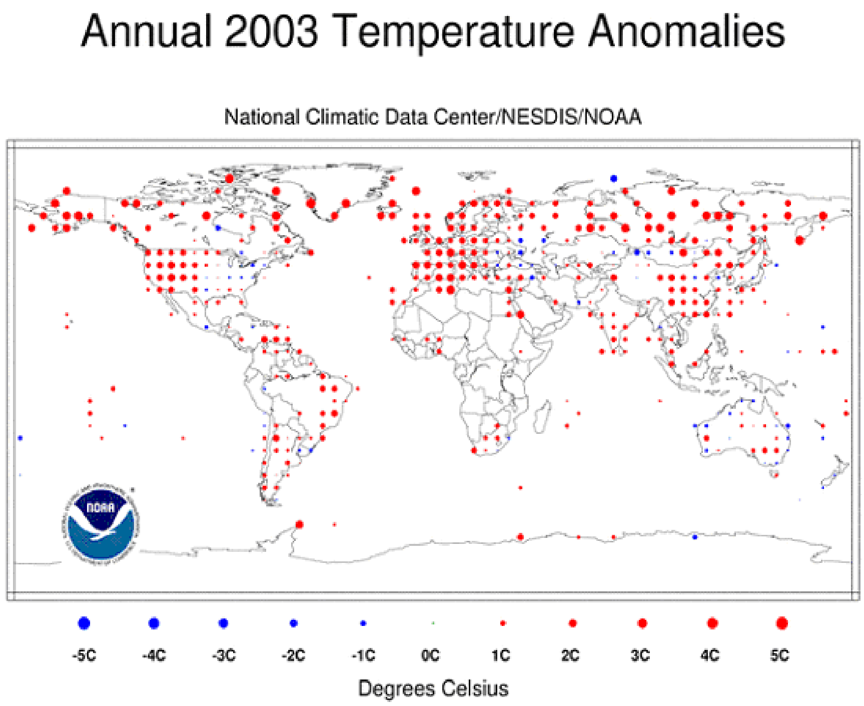


Figure 3. The distribution of year 2003 temperature anomalies relative to the 1960-1991 average. (Source: U.S. National Oceanic and Atmospheric Administration.)

Internet Sources:
http://www.ncdc.noaa.gov/oa/climate/research/anomalies/anomalies.html
http://www.ncdc.noaa.gov/oa/climate/research/2003/ann/ann03.html

Climate Indices

It is now generally accepted that patterns in fish abundance can often be linked to patterns in climate-ocean conditions. These conditions can be relatively stable for many years, then shift abruptly from one regime to another. Many indices have been developed to monitor the climate-ocean states. In this section we present and discuss a number of these indices. Generally, a regime shift in the state of the subarctic Pacific in 1998-1999 was captured by these indices and this new state continued into 2002. A weak El Niño in late 2002 and early 2003 brought conditions in the Subarctic Pacific back toward those of the 1990s, with slightly warmer temperatures. Conditions in since early 2003 appear to lie between the warm regime of the late 1990s and the cool years of 1999 to mid 2002.

Southern Oscillation, El Niño and La Niña.

Large negative values of the Southern Oscillation Index (SOI, Fig. 4, top panel) indicate 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 northeast Pacific. La Niña events (designated by large positive SOI) represent anomalous climatic conditions that are generalised as cooler in the northeast Pacific. The 1990s experienced several strong El Niño events, ending with an unusually strong El Niño in 1997/98. It was followed by La Niña of 1999 that lasted through 2001. A weak El Niño developed in the last half of 2002 and slowly declined through early 2003. Associated with this most recent El Niño was a strengthening of the Aleutian Low Pressure System in the Gulf of Alaska in the winter of 2002/03. (Stronger Aleutian Lows often accompany El Niño and strongly negative SOI in winter. The strong 2002/2003 Aleutian Low Pressure System followed this pattern.)

The SOI in Figure 4 derives from the method used by the Australian Bureau of Meteorology Troup SOI, which is the standardised anomaly of the Mean Sea Level Air Pressure (MSLP) difference between the island of Tahiti and the city of Darwin, Australia. It is calculated as follows:

$SOI = 10\ (P_{diff} - P_{diffav}) / SD_{(Pdiff)}$, where
P_{diff} = (average Tahiti MSLP for the month) - (average Darwin MSLP for the month),
P_{diffav} = long term average of P_{diff} for the month in question, and
$SD_{(Pdiff)}$ = long term standard deviation of P_{diff} for the month in question.

This version of the SOI ranges from about –35 to about +35, and the value of the SOI can be quoted as a whole number. The strong El Niño events of 1988/83 and 1997/98 were accompanied by SOI values of -20 to -30. The weak El Niño of 2002/03 coincided with an SOI of -10.

A table of monthly SOI values is available at http://www.bom.gov.au/climate/current/soihtm1.shtml

Arctic Oscillation

The Arctic Oscillation Index (AO Index, Figure 4) is the weighted sea-level air pressure anomaly northward of 20°N. 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.

The last half of 2003 was near-neutral. Additional information is available at: http://tao.atmos.washington.edu/data_sets/ao/ .

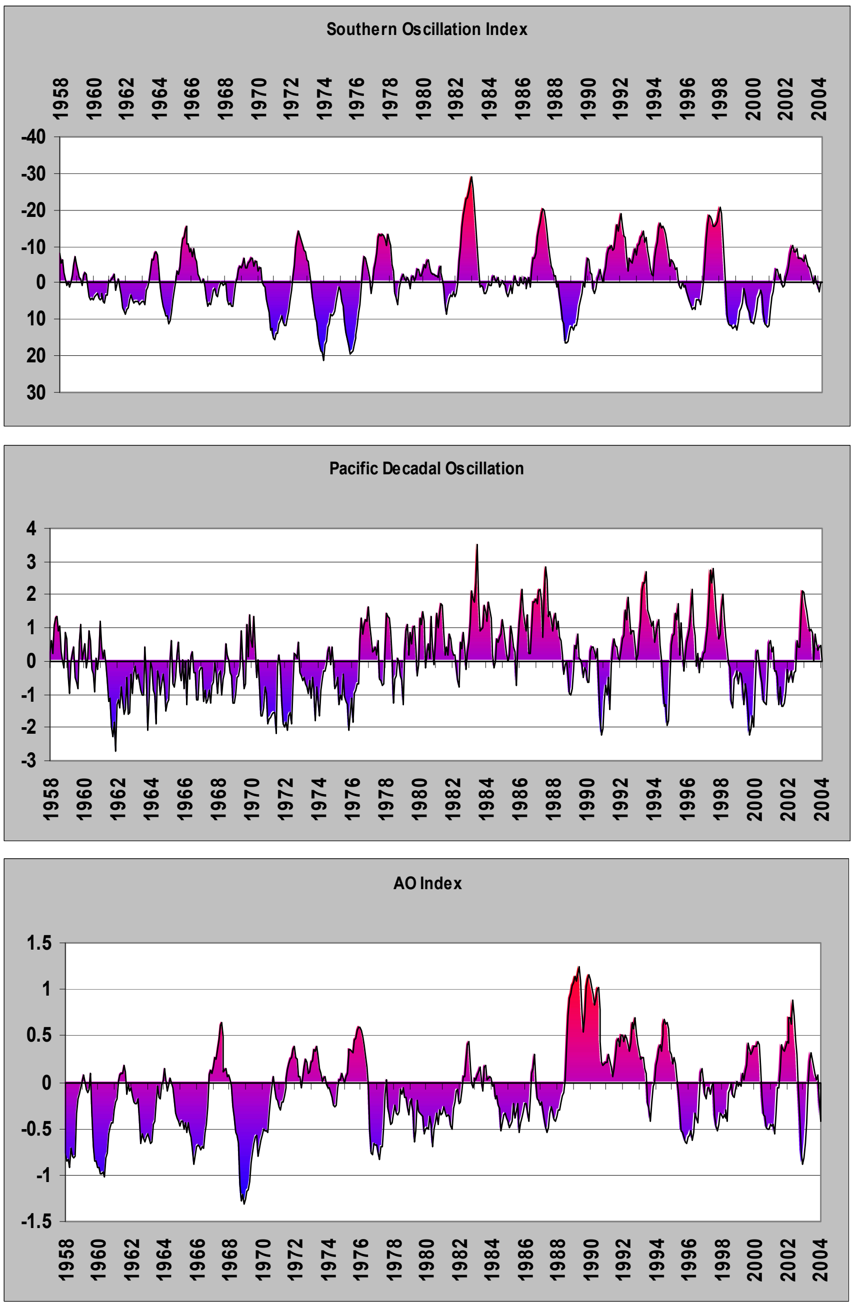


Figure 4. Variations in selected indices from 1958 to Feb., 2004. The scale in the top panel (SOI)was inverted to reflect warmer coastal conditions with negative index.

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is defined as the **first** component, PC1, of an EOF analysis of mean November-through-March sea surface temperature anomalies for the Pacific Ocean to the north of 20°N (Figures 5 and 6). It has generally been associated with only two states; a ***positive phase*** that is associated with warming of surface waters in the northeast Pacific and cooling in the central and western North Pacific, and a ***negative phase*** with opposite thermal patterns. These two states are correlated to an east-west spatial pattern in sea surface temperature. Recently, climatologists have used the **second** component, PC2, of the EOF analysis to represent the north-south spatial pattern in sea surface temperature whose positive phase prevailed from 1999 to 2002 (Fig. 6, time series PC2 from Bond *et al.*, 2003). To avoid confusion, this mode is frequently called the "Victoria Mode", while PC1 is called the "PDO".

The first principal component (PC1 or PDO) of the PDO (Figure 6) was the dominant pattern between 1970 and 1989 and its change in sign in 1977 accompanied the 1977 regime shift in the northeast Pacific Ocean. The second principle component (PC2 or Victoria Mode) increased in amplitude in the late 1980s. The Victoria Mode remained negative throughout the 1990s, and its shift to a positive phase between 1997 and 1999 accompanied the 1998/99 regime shift in the northeast Pacific Ocean. Much of the variability of Gulf of Alaska circulation and temperature since 1989 might be attributed to the Victoria Mode, plotted in Figure 6 and discussed in later in this report.

The Victoria Mode remained positive but very weak in winters of 2002/03 and 2003/04, whereas PDO increased in positive amplitude in the 2002/03 winter, perhaps due to changes in the Aleutian Low Pressure System that coincided with the 2002/2003 El Niño. PDO was positive but weak in the 2003/04 winter.

For more information on this topic, visit the web site http://tao.atmos.washington.edu/pdo/

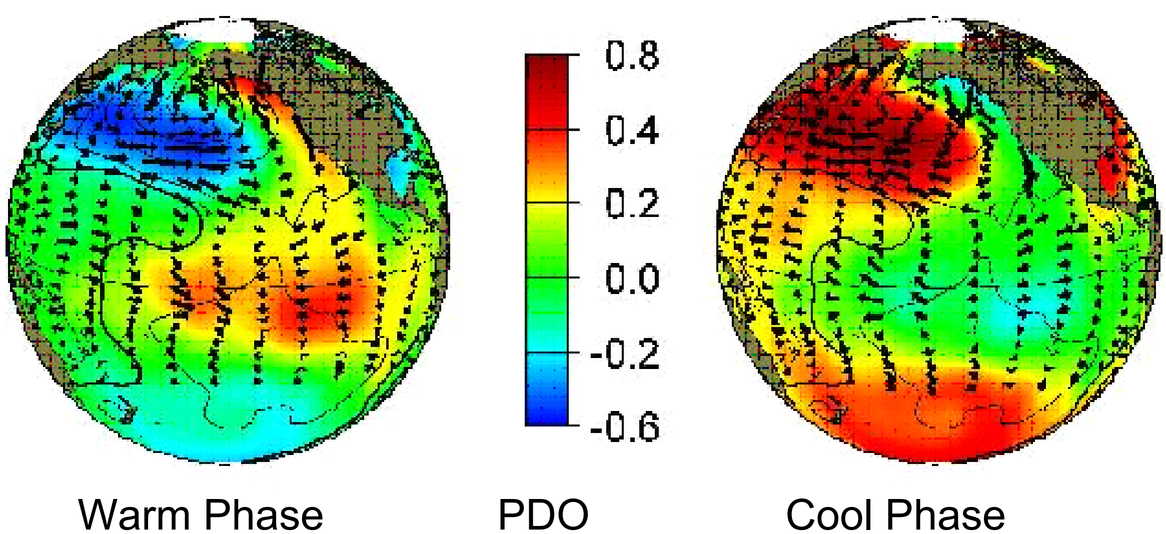


Figure 5.Typical wintertime sea surface temperature (colors), sea level pressure (contours) and surface wind stress (arrows) anomaly patterns during warm (left) and cool (right) phases of the first principle component, PC1, of the PDO. Scale bar indicates spatial amplitude of PDO mode.

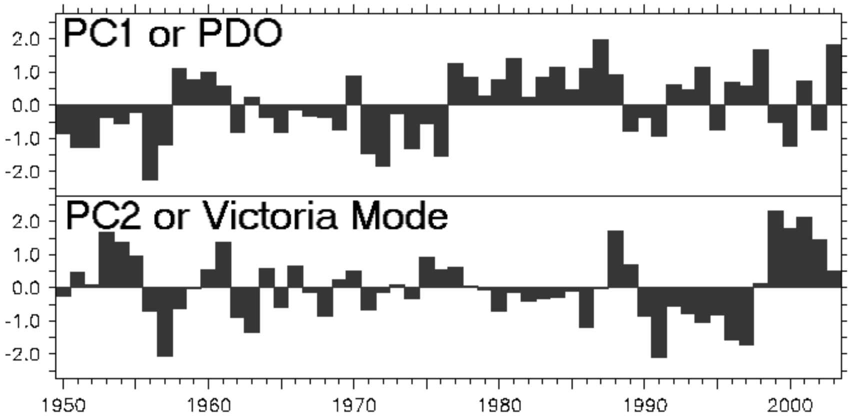


Figure 6. The first component (top) from an EOF analysis of North Pacific winter (November-March) sea surface temperature fields north of 20°, which represents the Pacific Decadal Oscillation Index (PDO) pattern. The second component (bottom) is a second pattern of sea surface temperature variability arising from the same analysis, labelled PC2 or Victoria Mode, and shows a shift to a large amplitude since the 1990s, with a shift from negative to positive values between 1997 and 1999. (Source: Bond *et al.*, 2003.)

North Pacific Temperature modes, 1982-2004.

To resolve the basin-scale variability more thoroughly, the EOF modes of ocean surface temperature were calculated using a higher resolution grid of temperature data from Reynolds Optimally Interpolated SST (Version 2) monthly mean data from 1982 to April 2004 (McKinnell, 2004). Each month was analyzed independently using the latitudinal range from 20°N to 60°N in the North Pacific Ocean. This analysis covers a shorter period than does the standard PDO index (23 years compared to 53 years of PDO), but it has higher spatial resolution (1° resolution compared to 2° for the PDO), and the technology and sampling intensity used to determine mean monthly SST (largely from satellites) is more consistent than for the longer record. This newer analysis examines February data only. Results reveal two distinct spatial patterns similar to the Victoria and PDO modes noted above, but in this case the Victoria* Mode is more dominant. (* denotes this higher-resolution calculation.) This is not surprising, given the dominance of the Victoria Mode since 1989 in Figure 6. The spatial pattern of the Victoria* Mode from 1982-2004 is characterized in February (Fig. 7) by an elliptical region of highest correlation centred in the subtropics near 31°N 175°W and extending south-westward. The region of greatest correlation of opposing sign appears along a well-defined arc stretching from west of the Baja California peninsula through the western Gulf of Alaska just to the west of Station Papa (51°N, 155°W) to the western Bering Sea (56°N, 168°E).

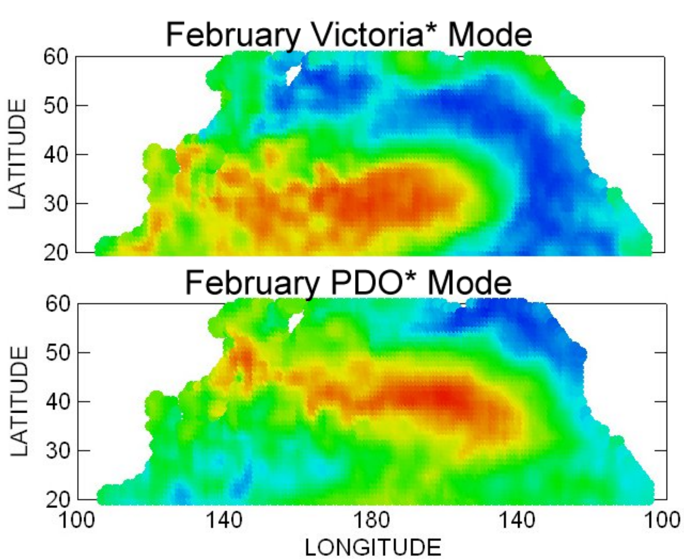


Figure 7. Sea surface temperature patterns of an analysis of 23-years of ocean data up to 2004 using data for February of each year.

This result emphasizes the point made by Bond *et al*. (2003) "strongest shift in recent years is a strongly negative phase of PC2 in the 1990s followed by a positive phase beginning in 1999." This analysis has been extended to 2004, with a time series of amplitudes of Victoria* and PDO* modes illustrated in Figure 8. below. The Victoria* Mode decreased to near zero amplitude in the El Niño winter of 2002/03, and remained at this level into 2004. The PDO* mode shifted to a very high level in February 2003, as often occurs during an El Niño, and dropped to nearly zero in February 2004 where it has remained through the spring of 2004.. Therefore both the Victoria* and PDO* modes were nearly neutral in the 2003/04 winter.

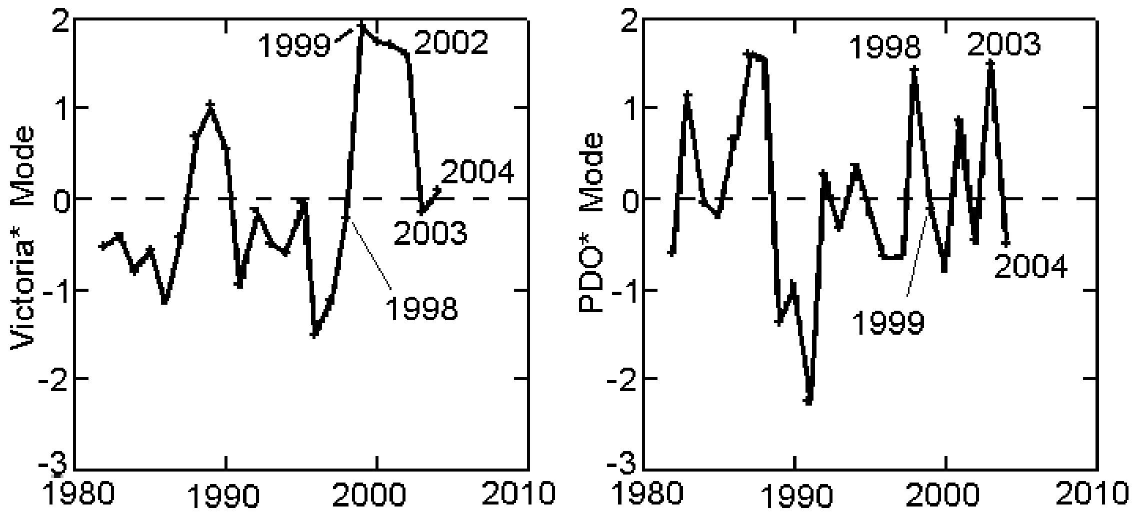


Figure 8. Time series of amplitudes of the Victoria and PDO Modes in February revealed by an analysis of sea surface temperature records since 1982. The final data point represents February 2004.

Aleutian Low Pressure Index (ALPI)

This index measures the relative intensity of the Aleutian Low Air Pressure System of the northeast Pacific (December through March). It is calculated as the mean area (km^2) having sea-surface air pressure below 100.5 kPa and is expressed as an anomaly from the 1950-1997 mean. A positive index reflects a relatively strong, or intense Aleutian Low. (Beamish *et al.*, 1997). It is often stronger and often covers a larger geographical area in El Niño winters, because the equatorial atmospheric systems that set up El Niño events also strengthen the Aleutian Low Pressure System of the Gulf of Alaska.

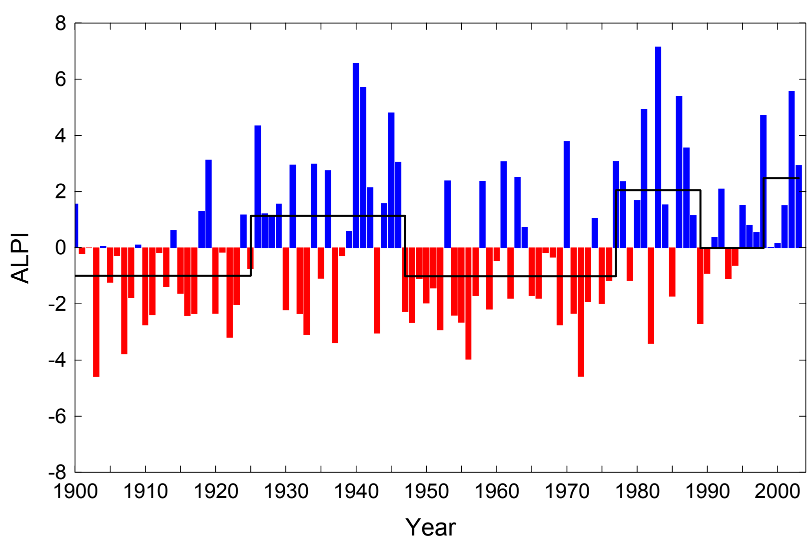


Figure 9. The Aleutian Low Pressure Index (ALPI). Solid horizontal lines represent the average indices value for each regime. Since the 1998 regime shift, the Aleutian Low Pressure system has been relatively strong as indicated by the continuance of mainly large positive values. Data available from http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_indx_alpi.htm.

Intense Aleutian Lows were present from 1977 to 1988, and again in 1991/92 and 1997/98, as noted by the high positive values of ALPI in Figure 9. Unlike many other indices, ALPI did not change sign in 1998/99, but instead has been consistently positive since 1995 (although with very small amplitude in 1999). In 2002, the ALPI value was extremely high, indicating a strong Aleutian Low. While the ALPI value in 2003 was not as high as in 2002, it still indicated a strong Aleutian Low.

Sea Surface Height Index (SSHI)

In the 2002 State of the Ocean report, an index of ocean variability for the northeast Pacific Ocean was introduced based on ***sea surface height*** (**SSH**) observations collected by satellites. This index, **SSHI**, is intended to complement the standard Pacific Decadal Oscillation (PDO) index that is based on ***sea surface temperature*** (**SST**). Satellite altimeters measure anomalies in sea surface height (SSH) over the world ocean. In a general sense, cold SST anomalies are associated with low sea level and negative SSH. For the purposes of this analysis, we use SSH data that has been gridded at 1 degree spatial resolution by Dr. Gary Mitchum of the University of South Florida.

The PDO is defined as the first principal component of an empirical orthogonal function (EOF) analysis of extra-tropical sea surface temperature (SST) observations. Likewise the index based on SSH is defined in terms of the first principal component of an EOF analysis of SSH data. The time series resulting from this SSH analysis provides information on the dominant mode of SSH variability over an eleven-year period of the TOPEX/POSEIDON and Jason satellite altimeters from January, 1993 to December, 2003.

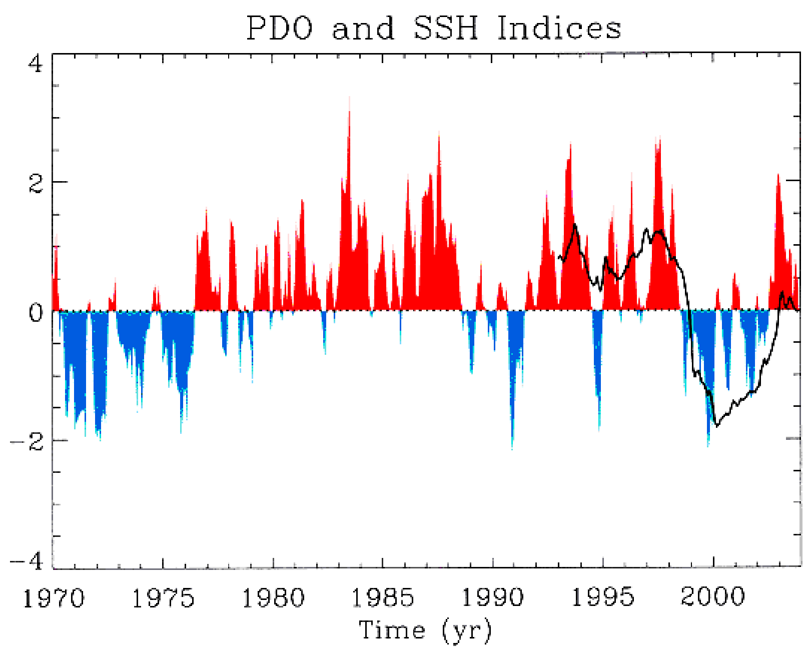


Figure 10. The PDO index is given with blue indicating the PDO cold phase and red the warm phase. The solid black curve gives the SSH index (SSHI) with positive (negative) values indicating elevated (lower) sea level off the west coast of North America.

The EOF analysis of SSH was applied to a northeast Pacific region delimited in the east and north by the coast of North America, in the west by the dateline at 180°W, with a southern boundary along 30°N. This is a smaller region than used for the PDO index, and it focuses attention specifically on changes occurring for the region that provides the major habitat of northeast Pacific salmon stocks. (The SSH index has little sensitivity to use of an expanded region for the analysis.)

Fig. 10 shows the recent history of the PDO index, along with the SSHI for the period January 1993 to December 2003. (The SSHI, which is restricted to a region of the Pacific in and adjacent to the Gulf of

Alaska, might place more weight on the PDO and Victoria modes of the Pacific Decadal Oscillation that are associated with the Aleutian Low Pressure System.)

The PDO mode and SSHI are clearly related, as illustrated in Figure 10. However, SSHI is less subject to high frequency variability, which is preferable for characterizing long term changes in the state of the ocean. The probable reason for this is that SSHI depends on heat and motion over the entire depth of the ocean, whereas SST is sensitive to temperatures at the ocean surface only. Accordingly, SSHI has greater "inertia" than SST and so is less subject to short term variability. Put differently, the decorrelation time scale of SST is shorter than that of SSHI.

Both indices in Figure 10 indicate that significant changes in the state of the North Pacific occurred during 1998/99 and that these changes persisted until 2002. These changes are marked by colder SST and lower sea surface height over the northeast Pacific. However, in late 2002 a weak El Nino event in the tropics set up atmospheric conditions that produced anomalously warm SST and higher SSH over the northeast Pacific, leading to a change of sign in the PDO index, along with positive but small SSHI anomalies. By the end of 2003 the SSHI had dropped to low amplitude.

Gulf of Alaska

Large-Scale Air-pressure Anomalies

Much of the decadal variability in the Gulf of Alaska ocean conditions is explained by persistent wind patterns over the gulf that set up regimes in the ocean. These regimes can shift within a year should the winds change.

The four panels of Figure 11 are annotated versions of those published by Bond *et al.* (2003) to explain some of the unusual features of the gulf. The left panels are averages of sea-surface air-pressure simulations by the U.S. National Center for Environmental Prediction (NCEP). Arrows in the left panels show anomalies in the winds due to the atmospheric pressure systems. These winds in the Northern Hemisphere always blow clockwise around the high air pressure system, counter-clockwise around a low. The right panels present averages of the sea surface temperatures. (See the following web site for a summary of Bond *et al*. 2003): http://www.gsfc.nasa.gov/topstory/2004/0226northpacific.html)

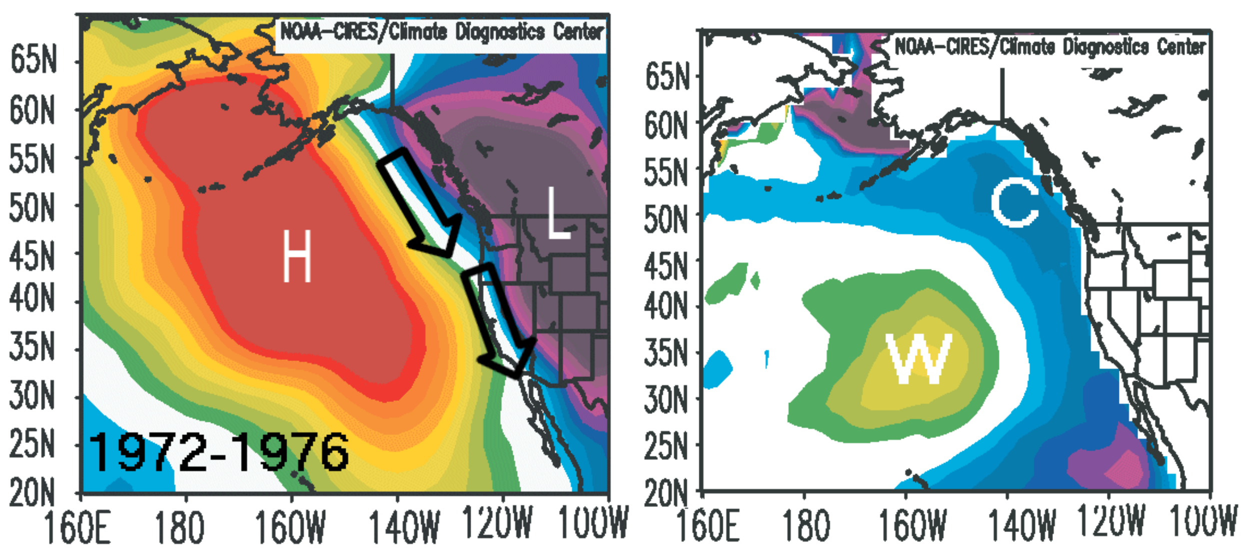


Figure 11a.   Left panel presents sea-surface air pressure anomalies in winters of 1972-1976. Letters H and L denote high and low air pressure anomalies. Arrows indicate wind anomalies due to these air pressures. Right panel presents a map of sea surface temperature anomalies in these same winters with W and C for warm and cold (adapted from Bond *et al*., 2003).

The winds of 1972 to 1976 represent the cold phase of the Pacific Decadal Oscillation (PDO), with cool winds blowing from the northwest along the west coast of North America, or more likely, weaker winds blowing from the southeast. These conditions cooled the waters along the west coast. Waters inside an atmospheric high pressure system tend to flow into the middle of this system, pushing warm surface waters and creating a warm anomaly, as noted in the right panel of Figure 11a near 35°N, 160°W.

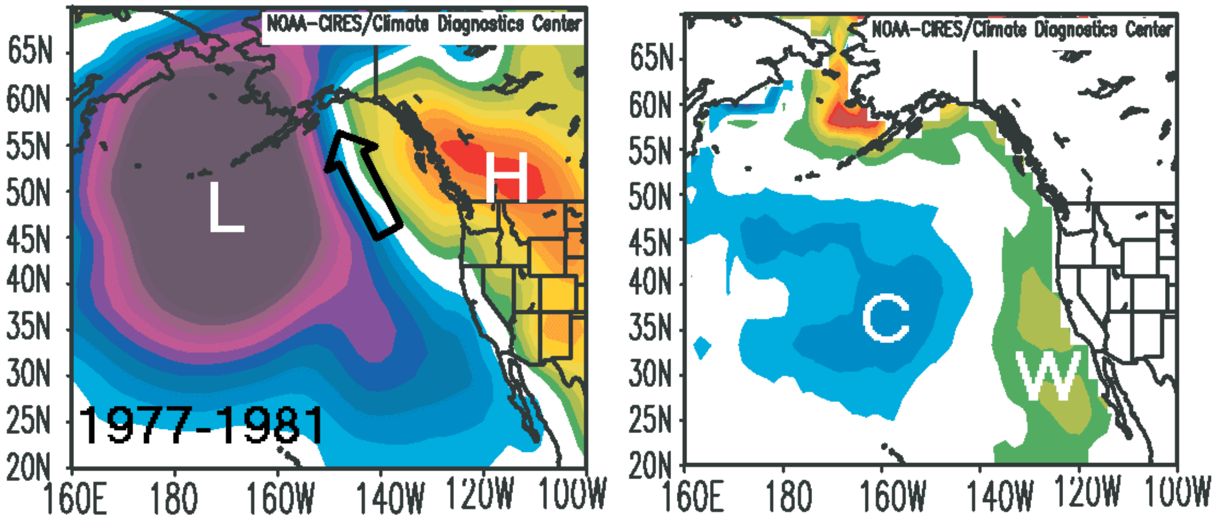


Figure 11b. Left panel presents sea-surface air pressure anomalies in winters of 1977-1981. Letters H and L denote high and low air pressure anomalies. Arrows indicate wind anomalies due to these air pressures. Right panel presents a map of sea surface temperature anomalies in these same winters with W and C for warm and cold (adapted from Bond et al., 2003).

Following El Niño of 1976/77 the Gulf of Alaska winter air pressure shifted to a warm phase of the Pacific Decadal Oscillation that lasted almost to the end of the 1980s. Air pressures of the 1977-1981 winters display this pattern in Figure 11b, almost the reverse of the cool phase that preceded it in 1972-1976. With these conditions in 1977-1981 the warm winter winds accelerate from the south along the west coast, pushing warm waters northward along the coast. These winds give the El Niño waters a boost and push them far northward along the coast. When El Niño hits, it often deepens the Aleutian Low further and increases the winds even more. For this reason, the warm phase of the PDO enhances El Niño warming around the Gulf of Alaska coast. Surface ocean waters inside an atmospheric low pressure system tend to flow out of this system, creating a cold anomaly near the centre of this low, as noted in the right panel of Figure 11b near 35°N, 160°W.

During the strong La Nina of 1999 it at first appeared that the PDO had reversed again to a cool phase. Instead, it did indeed shift phases but also changed its shape, and winters of 1999 to 2002 experienced high air pressure in the south of the region of Figure 11c only. The northern part of the Gulf of Alaska saw lower air pressures, centred closer to the Aleutian Islands than in the previous cool phase. This mode of circulation has been observed previously, but its strength in this period was unusually strong, and it is now referred to as the Victoria Mode. Winds from the northwest brought cold ocean temperature anomalies to the west coast of the lower 48 states of the USA. Canadian and Southeast Alaskan coastal regions experienced less severe anomalous ocean anomalies. Again, warm water appeared inside the atmospheric high pressure system near 33°N, 170°W.

The Victoria mode failed to survive the weak El Niño of 2002 to 2003, and the air pressures of this winter (Figure 11d) resembled typical El Niño winters and warm (positive) PDO. The stronger winds from the south along the coast brought warmer waters to the coast at surface, but failed to penetrate below 100 metres depth, leaving the cold waters at 100 to 150 metres below surface, as noted later in this section. Cold ocean surface water appeared inside the atmospheric low pressure system near 43°N, 170°W.

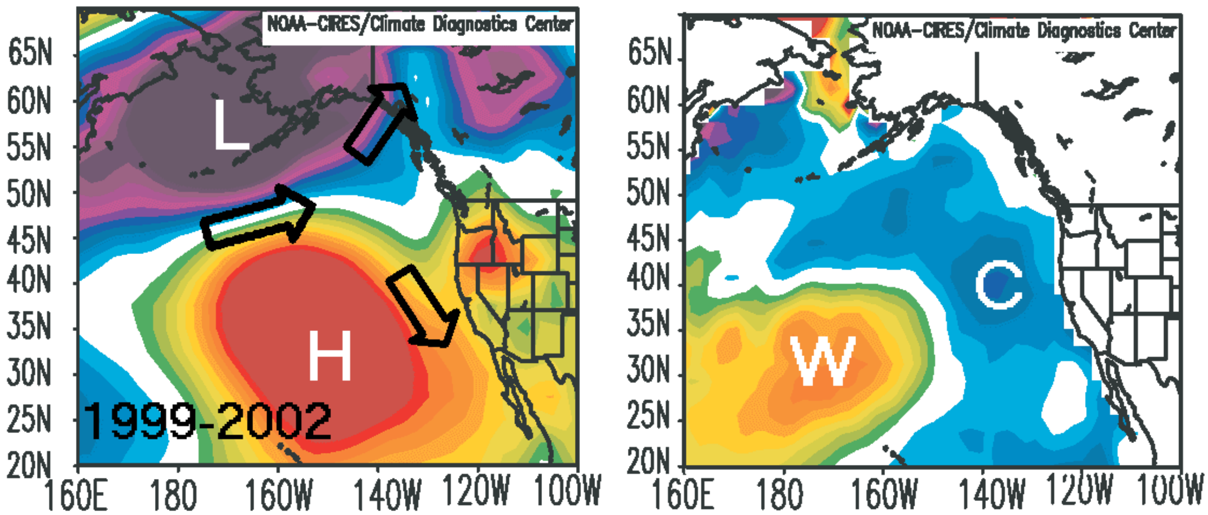


Figure 11c. Left panel presents sea-surface air pressure anomalies in winters of 1999-2002. Letters H and L denote high and low air pressure anomalies. Arrows indicate wind anomalies due to these air pressures. Right panel presents a map of sea surface temperature anomalies in these same winters with W and C for warm and cold (adapted from Bond *et al*., 2003).

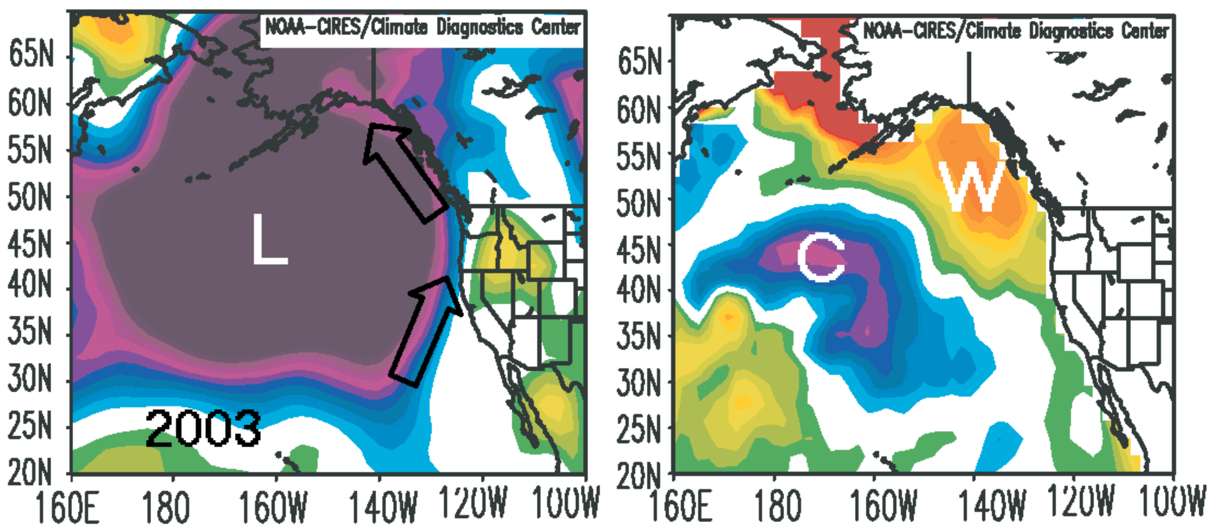


Figure 11d. Left panel presents air pressure anomalies in winter of 2003. Letters L denotes low pressure anomaly. Arrows indicate wind anomalies due to these air pressures. Right panel present a map of sea surface temperature anomalies in these same winters, with W and C for warm and cold. (adapted from Bond et al., 2003).

Conditions along Line-P and at Ocean Station Papa in the Gulf of Alaska

Temperature Anomalies

Line-P is a survey section sampled by Fisheries and Oceans Canada three times each year to monitor changes in water properties. The section extends 1400 km from the southern coast of Vancouver Island to Ocean Station Papa (OSP) at 50˚N, 145˚W in the Gulf of Alaska. The Newport Line is sampled regularly by American oceanographers. Both are plotted in Figure 12.

We saw an inflow of cold sub-Arctic water at 120 metres depth along Line-P and the Newport Line in the eastern Gulf of Alaska during 2002 and extending into early 2003. Coincidental with this cold event was a large-scale warming of the surface waters of the eastern Gulf of Alaska. These events were described by

Freeland *et al* 2003 with additional information published by Bograd and Lynn (2003), Kosro (2003), Wheeler *et al* (2003). Both the warm and cold anomalies weakened in 2003 and early 2004.

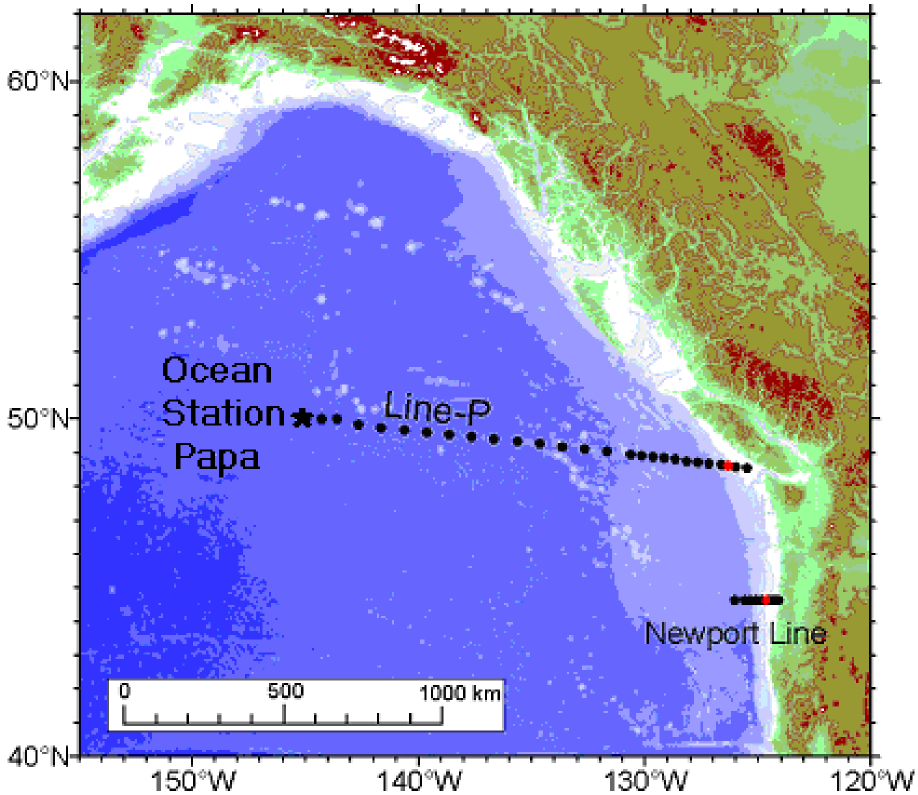
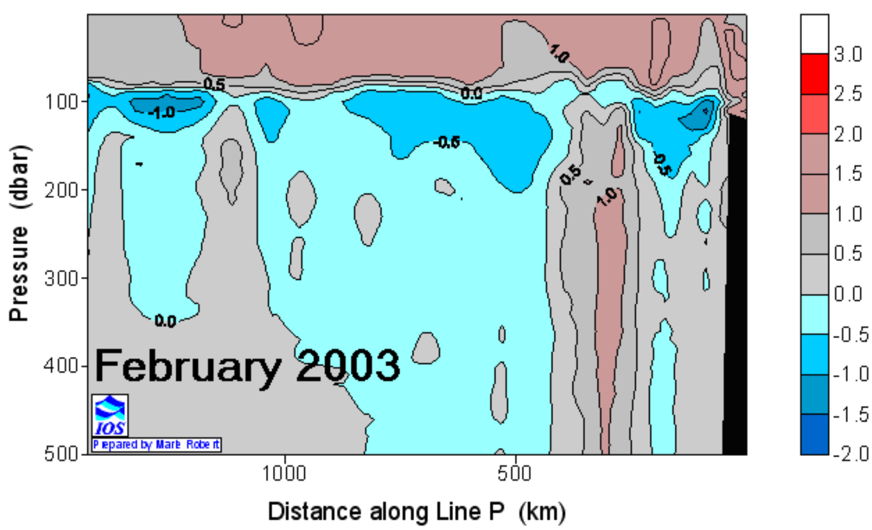


Figure 12. The locations of the Newport Line and Line-P of oceanographic stations. Red dots denote stations on the continental slope with anomalously cold water in 2002.

The three diagrams in Figure 13 show the deviations from normal temperature along Line-P in February (mid-winter in the Gulf of Alaska) and July of 2003, as well as in February 2004. The low-temperature intrusion just below 100 metres depth that was very strong in February 2002 (not plotted) was weaker but still present in February 2003, and weakened further in February 2004. The very warm near-surface anomaly also weakened through 2003. The low temperature water just below 100 m depth was also slightly fresher than normal in 2003 and this tended to compensate density change there.



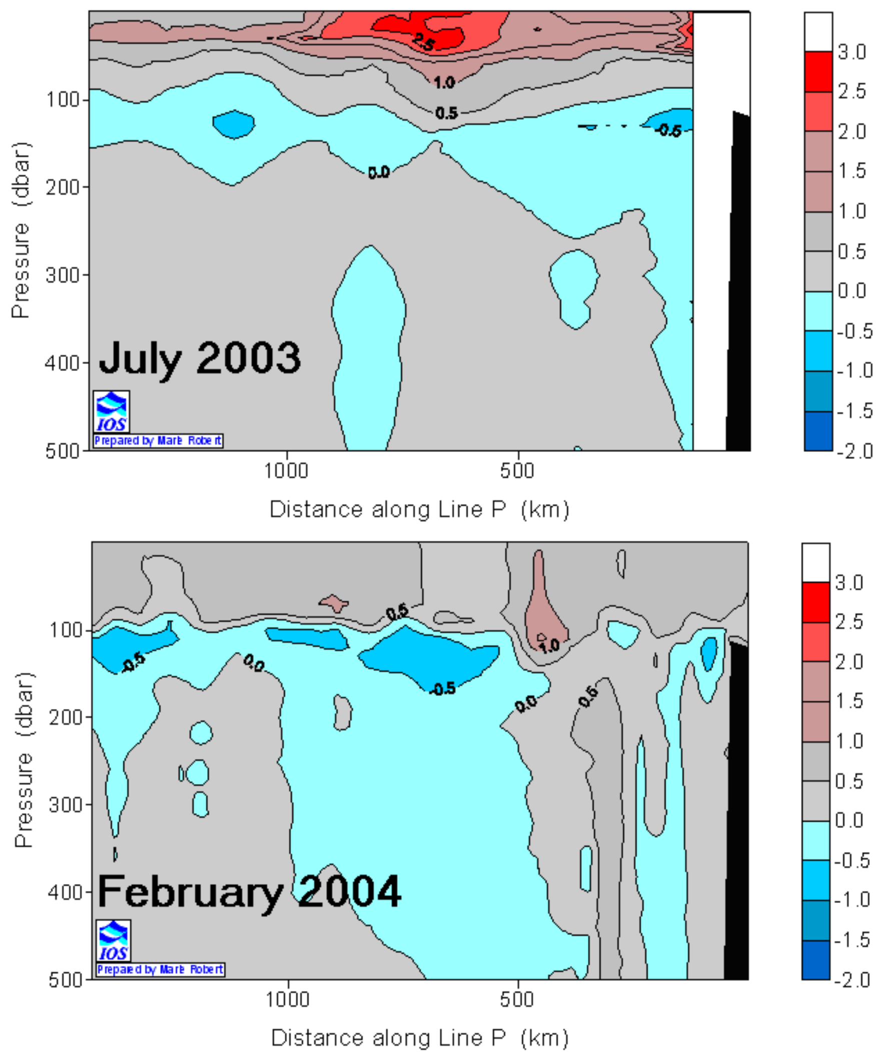


Figure 13: Temperature anomalies (°C) along Line-P westward from Juan de Fuca Strait. Vertical axes denote depth of water as measured by pressure sensors on profiling instruments. An increase of pressure by one decibar (dbar) represents an increase in sea water depth of one metre. February measurements were taken from *CCGS John P. Tully*; July measurements were by Argo profilers.

Temperature at 10 Metres and 120 Metres Depth

Maps below present summer temperatures and their anomalies throughout the Gulf of Alaska at 10 and 120 m depth.

Figure 14 shows maps of average temperatures at 10 and 120 metres depth in summer. These summer ocean temperature maps were prepared from archived profiles of observed temperature during all years with neither El Niño nor La Niña. Summer extends from 1 July to 30 September. Archived data were retrieved from Marine Environmental Data Service in Ottawa, the U.S. National Ocean Data Centre in Washington, DC, and the Institute of Ocean Sciences in British Columbia for the years 1929 to 2002.

These maps show the warmest waters to lie several hundred kilometres west of Vancouver Island, and the coldest waters to be southeast of the Aleutian Islands of Alaska. The band of cooler water on the continental shelf adjacent to Vancouver Island's west coast in summer is part of the process of coastal upwelling, which brings deep cool water to the ocean surface when winds blow from the north or northwest. Such winds are typical in summer all along the Canadian west coast, as well as the US coast to the south. Summers with stronger winds from the North will see cooler surface, and even sub-surface waters along the Canadian and US west coasts.

Cool waters in the northwest Gulf of Alaska are found near 52°N, 152°W, which lies inside the Aleutian Low Pressure System of atmospheric winds in winter. When winter winds blow in the counter-clockwise direction around this low pressure system, ocean surface water is pushed away from mid-gyre and colder water upwells to take its place, lowering the water temperatures at the ocean surface, and even at depths of 120 m as shown in Figure 13. Winters with stronger Aleutian Low Pressure Systems will see even cooler temperatures in this region.

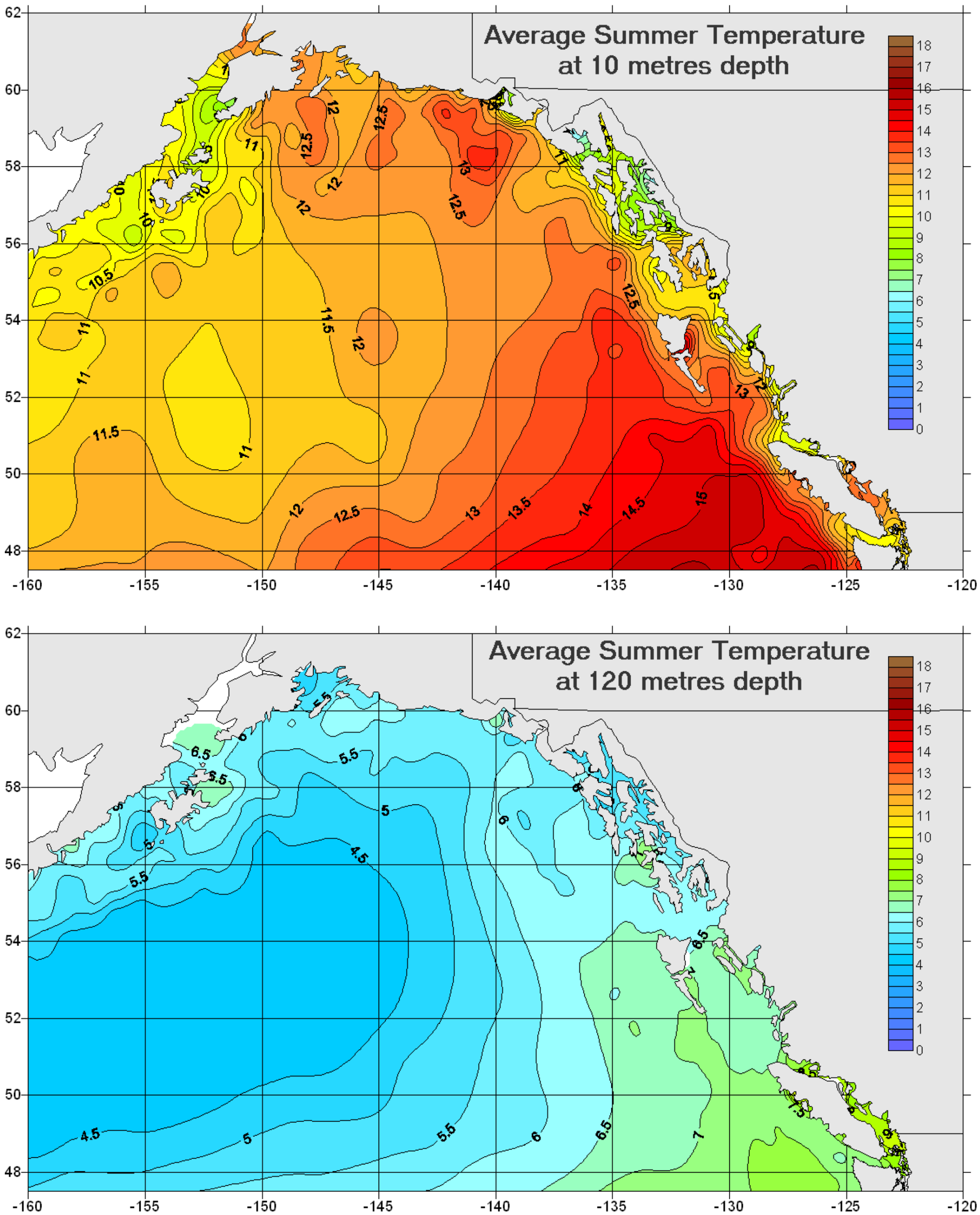


Figure 14. Average summer temperatures at 10 m and 120 m depths (Degrees Celsius).

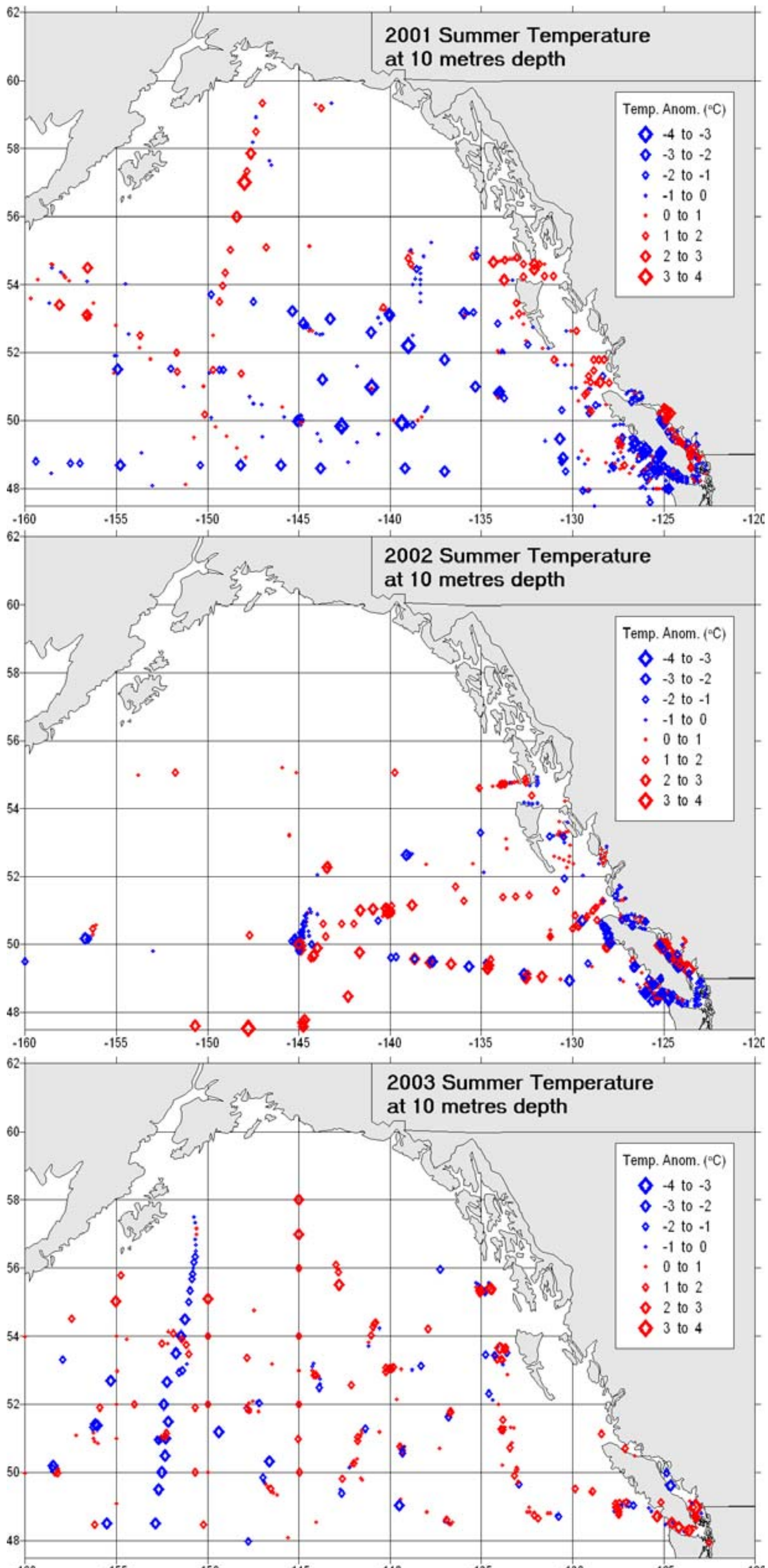


Figure 15. Temperature anomalies (°C) at 10 m depth in summers of 2001 to 2003. The N-S line of cold anomalies near 152°W appears to derive from a single data source of XBTs.

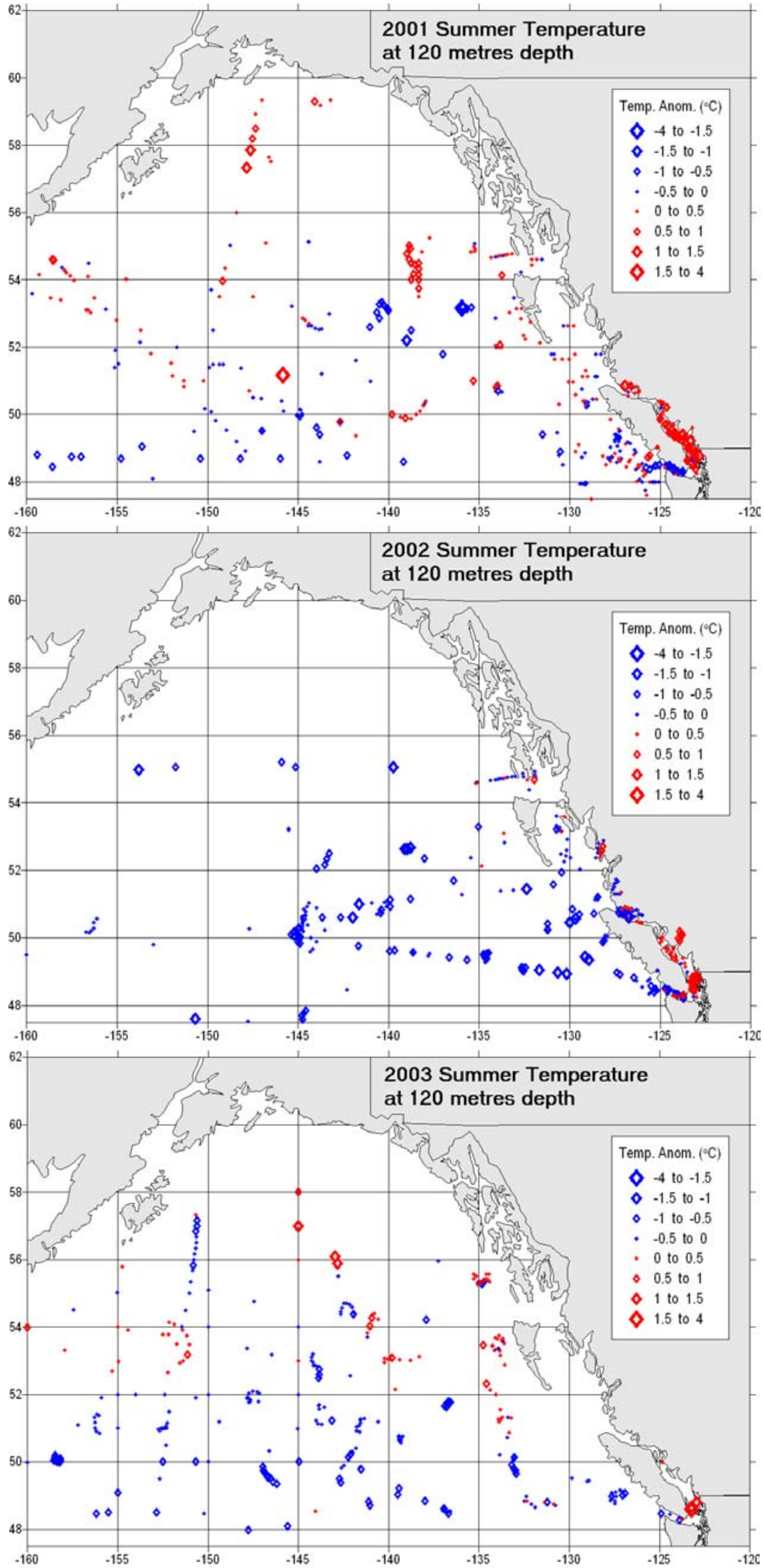


Figure 16. Temperature anomalies (°C) at 120 m depth in summers of 2001 to 2003.

Figures 15 and 16 show the anomalies of ocean temperature at 10 m below surface (Fig. 15) and at 120 m below surface (Fig. 16). Each diamond symbol represents a data point as measured by a CTD profiler on a research vessel, or by an autonomous Argo profiler, or by an expendable bathythermograph (XBT) deployed from a naval vessel or a ship-of-opportunity. The size of the diamond represents magnitude of the warm (red) or cold (blue) anomaly, according to the inset scale on each map. The depths of 10 and 120 m were chosen rather than the more familiar 0 and 100 m depths for several reasons. A 10-m depth is more suitable than the 0-metre depth (ocean surface) for the sampling program of Argo profilers. Figure 13 indicates the cold anomaly was close to 120 m depth.

The maps in Figure 15 show the waters at 10 metres depth were cooler than normal in 2001 in the southeast region of the gulf, and somewhat warmer in the northwest gulf. The cool anomaly weakened in 2002 summer and then reversed in the summer of 2003 near Vancouver Island. Conditions in the northwest gulf in 2002 are not clear, due to lack of observations in the archives. The 2003 warming in the southeast revealed in Figure 15 supports the observations noted in previously, that winds near the west coast pushed more warm water northward at the ocean surface into Canadian waters in 2002 and early 2003. This warming was likely associated with El Niño and the atmospheric air pressure pattern of the winter of 2002/2003 plotted in Figure 11d.

The maps of temperature at 120 metres depth, plotted in Figure 16, show significant cooling in the southeast Gulf of Alaska from 2001 summer to 2002 summer, as noted along Line-P and off Oregon earlier in this report. The cold anomaly weakened somewhat but was still present in the summer of 2003. The winter winds of 1999 to 2002 (See Figure 11c) are suspected to have formed this cold anomaly near the middle of the Alaskan Gyre, and the anomaly slowly deepened and drifted to the south-eastward, reducing temperatures along its path over the next few years. (Crawford *et al*. submitted) The depths from 100 to 150 metres below surface are only weakly influenced by local winter winds, so once a cold anomaly reaches this depth it may persist and spread out for several years. During the winters of 2002/03 and 2003/04 this deep mixing was much reduced, as described later. Therefore, temperatures at 10 m depth are more quickly altered by changing wind patterns, and the ocean surface currents pattern of 2002 to early 2003 likely warmed the surface waters of the southeast gulf during this period.

To assess changing conditions in early 2004 the temperature anomalies at 120 m depth were determined for ship-based and Argo data only and plotted for winters of 2003 and 2004 in Figure 17. The cold anomalies appear to have persisted. The warm anomalies at 51°N, 140°W in 2003 and northward of 51°N at 141°W and 143°W in 2004 indicate the presence of 200-km-diameter Haida Eddies with warm cores. These eddies will drift westward and dissipate over the next few years.

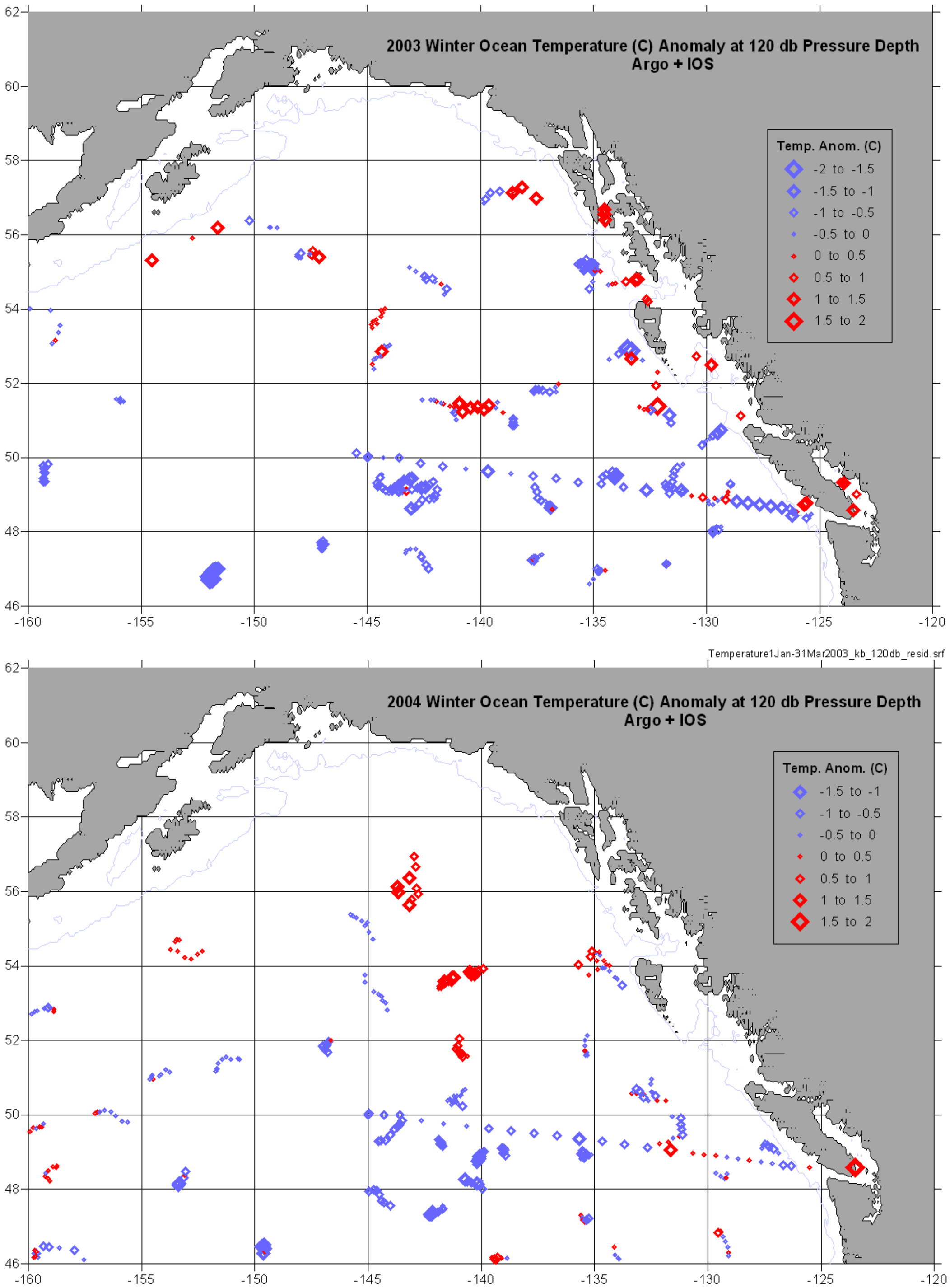


Figure 16. Anomalies of ocean temperature at 120 m depth in the winters of 2003 and 2004.

Temperature Anomalies along Line-P, 1968 to 2003

Canadian scientists have measured ocean temperature carefully along Line-P since the 1960s, with measurements since 1968 of sufficient frequency to track the changes in temperature at different depths. A long-term perspective of this water mass is provided in two panels in Figure 18, showing anomalies of temperature along Line-P, vertically averaged from ocean surface to 50 m depth, and from 100 to 120 metres depth. This plot includes the 2003 summer observations.

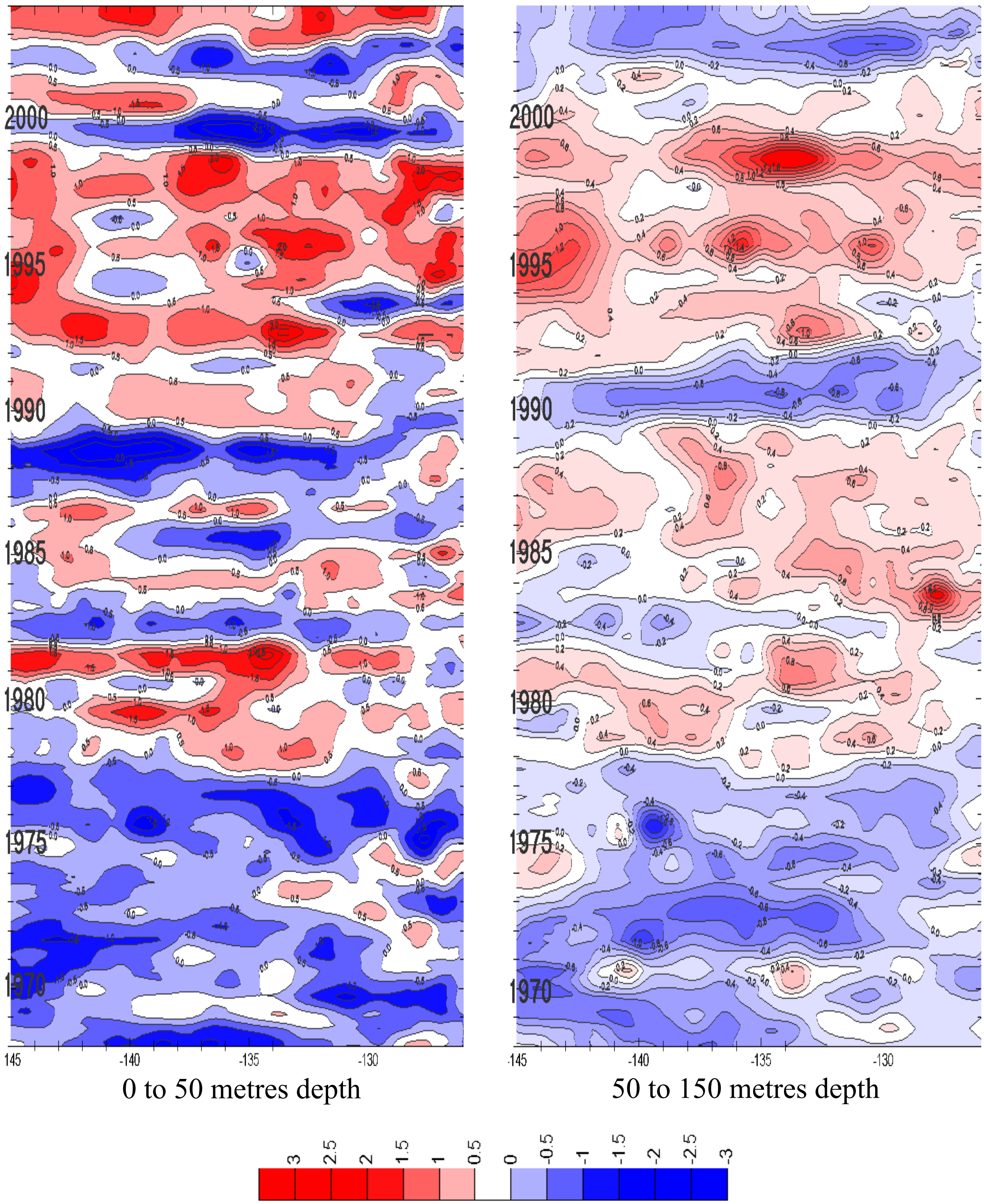


Figure 18. Anomalies of temperature in summer along Line-P, averaged between two depth ranges below the ocean surface. Scale bar above displays the temperature anomaly in degrees Celsius. Longitude along Line-P is plotted along the bottom axis. Continental Shelf is at right side of each panel; Ocean Station Papa is at left side, at 145°W. Year is plotted along the vertical axis.

In most summers the anomalies in both layers are similar, but in 1990 to 1991 and again in 2003 to 2004 a cold sub-surface anomaly was found below a warm surface anomaly. Both events followed cold La Niña conditions, and we suspect the cold waters at surface during La Niña events took a year or more to extend down to sub-surface waters at 100 to 150 m depth, and then persisted in this deep layer while surface waters were warming.

Mixed Layer Depth and Nutrient Supply at Ocean Surface

Phytoplankton growth depletes the store of nutrients in surface waters in spring and summer. These surface nutrients in mid-gulf are renewed in the autumn and winter when storm winds mix nutrient-rich, subsurface waters up to the surface, creating a nutrient-rich surface layer for plankton growth the following spring. A typical mixed layer depth at winter's end at Ocean Station Papa is 110 m. Shallower mixed layers typically hold fewer nutrients. Large density differences between surface and 75 metres depth inhibit deep mixed-layer formation, as do weak winds in autumn and winter, so two important indicators of nutrient supplies are density differences (**stratification**) in late summer, and **mixed layer depth** in winter in mid-gulf. Nutrient levels in subsurface waters are a third factor that will be discussed later.

Stratification in the upper ocean is determined mainly by temperature and salinity changes. Figure 19 shows these changes with depth over the 2002 to 2004 winters at Ocean Station Papa. **Mixed layer depth** for each winter is indicated in the salinity graph. Note that deeper mixed layers tend to be cooler and saltier, because they contain a higher fraction of cold, salty, subsurface seawater.

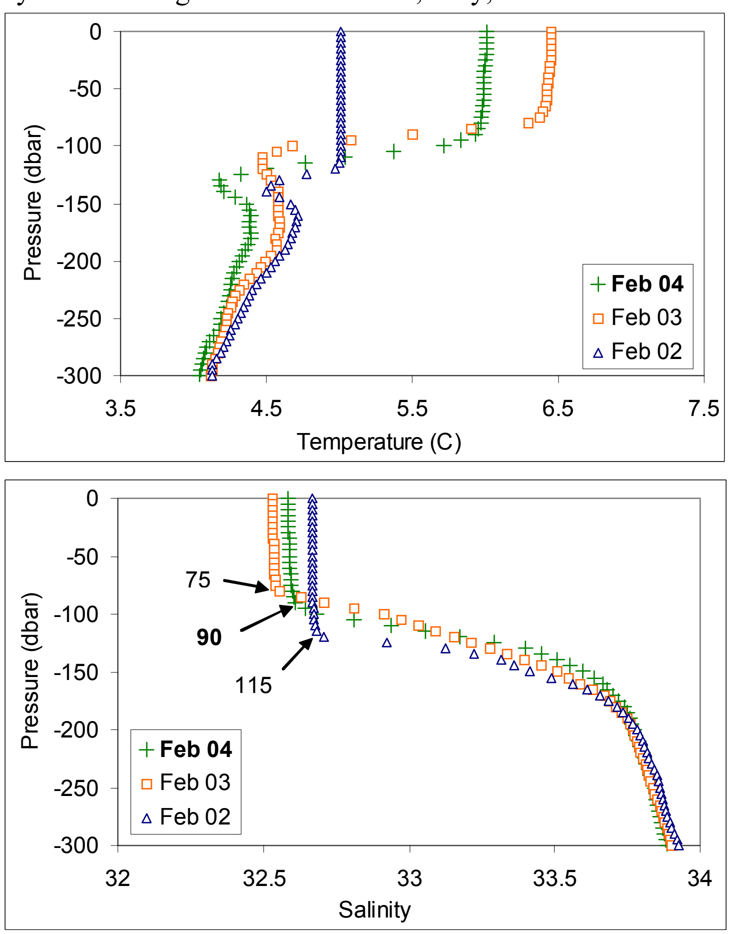


Figure 19. Temperature and salinity profiles at Ocean Station Papa in February of 2002 to 2004. The pressure in decibars (dbar) along the vertical axis corresponds to the depth in metres.

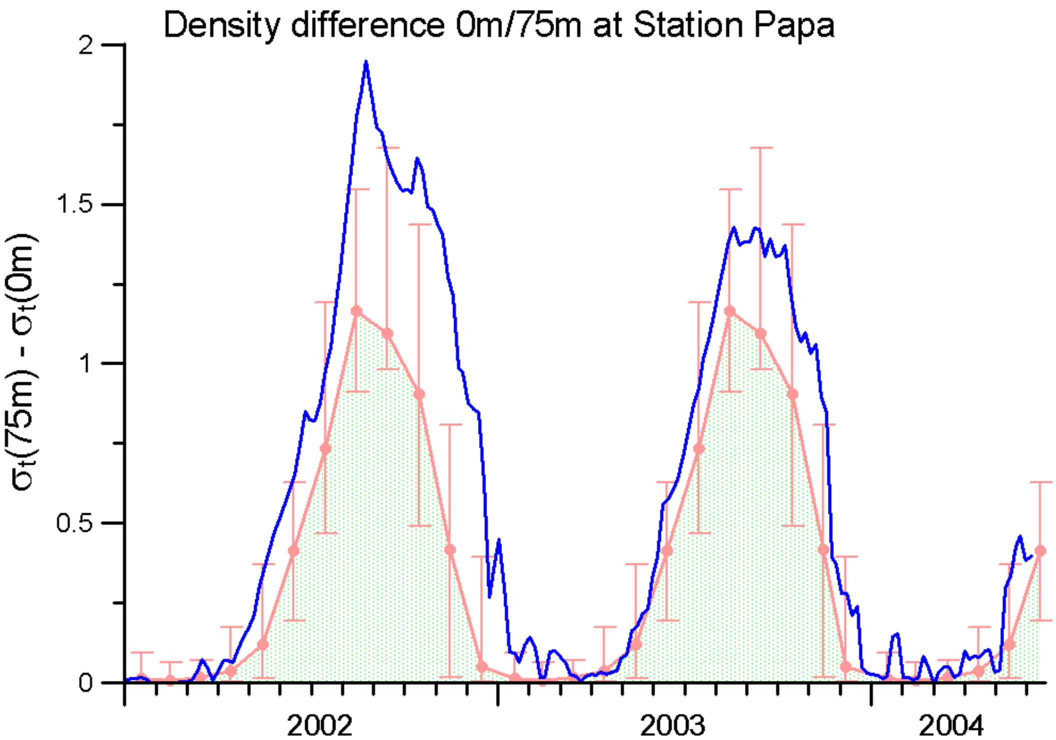


Figure 20. Blue line reveals the density difference between ocean surface and 75 metres depth at Ocean Station Papa through 2002, 2003 and into 2004 observed by interpolation from the Argo array. Density is measured in units of sigma-t (σ_t), defined as the density of water in kilograms per cubic metre, minus 1000. Faint red line shows the average monthly difference in the historical record. Vertical bars enclose 95% of all historical observations.

Figure 20 shows a plot of the stratification near Ocean Station Papa in the top 75 m of the ocean through 2002, 2003 and into 2004. The blue line is the observed near-surface stratification at 10-day intervals and the faint red line is the long-term, monthly average over all observations at Ocean Station Papa. The vertical red bars enclose 95% of all historical observations for each month. This diagram tells us that the stratification of the upper ocean in mid Gulf of Alaska was exceedingly strong prior to the winters of 2002/03 and 2003/04. Stratification was unusually strong in spring of 2004.

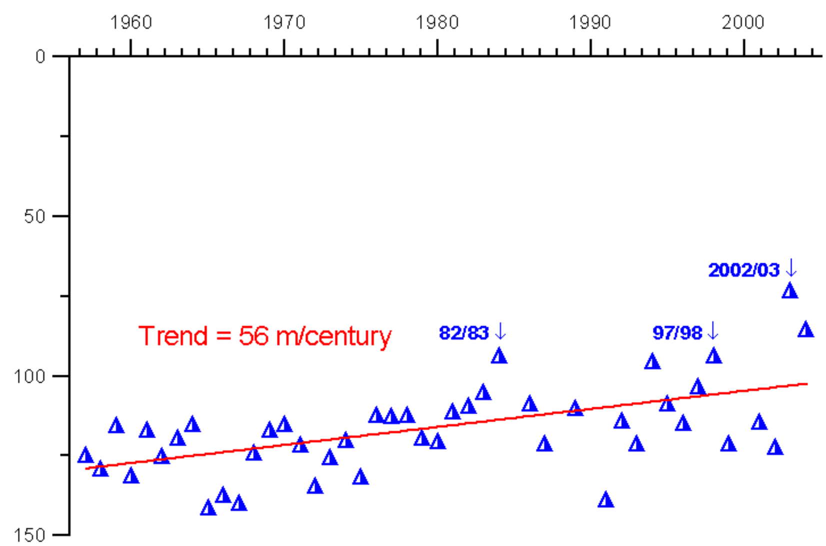


Figure 21. The time series of mid-winter mixed layer depths from 1956 to 2004. El Niño took place in each of the three annotated winters. The final El Niño winter was much weaker than the first two, but produced a shallower mixed layer depth. Note the absence of observations in the 1999/2000 winter.

Figure 21 shows the time history of estimates of the mid-winter mixed layer depth at Ocean Station Papa. The mixed layer depth at Station Papa was estimated at only 76 metres depth in February 2003, and 87 metres depth in 2004. These are two shallowest mixed layers observed at Ocean Station Papa since 1956; however, surface nutrient supply is also governed by the **nutrient concentrations of subsurface waters**. During the 1990s, warm, saline, nutrient-poor waters advected northward into the Gulf of Alaska during persistent El Niño conditions (Fig. 22), reducing nitrate (a typical nutrient indicator) concentrations at Ocean Station Papa in both surface and subsurface waters for several years. Once the 1997/98 El Nino ended, winter nitrate levels began to return to the higher levels commonly observed in the 1970s, reaching peak levels in the 2001/02 winter (see Whitney and Freeland, 1999).

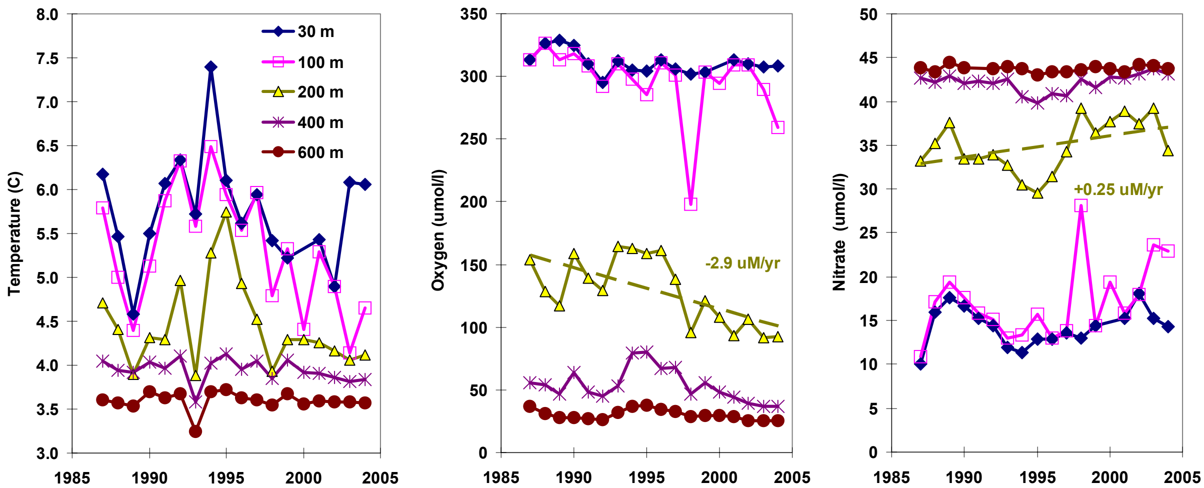


Figure 22. Ocean Station Papa temperature, oxygen and nitrate at fixed depths for late winter from 1987 to 2004.

These conditions at Ocean Station Papa represent nutrient levels in mid Gulf of Alaska. The following discussion includes regions along Line-P closer to the British Columbia coast. By late summer, three distinct regions along Line P can be defined by nutrient supply as labeled in Figure 23.

1. *Coastal*, in which surface nutrients are re-supplied via summer upwelling and tidal mixing.
2. *Transition*, in which surface waters experience seasonal nitrate depletion.
3. *Oceanic*, in which nitrate is never depleted due to iron limitation. This region includes Ocean Station Papa and is labeled High Nitrate-Low Chlorophyll (HNLC).

Higher **winter** nitrate levels were observed in surface waters along much of Line-P in 2003 and 2004, especially when compared with the warm year of 1995 (Figure 23). Nitrate concentrations by late summer of 2003 (Fig. 23) were much higher than in 1995, and similar to the pre-1990s period (Whitney and Freeland, 1999), with a much narrower *transition* zone of nitrate-depleted water.

Summer chlorophyll concentrations are an indicator of primary productivity and available food for predators. Along Line P they show the effect of variable nutrient supply (See Figure 24). Low nutrient supply limits chlorophyll concentration in the *transition* region between about 127 and 134˚ W. In summer 1999 when nitrate was not broadly depleted, chlorophyll averaged 0.3 µg/l whereas the 1995 (<0.1 µg/l) and 2003 (0.1 µg/l) concentrations were much lower. In *oceanic* HNLC waters, chlorophyll levels varied between 0.2 and 0.6 µg/l, these levels being regulated largely by light and iron supply rather than by nitrate concentrations. Chlorophyll levels were an order of magnitude higher in the coastal region compared with oceanic waters (Figure 24), and were relatively high in 2003.

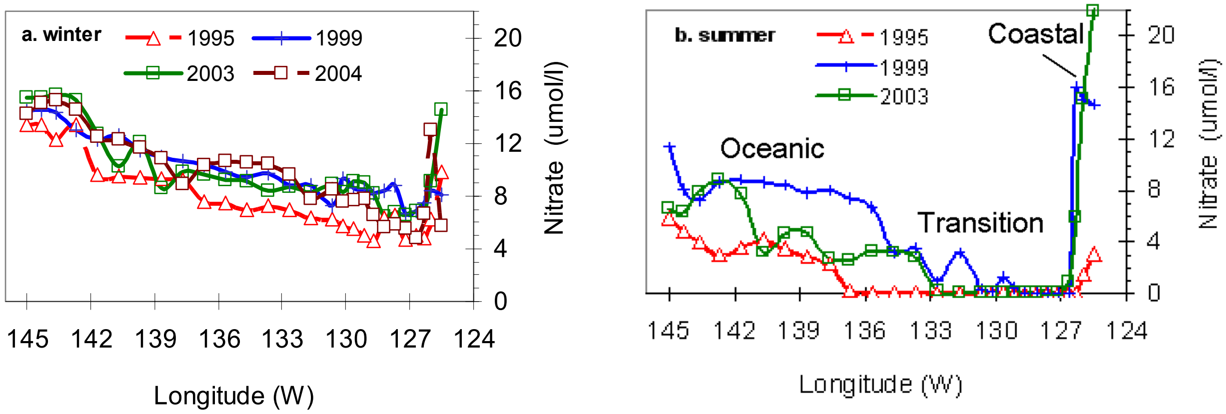


Figure 23. Surface nitrate concentrations along Line P in (a) winter and (b) summer for 2003, as well as for low (1995) and high (1999) supply years.

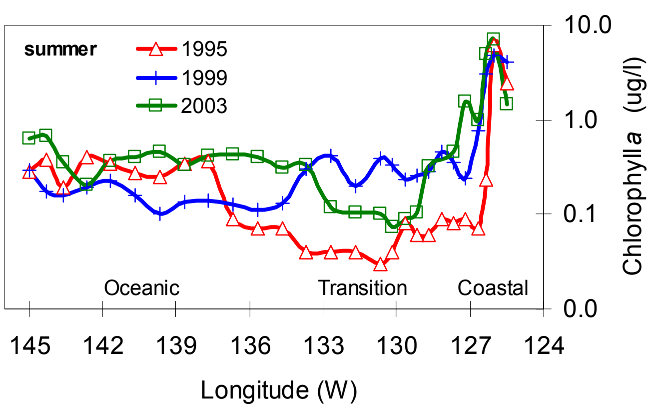


Figure 24. Summer chlorophyll concentrations in surface waters along Line P for 1995, 1999 and 2003. *Coastal* waters include those overlying the continental shelf and slope. *Transition* waters are those influenced by flow from the subtropics, and *oceanic* waters have subarctic characteristics. Note logarithmic scale for chlorophyll.

Surface Currents

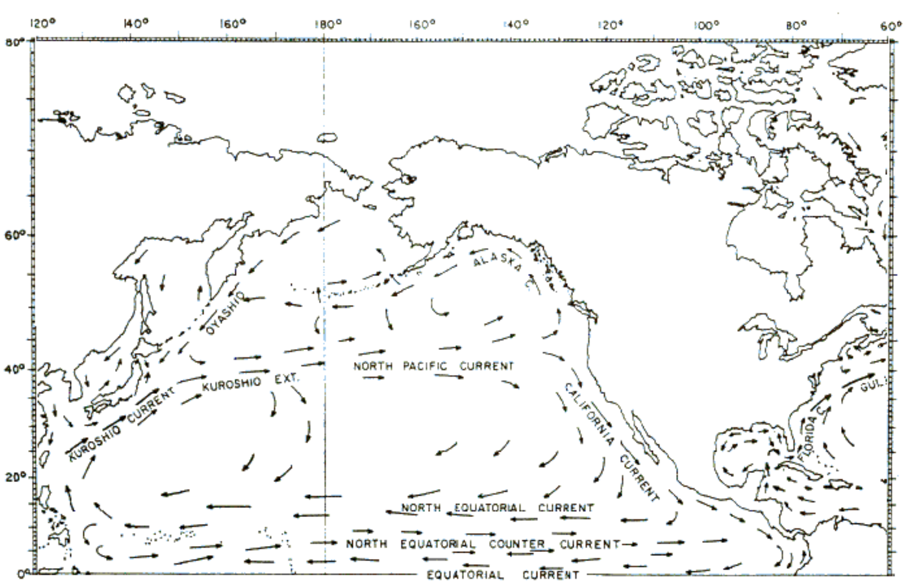
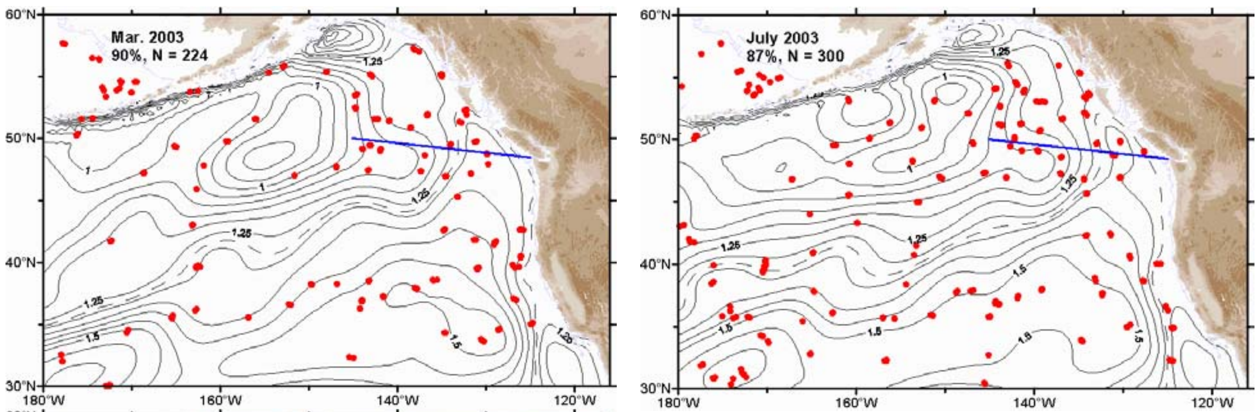


Figure 25: The general circulation of the N. Pacific.

Several of the papers cited early in this report suggested that associated with the unusual events of 2002 and continuing into 2003 were unusual changes in the circulation of the Gulf of Alaska. Figure 25 presents the general circulation of the surface waters of the North Pacific Ocean. The mid-ocean flow patterns are dominated by the North Pacific Current (NPC) which is effectively the broad extension of the Kuroshio Current. The NPC approaches the coast of North America roughly along 40°N and eventually splits into two branches. The northern branch heads northwards along the coast of BC and Alaska as the *Alaska Current* (AC) and the southern branch heads southwards along the coasts of Oregon, California and Baja California as the *California Current* (CC). Many writers have previously suggested that conditions in the Gulf of Alaska or the California Current system might be sensitive to variations in the latitude of this bifurcation region. We examine recent measurements to monitor the area for such variability.



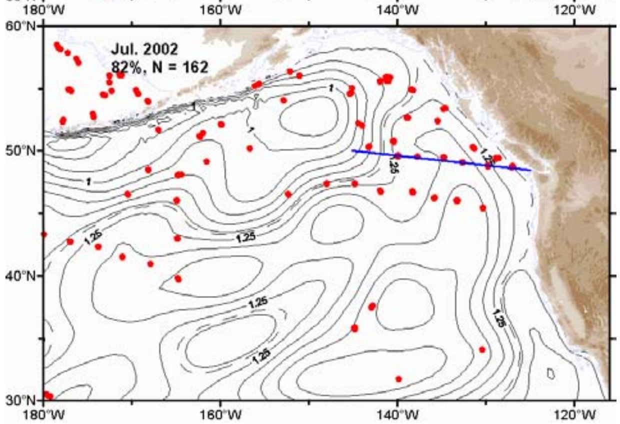


Figure 26: Dynamic height contours in metres of the NE Pacific in July 2002, February 2003 and July 2003 showing some part of the variability observed. Dynamic height is the part of sea surface height anomaly due to density changes and ocean currents, and was calculated at ocean surface relative to 2000 m depth. Ocean surface currents tend to flow along these contours toward the northwest. Dashed line denotes apparent location of North Pacific Current and its extension to the coast. Blue line shows location of Line-P. Red dots are locations of Argo profilers. N is the number of profiles that go into the computation of each map, and the % is the percent of the total variance accounted for by the fit.

The diagrams making up the elements of Figure 26 show some degree of the variability observed. We have computed the surface circulation of the NE Pacific starting early in 2002 when the Argo array was first sufficiently dense to support such calculations. What these show is that the NPC (dashed line in Figure 26) was very much farther to the north in 2002 than it was in most of 2003. Blue lines on panels of Figure 26 show the location of Line-P. Apparently during 2002 and extending into early 2003 the NPC flowed north-westward across Line-P, perhaps explaining the temperature increase in surface waters. The dashed line on each part of Figure 26 is what appears to be “the dividing streamline”. Any water to the north of the dashed line ultimately heads northwards, and anything south of that line eventually becomes part of the California Current.

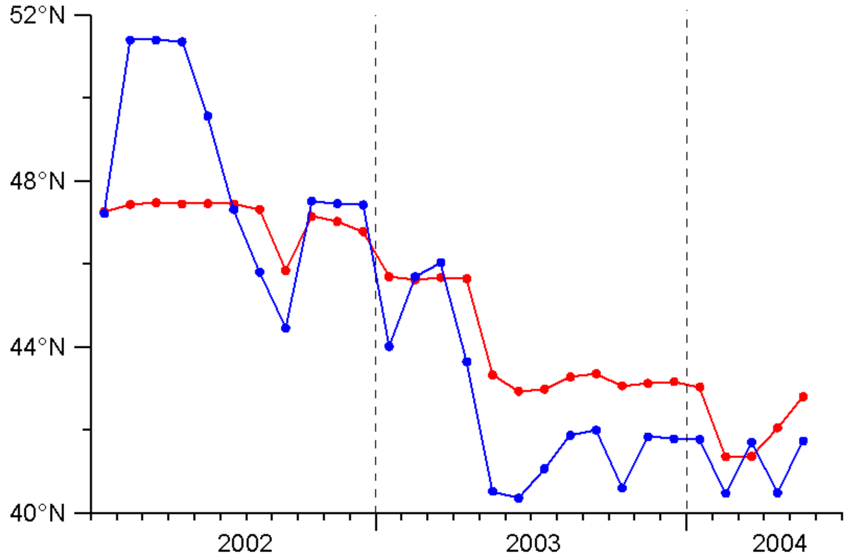


Figure 27: The latitude of the North Pacific Current from Feb. 2002, to May 2004, determined by location of steepest gradient in dynamic height field along 145°W (red line) and 150°W (blue line) longitude in maps of monthly mean dynamic height anomaly. Three such maps are presented in Figure 26.

For each monthly map of the type presented in Figure 26 we searched along a longitude of 145°W (the longitude of Ocean Station Papa) and 150°W for the steepest north-south gradient in the dynamic height field. The latitudes of these entries are presented in Figure 27, showing that the NPC was very much farther to the north in 2002 and early 2003 than it was later in 2003 and early 2004. There appeared to be a rapid southward shift in early 2003, perhaps coinciding with the decay of the Aleutian Low and El Niño in early 2003. The Argo array has been in place for a short enough time that we cannot say from these observations whether 2002 or 2003 is "normal", but the conditions observed in 2003 do appear to be much closer to the generally accepted vision of the circulation of the NE Pacific.

During the period extending from the beginning of 2002 to the beginning of 2004 the circulation of the North Pacific Ocean and the conditions in the Gulf of Alaska have shown remarkable variability. For a large part of this period the stratification of the upper ocean has been exceedingly large, outside of any previous experience during all of our observations at Ocean Station Papa.

Long-Term Sea Level Change

Monthly average sea levels are available since 1910 or so at several British Columbia ports. Time series of annual average levels are presented in Figure 28 for the ports of Victoria, Tofino and Prince Rupert. (See Figure 47 for gauge 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. Dashed lines denote a linear trend in sea level computed over the length of the record, showing increasing relative sea level at Victoria and Prince Rupert, and decreasing relative sea level at Tofino. At Tofino the upward movement of the bedrock exceeds the rate of sea level rise; therefore the local sea level is falling at a rate of 15 centimetres per century. At Victoria and Prince Rupert the local sea level is rising, at rates of 5 and 10 centimetres per century respectively. (These rates have changed by a centimeter or two over recent years with the addition of recent data, increasing during the 1997/98 El Niño and decreasing during low levels of 2000 to 2002.)

El Niño often coincides with high sea levels at these (and other) British Columbia ports. Elevations at all three ports rose in 2003 to levels higher than observed in the previous few years, likely due to the impact of the weak El Niño in late 2002 and early 2003.

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

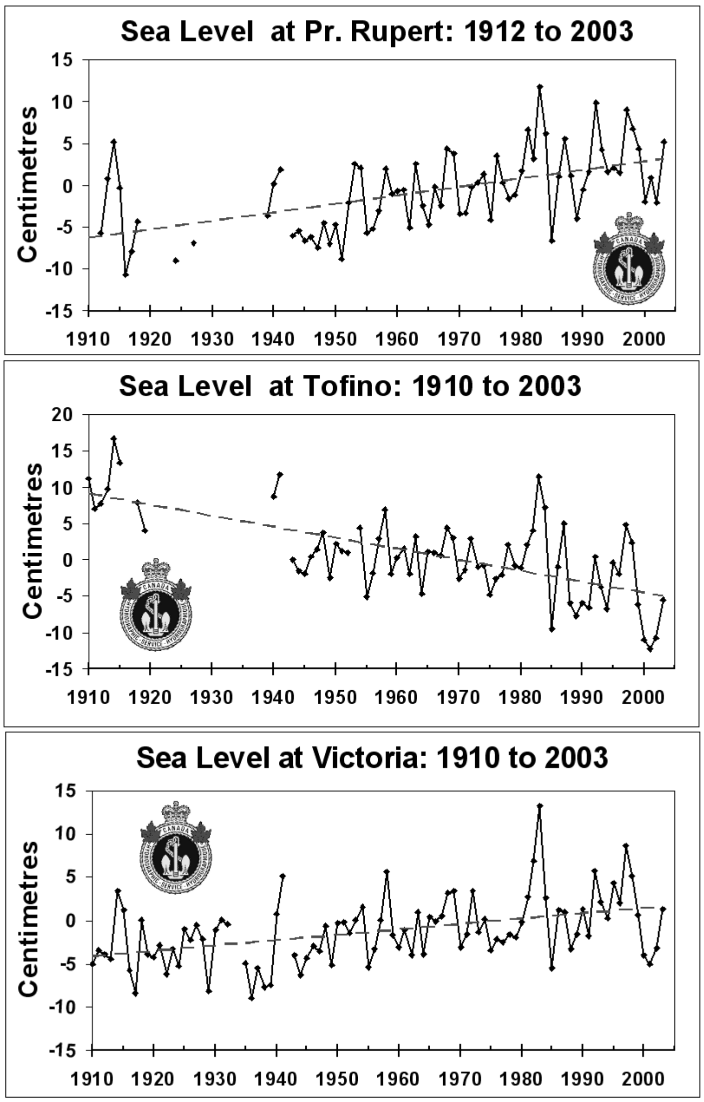


Figure 28. Long-term sea level change. All observations have been collected by the Canadian Hydrographic Service, Pacific Region, and are archived by the Marine Environmental Data Service in Ottawa. Annual average levels are presented for the ports of Victoria, Tofino and Prince Rupert. Dashed line denotes average trend over all years of data. The record at Victoria is almost continuous, other ports are missing data through the early 1900s.

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. The previous major earthquake took place in the year 1700, and sediment records suggest such major earthquakes occur at intervals of 200 to 900 years. Scientists expect the earthquake will be followed by the arrival of large tsunamis at the British Columbia outer coast within 20 minutes or more.

SeaWiFS Global Composite Data

Satellites that measure ocean colour can detect phytoplankton in the ocean surface waters. One such system is the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) on OrbView-2 (OV-2) satellite, funded by NASA of the United States. More information is available at http://seawifs.gsfc.nasa.gov/SEAWIFS.html.

This sensor provide images with a spatial resolution as small as 1 km, but for images below of the Gulf of Alaska we present the 10-km resolution images. Each image is a composite of all measurements by SeaWiFS during the month, comprising averages over many measurements at sites with little cloud cover, or the single measurement if only one cloud-free day occurred. Black areas denote regions of land, or total cloud cover with no measurements.

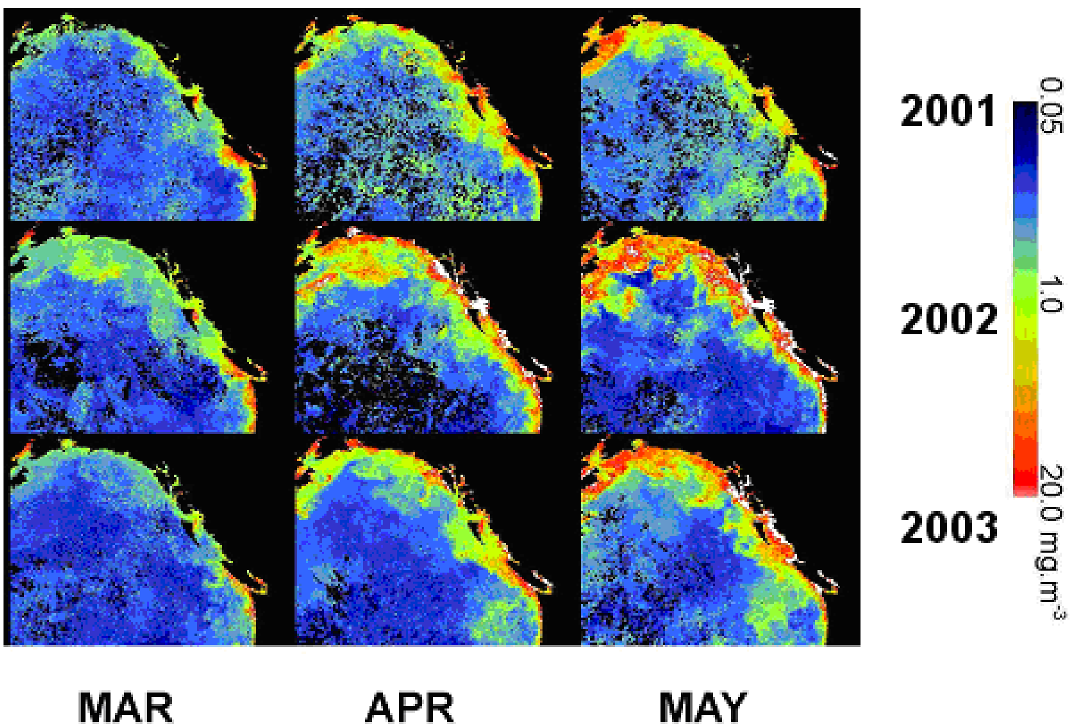


Figure 29. Chlorophyll images for March to May, 2001 to 2003 along with colour scale. The concentration of chlorophyll in surface waters is denoted by colour in the figures above, with blue denoting fewest phytoplankton and red the most. The spring growth sequence for 2003 leads to higher concentrations near shore in May 2003 than May 2001. These concentrations are comparable to 2002, but over a smaller area.

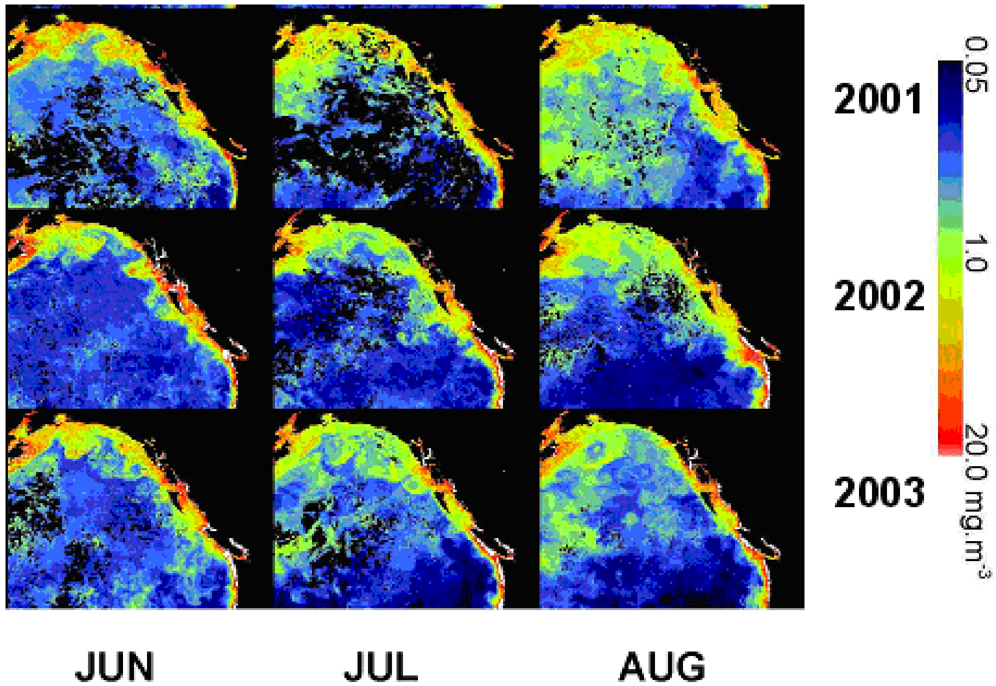


Figure 30. Chlorophyll images for June to August, 2001 to 2003 along with colour scale. Black areas are land or regions which were cloud covered on all days of the month. These are especially common in June and July.

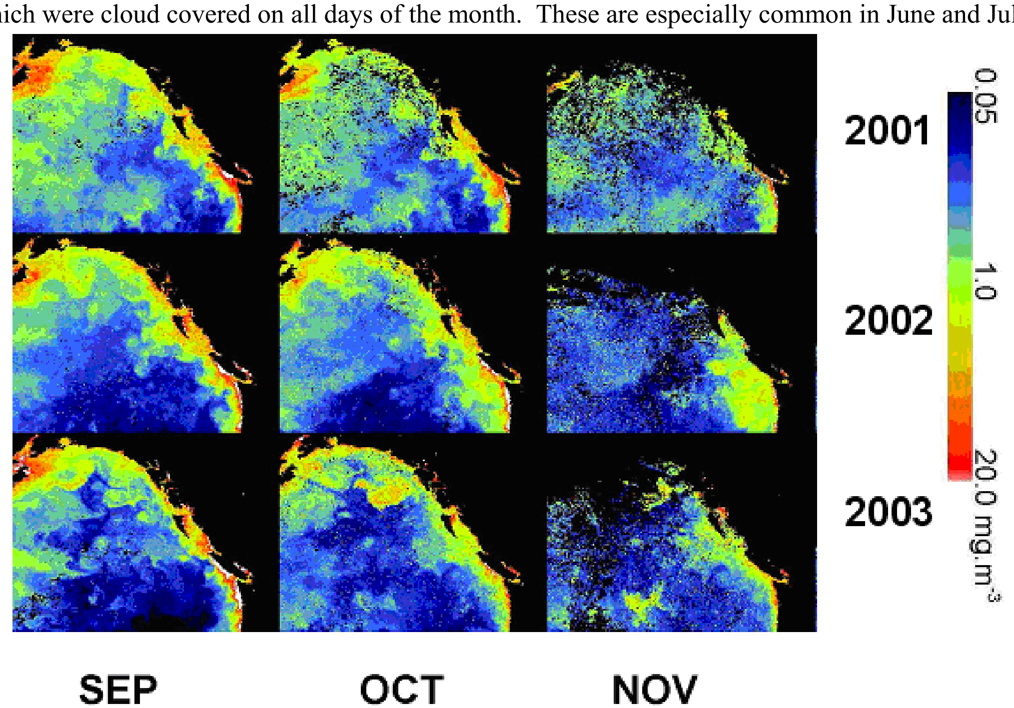


Figure 31. Chlorophyll images for September to November, 2001 to 2003 along with colour scale. Several eddies are visible as relative high or low chlorophyll concentrations. The patch of high chlorophyll in the November 2003 image was not seen in other years.

SeaWiFS data also show water brightness (at 555 nanometres, green light). The data are corrected for lower sun angles in winter, so brightness in the Gulf of Alaska should indicate concentrations of surface scattering material, probably coccolithophores, whose concentration peaks in summer and whose distribution is patchy on scales of a few hundred km. A series of such images is presented next.

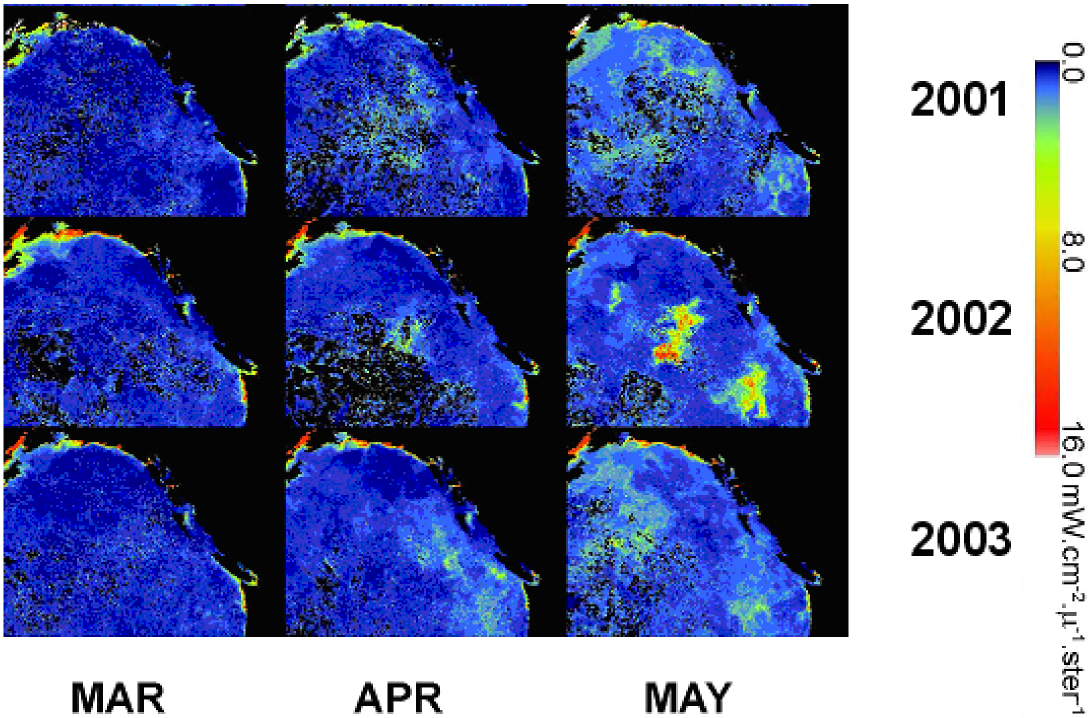


Figure 32. Images of water brightness for March to May, 2001 to 2003 along with colour scale. Patches of very bright water appeared in the Gulf in May 2002. These were absent or of lower concentration in 2001 and 2003. They do not show in the chlorophyll images, suggesting they are caused by a bright species of algae such as coccolithophores.

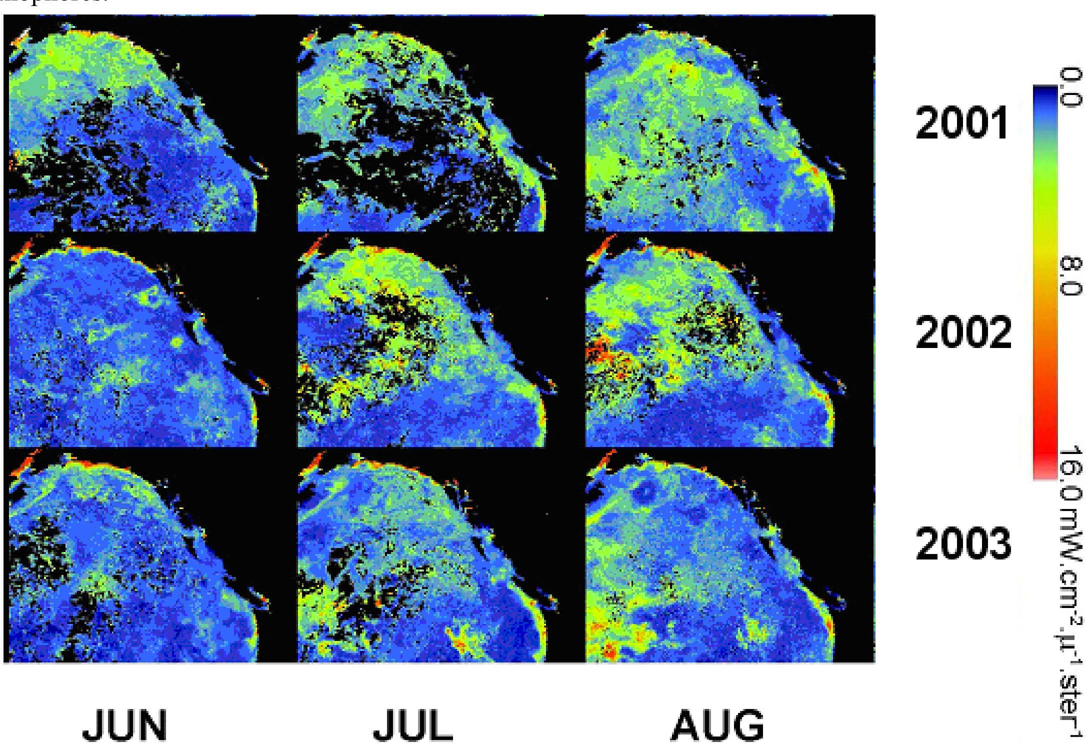


Figure 33. Images of water brightness for June to August, 2001 to 2003 along with colour scale. Black areas over water are clouds, as before. The two eddies in the northern Gulf are visible in both chlorophyll and brightness images.

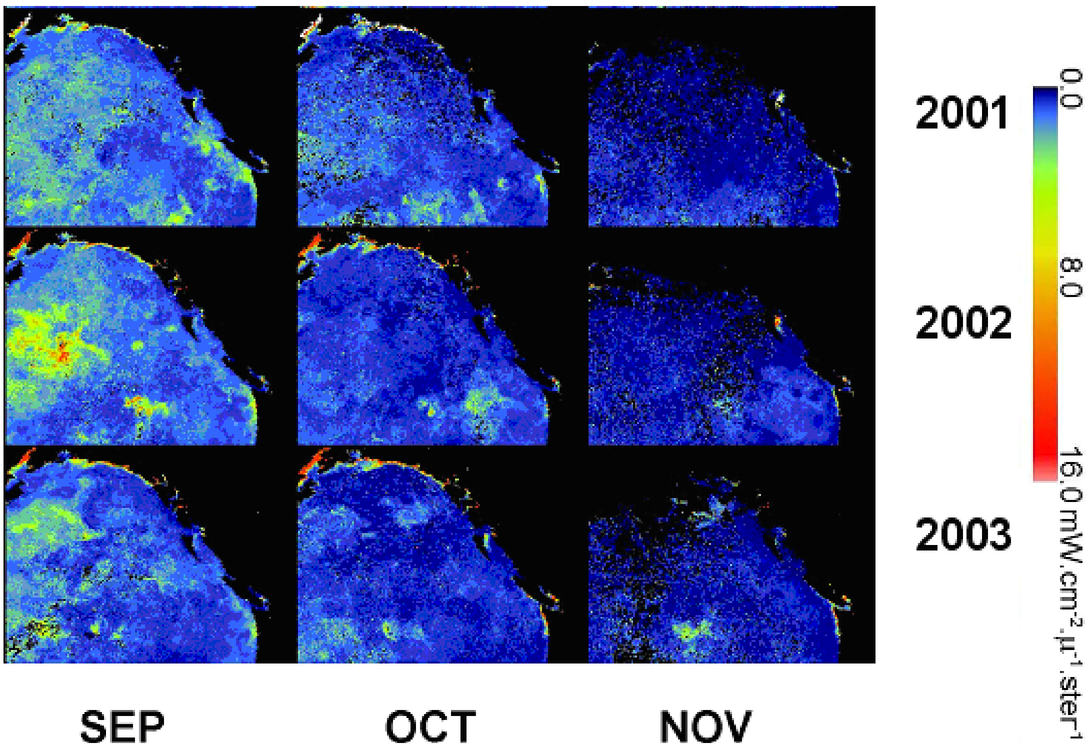


Figure 34. Images of water brightness for September to November, 2001 to 2003 along with colour scale. The patch of high chlorophyll in the November 2003 image is seen here due to its relative brightness.

Zooplankton

A Continuous Plankton Recorder (CPR) was towed behind a commercial vessel on a transect from Alaska to California as a pilot project in 1997 and routinely since 2000 on this transect and one other across the North Pacific (Figure 35). This program in the Gulf of Alaska uses technology developed many years ago for use in the North Atlantic Ocean. Approximately 1800 samples are collected and archived each year in the Gulf of Alaska (transects are sampled from spring to fall) and about 450 samples are processed for zooplankton abundance.

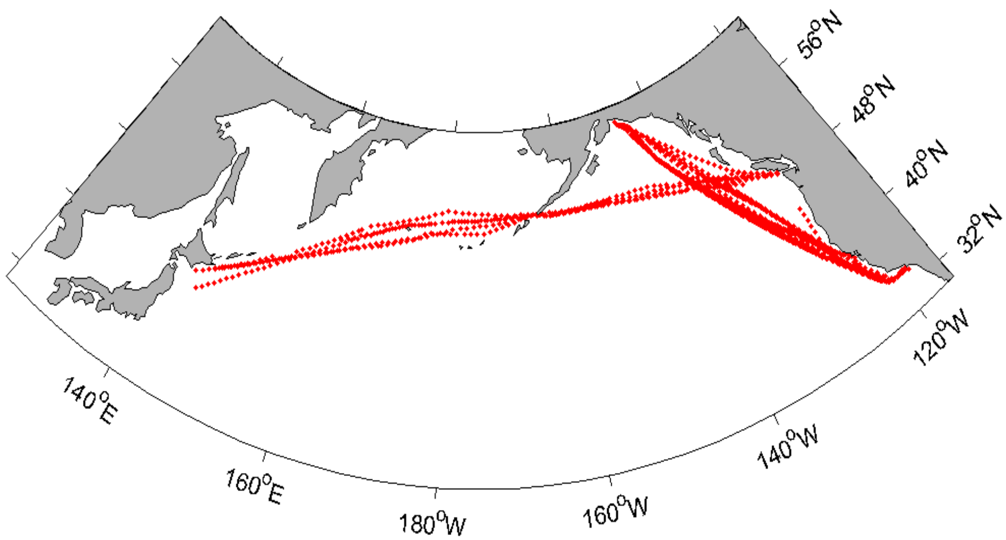


Figure 35. Continuous Plankton Recorder (CPR) sample tracks from 2000-2002.

The normal time taken to process the plankton samples and produce quality-controlled taxonomic abundance data is about 1 year because the Pacific samples are combined with the samples collected in the North Atlantic and processed at Sir Alister Hardy Foundation for Ocean Science (SAHFOS) in the United Kingdom in order of collection. In 2003 it was decided that a subset of the samples would be processed rapidly at the Institute of Ocean Sciences (IOS) within a few months of collection through a collaborative agreement between SAHFOS and Fisheries and Oceans Canada. Summary data would be published on the SAHFOS website (www. sahfos.org) to provide timely information on the status of the plankton populations.

The impetus for this approach was provided by the recognition that 1999 saw a switch in plankton populations in this region from a warm-water community to a cold-water community with consequent changes in various fish abundances (Batten and Welch, in press; Peterson and Schwing, 2003).

Five transects from Alaska to California are normally sampled each year, spaced about 5-6 weeks apart to cover the spring and summer. The subset of samples in 2003 consisted of about 25% of the samples that would normally be processed, spread evenly along the transect (10-13 samples each transect). Until all the samples from each transect have been processed (sometime in late 2004) it will not be possible to determine how reliable the conclusions based on data from this sub-set have been. However, the results show a consistent pattern for each month of 2003, suggesting a good representation of the 2003 plankton populations. Mesozooplankton biomass is a summary parameter that has been estimated from the zooplankton abundance data and the time series for the Gulf of Alaska is shown in Figure 36.

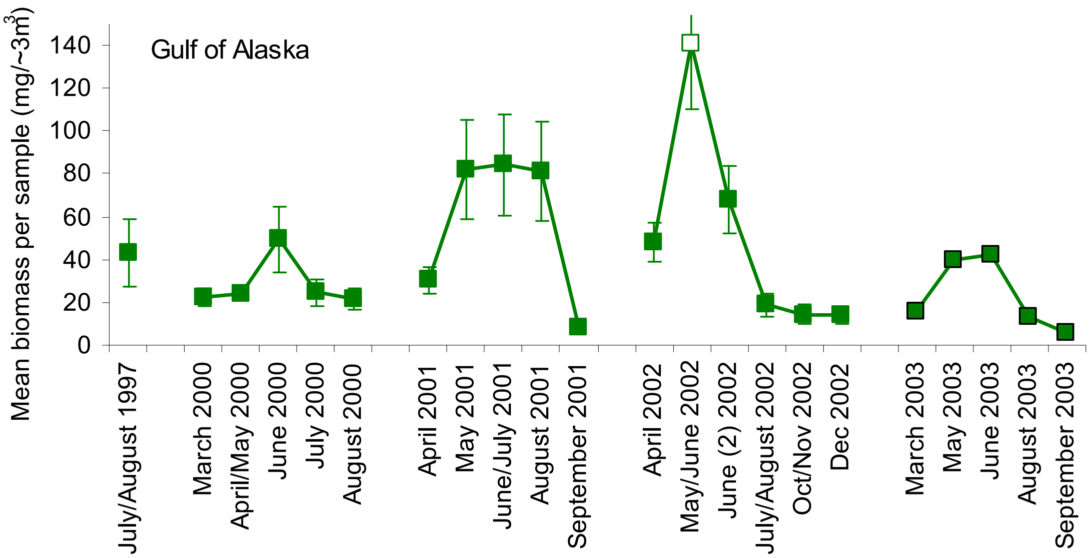


Figure 36. Mean mesozooplankton biomass (± 1 standard error) for the Gulf of Alaska region (the unfilled point in May/June 2002 indicates when the transect was much further east than normal and was probably influenced by shelf populations)

Biomass during spring (May-June) was lower in 2003 than in the previous two colder years by about a factor of 2, although similar to levels observed in 2000 and so not unusual (at least as far as 'usual' can be determined from this short time series). Since changes in species composition are known to occur in this region in response to oceanographic fluctuations (e.g. Mackas *et al*., 2001) two suites of copepod species retained in CPR samples, that could act as indicators of ocean conditions, were examined:

- Boreal species: *Acartia longiremis, Calanus marshallae, Centropages bradyi, Eucalanus bungi, Neocalanus cristatus, Pseudocalanus spp.*
- Subtropical species: *Calanus pacificus, Clausocalanus spp., Corycaeus spp., Mesocalanus tenuicornis*

Mean total abundance of each group was compared for summer samples (late June through August). In 1997 (an El Niño year, surface conditions were warm) subtropical species were abundant right into the northern Gulf of Alaska whereas boreal species were not abundant and only really in the northern areas. In 2000-2002 (cold surface conditions) boreal species became much more abundant and subtropical species were confined further south. For 2003, bearing in mind that only about 20% of the samples have been processed so far, it appears that subtropical species extended further north *and* boreal species were still doing well throughout the region. The latitude at which 75% of the copepods (cumulatively) in each group had occurred was calculated. In the case of subtropical species this meant summing them from south to north (off the shelf only) and the higher the latitude at which 75% of them were found the further north they had spread. For boreal species this meant summing them north to south along the oceanic part of the transect and the lower the latitude at which 75% of them were found, the further south they had spread (Figure 37).

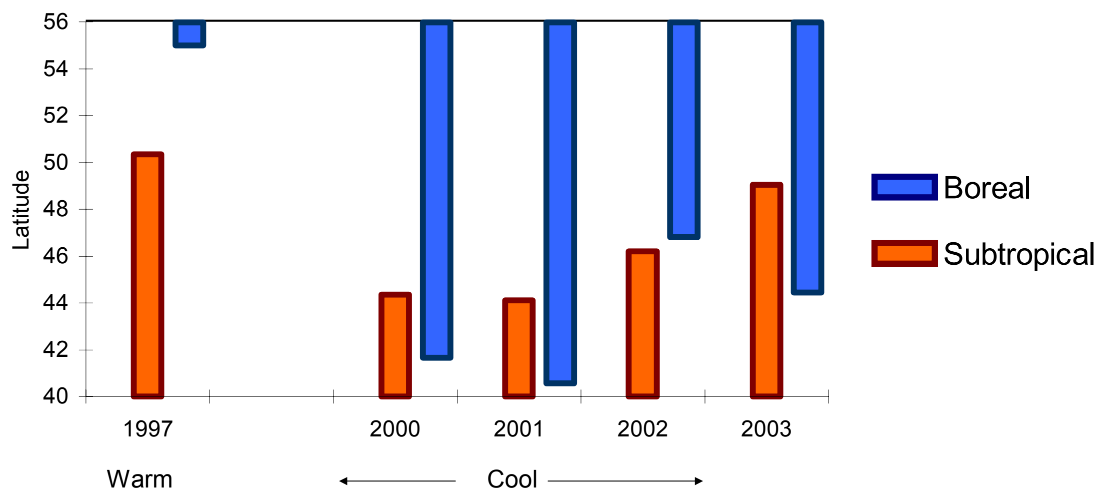


Figure 37. The latitude that 75% of each population of copepods extended to in the summer of each year.

The pattern mentioned above is clear, boreal species were still extending south in 2003 but subtropical species moved further north. Furthermore, 2000 and 2001 saw the most extreme values of these indices and these were the coldest years at the surface. Sea surface temperature anomalies shown on the website at http://www-sci.pac.dfo-mpo.gc.ca/osap/data/sstarchive_e.htm make this clear: In 1997, temperatures were up to 2º warmer than normal along the transect. In 2000 and 2001 they were about 1º colder than normal, and in 2002 they were close to normal. Warm surface conditions also existed in the eastern north Pacific in 2003.

These results could mean that the potential regime shift that was thought to have happened in 1998 is over and there is a return to persistent warm conditions. But the large boreal species are still well spread through the Gulf of Alaska, so conditions have not returned to the pre-1999 state and 2003 could perhaps just be an anomalous year in a continuing 'cool' regime. The boreal species may take a while to 'die out' and several successive years of warm conditions may be needed to cause a retraction in their distribution. It is also interesting to note that even though surface waters were warmer in 2003 there was still an anomalously cold deeper layer present between 100 and 200 metres depth in the winter of 2002/2003 (See Figure 16).

The large boreal species overwinter in these deep layers and it is possible that the winter conditions were favourable for them and produced a strong population the following spring.

The same pattern was also seen in zooplankton sampling from the continental margin off British Columbia (D. Mackas, pers. comm.) where southern species were more frequent than in 2002, but northern species were still abundant. This suggests the signal is wide spread, from the shelf to the open ocean of the Gulf of Alaska. If it persists there may be implications for stocks that forage both coastally and offshore. Overall, these results show the value of processing a subset of the samples quickly, to obtain an earlier picture of how changing conditions may be influencing the oceanic plankton.

Predator and Euphausiid Populations

Euphausiid sampling in Barkley Sound continued in 2003. Figures 38 and 39 present the median annual biomass estimates for larvae (<10 mm) and adults (>9 mm) of the two predominant species (*Thysanoessa spinifera*, *Euphausia pacifica*). Specific size ranges of *T. spinifera* adults are preferred food for Pacific herring (*Clupea pallasi*), Pacific hake, eulachon (*Thaliechthys pacificus*) and coho salmon (*Oncorhynchus kisutch*) smolts, whereas sockeye (*O. nerka*) and chum (*O. keta*) smolts prefer different sizes of *T. spinifera* larvae. Biomasses of *T. spinifera* larvae and adults in 2003 were the lowest in the time series; adult biomass was at least 10 times lower than in most other years and 100 times less than in 2000.

Hake piscivorous biomass in the Canadian Zone appears to have been declining over the 1990's and into 2001 (Fig. 40). However, the 1999 year-class is strong as indicated by Figures 44 and 45 later in this report. Fig. 44 shows that the age 4 (1999 year class) fish dominated in samples collected during the 2003 US-Canada survey and hake piscivorous biomass is likely to increase in 2004 when these fish become large enough to start eating fish. At that point they could begin to impact herring and other species in the pelagic zone.

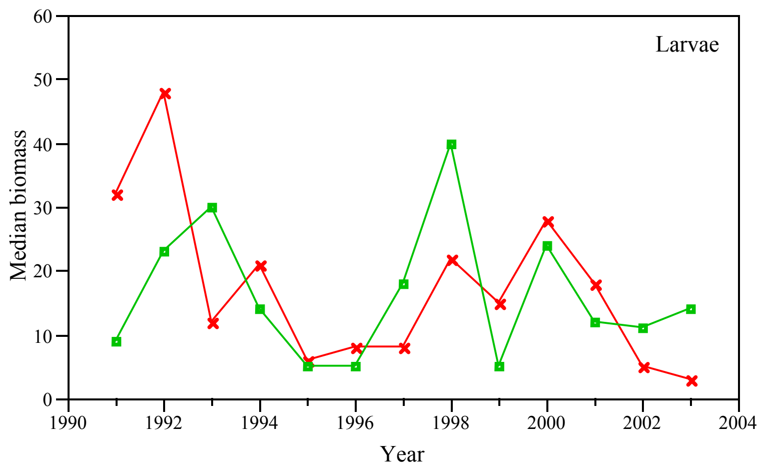


Figure 38. Annual median biomass (mg dry mass • m^{-2}) of *T. spinifera* (crosses) and *E. pacifica* (squares) larvae.

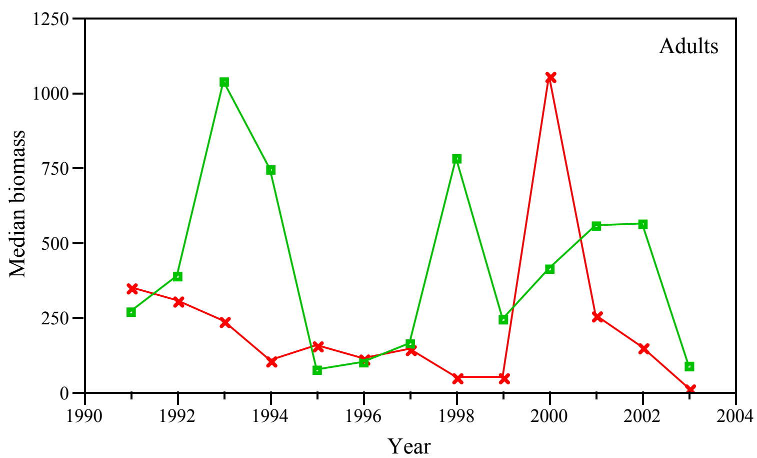


Figure 39. Annual median biomass (mg dry mass • m^{-2}) of *T. spinifera* (crosses) and *E. pacifica* (squares) adults.

Euphausiid biomass appears to have an effect on marine survival of **coho** and **sockeye salmon** (Tanasichuk, personal communication).

- **Coho**: As shown in earlier State of the Ocean reports, Carnation Creek wild coho survival is significantly correlated with euphausiid biomass early in marine life. Coho survival for the 2004 return year is forecasted to be very poor (<1%) (Simpson et al. 2004) because the biomass of euphausiids in 2003 was the lowest in the time series.
- **Sockeye**: Results of recent analyses show that Barkley Sound sockeye (Great Central and Sproat lakes), and Central Coast sockeye (Owikeno and Long lakes)) survival is a consequence of prey biomass. Sockeye prey biomass has been declining consistently since the 2000 smolt year. Considering that the age groups of sockeye that account for most of the run spend two or three years at sea, it seems that sockeye returns may decline until at least the 2006 return year.

A biomass index of **eulachon** along the WCVI is a product of the May shrimp survey. As described in previous reports, there appears to be a relationship between prey (*T. spinifera* > 17 mm) biomass in the first marine year and the index. Prey biomass has been declining over the past few year; low euphausiid biomass in 2003 suggests that the index should be low in 2004.

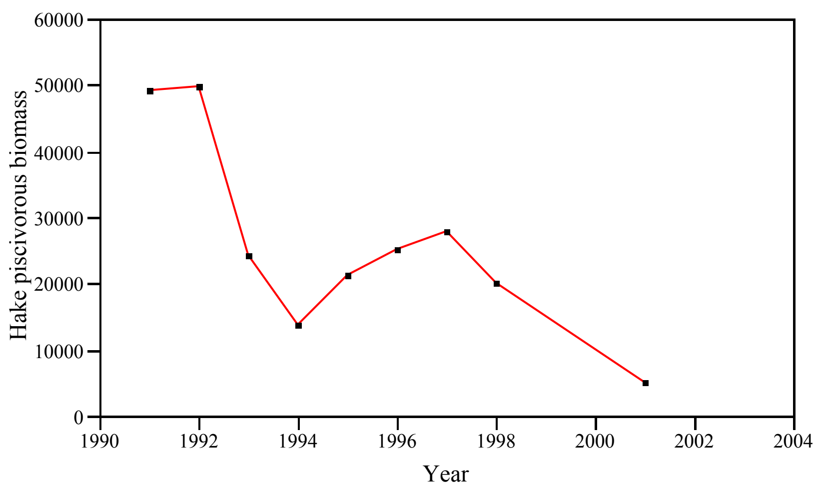


Figure 40. Biomass (tonnes) of piscivorous hake in the Canadian zone.

Pacific Hake

Pacific hake range throughout the California Current System from Baja California to the Gulf of Alaska. Their distribution and abundance are closely linked to oceanographic conditions in the NE Pacific. The biomass is typically over 1 million metric tonnes and supports large domestic fisheries in both Canada and the U.S. An integrated acoustic and trawl survey has been conducted every three years or so since 1977 to assess the distribution, abundance and biology of coastal Pacific hake. Results of the three most recent surveys are shown in Figure 41.

Unusual juvenile and adult distribution patterns have been seen in the Pacific hake population in since 1994 along the US and Canadian coasts. Juvenile settlement spread northward during the 1994-99 years of warmer waters in the northern region and stronger northward currents. Evidence for this was found in the numerous age-1 fish (1997 year class) seen in the 1998 acoustic survey off Queen Charlotte Islands, far to the north of their traditional domain, as well as increased numbers of age-2 and age-3 hake taken in the Canadian fishery in 1994 and 2000 respectively. Equally dramatic was the low occurrence of hake off

Canada in 2000 and 2001 (Fig. 41), resulting in less-than-full utilization of the Canadian Total Allowable Catch (TAC). This shift correlated with cooler ocean conditions off Canada in 1999-2001.

Hake distribution in the 2003 survey (Figure 41, next page) appears to be more representative of years prior to 1994. Aggregations of hake were found along the continental shelf break from just north of San Francisco Bay (38°N) to Queen Charlotte Sound (52°N). Peak concentrations of hake were observed north of Cape Mendocino, California (~ 43°N), and in the area spanning the US-Canadian border off Cape Flattery and La Perouse Bank (~ 48.5°N), and in Queen Charlotte Sound (~ 51°N). No hake were found north of transect 98 in Queen Charlotte Sound (52°N). Offshore distribution was generally confined to near the shelf break with the exception of transect 44 (42.9°N) where hake were found in a continuous aggregation to over 2500 meters of water and 20 nautical miles farther offshore than seen previously in this area.

Acoustic estimates of hake biomass in the California Current System declined steadily (Figure 42) from the early 1990s to the lowest observed in 2001 (738t mt). In contrast, the 2003 biomass estimate of 1.84 million metric tons is an increase of 120% over the 2001 survey estimate. (Figure 42) The strong 1999 year class shown as age 2+ hake in the 2001 survey (Fig. 43) entered the population as age 4 fish in 2003 and is principally responsible for the increase. This dominance of the 1999 year class is shown in Figures 44 and 45, based on midwater and bottom trawl samples in 2003.

The 2003 biomass estimate was derived from an age-structured assessment model (Figure 45). This assessment included several important modifications to the 2001 model, most notable of which include: 1) revision of acoustic survey biomass estimates from 1977-1992 to reflect new deep-water and northern expansion factors; 2) initialization of the population age composition in 1966 (vs. 1972) including estimates of recruitment at age 2 from 1966-2003; and 3) discrete temporal changes in the acoustic survey selectivity.

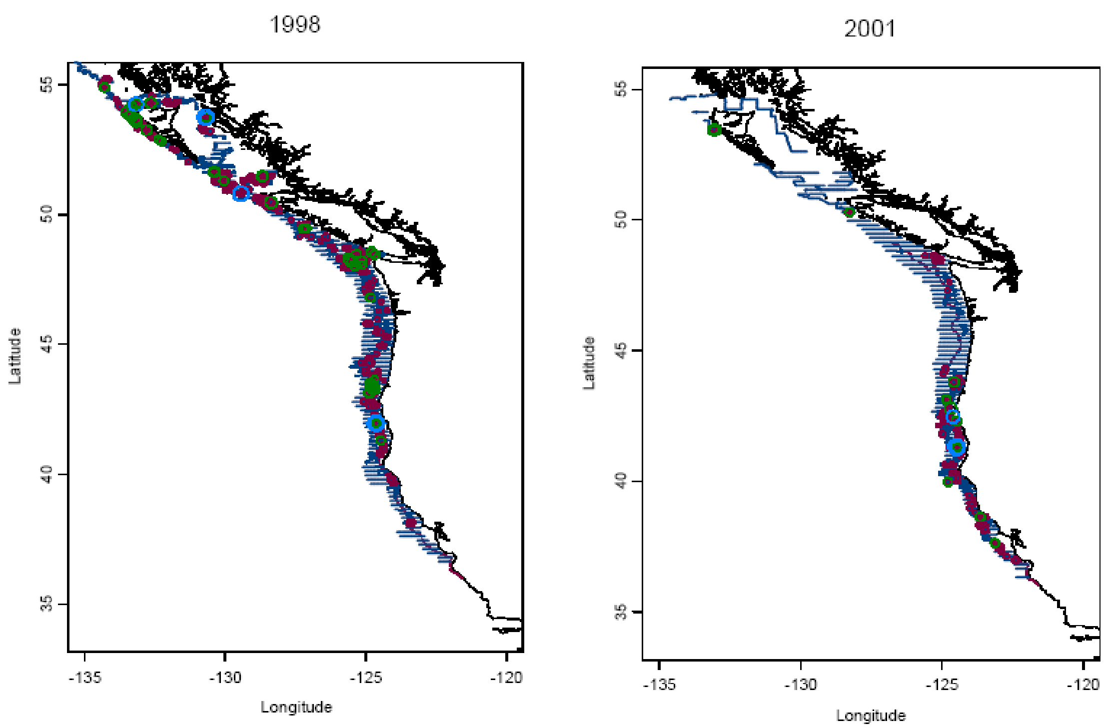


Figure 41. Acoustic backscattering (SA) attributed to Pacific hake along transects off the U.S. and Canada west coast shelf and slope between Monterey, CA, and SE Alaska, during the 1998 and 2001 surveys. Blue lines show survey grid. Red circles indicate distribution of hake along transects with circle size scaled to abundance. Blue and green circles show mid-water and bottom trawl locations, respectively. (Figure continued on next page.)

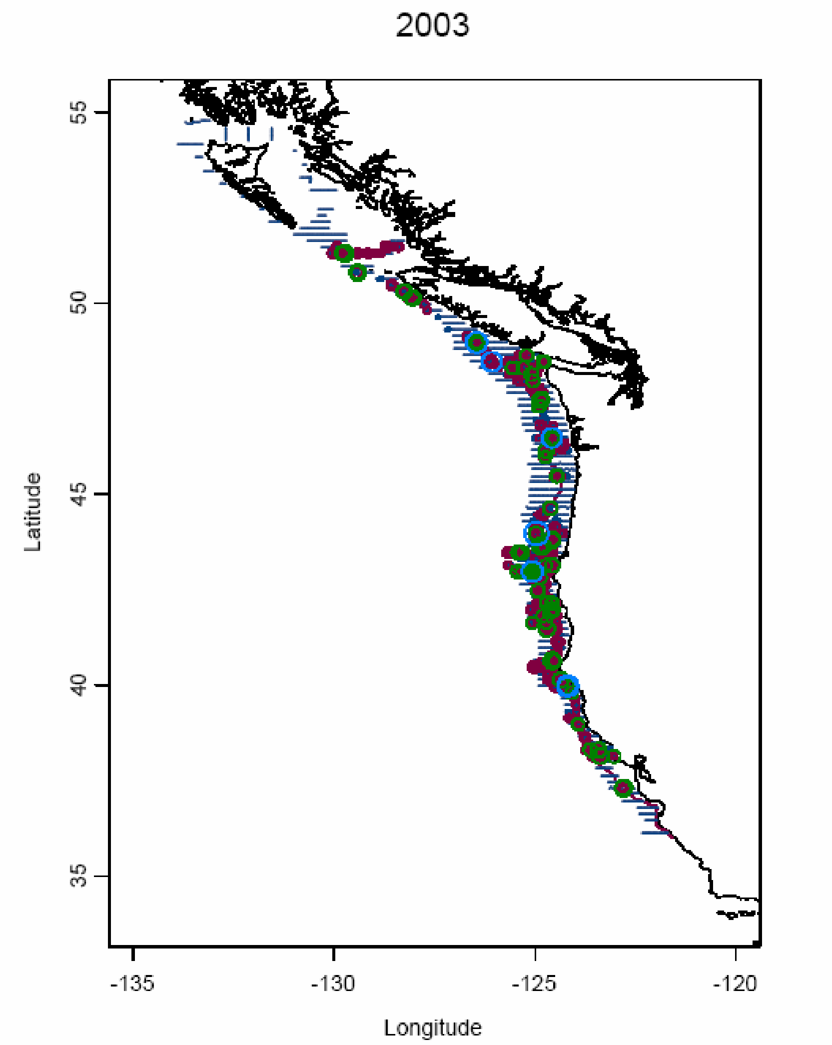


Figure 41. continued

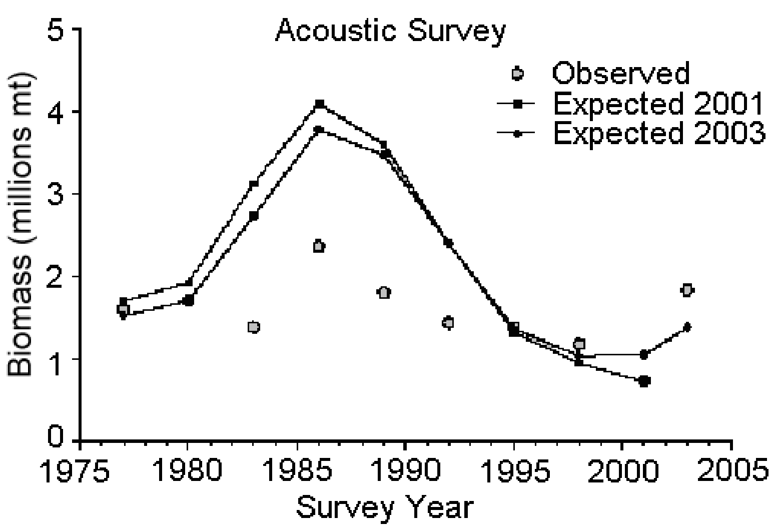


Figure 42. Comparison of observed and predicted acoustic survey biomass indices estimated from the 2003 model update presented in this document and the 2001 Pacific hake assessment. Both models employed the same model structure and assumptions. Observed and expected 2001 biomass in 2001 are both 0.76 million mt.

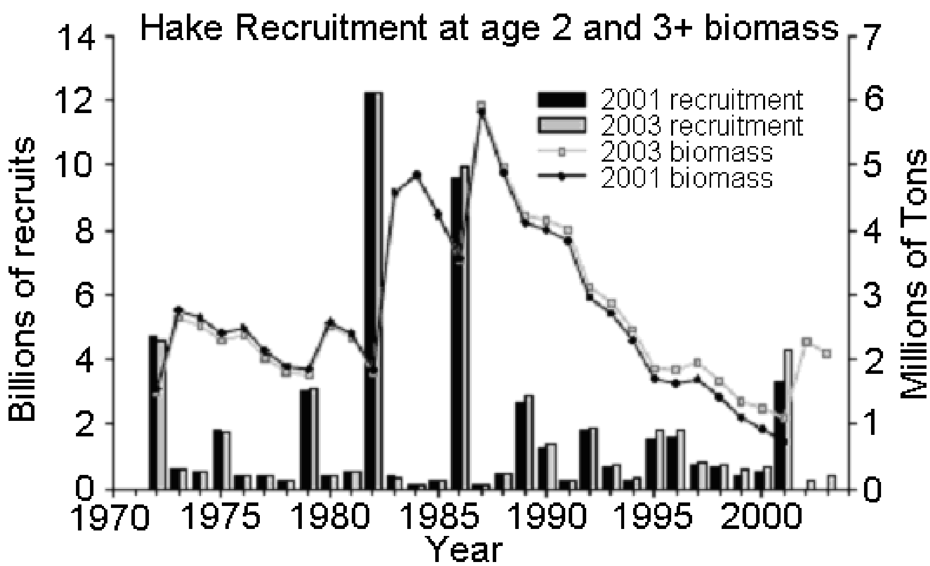


Figure 43. Comparison of trends in age 2+ biomass and recruitment between the most recent assessment 2003 model update presented in this document and the 2001 Pacific hake assessment model. Both models employed the same model structure and assumptions, but the 2003 update reflects only updated fishery catch and the new 2003 acoustic biomass estimate.

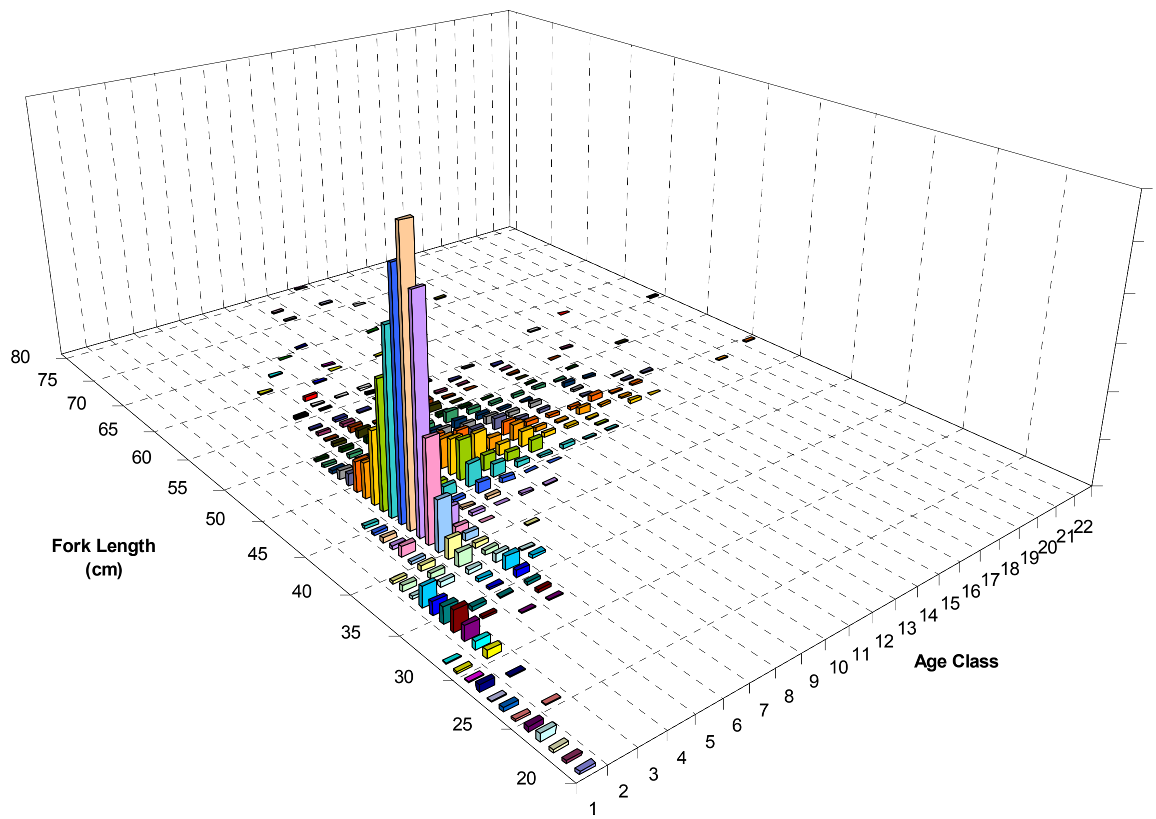


Figure 44. Age by length frequency based on mid-water and bottom catch information collected during the joint Canada-US Pacific hake acoustic-trawl survey conducted by the CCGS *W.E. RICKER*, June 24 – September 2, 2003.

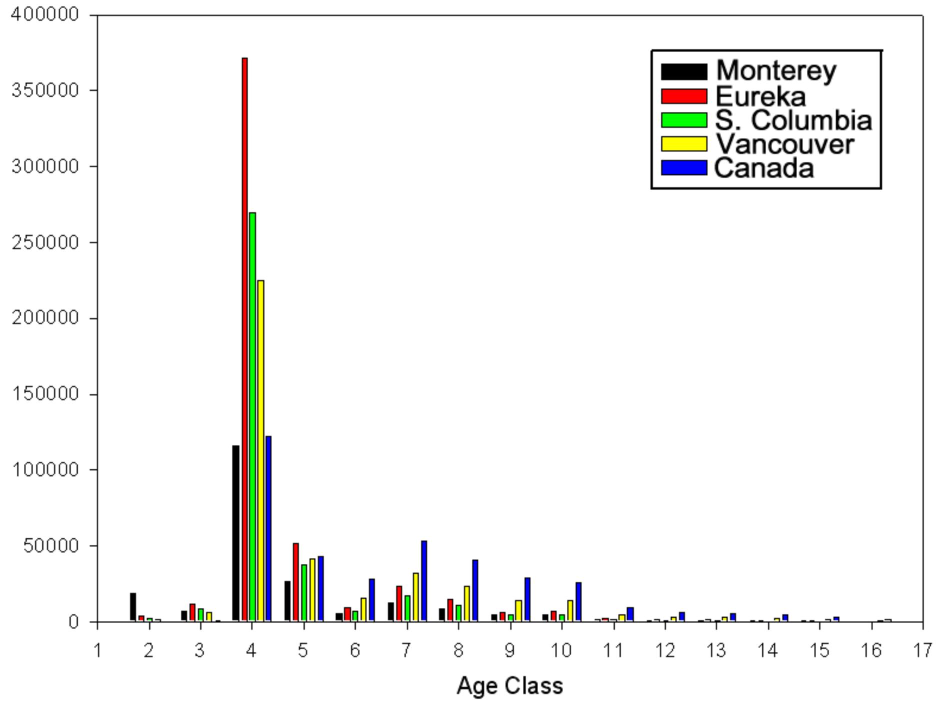


Figure 45. Biomass in metric tons by age reported by INPFC regions for the joint Canada-US Pacific hake acoustic-trawl survey conducted by the CCGS *W.E. RICKER*, June 24 – September 2, 2003.

West Coast of Vancouver Island

Physical Conditions

Physical, biological and chemical oceanographic conditions off the west coast of Vancouver Island undergo pronounced seasonal cycles in response to corresponding variations in coastal winds, freshwater runoff, solar heating, light conditions, atmospheric pressure, and offshore oceanic conditions. The seasonal cycles are, in turn, modified over a wide range of time and space scales, with especially marked changes arising from major El Niño/La Niña events in the North Pacific. Observations of these oceanic changes are monitored by the Department of Fisheries and Oceans using environmental data collected from research vessels, coastal monitoring stations, and moored instrumentation. Shipboard surveys provide detailed information on the spatial distributions of oceanic water properties (temperature, salinity, nutrients, water clarity), fish, plankton (chlorophyll) and zooplankton. Moored weather buoys maintained since 1989 by Environment Canada (with support from DFO) (Fig. 46) provide hourly time series information on winds, atmospheric pressure, wave height and period, and air/water temperature; lighthouse stations (Fig. 47) provide long-term time series of daily sea surface temperature and sea surface salinity. Tide gauge stations (Fig. 48) provide long-term series on hourly sea level variability and moored current meters (Fig. 49) yield hourly time series of current velocity, water temperature, and salinity at specified depths through the water column.

Most time series plots are referenced to the 1990-96 period, which is the longest period of mostly continuous data across all data sets presented in this section that is not influenced by the very strong 1997-98 El Niño. Averages over, and deviations from the 1990-96 period are thus more directly comparable across data sets.

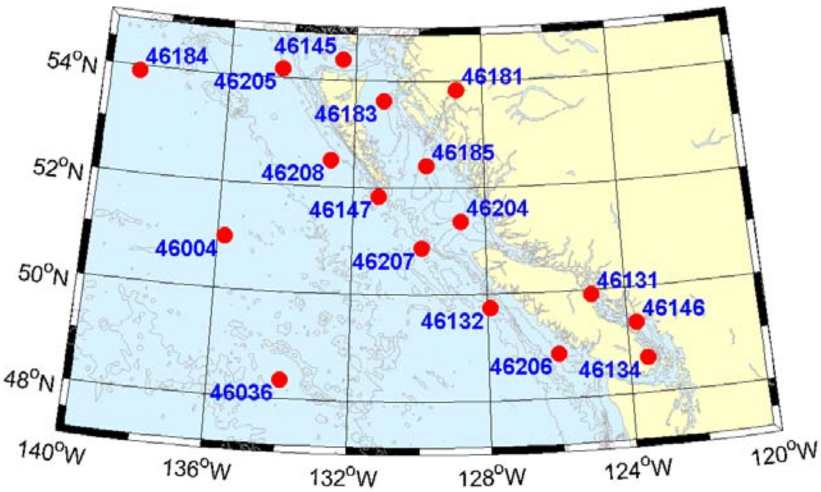


Figure 46. Canadian weather buoy locations in 2003.

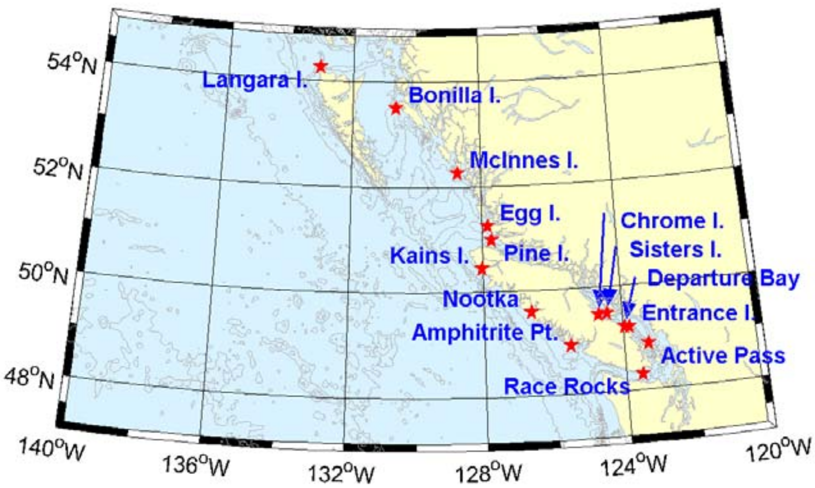


Figure 47. Canadian lighthouse water sampling stations in 2003.

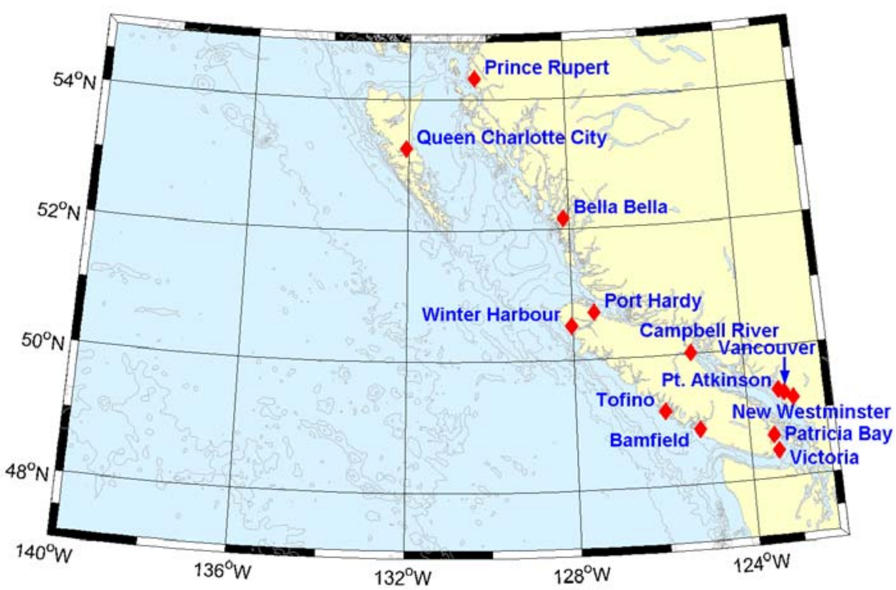


Figure 48. Canadian tide gauge locations in 2003.

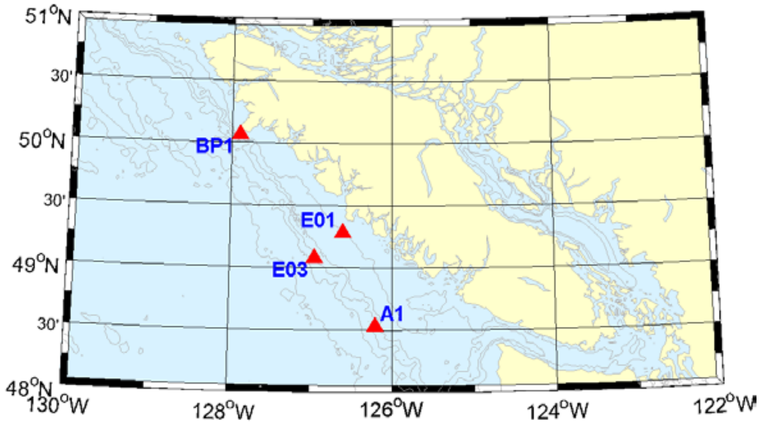


Figure 49. Fisheries and Oceans Canada current meter locations in 2003.

Ocean Surface Data

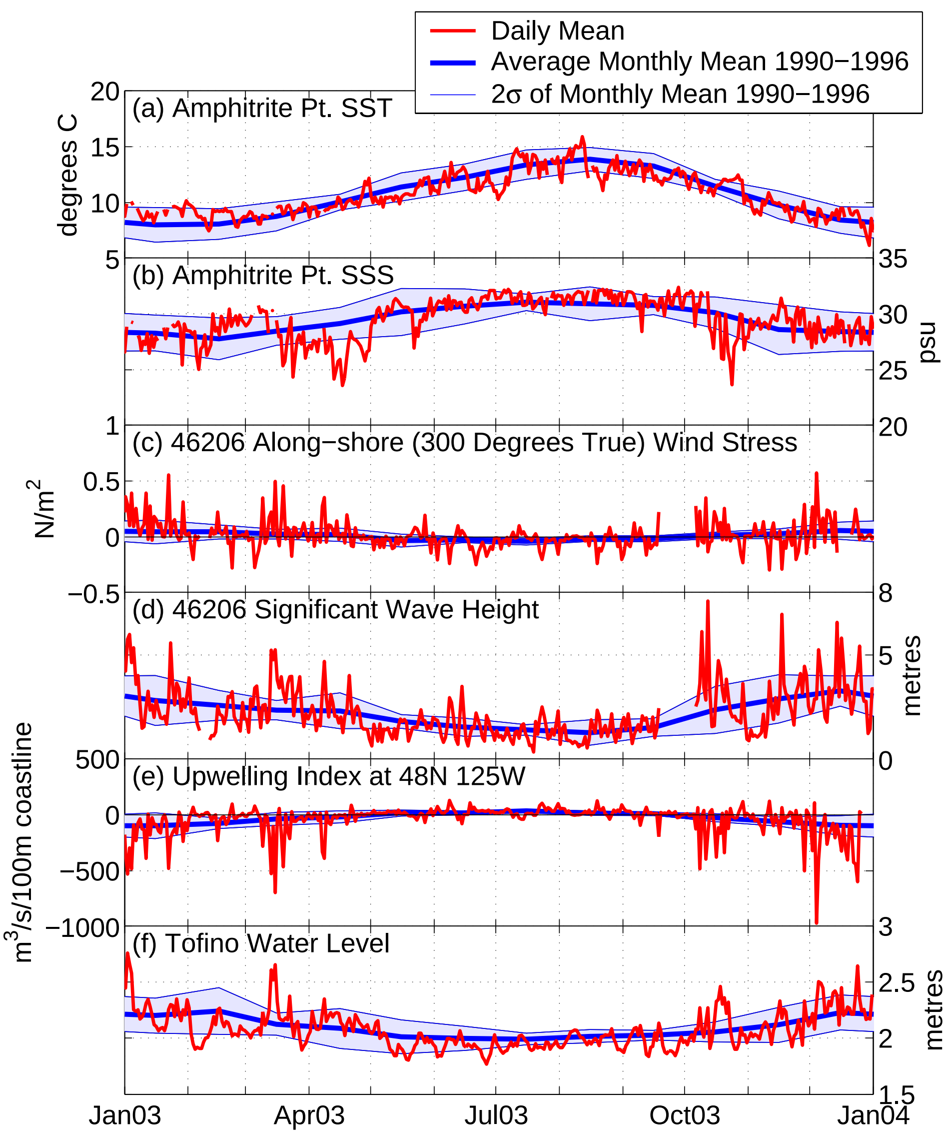


Figure 50. Year 2003 daily values of (a) sea-surface temperature, (b) sea-surface salinity, (c) alongshore wind stress, (d) significant wave height, (e) upwelling index, and (f) water level. Positive alongshore wind stress is due to the component of wind blowing toward 300°, approximately north-westward. Weather Buoy 48206 lies on the continental shelf southwest of Tofino (See Figure 46).

West Coast time series of sea-surface temperature (SST), sea-surface salinity (SSS), alongshore wind stress, significant wave height, upwelling, and water level over 2003 are shown in Fig. 50. Daily averaged values are shown in comparison to average monthly means over the period, 1990-96. (Daily averages are low-pass-filtered time series with periods shorter than 30 hours removed.) Warmer than average SSTs in January-February 2003 are likely associated with the El Niño event that began in late 2002 (Fig. 50a). For the rest of the year, SSTs remained near the 1990-96 average.

Sea-surface salinity (SSS) during 2003 was near the 1990-96 average over most of the year, but significantly fresher deviations lasted a week or more in April and October (Fig. 50b). These low salinities were likely due to large surface runoff events.

Nutrient supply to coastal waters is determined by tidal mixing and by upwelling winds. Tidal mixing change little from one summer to the next, but changes in upwelling winds can greatly impact nutrient supply and primary productivity on the continental shelf. Ekman transport is a ocean surface current that flows to the right of the wind due to effects of the rotation of the Earth. Winter storm winds from the Southeast push ocean surface currents along the west coast of Vancouver Island to the right toward the island. This flow is blocked near shore and accumulates there, raising sea level and also displacing other seawater downwards. Hence the term downwelling associated with winds from the Southwest, and upwelling for winds from the Northwest. Upwelling winds bring nutrient-rich seawater to the surface and therefore stimulate phytoplankton growth. A typical storm with downwelling winds might raise sea level by 30 *centimetres* at shore, and push the surface/subsurface water interface down by 30 *metres* on the nearby continental shelf.

Strongest upwelling winds blow from the northwest and bring cool, nutrient-rich water to the ocean surface; downwelling winds blowing from the southeast suppress nutrient supply to the ocean surface and warm the surface waters. Once upwelled to the surface, nutrient-rich waters flow away from shore if winds continue to blow from the northwest, a process labelled Ekman transport. In summary, winds from the northwest increase nutrient supply at surface, decrease water temperatures and decrease coastal sea levels.

During 2003 there were periods of a few days duration with strong southeasterly (downwelling-favourable) winds during January, March, April, October, and December (positive alongshore wind stress in Fig. 50c). Periods of moderately strong northwesterly, upwelling-favourable winds occurred in February, March, October, and November (negative alongshore wind stress in Fig. 50c). Most significant of these was in November, when repeated periods of upwelling-favourable winds enhanced upward transport of nutrients to the base of the mixing layer at a time when nutrients and not light would have been possible limiting factors for biological productivity.

Wave heights in 2003 were near the 1990-96 average over most of the year (Fig. 50d), with much higher-than-average values in January, March, April, and October-December during strong wind events (Fig. 50c). Sustained lower-than-average wave heights of about a week's duration were recorded in May, August, and November when winds were weak.

The PFEL (Pacific Fisheries Environmental Laboratory) FNMOC (Fleet Numerical Meteorology and Oceanography Center) Upwelling Index for the west coast of Vancouver Island and northwest Washington State (48° N, 125° W) is shown in Fig. 50e. This index characterizes the seaward component of the wind-induced Ekman transport.

The year 2003 had periods of strong downwelling (negative values) in January, March, October and December, as also indicated by positive (northward) alongshore wind stress in Fig. 50c. Weak to moderate upwelling events (positive values) occurred through February-November. The strongest upwelling occurred in November, coinciding with winds blowing from the northeast (Fig. 50c).

Water level was near the 1990-96 average throughout most of 2003. Water levels were much higher than average values over a few days in January, March, October, and December (Fig. 50f). These events coincided with downwelling-favourable southeasterly winds that pile water up along the coast, increasing the water level (Fig. 50c). Lower than average water levels over a few days or a week in February-March, May-June, September, and November occurred in conjunction with upwelling-favourable northwesterly winds that transport water offshore and lower coastal water level.

Multi-year time series of sea-surface temperature (SST), sea-surface salinity (SSS), alongshore wind stress, significant wave height, upwelling, and water level over their period of record are shown in Figure 51. Monthly mean anomalies relative to 1990-96 are shown with their 3-year running mean which depict lower frequency variability.

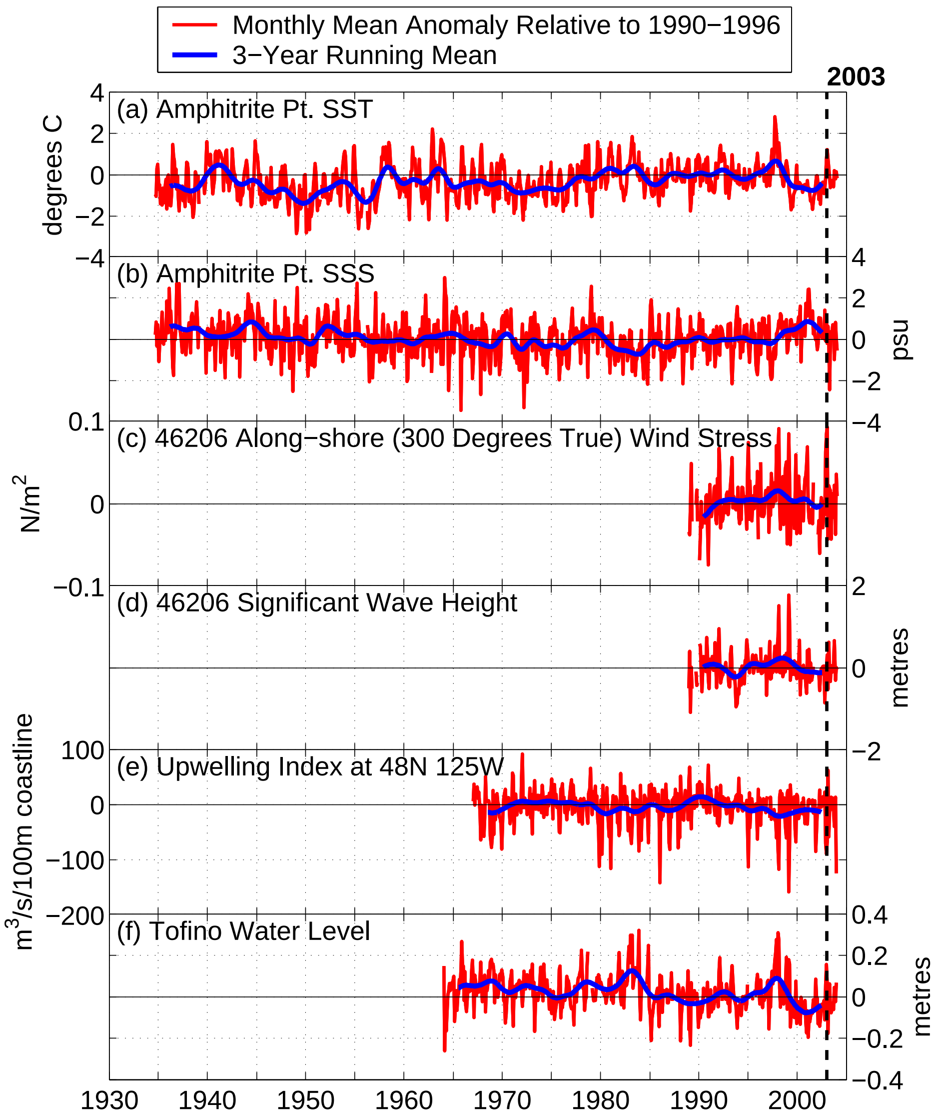


Figure 51. Monthly mean anomalies (red) relative to 1990-96 and their three-year running mean (blue) of (a) sea-surface temperature, (b) sea-surface salinity, (c) alongshore wind stress, (d) significant wave height, (e) upwelling index, and (f) water level. Dashed vertical line runs through 2002.

Year 2003 marked a return to near 1990-96 average temperature and salinity at Amphitrite Point after a prolonged cool and salty period that began during the La Niña of 1998/99 (Figures 51a and b). Alongshore wind stress and wave heights at Weather Buoy 42806 continued to be near the 1990-96 average in 2003 (Figures 51c and d). The upwelling index returned to near the 1990-96 average in 2003 after below average values observed since the mid-1990s. The interannual variability in water level at Tofino mirrored that of SST at Amphitrite since the 1970s, with very high levels in early 1980s and late

190s, and like SST, water level returned to near the 1990-96 average after below average values since 1998.

The spring of 2004 was characterized by an unusually early increase in upper-ocean temperatures along the Pacific Coast of North America. Temperatures and temperature anomalies for May, 2004, are plotted below.

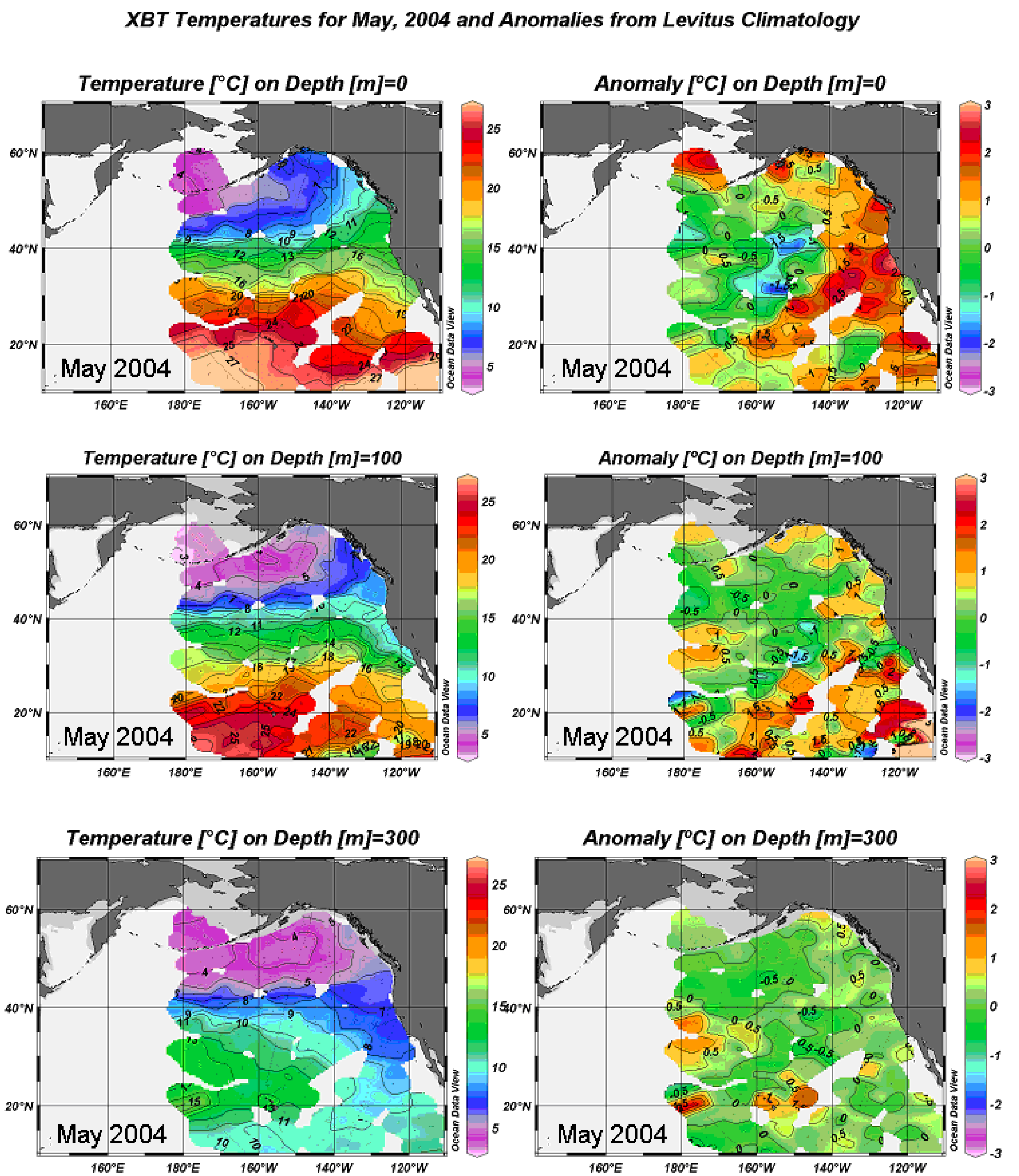


Figure 52. Temperature (left panels) and temperature anomalies (right panels) for the Eastern Pacific Ocean in May 2004 at three depths, Surface (top), 100 metres (middle) and 300 metres (bottom).

Contour plots of this data in Figure 52 show a 1000 km wide pool of anomalously warm surface water extending the whole length of the Pacific coast and into the Bering Sea. Surface anomalies were over 1ºC all along the coast, about .5 ºC at 100m, and close to zero at 300 m. Similar patterns of anomalies were measured in March and April.

Unusually high temperature anomalies for May have been measured at B. C. coastal lighthouses: Race Rocks, 1º;Amphitrite Point, 1.5º; Nootka Point, 1.5º; Kains Island, 1.5º above normal and all near record highs, at least for years without an El Nino. Up to June 13th, Amphitrite Point is still .5ºC above normal.

This situation could be alleviated by a cold June but so far it looks as if warm ocean conditions have returned to the coast.

Sub Surface Data (Continental Slope, La Perouse Region)

Subsurface temperatures at 35, 100, 175 (Fig. 53), and 400 (not shown) metres depth over the continental slope as measured at mooring A1 (See Figure 49) were warmer than the 1990-1996 average monthly mean over January-February 2003 before reverting to average or below average through to the fall (data series ends in late September 2003).

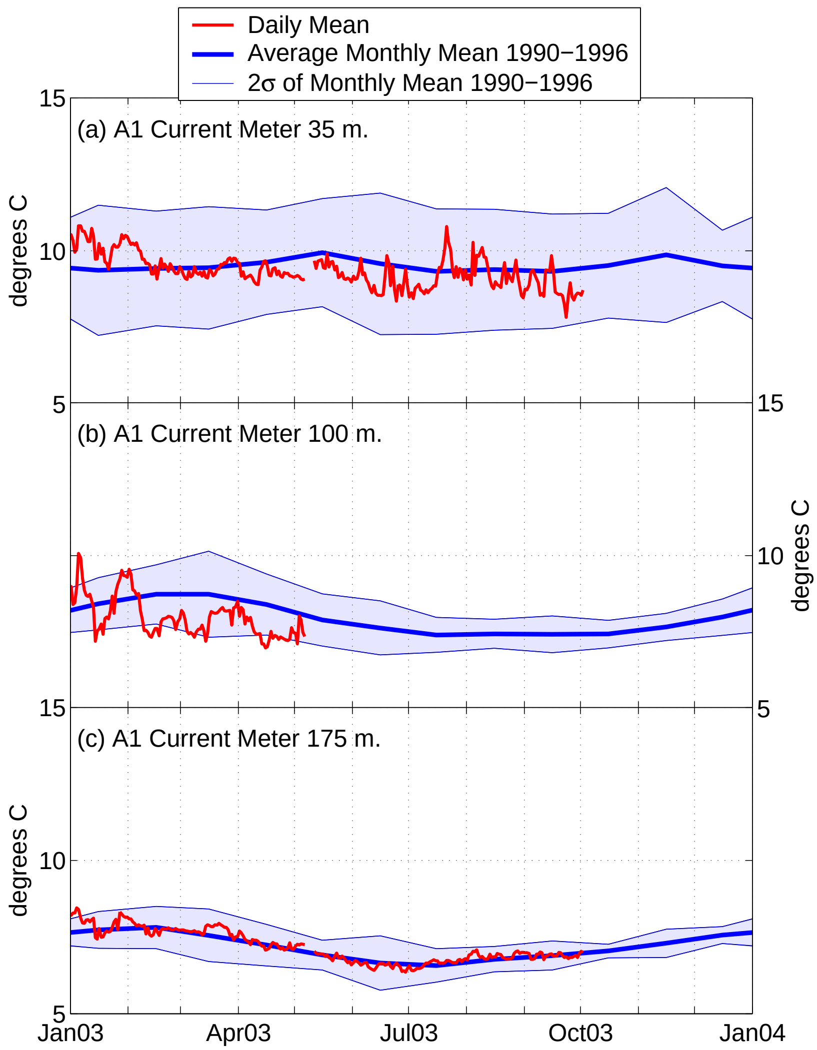


Figure 53. Temperatures at 35, 100, and 175 metres depth at mooring A1 for year 2003.

Positive anomalies of 2, 1, and 0.5 °C were recorded in January-February at the nominal depths of 35, 100, and 175 m, respectively. Note that the actual depth of the top three moorings in Figure 53 were 20 m deeper than the nominal depths, January-May, all other deployments were very close to the nominal depths. Had the January-May deployments been closer to the nominal depths (shallower), larger positive temperature anomalies would likely have been observed. During May-September temperatures were generally below average by 1-2 °C at 35 m and near or slightly above average at 175 m. (There were no data at 100 m, May-September.) Also of note were nearly isothermal temperatures at 100 and 175 in the spring, conditions that last occurred in late 2002.

Alongshore current velocity over the continental slope in 2003 as measured at A1 was poleward (flowing toward the Northwest) and slightly below normal magnitude throughout most of the winter and spring (peaking at around 60 cm s^{-1} in early January at 35 m depth) (Fig. 54a).

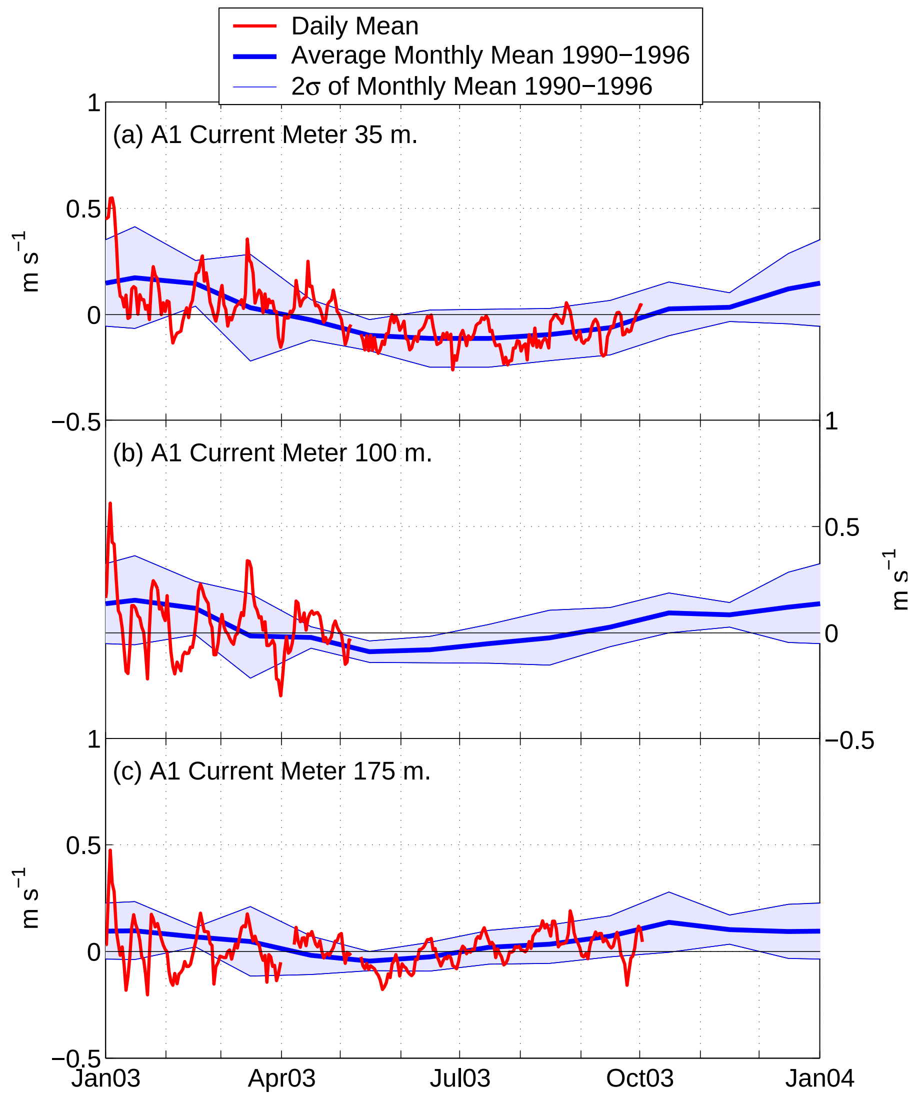


Figure 54. Alongshore (flowing toward the Northwest) current velocity at 35, 100, and 175 metres depth at mooring A1 for year 2003.

There were multiple reversals lasting a few days throughout the winter and spring, and a dramatic reversal lasting about two weeks in mid-February at all depths. Flow direction switched to mainly equatorward in

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

Relative to previous years, sub-surface temperatures at A1 in 2003 at 35, 100, and 175 m depths returned to near 1990-96 average monthly mean values after a period of cooler-than-average temperatures that began in 1998 (Fig. 55).

Alongshore current at A1 in 2003 marked a return to near 1990-96 average conditions since a gradual but dramatic shift to a more equatorward flow that began in 2000 (Fig. 56).

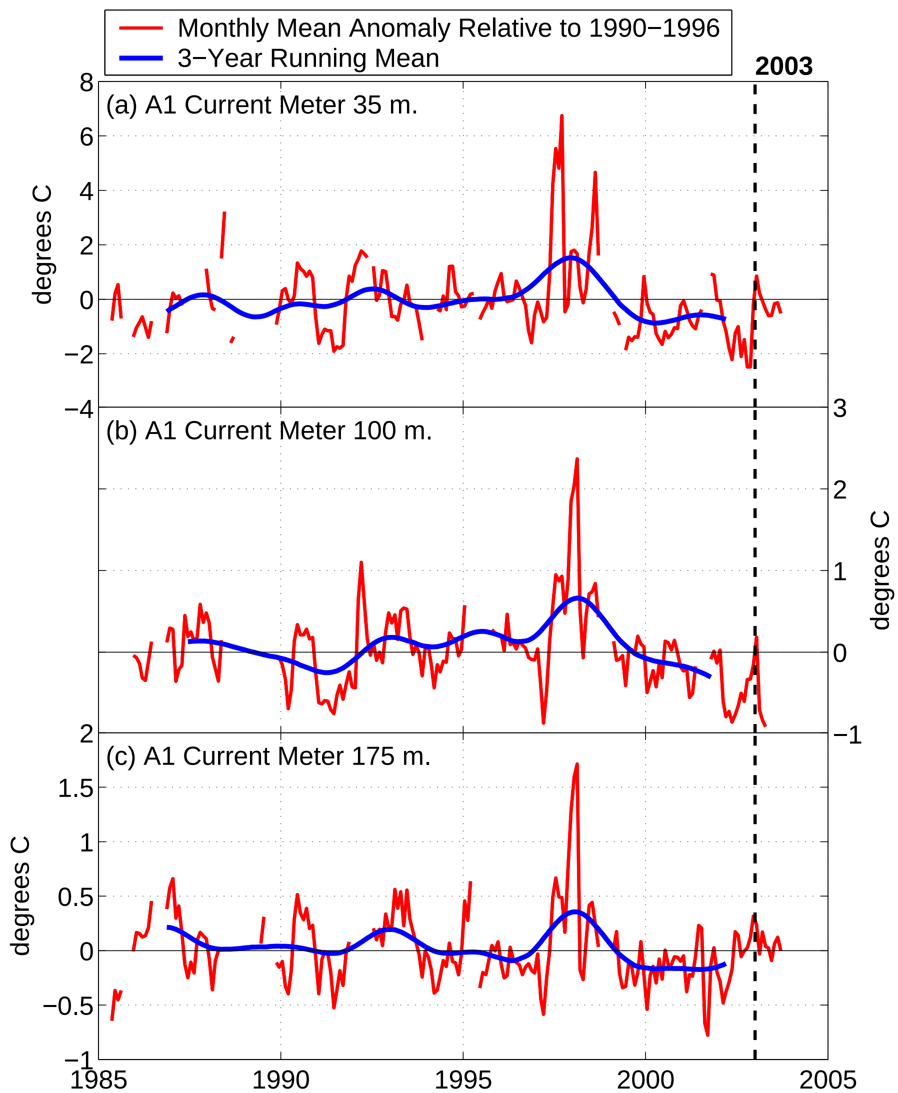


Figure 55. Temperature anomalies at 35, 100, and 175 metres depth at mooring A1 from 1985-2003. Note the different vertical scales in the three panels.

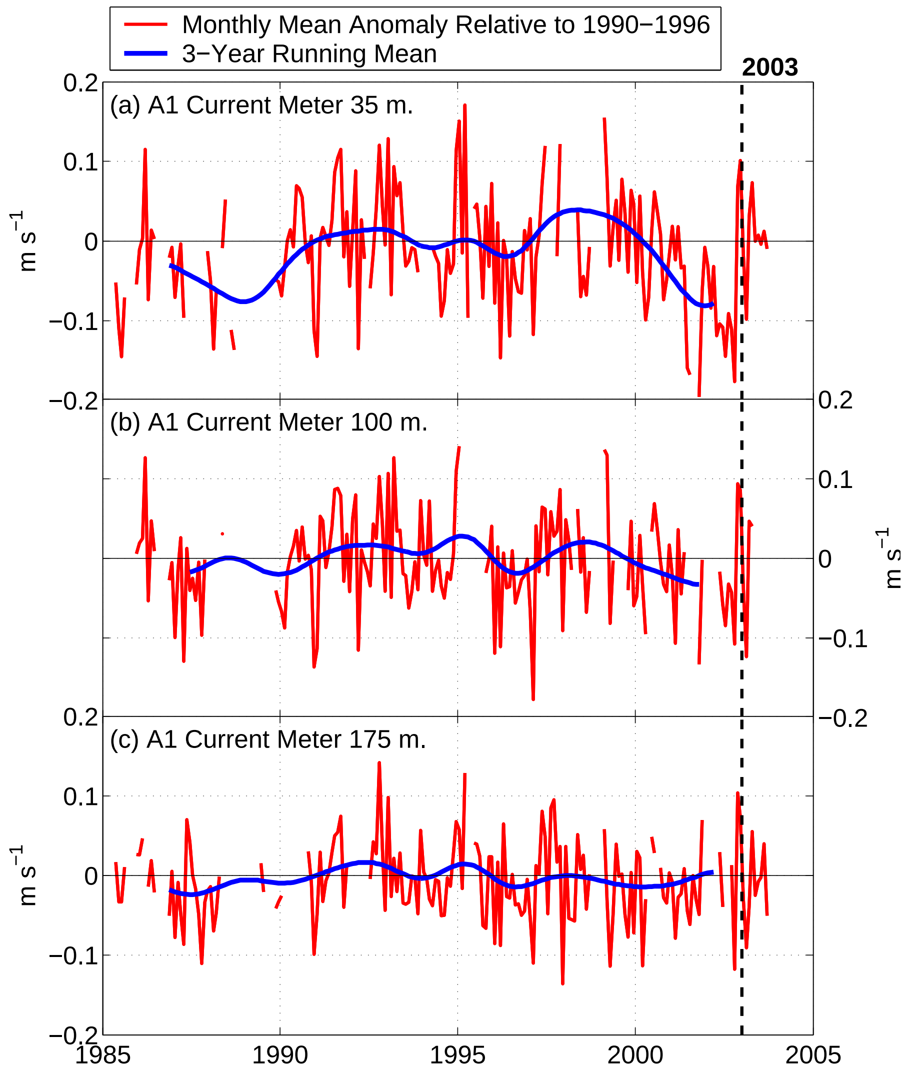


Figure 56. Alongshore (poleward) current velocities at 35, 100, and 175 metres depth at mooring A1 from 1985-2003.

Phytoplankton

The west coast of Vancouver Island experiences a high spatial and temporal variability in phytoplankton biomass. Monitoring therefore requires close interval sampling in both space and time that makes it difficult to monitor by ship observations alone. Using satellite colour sensors we can estimate ocean surface chlorophyll concentrations to indicate the distribution and abundance of phytoplankton in the upper ocean on synoptic scales and short time intervals. Time-series of SeaWIFS color satellite observations are presented along two transects (Line C and Line J) offshore from Vancouver Island (Figure 57), beginning soon after the launch of the satellite sensor.

Chlorophyll concentrations at the ocean surface along the southwest coast of Vancouver Island (Line C; Figure 58) show that in 2003 the spring bloom of phytoplankton started in March as in the two previous years (2001-2) rather than in April as observed in 1998-2000. The most likely cause of the early spring bloom is early seasonal increase in solar radiation and water-column stratification. Unfortunately, field observations are lacking at this time of the year so we cannot corroborate chlorophyll satellite observations with *in situ* measurements, nor to identify factors responsible for variations in the timing of the spring bloom. Numerous studies have shown that the timing of the spring phytoplankton bloom can significantly impact food web production and in particular the growth and survival of copepods and fish larvae.

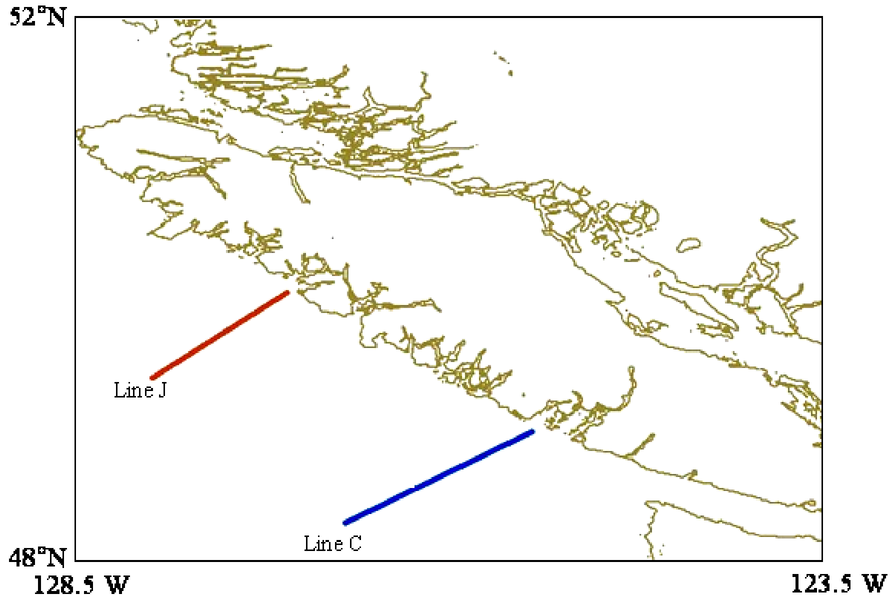


Figure 57. West coast of Vancouver Island transects location.

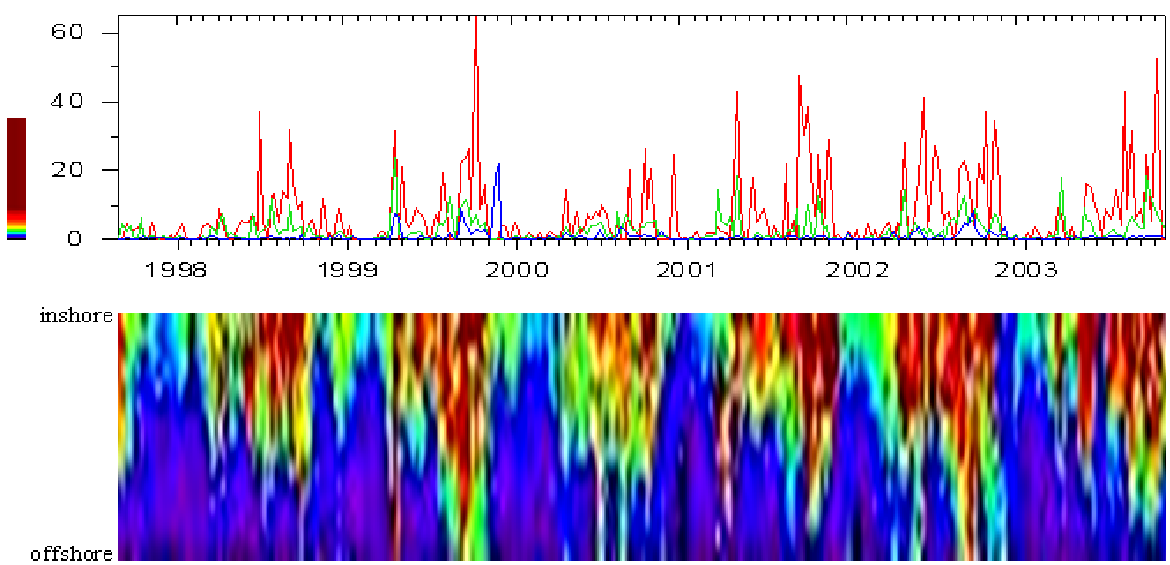


Figure 58. Time-series of SeaWIFS 8-day composite image of ocean surface chlorophyll concentration (mg m^{-3}) along Line C transect off Southwest Vancouver Island from September 1997 to November 2003. Top panel: chlorophyll concentration at the inshore (red line), middle (green line) and offshore (blue line) site. Bottom panel: chlorophyll concentrations along the transect, with colours denoting concentrations as noted in colour bar at left of top panel.

At the northern transect (Line J), surface chlorophyll concentrations are usually lower than in the southern region and a spring bloom was observed in 2001 only. In general, higher concentrations are observed at the end of the summer in this region. At both Line-C and Line-J, higher concentrations of ocean surface chlorophyll were observed later in the year (July-September) and were confined to the nearshore region in 2003 compared to observations in 2002.

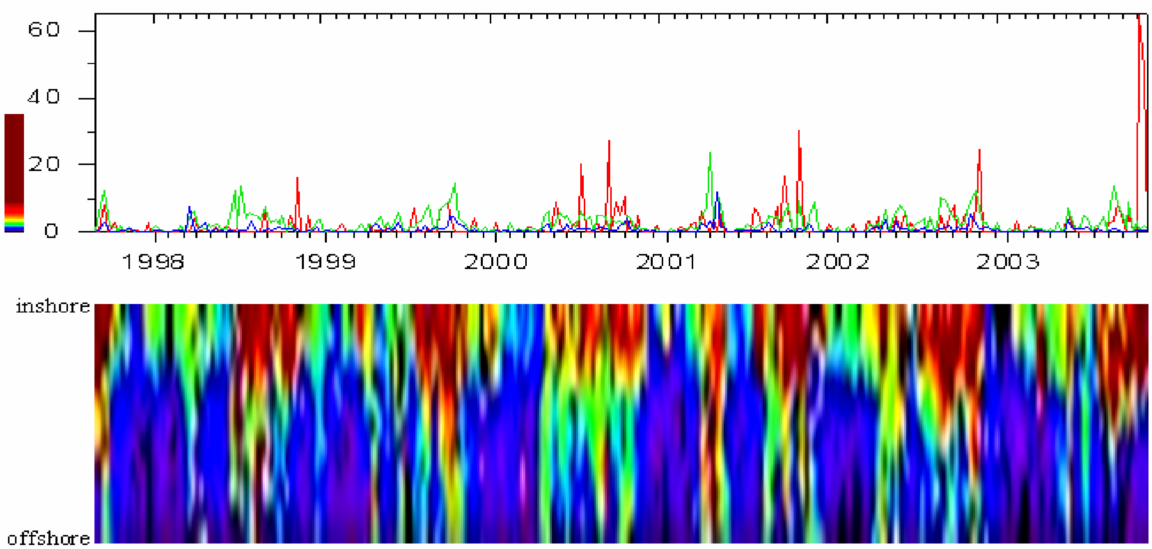


Figure 59. Time series of SeaWIFS 8-day composite image of chlorophyll concentration along Line J transect from September 1997 to November 2003. Top panel: chlorophyll concentration (mg m^{-3}) at the inshore (red line), middle (green line) and offshore (blue line) site. Bottom panel: chlorophyll concentrations along the transect, with colours denoting concentrations as noted in colour bar at left of top panel. No SeaWiFS observations are available prior to this time.

New Satellite Images for Coastal Monitoring

The two new ocean colour imagers launched by NASA (MODIS) and by ESA (MERIS) image chlorophyll fluorescence from near-surface phytoplankton. MODIS provides images at 1 km resolution. MERIS provides data at 1.2 km resolution and in some areas also at 300m resolution. Shown below is a Full Resolution (300 m) MERIS image for 05 Sept 2002. Scientists at Fisheries and Oceans Canada are involved in evaluation of MERIS image data through a collaborative project with the Canadian Space Agency.

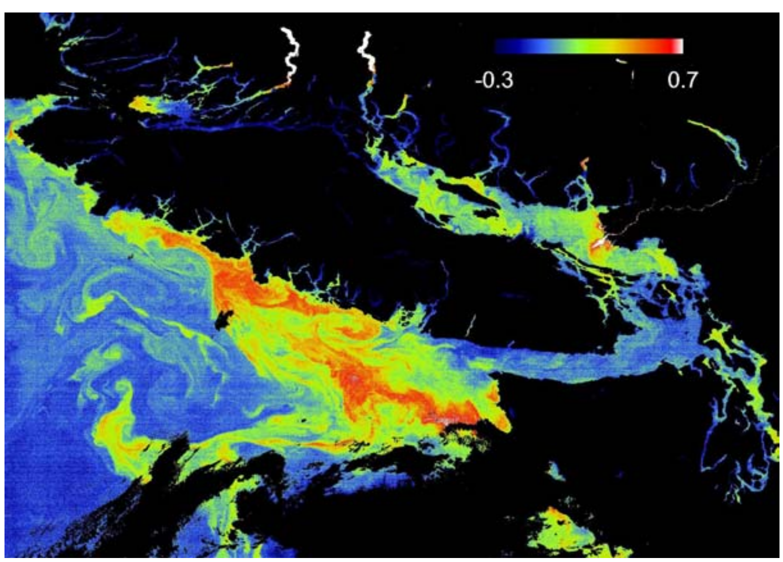


Figure 60. Full Resolution (300 m) MERIS image for 05 Sept 2002. Patterns of surface chlorophyll fluorescence can be seen along shore and in inlets. Values are suspect in areas with high concentrations of suspended material, such as heads of some inlets and in the Fraser River plume

Compared to other ocean colour satellites, MERIS has higher spatial resolution and spectral bands that allow detection of a spectral peak near 705 nm, which is a signature of bloom conditions (high surface chlorophyll concentrations, above 50 $mg.m^{-3}$). Images can be produced to show the height of this peak.

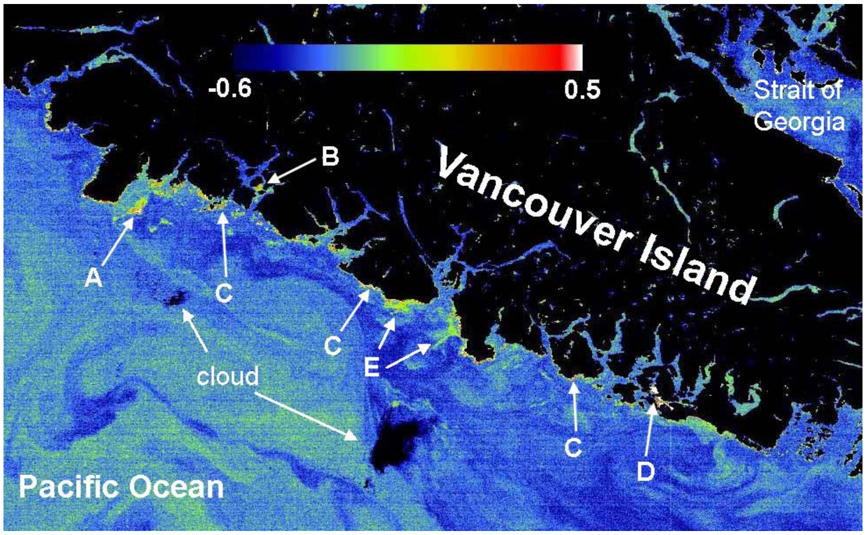


Figure 61. Height of peak of visible light spectrum at 705 nanometres, a signature of phytoplankton blooms. High values are indicated offshore at A and near a fish farm at B. The farm was reporting highly visible, surface bloom conditions at this time. Expected false alarms are kelp (C) and sea-grasses (D). Other areas (E) are interpreted as blooms with lower biomass concentrations.

Ship-based measurements of chlorophyll are collected during Line-P cruises, with the time series of late-summer observations extending back to 1994. Figure 62 illustrates concentrations of nitrate and chlorophyll on the coastal Line-P stations, based on one sample per summer at each of the four near-shore, Line-P stations. One expects high chlorophyll to develop in high nutrient summers. Figure 62 shows this is generally the case, although the measurements in 2003 do not show this pattern. We suspect this anomalous behaviour might be due to a small sample size and significant spatial variability, as noted on previous pages.

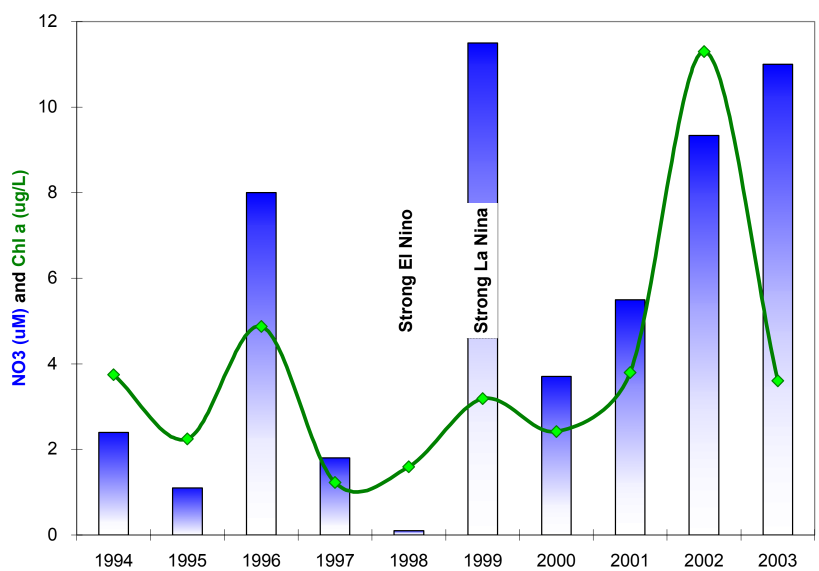


Figure 62. Average nitrate (bars) and chlorophyll (line) in late summer at the four stations on Line P closest to shore. All stations lie on the continental shelf or slope, shoreward of the 1300-metre depth contour.

Zooplankton

Time series sampling of zooplankton has been carried out three to six times per year at standard locations on the continental-shelf and the adjoining deep ocean off Vancouver Island (Fig. 63). The southern Vancouver Island region (SVI, 48°-49°N) has been sampled since 1979, and the northern Vancouver Island region (NVI, 50º-51.5ºN) since the early 1990s. These time series allow us to estimate annual anomalies of most of the major zooplankton species, relative to the average annual seasonal cycle over the length of these records. Mackas, Thomson and Galbraith (2001) and Mackas, Peterson and Zamon (2004) provide detailed descriptions of sampling and analysis methods. The time series were extended in both regions through 2003, although with a smaller-than-average number of sampling periods due to shortfalls in funding and ship availability.

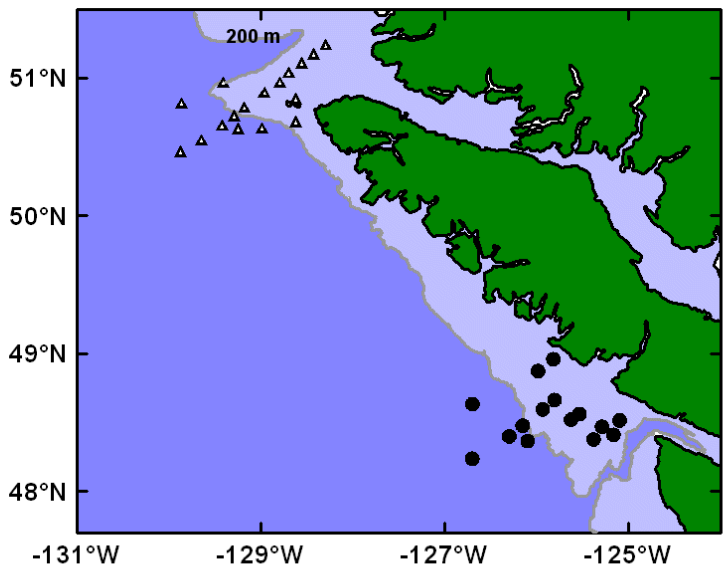


Figure 63. Standard zooplankton time series sampling locations off the west coast of Vancouver Island. Circles are Southern Vancouver Island (SVI) stations, triangles are Northern Vancouver Island (NVI) stations. Within each of these two regions, locations are further classified as continental shelf (shallower than 200 m bottom depth, light blue background) or continental slope (darker blue background)

Southern Vancouver Island

Year-to-year biomass variations for several of the major SVI copepod species groups are summarised in Fig 64, along with an index of large scale surface temperature variability in the North Pacific (from Bond et al., 2003). The zooplankton anomalies are shown on a logarithmic scale: an anomaly of +1 means that the zooplankton in that group were on average ten times more common than during the 1979-1991 reference period; an anomaly of –1 means that they were one tenth as common. The time period 1990-2000 included some very strong (factor of ten or larger) variations in concentrations of all major zooplankton species groups (not just the copepods shown in Fig. 65). 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, and reduction of abundance for the boreal-subarctic species. This trend reversed sharply in 1999, following the 1997-1999 El Niño-La Niña event. From 1999-2002, biomass of most zooplankton taxa along the Vancouver Island continental margin was similar to the 1979-1991 baseline period. Very similar zooplankton anomaly patterns extended southward at least as far as central Oregon (Mackas, Peterson and Zamon, 2004).

In 2003, the SVI zooplankton showed effects of a weak El Niño event that took place in late 2002-early 2003. This response can be interpreted as a partial (and probably temporary) return toward the zooplankton community of the mid-late 1990s. Southern species were significantly more abundant than average throughout 2003. Response of the 'northern' species was mixed: oceanic taxa (*Neocalanus* spp.) and shelf species that produce benthic eggs as an overwintering strategy (*Centropages* and *Acartia*) were slightly more abundant than average; other shelf species lightly less abundant than average. For most species, the strongest anomalies were in spring and early summer of 2003, and had returned to near-zero by our final sampling periods in early autumn.

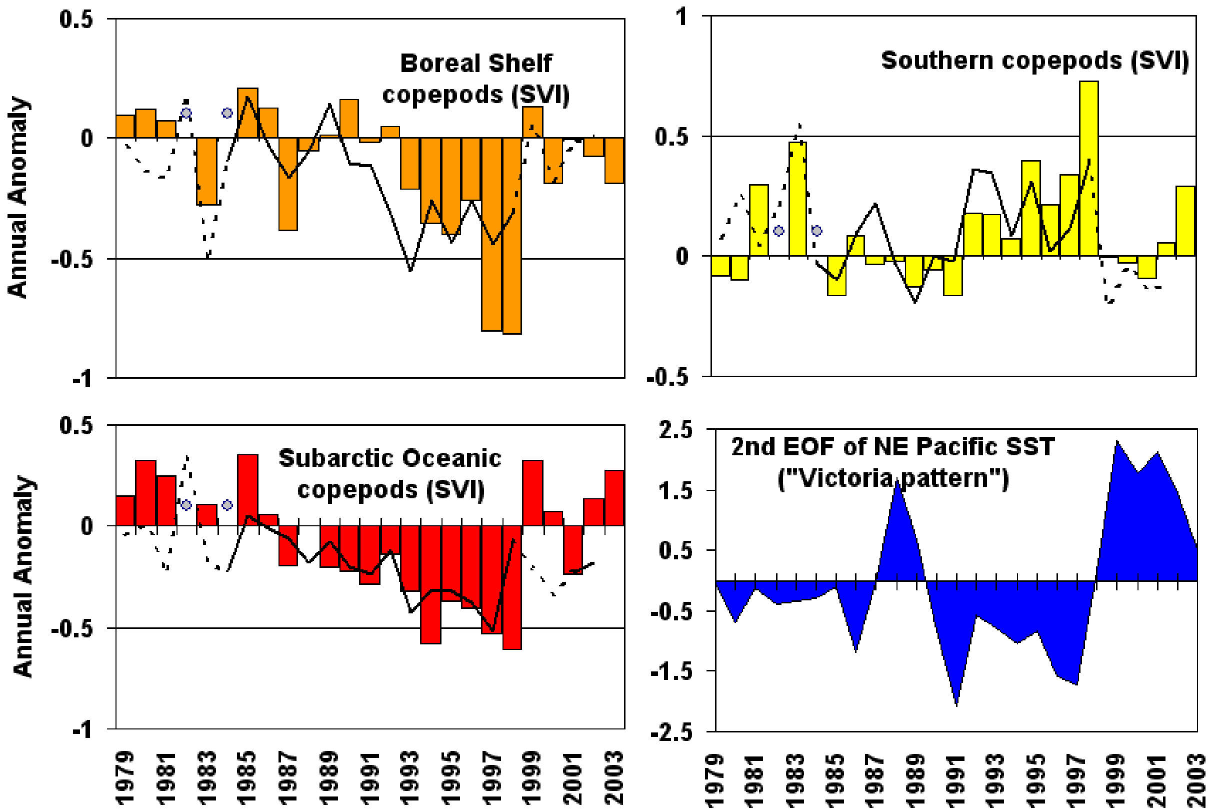


Figure 64. 1979-2003 time series of annual zooplankton anomalies averaged across southern Vancouver Island. Anomalies are relative to the average over 1979 to 1991. Statistical areas and within groups of ecologically similar species (coloured columns). Circles indicate years with too few samples to estimate annual anomalies. Lines show fits to the zooplankton anomaly time series from stepwise regressions on 1985-1998 time series of environmental indices: solid lines show the time periods for which the regressions were fitted, dashed lines show earlier and later years predicted by the regression. Note the continued good fit.

Northern Vancouver Island

Average seasonal cycles for the NVI region are described in Mackas, Peterson and Zamon, 2004. The main differences compared to the southern Vancouver Island regions are a greater average abundance of the oceanic copepods (probably because of the progressive northward narrowing of the Vancouver Island continental shelf) and a higher relative abundance of 'northern' species and lower relative abundance of the 'southern' species.

The Northern Vancouver Island anomaly time series are shown in Figure 65. The interannual variability of the NVI zooplankton (direction of magnitude of the anomalies), although significantly positively correlated with the anomalies of SVI and Oregon, has also been weaker (smaller anomalies) off NVI. In particular, the mid 1990s replacement of boreal shelf copepods by California Current species, and the reversal of this trend in 1999, were less pronounced in the NVI region.

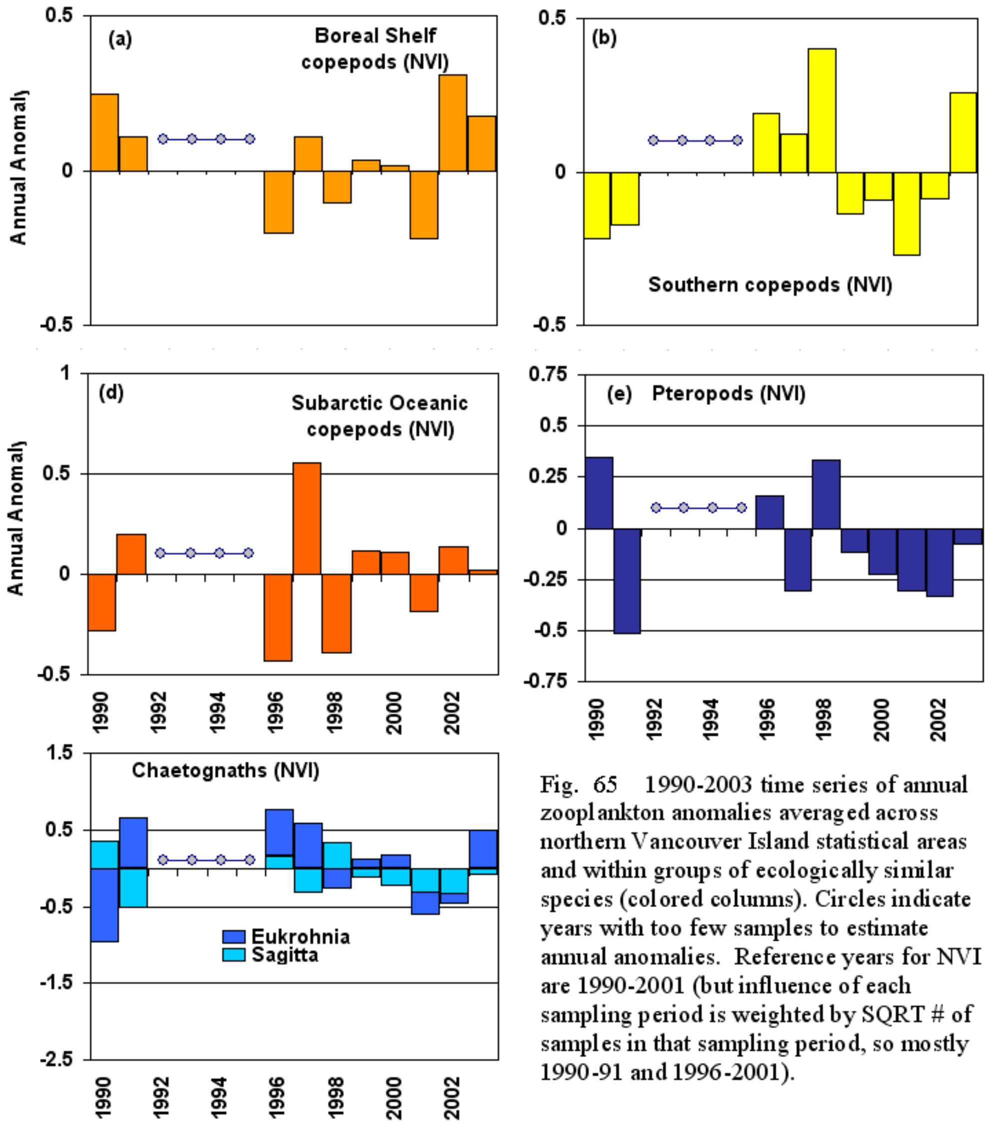


Fig. 65 1990-2003 time series of annual zooplankton anomalies averaged across northern Vancouver Island statistical areas and within groups of ecologically similar species (colored columns). Circles indicate years with too few samples to estimate annual anomalies. Reference years for NVI are 1990-2001 (but influence of each sampling period is weighted by SQRT # of samples in that sampling period, so mostly 1990-91 and 1996-2001).

Shrimp, Eulachon, Multi-Species Comparisons

Fishery-independent surveys have been conducted annually using research vessels in May of each year since the mid-1970's. These surveys use a small-mesh bottom trawl to assess the population of smooth pink shrimp (*Pandalus jordani*) off the southwest coast of Vancouver Island. The small-mesh of this net also collects many other species, which provides an integrated view of changes in the demersal fish and invertebrate community in this region over time. Abundances of smooth pink shrimp and several species of flatfishes have been increasing since 2000, peaked in 2002, but then declined in 2003 (Figure 66). This survey clearly observed the large and early migration of Pacific hake into west coast Vancouver Island waters that occurred in 1998 and a slight increase of walleye pollock that occurred in 1999 with the return of cold conditions (Figure 66, lower panel). Catches of pollock in these surveys have tended to be greater in Area 121 near the mouth of Juan de Fuca Strait, and these have increased since 2000 (not shown). Work is on-going to determine the relative effects of changes in distributions of fish compared with changes in abundance. An unusual occurrence of California tonguefish (*Symphurus atricauda*) was observed on these surveys in May 2003 in Barkley Sound, which is the first reported occurrence of this species in British Columbia (previous most northerly occurrence along the west coast of North America was in Yaquinna Bay, Oregon). This is consistent with warmer waters and a moderate El Niño in 2003.

Catches of eulachon during these research vessel shrimp surveys off Vancouver Island have been used as an index of the stock abundances of eulachon in rivers of southern B.C. This index suggests that a significant increase in eulachon has occurred since 1999 in southern British Columbia, reaching levels not seen in the past decade; however, the index showed a slight decline in 2003 (Figure 67).

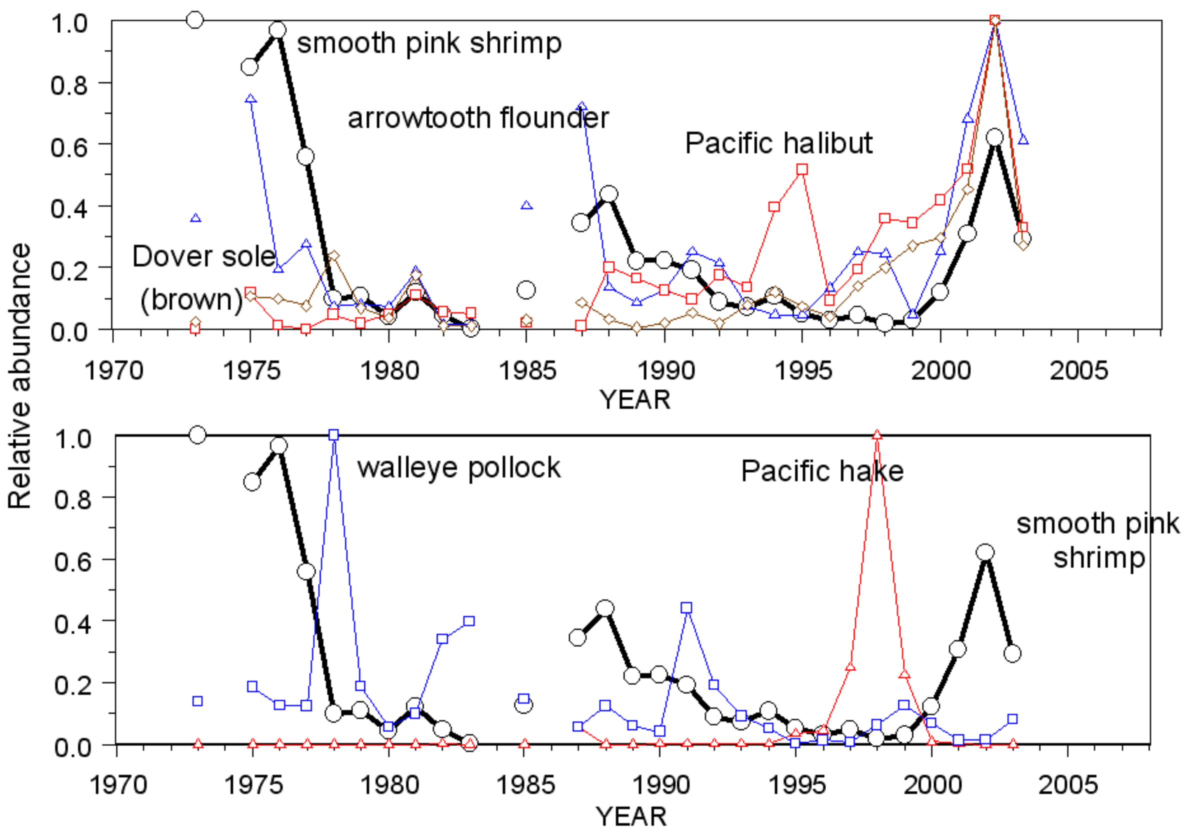


Figure 66. Time series of catches from small-mesh bottom-trawl surveys by fishery-independent research vessel in May of each year in Area 124 off Tofino, west coast Vancouver Island. Each species has been adjusted so that its maximum abundance during the time series is equal to 1. Target species for the survey was *Pandalus jordani* (smooth pink shrimp; heavy black line in both panels). Note increasing abundances in 2000-2002 but decline in 2003. Top panel shows several flatfishes whose abundances were increasing throughout the later 1990's, peaked in 2002 but declined in 2003; bottom panel shows two semi-demersal species with different temporal distributions: Pacific hake (a warm-water species whose by-catch in this survey peaked in May 1998), and walleye pollock (a cold-water species whose by-catch started to increase in 1999 but then declined).

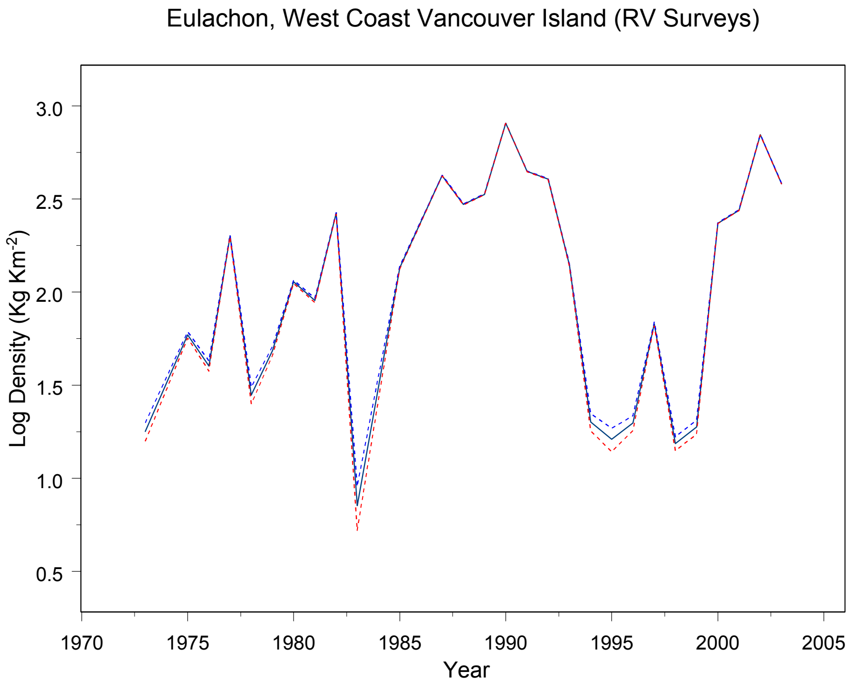


Figure 67. Eulachon abundance index derived from small-mesh trawl surveys by research vessel off west coast of Vancouver Island (Area 124). These have been used to index the abundance of eulachon stocks in southern British Columbia. Dashed lines represent upper and lower standard errors of the mean estimate each year.

Herring

Since about 1977, the recruitment of herring off the west coast of Vancouver Island has been generally poor (Figure 68). The productivity of the west coast of Vancouver Island herring stock (Figure 69) has been declining since 1989, primarily because recruitment to this stock has been poor for 6 of the last 10 years (Figure 68) although there are recent signs of some recovery. In 2003, the spawning biomass (Figure 69) increased to the average for the past two decades. A long-term research program has shown that herring recruitment in this region tends to be below average when ocean temperatures are warm and the summer biomass of migratory predators (primarily hake and mackerel) is high. The negative correlation between herring recruitment and temperature probably reflects: 1) poor feeding conditions for herring larvae and juveniles during their first growing season; and 2) a general increase in the mortality rate of the larvae and juveniles, due to an increase in the intensity of invertebrate and fish predation in the rearing area in warm years. Several field studies designed to measure the predation rate have confirmed that the negative correlation between herring recruitment and hake biomass could be caused by predation. Apart from predation by hake and other predators, ocean conditions were more favourable for herring survival in 2000 and 2001 and should result in improved recruitment to the stock in the years 2003 and 2004.

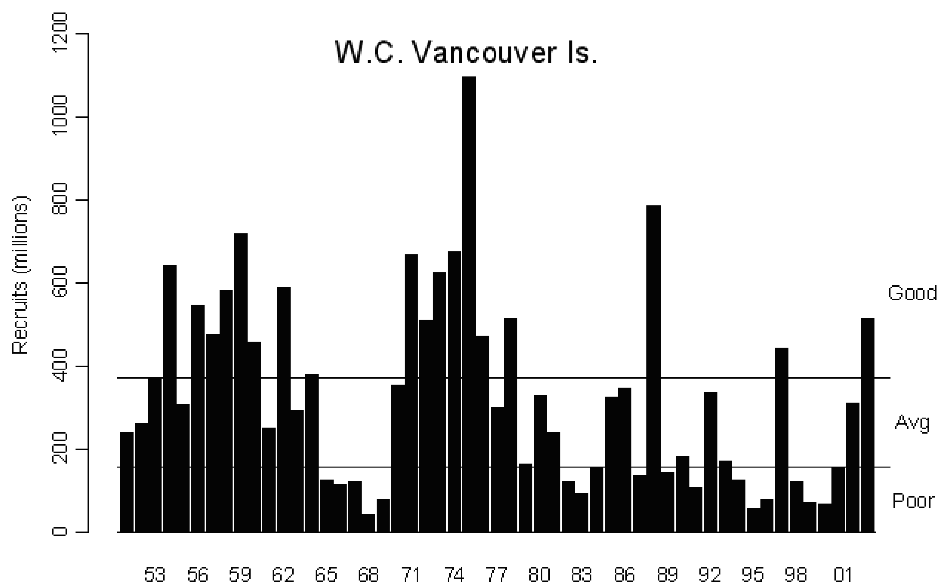


Figure 68. Interannual variability and decadal trends in recruitment to the west coast of Vancouver Island herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 6 of the last 10 recruitments have been 'poor'.

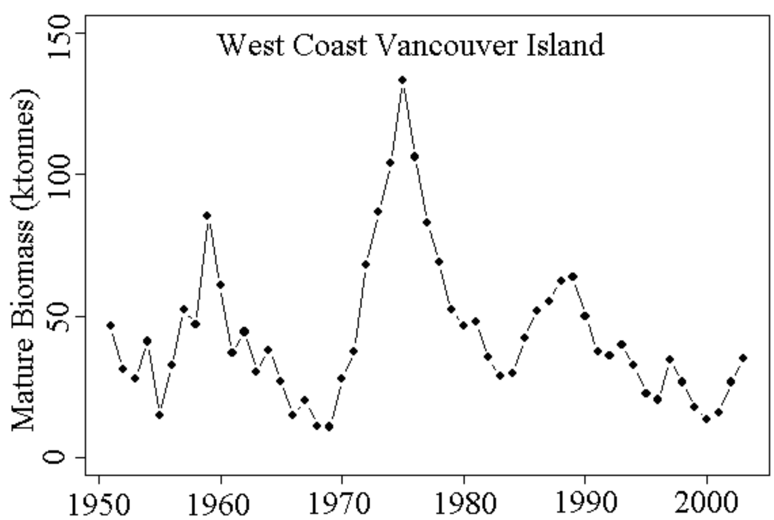


Figure 69. West Coast Vancouver Island herring abundance.

Pacific Sardine

Pacific sardine is a migratory species. When the northern sardine stock is large and ocean conditions are favourable, sardines migrate to British Columbia in the summer to feed. Most of these summer migrants make a return migration in the fall to the waters off central and southern California where they spawn. The sardine fishery in Canadian waters collapsed in 1947 without warning and by the early 1950s off California due to unfavourable environmental conditions. After a 45-year absence from British Columbia waters, sardines reappeared off the west coast of Vancouver Island in 1992. From 1992-1996, their distribution was limited to the southern portion of Vancouver Island. In 1997, their distribution expanded northward and by 1998 sardines inhabited waters east of the Queen Charlotte Islands throughout Hecate Strait and up to Dixon Entrance. Spawning was reported off the west coast of Vancouver Island in 1997 and 1998. In 1999 following the El Niño, sardine distribution again contracted southward. During 2003, sardines did not appear in Canadian waters until late-July and were confined to coastal inlets along Vancouver Island and parts of the Central Coast. The most recent U.S. assessment suggests a leveling off in sardine abundance (Fig. 70). The 2003 trawl survey off Vancouver Island (Fig. 71) found virtually no sardines in the offshore waters except in the south and some concentrations at the mouth of the inlets. Fewer sardines were present than in 1997-1999 when water conditions were warmer.

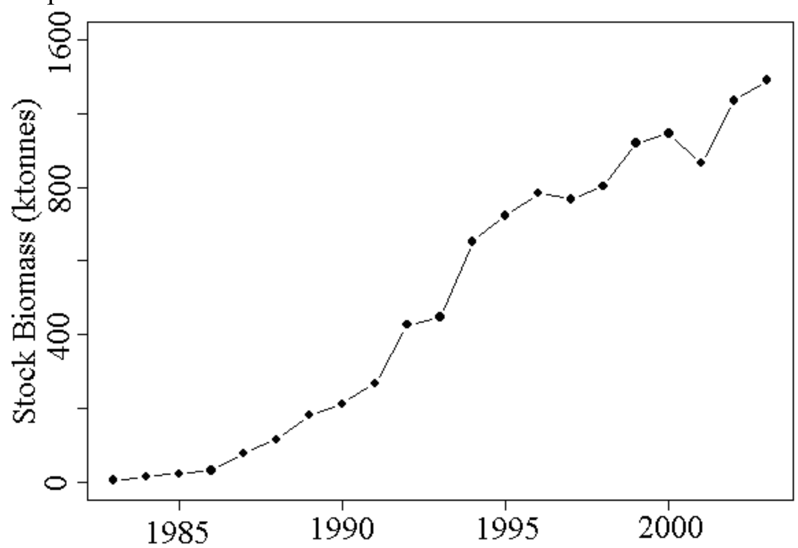


Figure 70. Time series of Pacific sardine stock biomass (x1,000 mt) of age 1 and older fish, estimated from an age-structured stock assessment model (data from Conser et al. 2003).

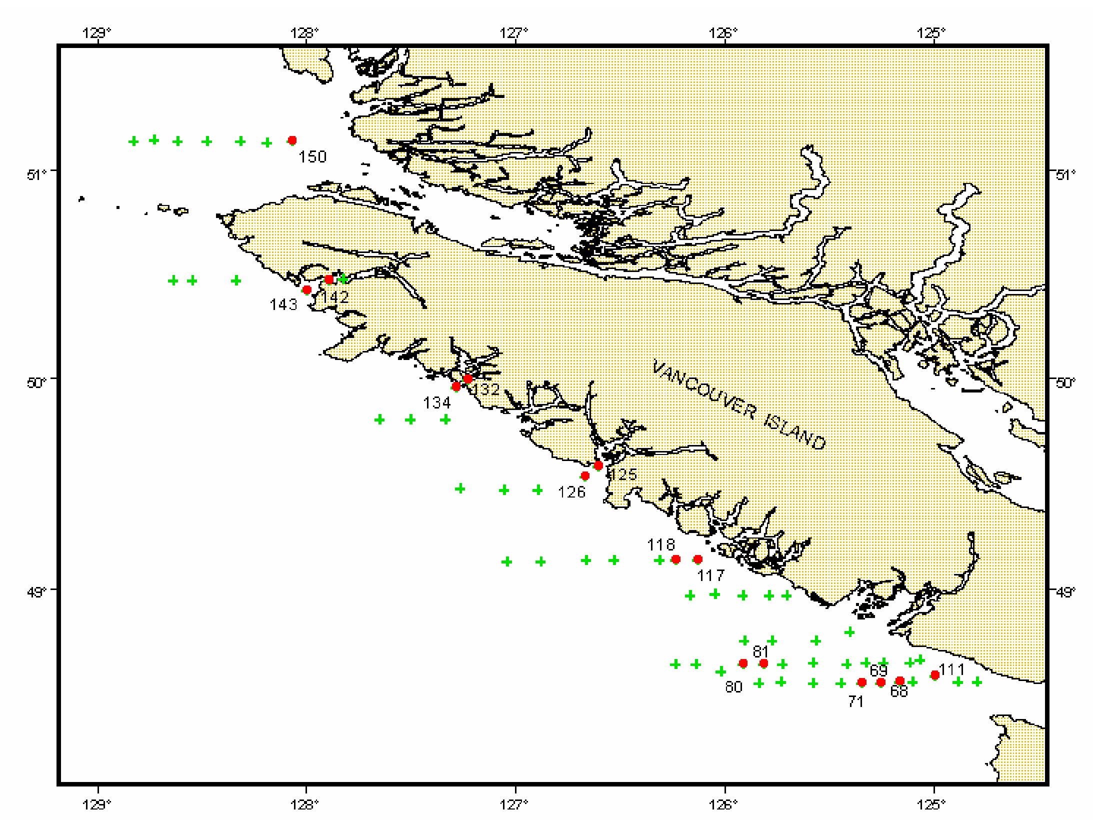


Figure 71. The distribution of Pacific Sardine was concentrated in southern offshore areas in 2003. The +'s represent sets at depths of 45m or shallower, in which no sardines were captured. Dots represent sets at depths shallower than 45m where sardines were captured.

Coho Salmon

Ocean surveys for juvenile salmon by the *CCGS W.E. Ricker* have been used to assess growth, condition, and survival of salmon in different parts of the British Columbia coastal ecosystem since 1998. The results for October 2003 indicate that the growth of juvenile coho salmon on the west coast of Vancouver Island was lower than in 2002, but well above the pre-1999 period. Over-winter condition of juvenile coho salmon in February 2004 was substantially better than in past winters (2001-2003) on the west coast of Vancouver Island. As marine survival of salmon is expected to be larger when they use a lower fraction of their lipid reserves (Beamish and Manhken 2001), the better condition observed in February 2004 suggests that adult returns might be improved in 2004 for coho stocks resident in the area of the survey.

In 1998 the size that juvenile coho attained by autumn was much smaller in the area off the west coast of Vancouver Island than in northern B.C. or SE Alaska (Fig. 72; 1998 panel). Proximate analyses indicate that coho salmon found off the west coast of Vancouver Island in 1998 had lower stored energy and were in poorer condition at the end of the growing season than animals foraging farther north (Fig. 72). The disparity in growth should have caused a large difference in the survival of salmon stocks resident in the southern area or those stocks that migrate through the area, because smaller fish have higher mortality rates (Holtby *et al.*1990). Consistent with this expectation, it is known that the B.C. salmon stocks resident as juveniles in the southern area of our survey (e.g. Strait of Georgia coho, west coast of Vancouver Island chinook) have poorer marine survival than do resident stocks in the northern B.C. or SE Alaska survey areas.

The 1999 and later surveys provided a test of this idea, as the changed ocean climate resulted in very similar juvenile growth for all areas of the survey (Fig. 72; 1999-2003). In addition, it appears that these juveniles were also in good condition with high energy reserves in all the surveyed areas (Fig. 73). This improved growth was subsequently followed by an increase in the adult returns of salmon that entered the ocean in 1999 and subsequent years. Columbia River chinook and steelhead and Fraser River pink salmon entering the ocean during these years as juveniles subsequently had record high adult returns. Coho returns were also observed to improve for stocks from the Columbia River region, but marine survival of coho remained relatively low for southern British Columbia stocks. Strait of Georgia coho had a slight increase in survival, although they were still poor. WCVI coho however, as indicated by Robertson Hatchery survivals, have had some of the highest survivals in the time series (since 1975). These relatively high survivals started with the 1997 brood year (1999 ocean entry year). Returns of Fraser sockeye were slightly above average in 2002 and near average in 2003. Survival (freshwater plus ocean) was slightly below average in both years.

The 2003 survey found that coho growth conditions off southern British Columbia were lower than in 2002, but similar to conditions seen in other post-1998 years (Fig. 72; 2003). There is some evidence that over-winter conditions in 2003/04 experienced by the coho salmon off the west coast of Vancouver Island were more favourable than in the past years, because they were not as lean at the end of the winter as in previous years (Fig. 73). Coded-wire tags analysis of marine survival shows that southeastern Alaska coho stocks had marine survival rates of 20-25% through most of the 1990s while Strait of Georgia coho stocks had marine survival rates of only 2-4%. Our results suggest that in 2004 significantly higher marine survival for southern British Columbia coho is thus also likely, since their growth condition was improved over the winter.

Since 2001, we have also been surveying juvenile salmon in February-March to determine over-winter growth and distribution, and to evaluate their status at the end of the winter. Our February-March surveys found that very few juvenile pink, chum, and sockeye salmon remained on the continental shelf during the 2001, 2002, and 2004 winter. However, in February 2003 large numbers of juvenile pink, chum, and sockeye salmon were found in the inlets and continental shelf on the west coast of Vancouver Island from Estevan Point to Quatsino Sound and in Dixon Entrance off northern British Columbia. This was surprising as, except for a resident population of pink salmon in Puget Sound, it is generally believed that these fish quickly migrate to offshore waters of the North Pacific by the end of the summer or early in the fall (Hartt and Dell 1986). The frequency at which juvenile pink, chum and sockeye salmon remain on the shelf throughout the winter is unknown, but may have been associated with the weak 2002-2003 El Niño that produced unusually warm waters during the 2002 fall and 2003 winter. At this point the link to El Niño is speculative, as it is the main factor that differs among those 4 years. It may be the first time that this has been reported. Because no sampling was done during the winter of the 97-98 El Niño we cannot compare with juvenile salmon behaviour then.

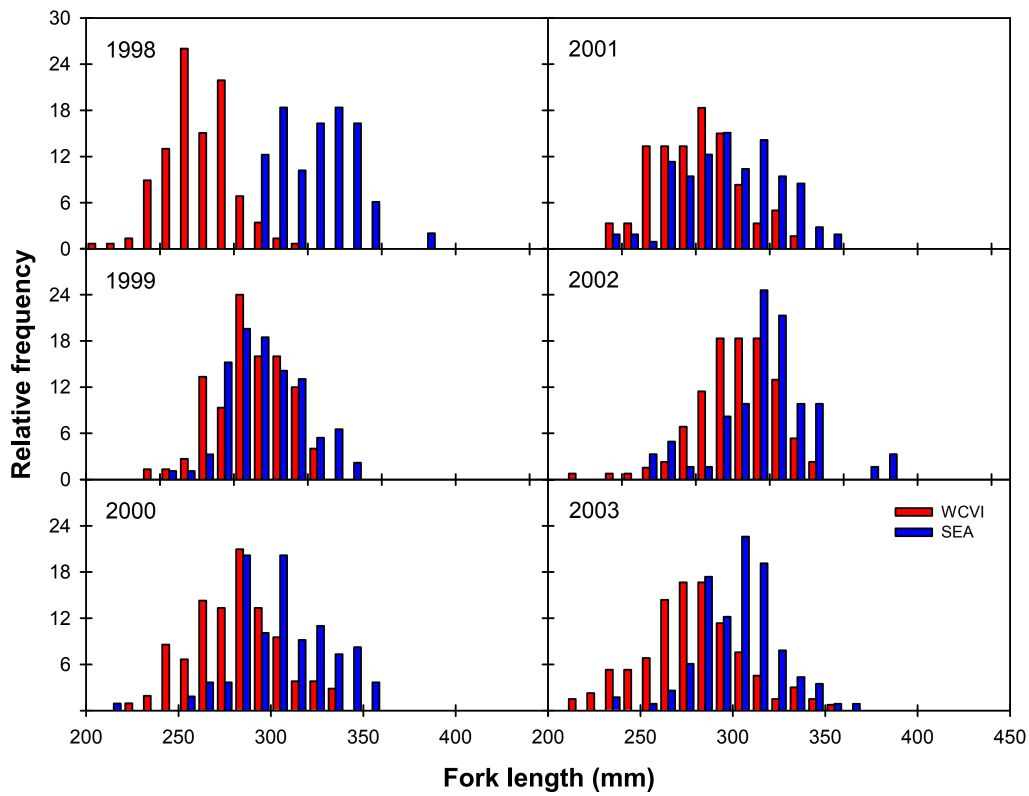


Figure 72. Size frequency distribution of juvenile coho salmon collected on the west coast of Vancouver Island (WCVI) and south east Alaska (SEA) in October 1998-2003.

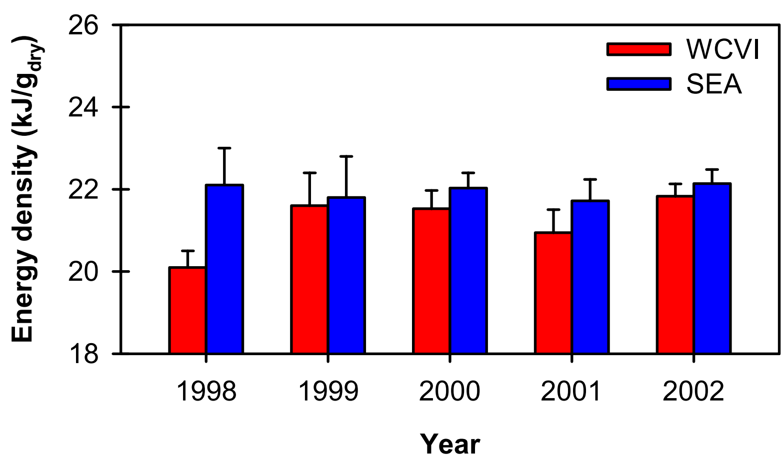


Figure 73. Energy density of juvenile coho salmon collected on the west coast of Vancouver Island (WCVI) and south east Alaska (SEA) in October 1998-2002. Energy density was determined using a bomb calorimeter in 1998-

2001, and estimated from water content of fish in 2002. Energy density was lower for coho salmon collected on WCVI in 1998. The error bars represent 2 x standard error.

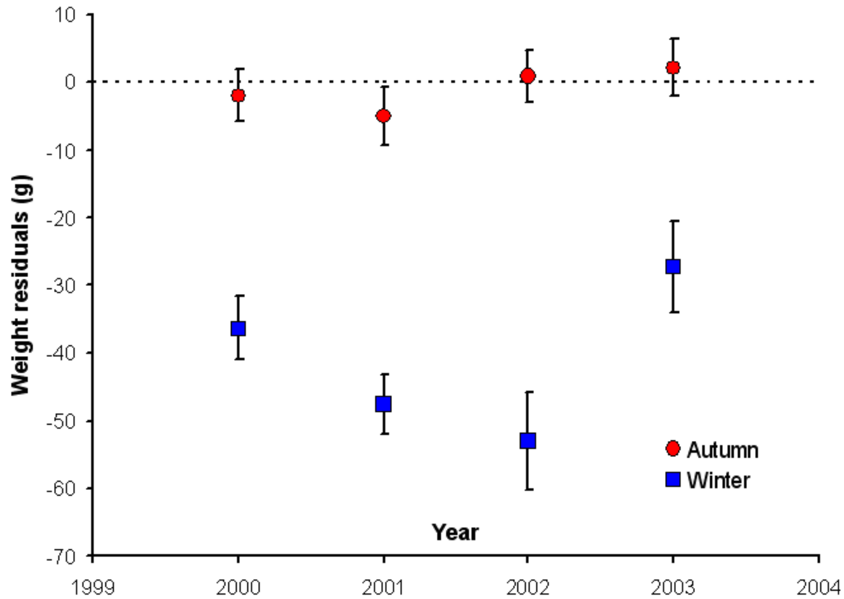


Figure 74. Condition index for juvenile coho salmon collected on the west coast of Vancouver Island during autumn (October) and winter (February/March). This index is positively correlated with lipid levels and was estimated as the average difference between observed weight and weight predicted from a general length-weight relationship derived for coho salmon by Trudel et al. (2004). The error bars represent 2 standard errors of the mean.

Large regional differences in the growth of coho salmon were also observed during the summer of 2003. Coho salmon growth was low in the Strait of Georgia and high in the Bering Sea (Bristol Bay) relative to the west coast of Vancouver Island (Fig. 75). This suggests that the area of marine residence may have a large effect on the adult returns. Further DNA analyses will be required to determine the stock-specific distribution and migration of salmon in the marine environment, and to understand how ocean conditions affect salmon production. The much increased proportion of age 2-or-older coho with latitude must also contribute to the size difference.

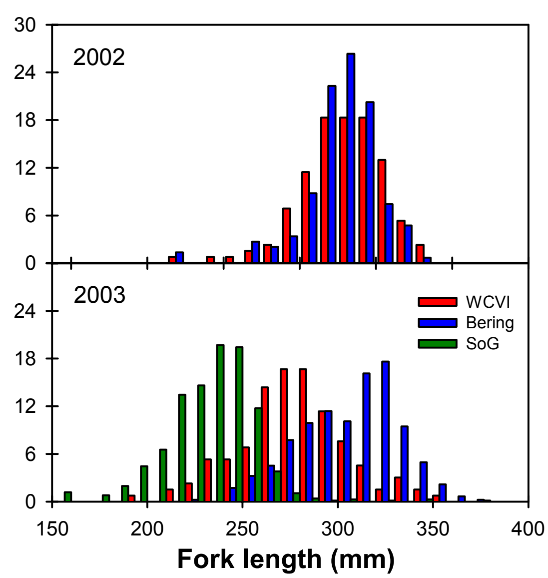


Figure 75. Size frequency distribution of juvenile coho salmon collected on the west coast of Vancouver Island (WCVI), the Bering Sea, and Strait of Georgia during September-October 2002-3003.

Seabird Reproductive Performance on Triangle Island

Marine birds can be effective indicators of the state of marine ecosystems because they are lower-to-upper trophic-level predators that gather annually in large aggregations to breed. Triangle Island (50°52' N, 129°05' W) supports the largest and most diverse seabird colony along the coast of British Columbia. It includes the world's largest population of Cassin's Auklets (*Ptychoramphus aleuticus*; estimated at 1.1 million breeders), British Columbia's largest populations of Tufted Puffins (*Fratercula cirrhata*; 52,000 breeders) and Common Murres (*Uria aalge*; 8,200 breeders), and a large population of Rhinoceros Auklets (*Cerorhinca monocerata*; 82,000 breeders), among others. Since 1994, researchers from the Centre For Wildlife Ecology (a partnership between the Canadian Wildlife Service and Simon Fraser University), have visited Triangle Island between late March and late August to collect annual time-series information on seabird demography and ecology. Here, we report on key indicators of seabird breeding at Triangle Island in 2003, focusing on species belonging to the family Alcidae (Auks, auklets, puffins, guillemots, murres, murrelets), and place the 2003 results in the context of the 1994-2002 time series.

Timing of avian breeding is thought to be determined primarily by female condition prior to and during the period of egg formation. In general, breeding among the alcids was late at Triangle Island in 2003, compared to previous years (Fig. 76). This suggests that females were in poor condition early in the season. The mean hatching dates of Cassin's and Rhinoceros auklets were among the latest recorded in the past 10 years, while Tufted Puffins hatched about 2-4 weeks later than in any year since 1994, and similar to the timing reported from the mid-to-late 1970s. In contrast, Common Murres hatched at about the same time in 2003 as they had in every year since 1999.

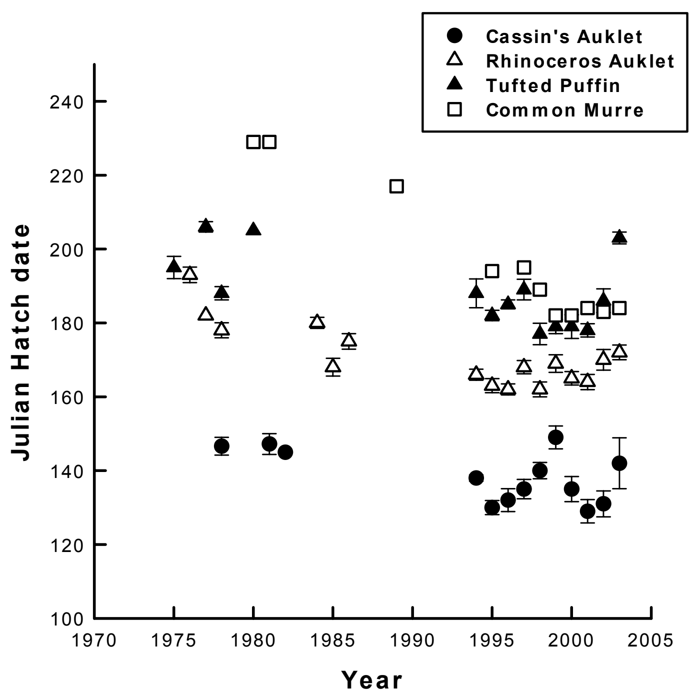


Figure 76. Timing of breeding for seabirds on Triangle Island, British Columbia, 1975-2003. Reported are mean hatching dates, with 95% confidence intervals, for Cassin's Auklets, Rhinoceros Auklets and Tufted Puffins, and dates when nestlings were first seen for Common Murres

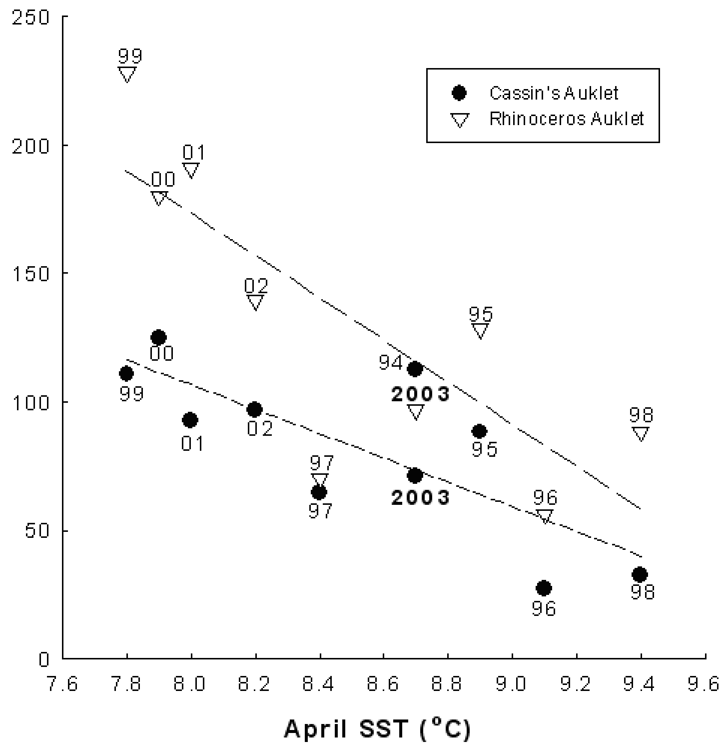


Figure 77. Consequences of April sea surface temperatures, measured at the Pine Island Lightstation (50°35'N 127°26'), for Cassin's and Rhinoceros auklets breeding on Triangle Island, British Columbia, 1994-2003. Fledgling production is calculated as: hatching success * % fledging success * mean fledging mass; or in other words, the mean mass of fledged chick produced per egg laid. The negative relationships are statistically significant (both $P < 0.01$) for both Cassin's Auklet (slope = -48 g/°C, $r^2 = 0.61$) and Rhinoceros Auklet (slope = -84 g/°C, $r^2 = 0.65$).

In general, breeding success among the alcids was low at Triangle Island in 2003. Tufted Puffins were especially affected: despite breeding late, many puffins got their eggs through to hatching, and many parents began delivering fish to their chicks. However, provisioning terminated very suddenly early in August, suggesting that the availability of key species of fish prey (such as Pacific sandlance) dropped very suddenly at that time, when chicks were still quite young (<20 days old). Adult puffins virtually abandoned the colony, and no chicks survived on Puffin Rock, although some did on Strata Rock, on the east side of Triangle. While not as dramatic, breeding success was also quite low in Cassin's and Rhinoceros auklets, and close to values predicted from the mean April sea surface temperature in both species (Fig. 77). In contrast, Common Murres bred successfully (76% of pairs raised chicks to depart the colony) even as other species did not, a pattern often reported elsewhere along the Pacific coast.

Fig. 77 shows that breeding success of Cassin's Auklets was very low through the warm years of the mid-to-late 1990s, but improved following the "regime shift" that began in 1998-1999. The mid-to-late 1990s was a period when the population at Triangle Island declined dramatically, largely due to low adult survival rates. Fig. 78 shows that we were catching fewer and fewer Cassin's Auklets at our night banding station in West Bay during this period, and by 1998-1999, were catching virtually no brown-eyed birds, the youngest birds in the population (1- and 2-year olds). However, the Cassin's Auklet population now appears to be recovering (Fig. 78), with improved reproductive success since 1999 having resulted in more young birds, potential recruits, being caught.

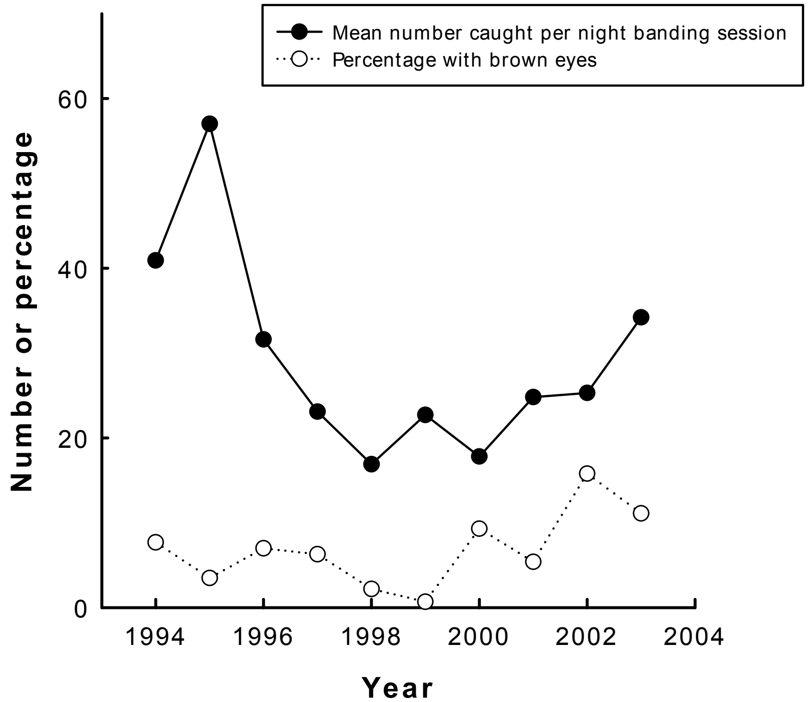


Figure 78. Mean number of Cassin's Auklets caught per night in the month of May, 1994-2003, at the Centre for Wildlife Ecology's banding station in West Bay, Triangle Island. The dashed lines shows the percentage of all captured birds that had brown eyes; these are the youngest birds in the population, predominantly 1- and 2-year olds.

North Coast

Average Temperature and Salinity

The annual average temperature at Bonilla and Langara light stations are plotted in Figure 79, for the period 1962 to 2003.

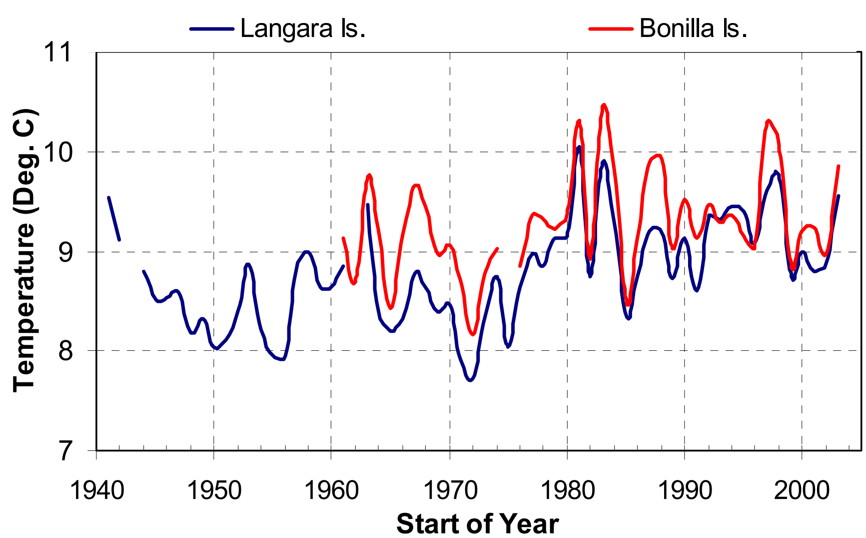


Figure 79. Annual average temperatures at coastal stations in northern British Columbia.

Temperatures were warmer in 2003 than in most previous years, reaching levels typical of El Niño years of the 1980s and 1990s. This warming is likely due to the impact of the 2002/2003 El Niño. Average annual salinity at Bonilla Island (Figure 80) was similar to the levels found in the previous two years, but the salinity of the local water at Langara Island continued its long-term decline that began in the early 1970s. This trend in salinity is not found at other stations in British Columbia, and its cause is not known.

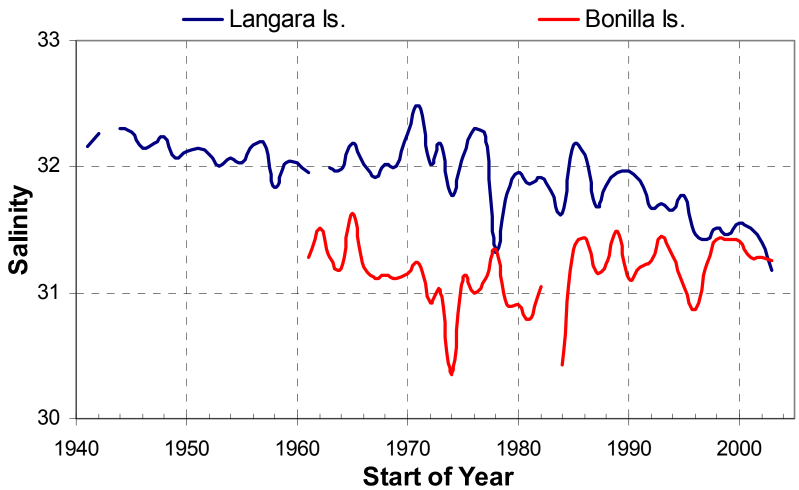


Figure 80. Annual average salinities at coastal stations in northern British Columbia.

Winter Sea Level and Pacific Cod.

Water temperature at Bonilla Island and pressure-adjusted winter sea level at Prince Rupert (Figure 81) have been used as indicators of winter currents in Hecate Strait and recruitment strength of Pacific cod. Generally, winters with high pressure-adjusted sea levels at Prince Rupert have strong currents through Hecate Strait and are poor recruitment years. "Winter" is the three month period of January to March inclusive. Recently Sinclair and Crawford (in press) determined that Prince Rupert adjusted sea levels alone were an excellent indicator of recruitment, and the temperature time series is a more minor factor and has been dropped from the prediction.

The term "pressure-adjusted" denotes a time series of sea level plus local air pressure, reported in the same pressure or height units. For the graph in Figure 81 the air pressure observations at Prince Rupert Airport were converted to an equivalent height of seawater, assuming that one centimetre of seawater exerts a pressure of one millibar. Ocean currents respond to the total pressure above, which is the sum of seawater and air pressure as described above.

Two curves in Figure 81 represent long term changes in Prince Rupert winter sea levels. The blue line shows measured winter values since 1962. The red line is winter sea level with a correction to remove long-term sea level trend at Prince Rupert. This long-term trend is due to a combination of local land movement and a general global sea level rise, both of which are irrelevant to local cod recruitment. Therefore it is the red curve that denotes interannual variability in winter sea level relevant to cod recruitment in Hecate Strait and possibly Dixon Entrance.

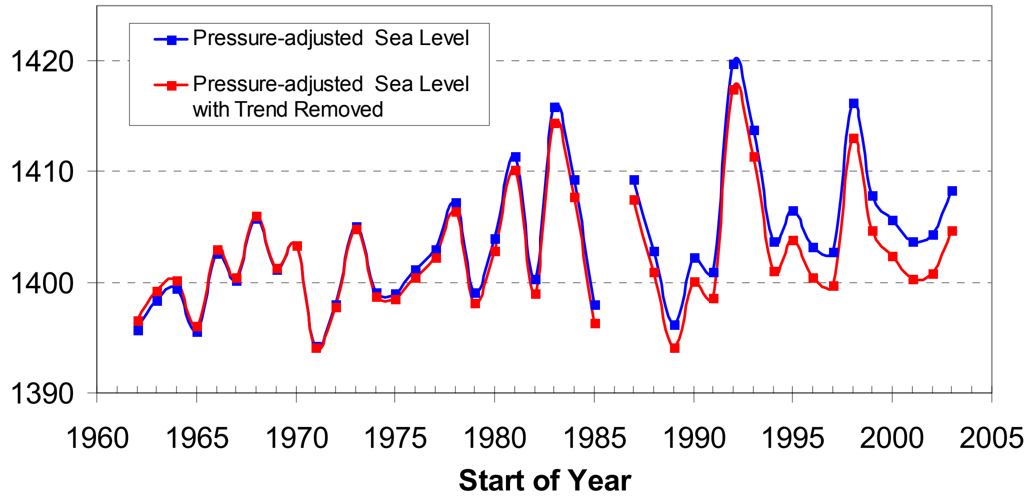


Figure 81. Pressure-adjusted sea level at Prince Rupert in winter, 2003, rose by several centimetres from the low levels of 12000 to 2002, but remained significantly below the extreme highs found during the 1997/98 El Niño winter. The level of 1405 centimetres at Prince Rupert in the 2003 winter was only a few cm higher than the low term mean of 1402 cm during the 1960 to 3002 period. Therefore, we expect to see a medium level recruitment of Pacific cod spawned in Hecate Strait in early 2003.

Set-up of Eddies along the Continental Margin

With the aid of sea level measurements from satellites we can observe the set-up and movement of 200-km-wide anticyclonic (clockwise rotating) eddies off the west coast of the Queen Charlotte Islands in British Columbia and the Alexander Archipelago of Southeast Alaska. Eddies are named Sitka and Haida after local geographic features along the coast where they are formed. One or two Haida Eddies form during most winters along the west coast of the Queen Charlotte Islands, whereas Sitka Eddies form along the Southeast Alaska coast. Eddies were larger in winters of very strong El Niño events in 1982-1983 and 1997-1998. The 1998 eddy was the largest ever observed, whereas eddies formed in 1999-2003 were considerably smaller. Generally, winters with very high pressure-adjusted sea levels at Prince Rupert will set up strong Haida Eddies. Although winter sea levels at Prince Rupert in 2003 were somewhat higher than in the previous three years, eddies formed in early 2003 were similar in height, and generally low amplitude.

Figure 82 displays images of eddies in the eastern Gulf of Alaska during four seasons in 2003. This image was prepared from observations by Jason-1 and ERS-2 satellites, using software provided by the Colorado Centre for Astrodynamics Research. Contours show sea surface height anomalies at 5-centimetre intervals relative to a multi-year average. Red denotes highest levels, blue denotes lowest.

Eddies in Figure 82 are denoted with labels of the form “Haida-2003a” (the first Haida Eddy to form in the year 2003). Thee eddies that formed in 2002 drifted slowly westward and decreased in height in 2003. By December 2003 they were both less than 5 cm in height, which is near the detection limit for satellite sea level measurements. The eddies Haida and Sitka Eddies that formed in 2003 also drifted westward. Sitka Eddies decreased in height by about 5 cm during 2003, whereas the two Haida 2003 eddies maintained there elevations.

Images from early 2004 (Figure 82) show a single Haida Eddy to have formed off the southwest coast of the Queen Charlotte Islands, reaching heights of 30 cm in May 2004. This height is twice the peak amplitude of the 2003 Haida Eddies.

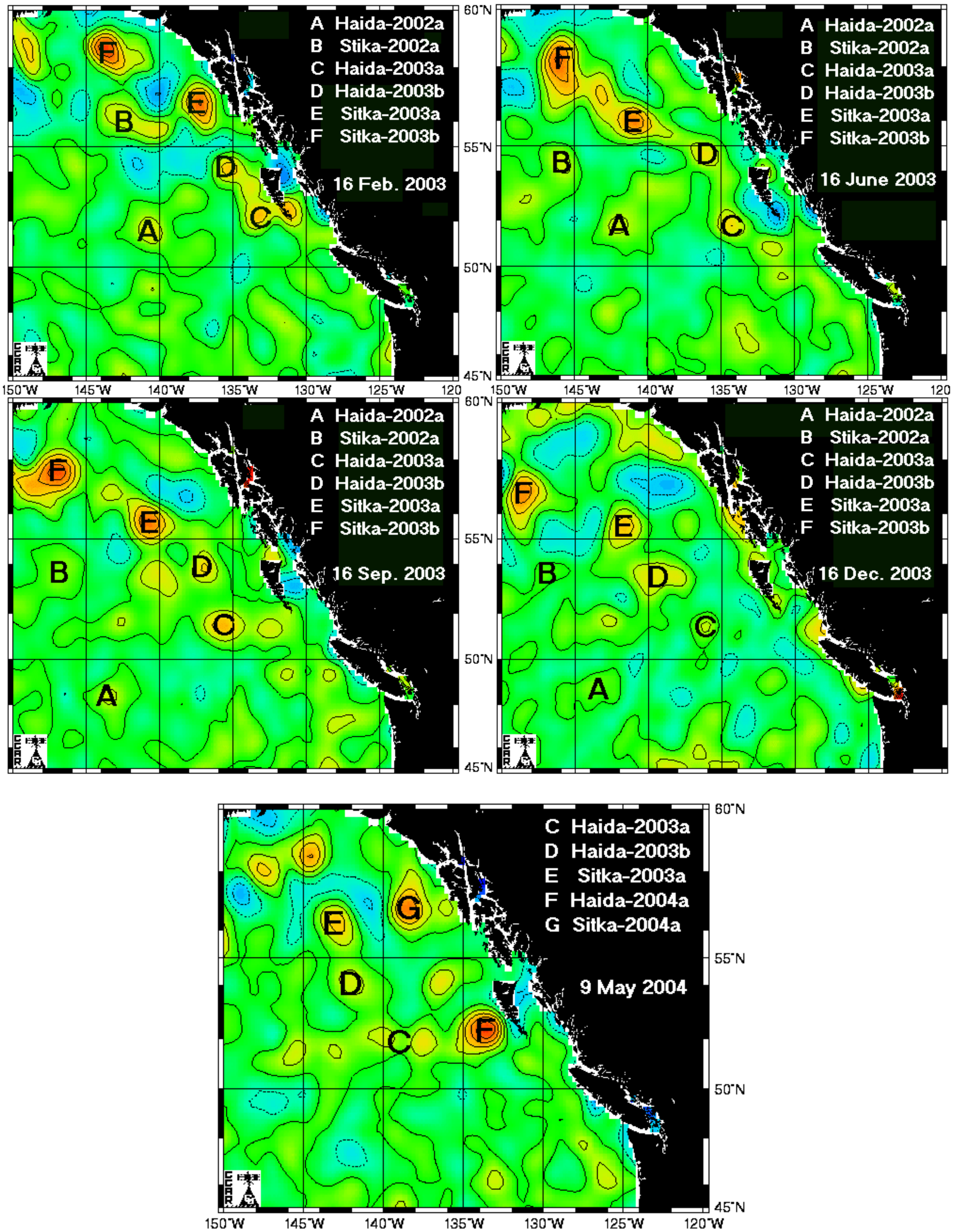


Figure 82. Eddies in the eastern Gulf of Alaska during four seasons in 2003, and May 2004.

Herring in Hecate Strait

The exploitable biomass of herring in the Hecate Strait area is an amalgamation of the three major migratory stocks in the Queen Charlotte Islands, Prince Rupert, and in the Central Coast. Over the past decade, abundance in the Queen Charlotte Islands has been depressed whereas abundance in both Prince Rupert and the Central Coast has remained at healthy levels (Fig. 83, 84, 85). Levels of recruitment to the Queen Charlotte Islands have been depressed (Fig. 84) with 6 of the past 10 year-classes being 'poor' while the Prince Rupert stock (Fig. 86) has experienced a good recruitment at least every 4 years since 1980. Recruitment to the Central Coast stock (Fig. 88) has been less regular but the 'good' year-classes that have occurred were very strong. Indications are that recent year-classes in the Queen Charlotte Islands have remained weak, except in 2003, while those in the Prince Rupert District and Central Coast have been getting stronger suggesting better survival conditions in the latter areas. Abundance in the Queen Charlotte Islands and Prince Rupert is expected to remain similar to recent levels while the Central Coast could decline slightly from the level of 2003.

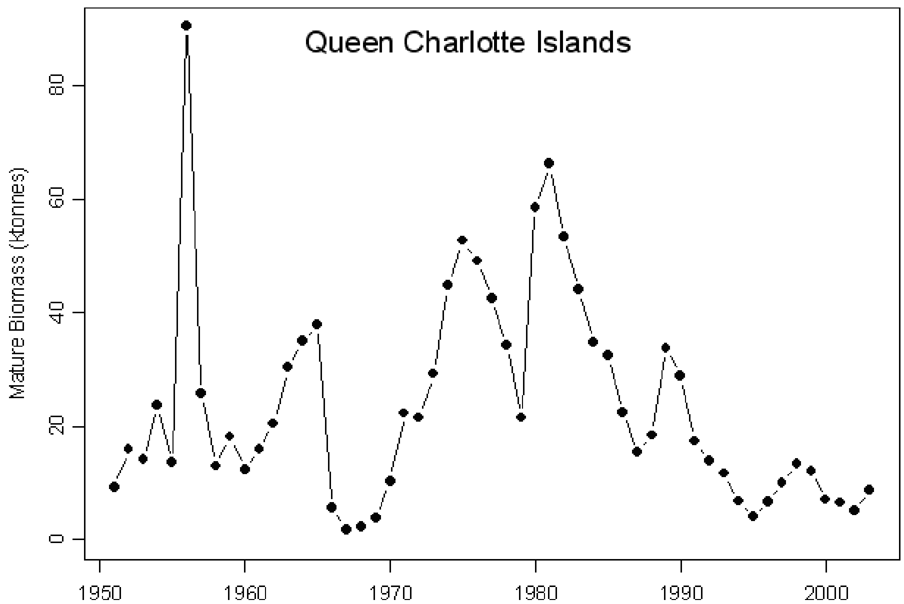


Figure 83. Queen Charlotte Islands herring abundance.

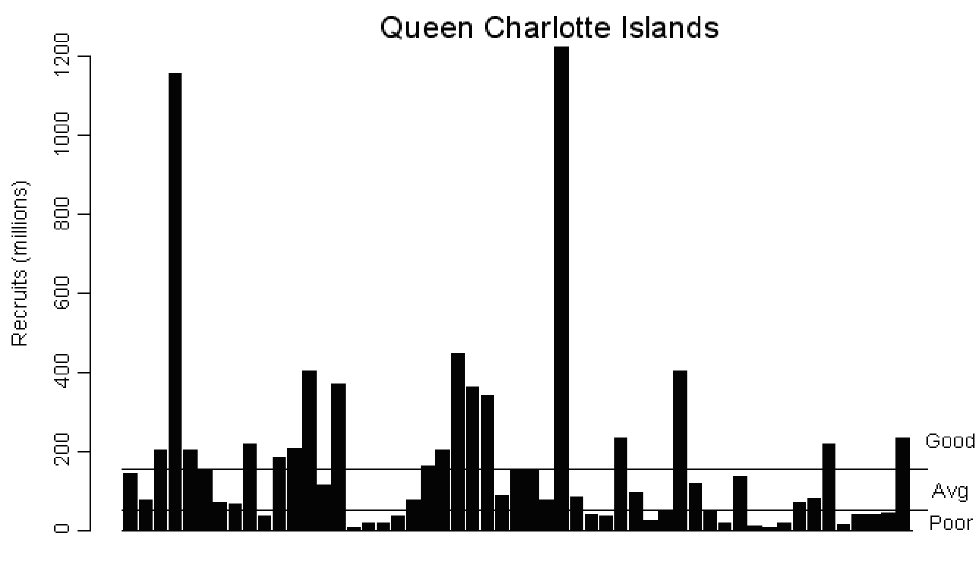


Figure 84. Interannual variability and decadal trends in recruitment to the Queen Charlotte Islands herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 5 of the last 10 recruitments have been 'poor'.

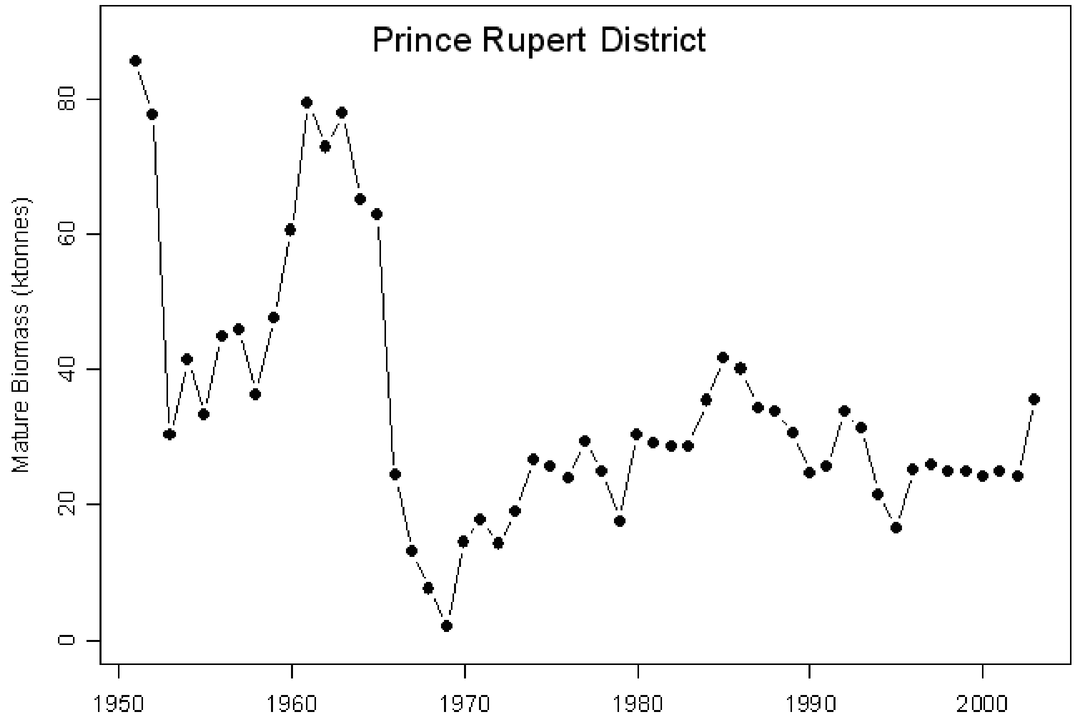


Figure 85. Prince Rupert District herring abundance.

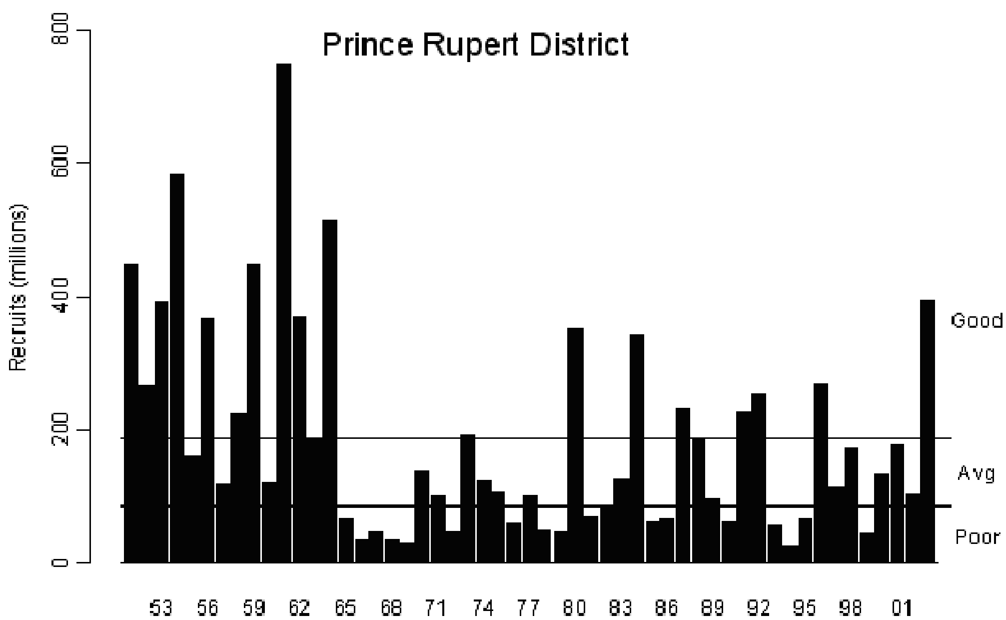


Figure 86. Interannual variability and decadal trends in recruitment to the Prince Rupert District stock. The boundaries for ‘poor’, ‘average’ and ‘good’ recruitment are shown. Note that ‘good’ recruitments have occurred almost every four years since 1980.

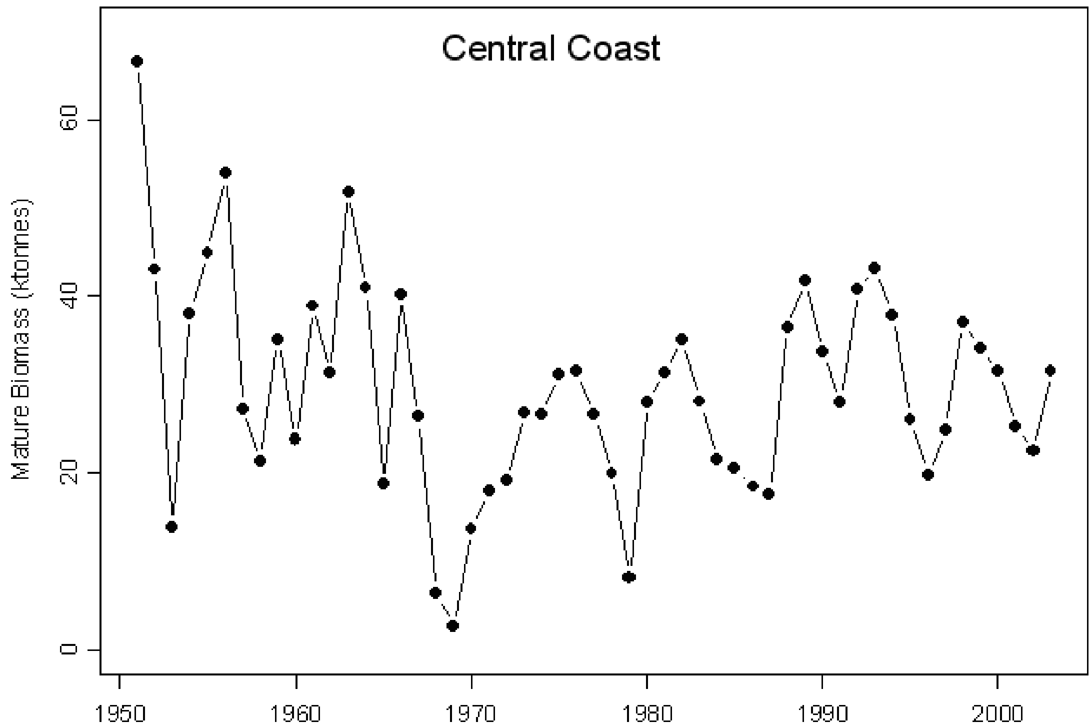


Figure 87. Central Coast herring abundance.

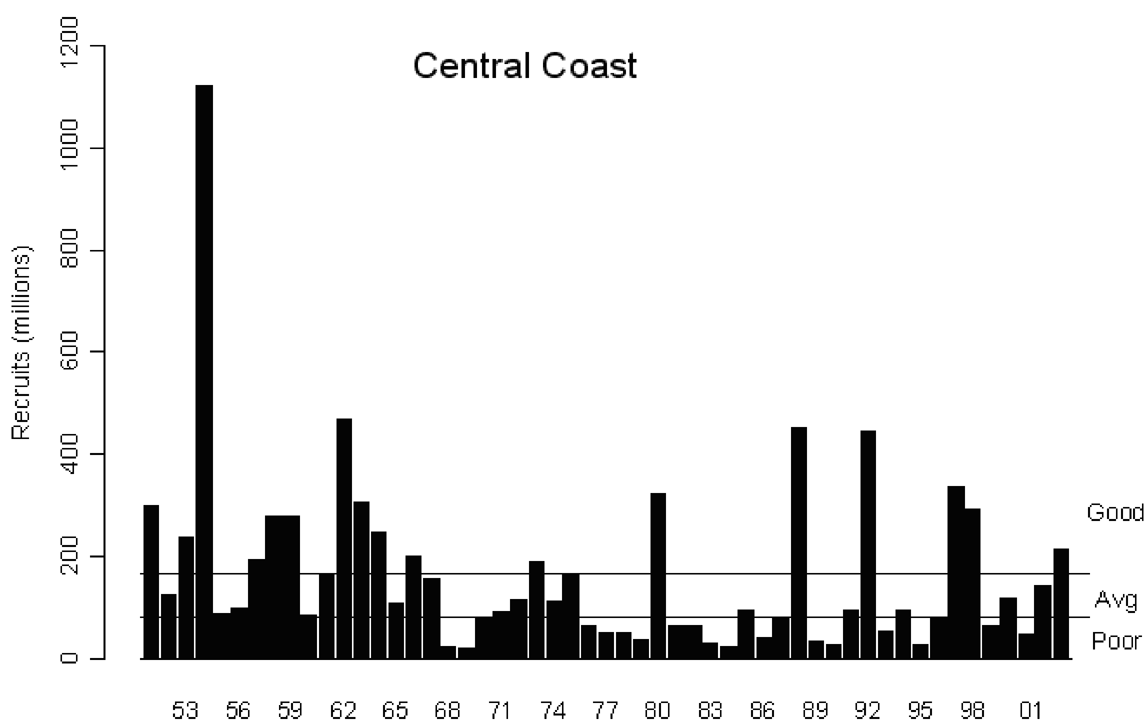


Figure 88. Interannual variability and decadal trends in recruitment to the Central Coast stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown.

Strait of Georgia and Adjacent Channels

Fraser River

The 2003 discharge rate for the Fraser River was lower than the long term average during most of the year due to lower-than-normal snow pack levels throughout its watershed in 2003, (Figure 89). The 2003 freshet peaked in early June with maximum discharge values of about 7500 m^3 s^{-1}, which is close to normal, but the freshet's shorter-than-normal duration reduced the overall 2003 discharge. After the peak discharge the flow rate remained below seasonal means for the rest of the year except for a short period in late October when heavy rain increased it significantly. Snow pack in spring 2004 was closer to normal, likely leading to more normal runoff in 2004 than in 2003.

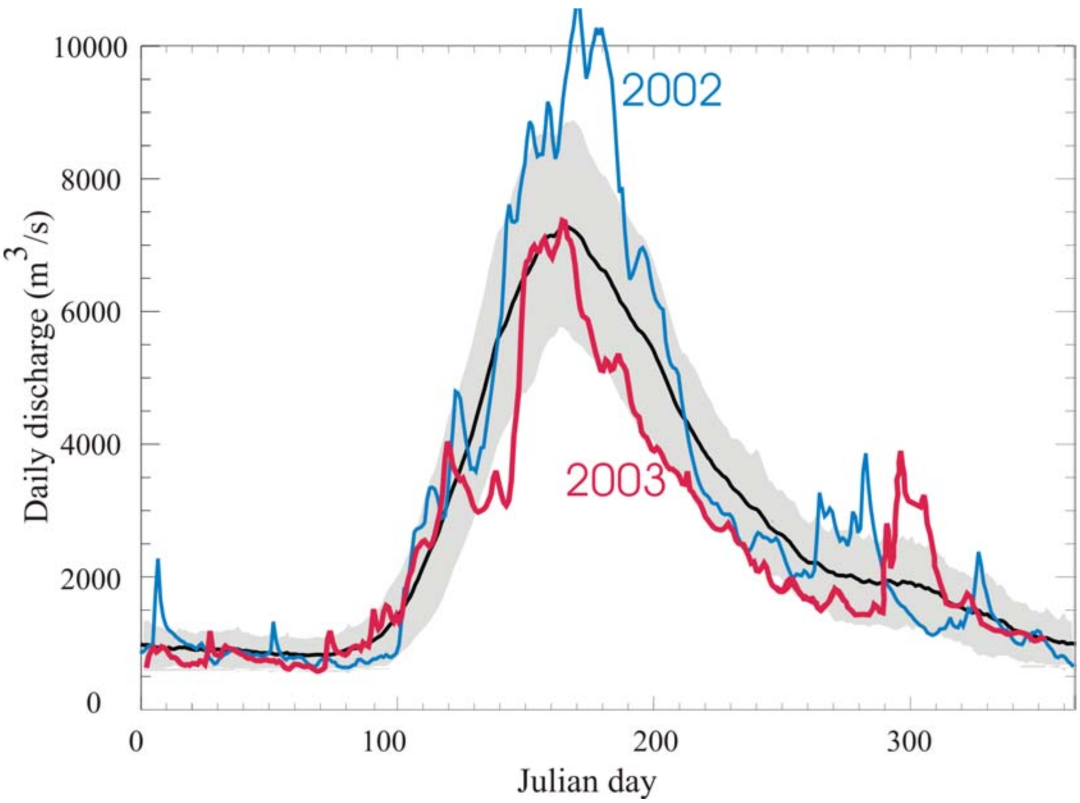


Figure 89. Fraser River discharge measured at Hope. The black line indicates the long term average discharge rate, and the shaded area the standard deviation about the mean.

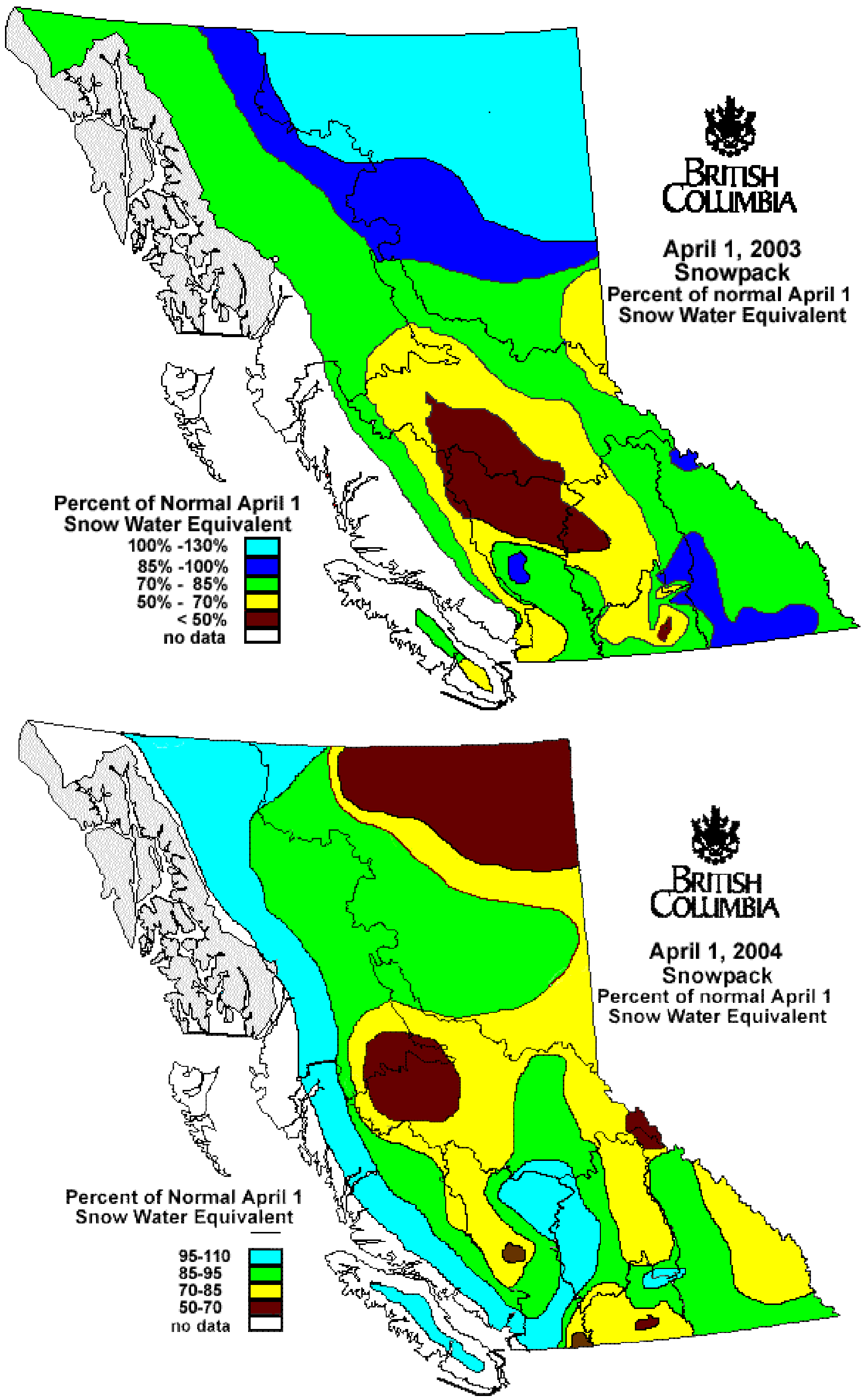


Figure 90. Snow water equivalent as of April 1 2003 (top) and 2004 (bottom), expressed as a percentage of the 1971-2000 normal.

Temperature and Salinity

Sea surface temperature (SST) in the Strait of Georgia remained above normal for all of 2003, with SST anomalies at Entrance Island reaching a maximum of almost 2 deg C in August (Fig. 91). The sea surface salinity (SSS) also remained higher than average for most of the year, with SSS anomalies varying from about 1 to 3 psu. However, in the months of October and November, the surface salinity significantly decreased due to high Fraser discharge caused by heavy rain. The data in Fig. 91 are monthly values measured at Entrance Island. Similar conditions were recorded at other lighthouse stations as well as at the Nanoose Bay station.

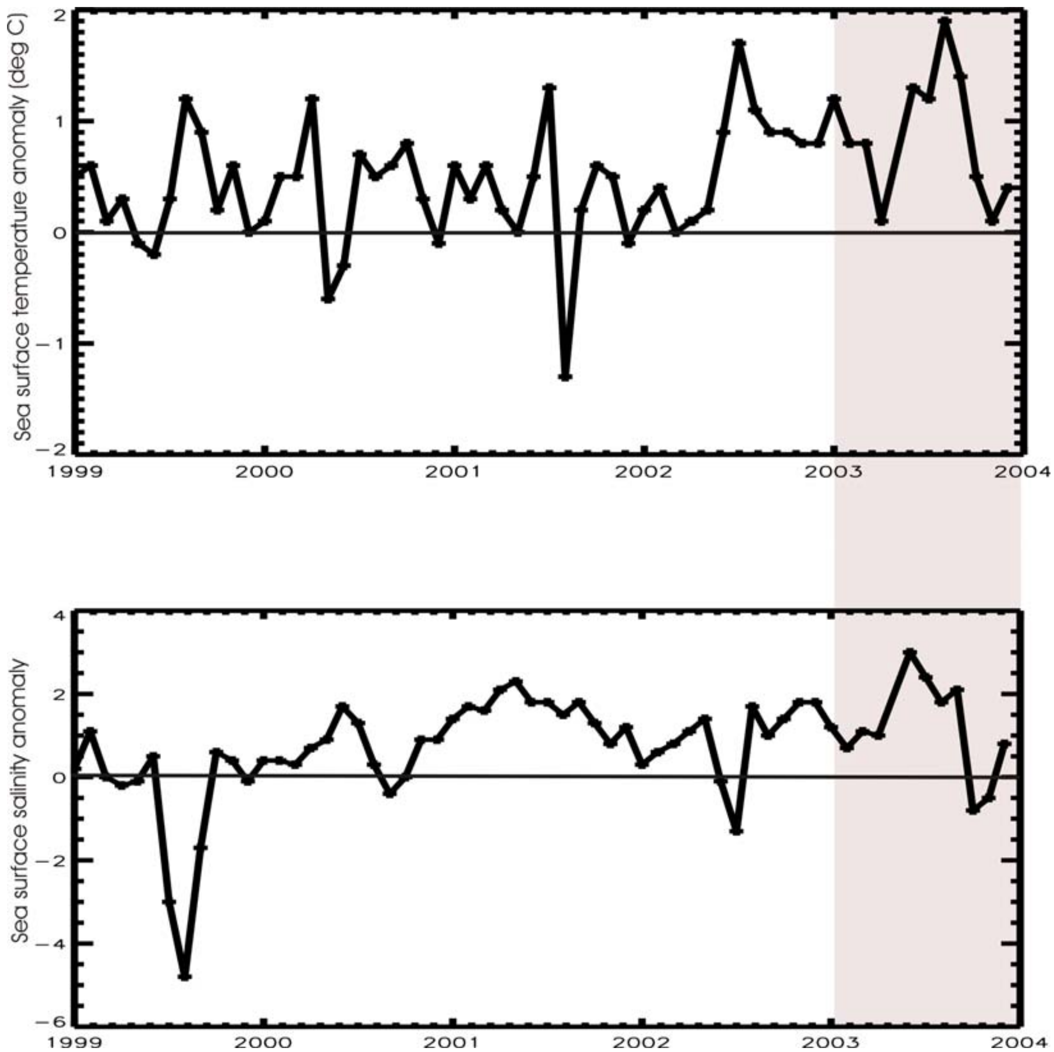


Figure 91. Monthly sea surface salinity (SSSA) and temperature (SSTA) anomalies measured at Entrance Island.

Data from shore sampling at light stations show that sea surface temperatures in the Strait of Georgia as a whole continued to increase from the 1999 nadir and the annual SST for 2003 showed a substantial increase over the previous four years (Figure 92). The average salinity also increased somewhat in the Strait of Georgia in 2003 (Figure 93), as observed in 2001.

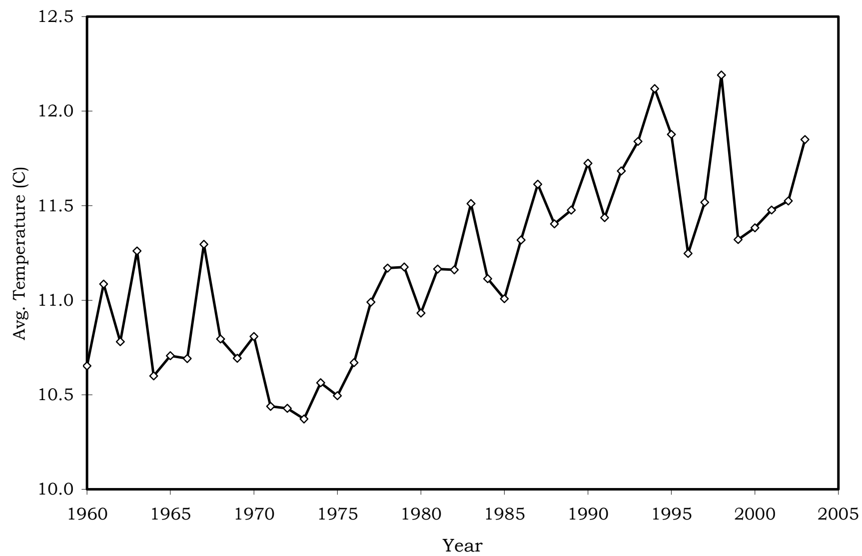


Figure 92. Annual (January to December) average sea surface temperature (ºC) in the Strait of Georgia. The average value is calculated using data from Cape Mudge, Chrome Island, Departure Bay, Entrance Island, and Sisters Island.

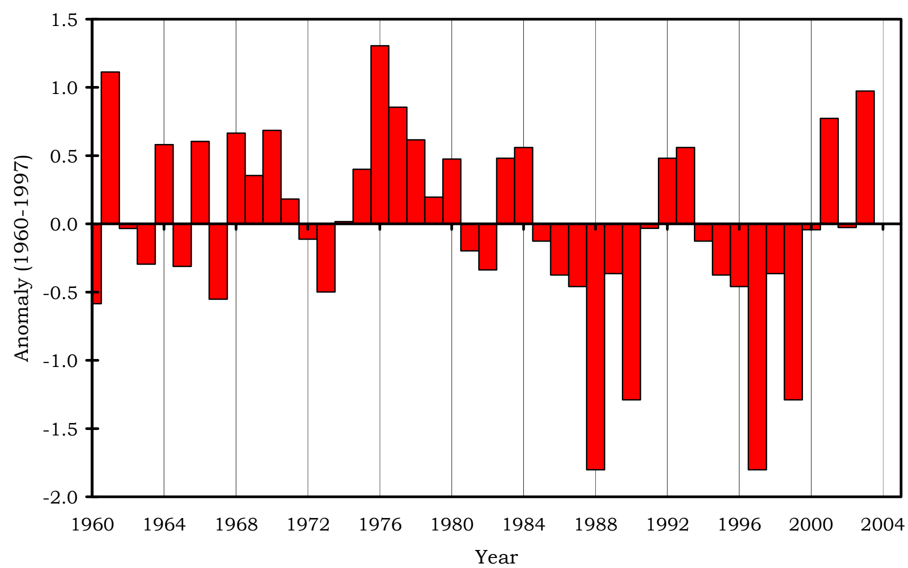


Figure 93. Annual (January to December) average sea surface salinity (expressed as the anomaly from the long-term average) in the Strait of Georgia. The average values are calculated using data from Cape Mudge, Chrome Island, Departure Bay, Entrance Island, and Sisters Island.

Below the surface, the Strait of Georgia was also warmer than normal in 2003. Fig 94 gives the time series of temperature anomaly measured at the Nanoose Bay station, located just off Ballenas Island in the central deep basin of the Strait. Following the warm temperatures associated with the El Niño of 1998, the sub-surface Strait of Georgia waters had remained cool relative to the previous two decades. This corresponds to the cooling associated with the 1998/99 "regime shift" also depicted in other coastal time series. However, the cool episode was interrupted by significantly warmer conditions in the Strait that began in 2003, similar to conditions typically associated with an EL Niño (such as in 1998).

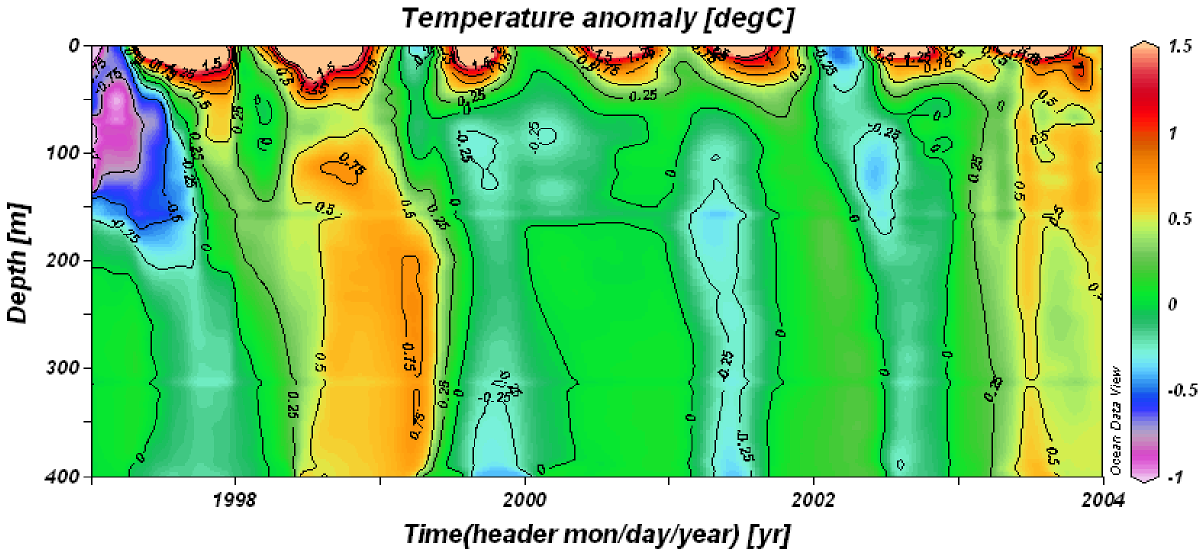


Figure 94. Temperature anomaly measured at the Nanoose Bay Naval Station, located just off Ballenas Island in the deep basin of the Strait of Georgia. The anomalies are computed in relation to the 1970-2003 period.

Spring Plankton Bloom and Start Dates.

Fluorometers, salinometer and optical sensors were mounted on a standard 3-meter weather buoy in Saanich Inlet in December 1998 to form a prototype Marine Environmental Observing System. A similar system was installed in the Strait of Georgia on Halibut Bank in February 2001. The Saanich Inlet system operated to February 2001, from June 2001 to October 2002 and from July 2003 onwards. The Halibut Bank system operated to May 2001 and then from December 2002. In the five years since 1999 one or other of these two buoys has operated during the start of the spring bloom in March, producing time series of hourly observations of chlorophyll fluorescence near the surface (1-meter depth) and at 8-meter depth.

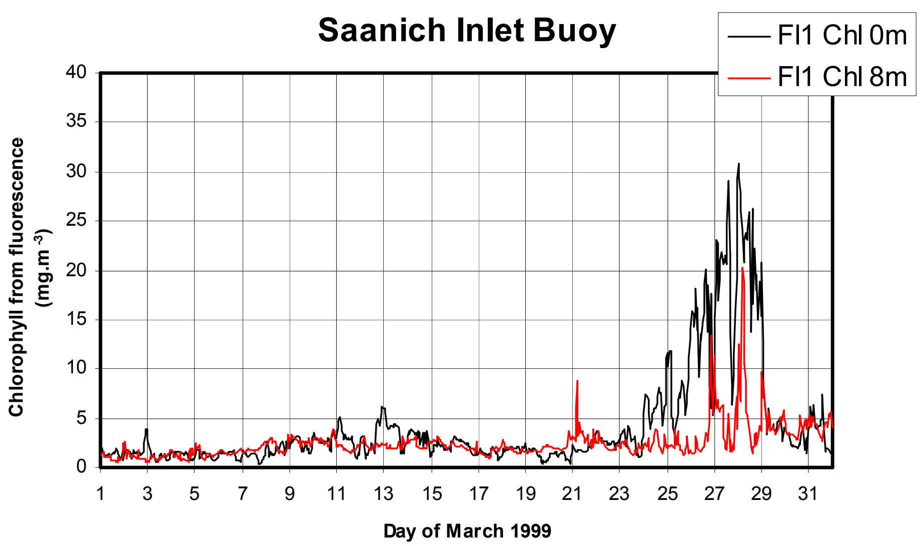


Figure 95. Chlorophyll concentrations at Saanich Inlet and Halibut bank buoys, measured by *in situ* fluorometer in March of each year, 1999 to 2003, at ocean surface (0m) and 8 metres depth (8m).

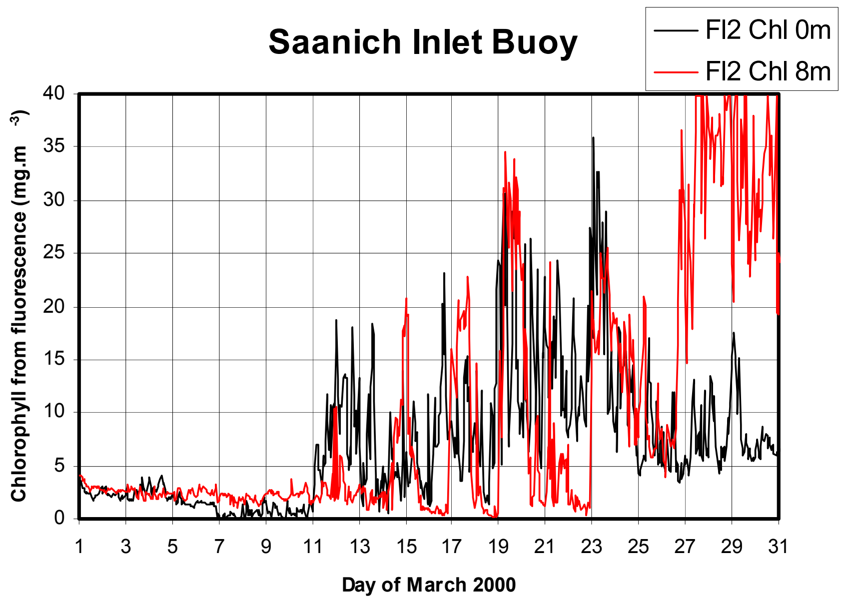


Figure 95 cont'd. Chlorophyll concentrations at Saanich Inlet and Halibut bank buoys, measured by *in situ* fluorometer in March of each year, 1999 to 2003, at ocean surface (0m) and 8 metres depth (8m).

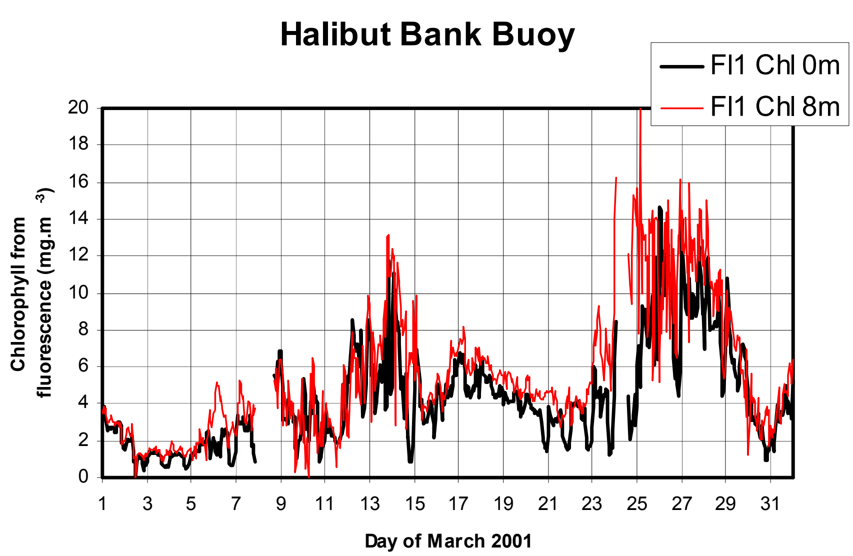


Figure 95 cont'd. Chlorophyll concentrations at Saanich Inlet and Halibut bank buoys, measured by *in situ* fluorometer in March of each year, 1999 to 2003, at ocean surface (0m) and 8 metres depth (8m).

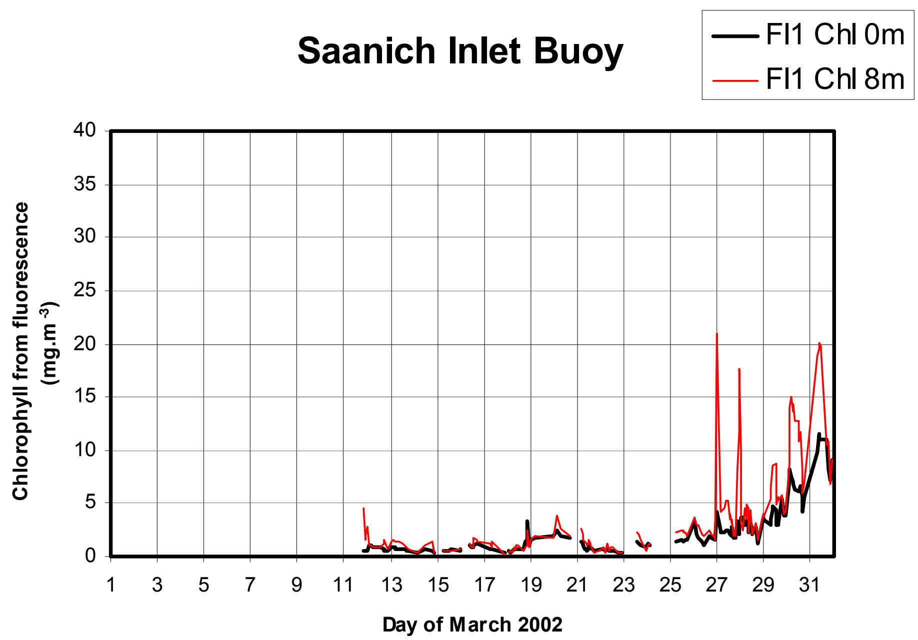


Figure 95 cont'd. Chlorophyll concentrations at Saanich Inlet and Halibut bank buoys, measured by *in situ* fluorometer in March of each year, 1999 to 2003, at ocean surface (0m) and 8 metres depth (8m).

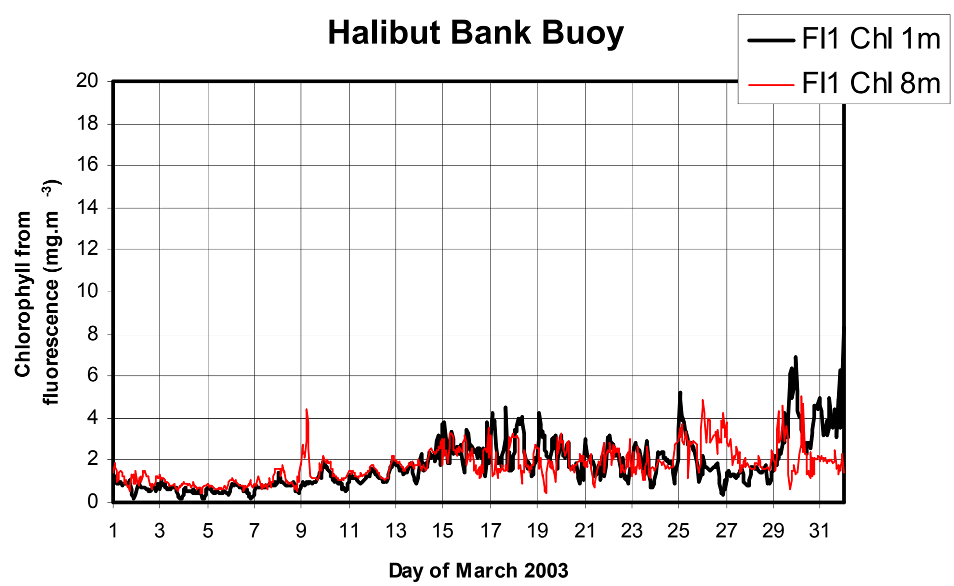


Figure 95 cont'd. Chlorophyll concentrations at Saanich Inlet and Halibut bank buoys, measured by *in situ* fluorometer in March of each year, 1999 to 2003, at ocean surface (0m) and 8 metres depth (8m).

The time series show start dates of the spring bloom for the five years as about: March 24 1999, March 11, 2000, March 7 2001, March 27 2002, and March 30 2003. The Saanich Inlet buoy appears to give a more distinct start date, with concentrations reaching 30 to 40 mg m^{-3}. On Halibut Bank the concentrations tend to be lower, and plots are scaled to show a range to only 20 mg m^{-3}. Up to 2003 there have been no simultaneous measurements at both locations, partly due to a sharing of hardware between the sites.

From February 11 to March 12 2002, transmission of data to IOS was interrupted by failure of the Anik link. Missing data should be recoverable from Environment Canada. Existing IOS data strongly suggest the bloom started after the data interruption. On April 1, concentrations reached 25 mg.m-3 at the surface and 37 $mg.m^{-3}$ At 8-meter depth. Halibut Bank data show that 2003 was a year with a late bloom start. March 30 represents the latest start of the five years, though there is some suggestion of an earlier slow rise on about March 15. April data show readings to 15 $mg.m^{-3}$ on April 1.

Herring

The Pacific herring stock in the Strait of Georgia migrates inshore in the fall and leaves the Strait in the spring following spawning. Survival conditions for juvenile herring in the Strait of Georgia have been unusually good during the last decade. Abundance of adult herring in the Strait of Georgia reached a recent high level in 2003 at just over 150,000 tonnes (Fig. 96) exceeding the historical high of 1955. Recruitment to this stock has been very strong with 9 of the last 10 year-classes being average or better (Fig. 97). Juvenile rearing conditions within the Strait of Georgia appear to be the main determinant of recruitment success for this stock since most juveniles do not leave the area until their second summer. Surveys of juvenile herring abundance within the Strait of Georgia for 2000 and 2001 corresponding to the 2003 and 2004 recruitments suggest that both should be 'good' year-classes. The recent strong recruitment should maintain the stock at very healthy levels for the next few years.

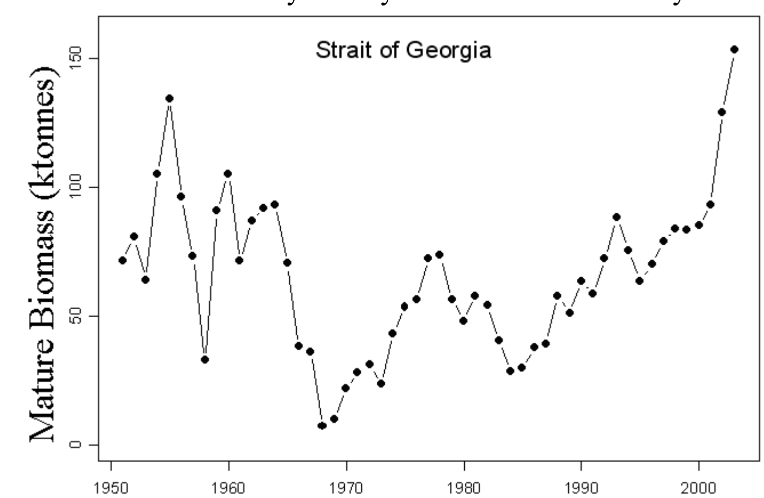


Figure 96. Strait of Georgia herring abundance.

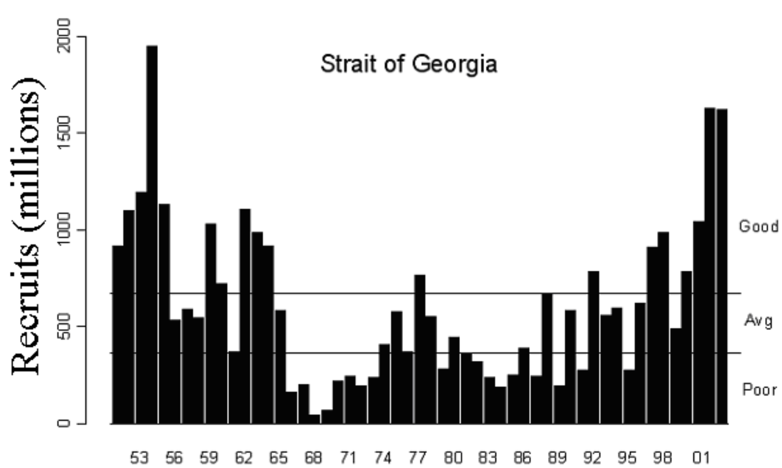


Figure 97. Interannual variability and decadal trends in recruitment to the Strait of Georgia herring stock. The boundaries for 'poor', 'average' and 'good' recruitment are shown. Note that 6 of the last 10 year-classes have been 'good'.

Salmon

A climate regime shift occurred in 1998 and was observed as shifts in several indicators in the Strait of Georgia, including sea surface temperatures (Figure 98) and the dominant winter wind direction (Figure 99). The impacts of the regime change on the productivity of the Strait of Georgia were first observed in 2000 (DFO 2002, Beamish et al. 2001, Beamish et al. 2002, Beamish et al. 2004) and have persisted through 2003. There was improved growth of juvenile Pacific salmon in 2000 and 2001, record returns of pink salmon to the Fraser River in 2001 and 2003 (entered the ocean in 2000 and 2002), above average returns of sockeye salmon to the Fraser River in 2002 and near average returns in 2003, the largest return of Fraser fall-run chinook salmon in 2003.and the largest biomass of Pacific herring in 2003 since 1952. We use the length of day index (Figure 100) to show that the new regime starting in 1998 is persisting, despite changes in the Strait of Georgia in 2002 and 2003 (Beamish et al. 2004). We propose that the apparent decrease in productivity for juvenile salmon in the Strait of Georgia in 2002 and 2003, reflects the impacts that local conditions and variability can have on basin-wide conditions within a regime.

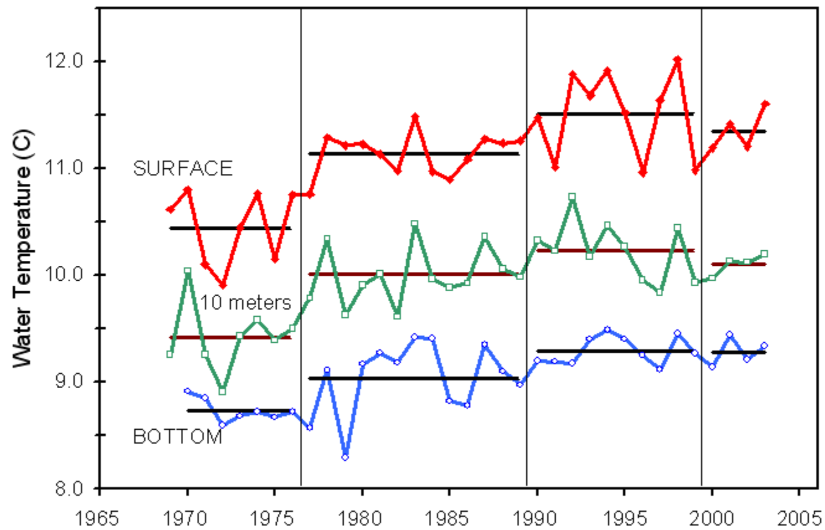


Figure 98. Annual mean water temperature profiles (0, 10 and 395m below surface) for 1969 to 2003, obtained from the Nanoose Bay Naval Station, located just off Ballenas Island in the deep basin of the Strait of Georgia. Vertical lines indicate timing of regime change. Horizontal lines indicate mean water temperature during regime. (See Figure 94 for a more detailed plot of the 1997-2003 period.)

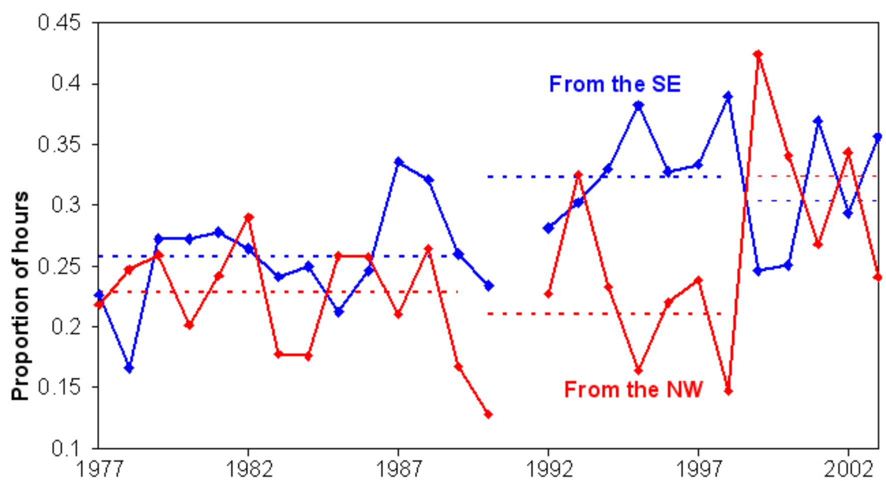


Figure 99. Dominant wind directions at Sandheads light station in the Strait of Georgia for October to December, 1977-2003. Solid lines indicate the proportion of hours the wind blew from the SE (blue) and the NW (red). Dashed horizontal lines indicate the average proportions for three regime periods.

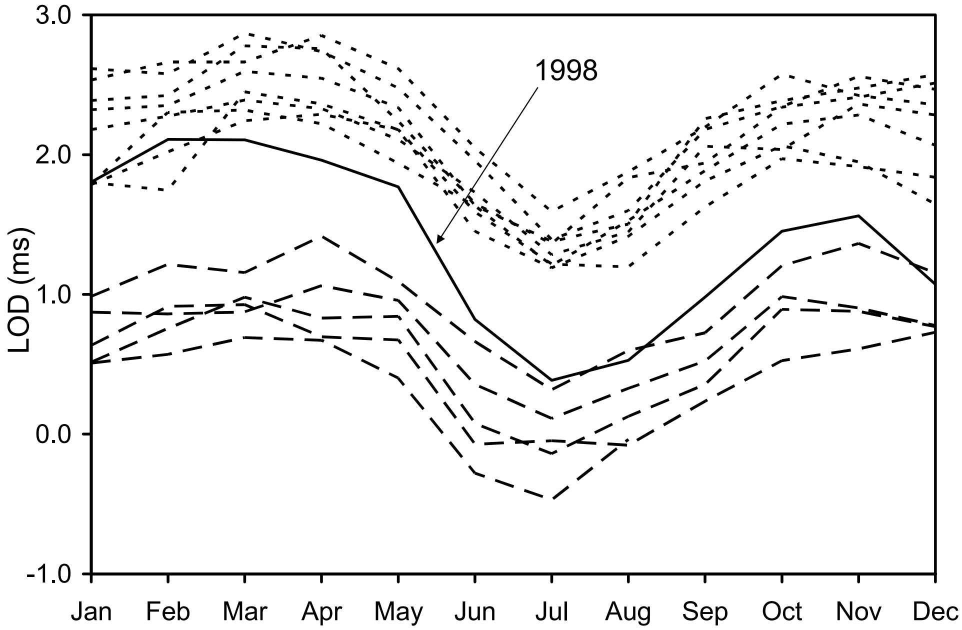
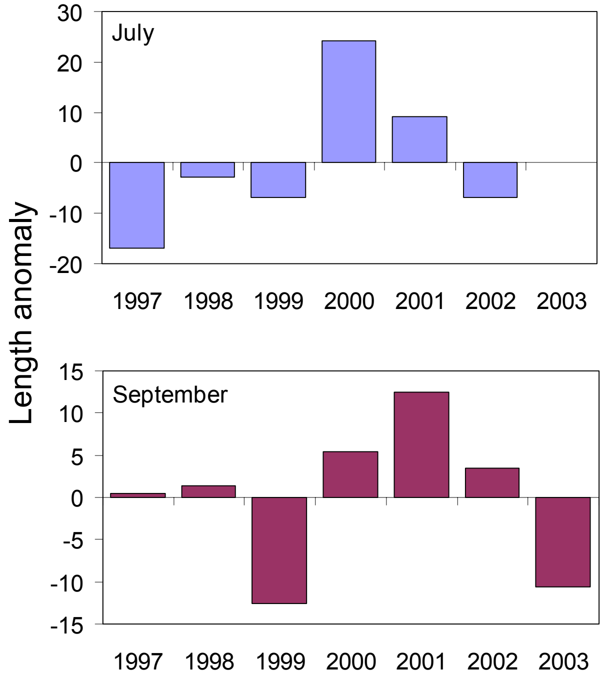


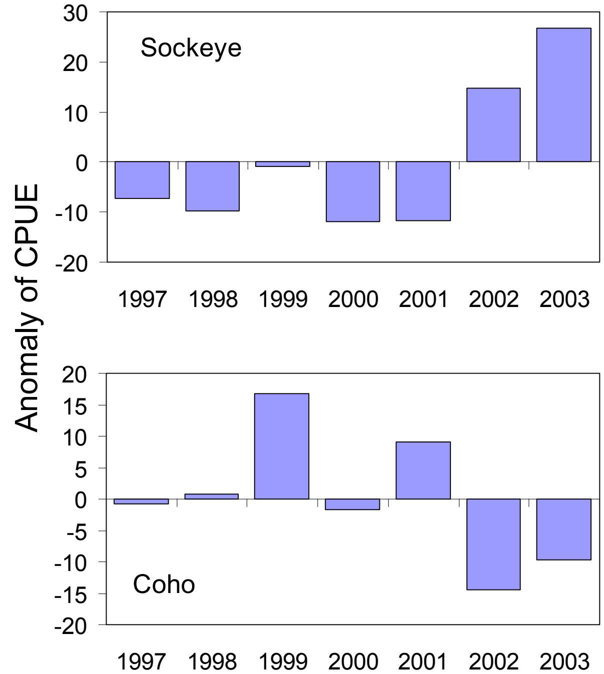
Figure 100. Seasonal pattern of the length of day (LOD). The LOD is the anomaly from the standard of 86,400 seconds. Dotted lines are the values from 1990 to 1997. The solid line is the pattern observed in 1998, showing the change to a new trend in mid-1998. The dashed lines show the trend from 1999 to August 2003.

In 2002, we had observed that juvenile salmon captured during our July survey were both less abundant and average size was smaller than in the previous two years (Table 1), and forecast that marine survival would be lower than in 2000 and 2001. (Juvenile CPUE in July are used to forecast adult returns the following year.) In July 2003, the W.E. Ricker was unavailable and a juvenile salmon survey was not conducted in the Strait of Georgia. Therefore the size, catch and abundance of juvenile salmon cannot be compared to previous years. However, the September 2003 survey was completed and juvenile coho salmon in September 2003 were smaller than observed in the September 2000 and 2001 surveys (Figure 101). In addition, the coho CPUE in September was low, similar to 2002 (Figure 102). This reduced size and CPUE are indications of reduced marine survival for the coho salmon that entered the Strait of Georgia in 2003. Therefore, reduced abundances resulting from reduced marine survival could be expected when these brood years return in 2004. Our forecast for 2002 using this methodology (using July survey data) was both the most pessimistic and the most accurate.

The average size of juvenile chinook salmon was larger in 2003 than in 2002, but still smaller than values observed in 2000 and 2001 (Table 1). Juvenile chum salmon in September of 2003 were larger than in the 2002 survey (Table 1).

In the September surveys of 2002 and 2003, we also observed large increases in the CPUE of ocean age 0 sockeye salmon in the Strait of Georgia (Figure 102). Catches of these sockeye salmon in September of 2003 were actually greater than for coho, which had not been seen previously in our September surveys. Furthermore, ocean age 1+ sockeye were also caught in the Strait of Georgia in February 2004. DNA analysis indicated that these sockeye all were from Fraser River stocks, and were mostly Late Run Adams River fish. These observations suggest that some sockeye are over-wintering in the Strait of Georgia. This is a change in behaviour for sockeye salmon, the implications of which on the survival of sockeye salmon and on other species of salmon is not known. However, over-winter residents may result in increased interaction between the salmon species, particularly juvenile chum and pink salmon which enter the Strait of Georgia early in the year and at small sizes.





(Left) Figure 101. Coho salmon fork length (cm) anomaly for July and September surveys in the Strait of Georgia from 1997-2003, relative to the average over this period. Note that these are ocean age 0 coho and that there was no July 2003 survey.

(Right) Figure 102. CPUE anomaly for ocean age 0 sockeye and coho salmon in Strait of Georgia in September surveys from 1997-2003, relative to the average over this period.

Species	1997	1998	1999	2000	2001	2002	2003
Chinook	142.7 (45.28)	169.3 (41.53)	174.0 (42.47)	184.7 (40.15)	188.3 (43.32	151.7 (42.18)	161.3 (31.74)
Chum	191.7 (22.38)	190.3 (13.30)	190.7 (24.50)	202.6 (18.36)	194.5 (18.17)	191.5 (17.88)	196.4 (11.61)
Coho	243.4 (22.76)	243.9 (29.24	229.5 (22.32)	248.0 (23.82)	254.8 (24.92)	245.6 (23.13)	232.5 (22.99)

Table 1. Average fork lengths in millimetres (SD) for ocean age 0 chinook, chum and coho salmon captured in the Strait of Georgia in September surveys from 1997-2003. Sample sizes range from 1098-3655 for chinook, 809-2930 for chum, and 566-2400 for coho. Note the increases in average fork length in 2000 and 2001 for chinook and coho, and the decreased sizes observed in 2002 and 2003.

In summary, the poor ocean conditions for juvenile salmon observed in the Strait of Georgia in 2002 continued in 2003, evidenced by low catches and low average size of juvenile salmon. Oceanographic and climatic conditions did not show any clear trend to explain this decline from 2000-2001, and we continue to investigate the underlying causes for this variability within the current regime. Juvenile sockeye salmon may also be exhibiting a change in behaviour, in that they appear to be spending much longer period of time in the Strait of Georgia than either the literature or our previous experience suggests.

Fishery Interpretation and Speculative Results

West Coast Vancouver Island

Herring: Herring on the west coast of Vancouver Island are expected to show a trend of increasing abundance given that ocean conditions were more favourable for herring survival in 2000 and 2001. However, reduced euphausiid biomasses may limit the rate of stock increase.

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 2002 and 2003, the distribution of sardines in B.C. was again reduced and limited to the inlets of Vancouver Island and offshore areas in the south.

Hake piscivorous biomass in the Canadian Zone appears to have been declining over the 1990's and into 2001. However, the 1999 year-class is strong and hake piscivorous biomass is likely to increase in 2004 when these fish become large enough to start eating fish. At that point they could begin to impact herring and other species in the pelagic zone.

Euphausiid biomass appears to have an effect on marine survival of **coho** and **sockeye salmon** (Tanasichuk, personal communication).

As shown in earlier State of the Ocean reports, Carnation Creek wild **coho** survival is significantly correlated with euphausiid biomass early in marine life. Coho survival for the 2004 return year is forecasted to be very poor (<1%) (Simpson et al. 2004) because the biomass of euphausiids in 2003 was the lowest in the time series.

Results of recent analyses suggest that **Barkley Sound sockeye** (Great Central and Sproat lakes), and **Central Coast sockeye** (Owikeno and Long lakes)) survival is a consequence of prey biomass. Sockeye prey biomass has been declining consistently since the 2000 smolt year. Considering that the age groups of sockeye that account for most of the run spend two or three years at sea, it seems that sockeye returns may decline until at least the 2006 return year.

A biomass index of **eulachon** along the WCVI is a product of the May shrimp survey. As described in previous reports, there appears to be a relationship between prey (*T. spinifera* > 17 mm) biomass in the first marine year and the index. Prey biomass has been declining over the past few year; low euphausiid biomass in 2003 suggests that the index should be low in 2004.

North Coast

Herring: Herring stocks in the Hecate Strait area consist of migratory stocks from the Queen Charlotte Islands, Prince Rupert and Central coast areas. For the past ten years, recruitment and abundance of the Queen Charlotte Islands stock has been low while recruitment and abundance of the Prince Rupert and Central Coast stocks have been generally good. As a result, abundance is therefore expected to remain at current levels in the Queen Charlotte Islands and increase slightly in Prince Rupert and the Central Coast region.

Sockeye salmon: Central Coast sockeye (Owikeno and Long lakes) should decline because of falling euphausiid biomass since 2000.

Pacific Cod: A transport hypothesis was used to explain recruitment anomalies for the Pacific cod stock in the Hecate Strait area, and inclusion of an index of sea level height improved the assessment model fit for Pacific Cod. High sea levels indicate high transport, which removes Pacific cod eggs and larvae from Hecate Strait, resulting in poor recruitment. High transport is associated with lower production, lower target stock biomass, and lower target fishing mortality. Throughout the 1990s sea level conditions were unfavourable for recruitment, but sea levels decreased after the El Niño winter of 1998, with low values continuing to 2002. A rise in sea levels in the 2002-2003 winter indicate a reduction in recruitment from the levels of the preceding four years.

Strait of Georgia and Adjacent Channels

Herring: The abundance of herring in 2003 is considerably stronger than recent years at just over 150,000 tonnes. Current abundance exceeds the historical high of 1955 (140,000 tonnes) and is well above the lowest abundance estimated in 1968 (11,000 tonnes) in the time series from 1951-2003. The abundance of this stock has been increasing steadily since the low of the mid-1980s. Juvenile surveys in 2000 and 2001 suggest the trend of recent strong recruitment is likely to continue over the next few years. This is supported by the recruitment analysis in the sense that recruitment strength should not decline.

Coho salmon: Reduced size and CPUE of age-0 coho salmon in the Strait of Georgia in September surveys in 2002 and 2003 are indications of reduced marine survival for the coho salmon that entered the Strait of Georgia in 2003. Therefore, reduced abundances resulting from reduced marine survival could be expected when these brood years return in 2004.

Sockeye salmon: In the September surveys of 2002 and 2003, we also observed large increases in the CPUE of ocean age 0 sockeye salmon in the Strait of Georgia. Furthermore, ocean age 1+ sockeye were also caught in the Strait of Georgia in February 2004. DNA analysis indicated that these sockeye all were from Fraser River stocks, and were mostly Late Run Adams River fish. These observations suggest that some sockeye are over-wintering in the Strait of Georgia. This is a change in behaviour for sockeye salmon, the implications of which on the survival of sockeye salmon and on other species of salmon is not known. However, over-winter residents may result in increased interaction between the salmon species, particularly juvenile chum and pink salmon which enter the Strait of Georgia early in the year and at small sizes.

In summary, the poor ocean conditions for **juvenile salmon** observed in the Strait of Georgia in 2002 continued in 2003, evidenced by low catches and low average size of juvenile salmon. Oceanographic and climatic conditions did not show any clear trend to explain this decline from 2000-2001, and we continue to investigate the underlying causes for this variability within the current regime.

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