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Ecosystem Status and Trends Report: Coastal Waters off the west coast of Vancouver Island, British Columbia

Rapport de l'état des écosystèmes et des tendances : eaux côtières au large de la côte ouest de l'île de Vancouver, Colombie-Britannique

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ABSTRACT

Climate variability, including human-induced climate change, drives most of the trends seen in the physical/chemical properties and so appears to drive most trends seen in the marine ecosystem on the West Coast of Vancouver Island (WCVI).

Dissolved oxygen levels are decreasing and dissolved CO_2 levels are increasing (therefore pH is decreasing, making waters more acidic) in intermediate waters of the NE Pacific basin and are likely to impact marine ecosystems over the shelf.

Many organisms shift their locations depending on sea surface temperature (SST), moving with the water temperature that suits them best. Marine ecosystems on the WCVI appear to be changing and are likely to continue to change, probably rapidly relative to shifts in the past, due to climate change. Because of shifts in lower trophic levels, some organisms higher on the food chain are experiencing decreased productivity as their target prey items are no longer as abundant as they once were.

Populations of most marine mammals that had been commercially harvested or purposefully culled in control programs during the previous centuries and have since gained protected status are recovering. In some cases they appear to have reached their carrying capacity. Human activities still pose a threat to many of these animals primarily through contaminants, lost or damaged fishing gear, shipping and decline of prey food items.

RÉSUMÉ

La variabilité du climat, y compris le changement climatique d'origine humaine, provoque la plupart des tendances observées dans les propriétés physiques/chimiques et semble donc provoquer la plupart des tendances observées dans l'écosystème marin de la côte ouest de l'île de Vancouver.

Les niveaux d'oxygène dissous diminuent et les niveaux de CO_2 dissous augmentent (par conséquent, le pH diminue, rendant l'eau plus acide) dans les eaux intermédiaires du nord-est du bassin du Pacifique et sont susceptibles d'affecter les écosystèmes marins au-dessus du plateau.

De nombreux organismes se déplacent selon la température à la surface de la mer, suivant la température qui leur convient. En raison des changements climatiques, les écosystèmes marins de la côte ouest de l'île de Vancouver semblent changer et sont susceptibles de continuer de changer, probablement de façon accélérée à cause des déplacements dans le passé. En raison des tendances dans les niveaux trophiques inférieurs, certains organismes se situant à un niveau supérieur dans la chaîne alimentaire connaissent une diminution de productivité étant donné que leurs proies cibles ne sont plus aussi abondantes qu'elles l'ont déjà été.

Les populations de la plupart des mammifères marins ayant fait l'objet de récoltes commerciales ou d'éliminations intentionnelles dans le cadre de programmes de contrôle pendant les siècles précédents et ayant reçu le statut protégé sont en voie de rétablissement. Dans certains cas, elles semblent avoir atteint leur capacité de charge. Les activités humaines constituent toujours une menace pour bon nombre de ces animaux, principalement par l'entremise de contaminants, d'engins de pêche perdus ou endommagés, de l'expédition et du manque de nourriture provenant des proies.

1. STATUS AND TRENDS

This chapter presents trends and the recent status of physical circulation, chemical water properties and biological inhabitants of the coastal waters west of Vancouver Island. Some potential indicators of stress or change to the system are discussed.

The study region is part of the eastern boundary current system of the North Pacific Ocean, or California Current, on the west coast of North America (Hickey 1998). Over the mid-shelf, flow in the surface is equatorward in the summer and poleward in the winter in response to the large scale pressure systems and the winds that are associated with them. Over the inner shelf there is a poleward flowing buoyancy current year round, the Vancouver Island Coastal Current, VICC (Hickey *et al.* 1991) that supplies nutrient rich water from the Juan de Fuca Strait to the continental shelf. In the subsurface waters, the California undercurrent flows poleward year round, strongly influencing the composition of subsurface waters (Mackas *et al.* 1987). More importantly these wind patterns cause upwelling, or transport of subsurface water to the surface, during the summer and downwelling in the winter (Lentz 1992). This physical circulation drives both the chemical and biological systems in the region (e.g. Smith 1994). In addition larger, basin-scale changes, such as a decrease in dissolved oxygen concentration in intermediate depth waters (Whitney *et al*. 2007), may be transferred to the coast in this manner. Many of these changes are expected to vary on a decadal time scale (e.g. Mantua *et al*. 1997). On the other hand upwelling events themselves occur over time-scales of days and chemical and biological responses are rapid. As such many time-series are hampered by their duration (inability to capture effects of the decadal oscillation) as well as their temporal resolution (inability to capture the higher frequency variability associated with upwelling events).

In addition, the data concerning all marine organisms are only a representation of the natural population due to our ability to collect these data. For example, nets catch some organisms well, while others are able to swim rapidly enough to avoid capture. In addition some captured organisms are destroyed by the nets (e.g. gelatinous organisms). Furthermore, our knowledge does not reflect whole ecosystems, as research has often been driven by commercial fisheries. As such trends are available for species that are, or have been, economically valued but not for others.

Most oceanic primary production uses light as an energy source and so occurs in the surface ocean, or ‘euphotic zone’. The entire water column is referred to as ‘pelagic’ so the region below the euphotic zone is the ‘mesopelagic’. The bottom is termed the ‘benthos’ and provides substrate for a variety of organisms, depending on the depth of the water column and the chemical environment.

2. CLIMATIC AND OCEANOGRAPHIC PARAMETERS

2.1 SURFACE AIR TEMPERATURE

Surface air temperature (SAT) is one of the most widely used measures of the state of the environment and is a leading indicator of global climate change. Time series data on SAT exist dating back to the closing decades of the nineteenth century. It is now recognized that SAT has been increasing due to anthropogenic climate change associated with fossil fuel combustion. Over the last hundred years, globally averaged SAT has risen by $0.6 \pm 0.2\ ^{\circ}\mathrm{C}$. Figure 1 shows that the record of SAT of the entire globe and separated into SAT over ocean and land. Under the emission scenarios considered by the Intergovernmental Panel on Climate Change (IPCC, 2007), continued global warming is projected over the next 100 years, in response to past and future accumulations of atmospheric greenhouse gases. This warming is anticipated to be one of the leading drivers of ecosystem trends over the course of the 21st century, both globally and for the coastal and terrestrial environments of British Columbia.

2.2 SEA SURFACE TEMPERATURE

Globally averaged sea-surface temperatures are a key indicator of climate change in the ocean. Monthly global SST averages, since the early 1980s, computed from the Reynolds SST dataset, show a clear warming trend in ocean temperatures (Figure 2a). The time series is punctuated by strong interannual and low frequency variability, such that the highest globally averaged temperature occurred in association with the 1997/98 El Niño event in the tropical Pacific. More recently, the rise in globally averaged SST is approaching values similar to those recorded during that peak event.

The status of SST anomalies in 2008 is illustrated in Figure 2b, which shows the complex spatial pattern over the global ocean. Along the west coast of North America, temperatures in 2007/2008 have cooled relative to the 1961-1991 average, such that temperatures are now about 1º C *below* the long term mean of the region (DFO, 2009). This change from warm to cool status is associated with atmospheric cycles, specifically changes in the Pacific Decadal Oscillation (Mantua *et al*. 1997), which has switched to its 'negative' or cooler phase over 2007 – 2008. As a result, a particular spatial pattern of temperature anomalies has developed over the North Pacific, with positive temperature anomalies in the central Pacific, and negative temperatures in a broad horseshoe-shaped band adjacent to the coast. PDO variability is characterized by decadal time-scales and therefore it is possible that SST off North America will remain below average for many years.

Extended time series data of surface water properties are available from a number of lighthouse stations located within BC coastal waters (Figure 3a). Figure 3b compares long-term annual mean SST records representative of three broad regions of coastal British Columbia. The Langara Station is representative the North Coast and Hecate Strait/Haida Quainnis ecozone, while the Departure Bay lighthouse is representative of the Strait of Georgia, and Amphitrite Point is representative of the west coast of Vancouver Island (WCVI). Common features occur in all of these records, suggesting considerable spatial coherence in the long-term variability over coastal British Columbia. This is consistent with the findings of Masson and Cummins (2007) that temperature variability in the Strait of Georgia reflects large-scale variations occurring over the northeast Pacific. The three stations have shown a common warm period from the late 1970s to about 1999. As well, there is considerable interannual and low frequency variability. In particular, the signature of the 1997/98 El Niño is evident in the three records, as is the subsequent period of cooling that occurred following the 1999 La Niña event (Peterson and Schwing, 2003). The last two years has seen a cool period as sea surface temperatures have fallen below the long-term average.

2.3 SEA SURFACE SALINITY

Time series of sea surface salinity (SSS) at three representative coastal British Columbia lighthouses are presented in Figure 4, and show contrasting variability along the coast. The Langara station, which is within the North Coast and Hecate Strait/Haida Quainnis ecozone, shows a remarkably consistent freshening trend over the last 20 years. The situation is different at the other stations situated on the west coast of Vancouver Island and in the Strait of Georgia, which show no consistent trend. All three stations show pronounced low frequency variations, but these do not appear to be directly linked to El Niño/La Niña events. The reason for these differences in trends is not known. It may be that the Langara station, which is not in proximity to a major river or other immediate source of fresh water, may reflect larger scale changes over the northeast Pacific. The other stations may be dominated by locally driven variability. In particular, since 1956 data have been collected on a regular basis from Ocean Weather Station P (145°W, 50°N), a site considered representative of the subpolar North Pacific Ocean. This record also shows a tendency to freshening of SSS over recent decades (DFO, 2007). It is not possible to say whether these long term changes in salinity will affect the biodiversity of the region. However, it is assumed that the freshening in the subpolar gyre will cause increased stratification which may cause the upper mixed layer to become shallower and nutrient injections from below to decrease, subsequently decreasing primary production (Whitney and Freeland 1999).

2.4 SEA LEVEL

Long term changes in sea level result from relative changes in vertical displacements of land and ocean. Vertical motion of the land along the BC coast has two components: local tectonic movement, and continued isostatic rebound following deglaciation of British Columbia approximately 10,000 years ago. Secular changes in the vertical position of the ocean also have two components. Steric changes in sea level occur as the water column expands or contracts in response to changes in water temperature, while eustatic changes are associated with changes in the amount of water in the ocean due to losses/accumulations of land-borne ice. The relative importance of these land and ocean components accounts for the different trends in sea level along the BC coast (Figure 5). For example, the dominant effect for Tofino is the upwards vertical motion of the west coast of Vancouver Island so that relative sea level at Tofino is falling. In contrast, the Prince Rupert location, which is representative of the changes along the northern mainland coast of BC, shows a rise in relative sea level of about 10 cm/century. This time series shows pronounced interannual/decadal variability that is associated with oceanic events, in particular El Niño and PDO variability (Abeysirigunawardena and Walker, 2009). The northeast coast of the Queen Charlotte Islands, specifically the region adjoining Rose Spit, is one of two BC regions considered highly sensitive to rising sea level. (The other is the low-lying area of Richmond, south of Vancouver on the Strait of Georgia.)

2.5 UPWELLING INDEX

Upwelling delivers nutrients to the euphotic zone and drives high primary productivity in occasional bursts or events. Upwelling on the WCVI occurs in the summer months and downwelling during the winter. The summer season is longer than the winter, but the winter events are generally stronger. Predictions of upwelling or downwelling strength made from the local wind field (Figure 6) are generally reasonable for downwelling and poor for upwelling because some of the upwelling on the coast is driven by shelf waves that propagate from the stronger upwelling centers further south (Battisti and Hickey, 1984). For this reason, current indices, such as the one developed by Thomson and Ware (1996), are better measures of upwelling. In addition, topographically enhanced upwelling plays a critical role in areas such as Barkley Canyon in the La Perouse banks region (Freeland and Denman, 1982).

Inlets along the BC coast are rejuvenated by annual flushing events tied into the seasonal pattern of upwelling. During summer, saline and cool waters are drawn onto the continental shelf and into fiord basins. This annual pattern helps prevent many inlets from becoming anoxic, although smaller basins with restricted entranceways (e.g. Nitinat Lake and Effingham Inlet) do lack oxygen.

The data do not indicate any specific trends in upwelling or downwelling, at least during the past 40 years (Figure 6a). However, there is some evidence that downwelling is stronger during ENSO years (Hsieh *et al.* 1995). Increased downwelling appears to have implications for primary production (specifically, a decrease) the following summer (Ianson and Allen, 2002). Increased downwelling also lowers the carbon content of the subsurface waters over the shelf during the following year (Ianson *et al*. 2009) which lowers the acidity (i.e. raises the pH).

3. WATER CHEMISTRY (OXYGEN, CARBON AND NUTRIENTS)

3.1 DISSOLVED OXYGEN

Figure 7 presents trends in oxygen concentration for waters below 100 m depth along the North American coast from South California to the Queen Charlotte Islands (DFO, 2009). These trends are based on time series data of at least 25 years duration. Declines in dissolved oxygen are seen at all depths below the mixed layer along the entire coast. The greatest declines are found within the 200-300 m depth range. Within this depth range, the rate of decline represents about 1% of the dissolved oxygen per year in BC coastal waters. This decline has been attributed to the weakening of the ventilation of surface waters off the coast of Asia, due to freshening and warming of these waters (Whitney *et al*. 2007). The decline in dissolved oxygen at these depths may affect the habitat of groundfish. Whitney and Sinclair (pers. comm.) have found evidence that depths inhabited by the groundfish community has been shoaling by 2 to 3 metres per year over the past decade, as the fish move to shallower waters. It is suggested that this is associated with loss of habitat due to shoaling oxygen isopleths.

3.2 NUTRIENTS

Dissolved macronutrients in the water column (e.g. nitrate, silicic acid and phosphate) have been measured periodically as part of directed studies off the WCVI (e.g. Ianson *et al*. 2003), mostly during the summer, and more recently as part of DFO monitoring programs (La Perouse and Line P, Figure 8, F. Whitney, pers. comm.). The seasonal cycle has a large amplitude and dominates any overall trend over time, based on the data currently available. Because nutrients are integral to the biological cycle, surface nutrients that have accumulated during winter are drawn down to near zero by primary producers in spring and summer when light is not limiting. Over the outer and mid-shelf nutrients are injected into the upper mixed layer by wind mixing and upwelling events, although the entire shelf is kept Si rich by discharges from major rivers (Whitney *et al.,* 2005).

In the nearshore, the Juan de Fuca Strait is a major and consistent nutrient supply due to strong tidal mixing in the Strait (Crawford and Dewey 1989). It provides the source water for the VICC that brings nutrients northward throughout the year along the WCVI, and is partly responsible for making this region the most productive on the entire west coast of North America (Ware and Thomson 2005).

Further offshore, Whitney and Freeland (1999) argue that, over the last several decades, the increased stratification in the NE Pacific, due mainly to basin freshening, has meant that less nutrients are being injected into the surface layer and that primary production has thus decreased.

3.3 INORGANIC CARBON

The seasonal cycle in dissolved inorganic carbon is expected to be similar to that of macronutrients. The exception is that there are less data, currently only two published studies over the shelf in this region (Ianson *et al*. 2003; Feely *et al.* 2008), and so there is no way to identify trends. The anthropogenic carbon signal, and the increased acidification concurrent with this signal, will be felt earlier on the NE Pacific shelf than at other locations in the world's ocean due to the shallow saturation horizons in the North Pacific basin and the upwelling circulation (Feely *et al*. 2008). The acidity of upwelled water is increasing to the point where saturation horizons for aragonite have reached the surface at times off the Oregon and California coast and may reach the surface on the WCVI (Feely *et al*. 2008). It is likely that this increased acidity will have negative effects on specific species that precipitate calcium carbonate (such as shellfish and corals) and marine ecosystems on the whole (Guinotte and Fabry 2008).

4. PRIMARY PRODUCTION (PHYTOPLANKTON)

There are no time series of primary production or phytoplankton biomass available from the WCVI with the exception of surface chlorophyll a measurements (an indicator of phytoplankton biomass) that were made on Line P cruises in winter, spring and summer each year over the outer shelf and slope (blue curve) and offshore (red curve; Figure. 9). These data show that biomass is high during summer upwelling season in the coastal zone and consistently low during winter. The Global Ocean Ecosystem Dynamics (GLOBEC) program, in 1997/98, indicates that primary production is high in summer over the shelf (ranging from 1 to 13 g C m-2 d-1), particularly in the larger size class (> 5 um) of phytoplankton that is generally dominated by diatoms, which are silicious phytoplankton (Ianson *et al*. 2003; Harris *et al*. 2009). Beyond the shelf break primary production is generally low (0.3 -- 0.8 g C m-2 d-1; Ianson *et al*. 2003; Harris *et al*. 2009) and dominated by smaller pytoplankton.

5. SECONDARY PRODUCTION (ZOOPLANKTON)

Time series of zooplankton standing stock for the West Coast of Vancouver Island (WCVI) begin in 1979 with an ongoing study of zooplankton community composition (Mackas *et al*. 2001, 2007). There are no time series of secondary production on the WCVI. Initial measurements of secondary production (using the methods of Sastri and Dower (2009), in May and September 2005 in the region show north-south and cross shore differences, but as of yet no generalizations can be made (Sastri, pers. com.).

To filter out the strong seasonal cycle, zooplankton biomass data for individual species and sampling period were compared to their average seasonal cycles. Differences from the seasonal cycle are averaged to estimate annual anomalies, which are further averaged within ecologically similar species groups (Figure 10). The anomaly plots are on a $\log_{10}$ scale, so an anomaly of +1 corresponds to a 10 fold increase in the long term average; an anomaly of -1 to 0.1x the long term average. Correlations with physical time series indicate that the zooplankton community is affected significantly by global-scale forcing (i.e. ENSO), basin-scale forcing, (i.e. the Pacific Decadal Oscillation, PDO), as well as the local upwelling index, alongshore wind and currents (Mackas *et al*. 2001, 2007). These physical forcing mechanisms are not entirely independent.

The zooplankton anomalies are also strongly correlated with several fishery time series (e.g. salmon marine survival, sablefish recruitment, herring production and offshore distribution, sardine production and distribution Mackas *et al.* 2007; Tanasichuk 1988a, b). Although there is a weak downward trend of total biomass, the strongest and most interesting signal is in changing community composition. Southern species of copepods (eg. *Paracalanus parvus*, *Ctenocalanus vanus*, *Mesocalanus tenuicornis*) and the northern, or boreal copepods (eg. *Calanus marshallae*, *Pseudocalanus minimus*, *Acartia longiremis*) vary inversely to one another, each group thriving when conditions are suitable to them. The southern species have (despite oscillations) shown a long-term upward trend, suggesting that climate change could produce a shift in dominant species. Note that the southern copepod species do not undergo diapause, and so they do not lay down rich lipid stores, making them energetically less valuable as a food source than than the northern spp. (J. Dower, pers. com.).

An additional study places special emphasis on euphausiid (krill) production in Barkley Sound and includes samples collected since 1991.The time series of euphausiid productivity (Tanasichuk, 1998 a,b) has been studied in size classes related to the fish that prey upon them (Figure 11). No trend is visible. The biological basis of euphausiid production variability is unknown.

6. FISHES

In the past, the availability of population trends data, for finfish and invertebrate populations on the WCVI, have been largely dictated by what is commercially valuable, ecological significance. Although efforts are being made to correct this bias, there exist few studies that are ecologically based, and those that are in place are relatively young.

Trophic interactions can be complex, because the feeding behaviour of most species is adapted to their life stage and food availability. Furthermore, seasonal migrations and tendencies to inhabit multiple zones of the water column link benthic, demersal and pelagic communities. Examples of prominent WCVI pelagic fishes that forage on plankton are sardine and herring. Examples of prominent WCVI fish that feed on species of zooplankton or bottom invertebrates, but are also known to be voracious piscivores in their larger stages, are salmon, hake, spiny dogfish, ling cod and turbot (Pearsall and Fargo 2007; Tanasichuk *et al*. 1991).

On the WCVI as in other parts of the coast, fishing using trawl nets (bottom and mid water), purse seine nets, traps and hook and line gear are used to catch fish. Commercial catch records often provide insightful information on species trends, especially when no directed research surveys have been conducted. At the very least, these data tell us something about distribution and minimum abundance over time. This report presents groundfish, sardine and salmon summary catch records, because other datasets for these species are not available in this region. Methods of standardising commercial catch by fishing effort are applied when relevant and when reliable units of effort are available; for example, sablefish and turbot.

This report does not elaborate on spatial and temporal variability of WCVI species associations, because so few published studies address such questions. There is a considerable amount of natural variability, the reason for which is poorly understood, between different seasons, fishing grounds, substrates, bottom relief and oceanographic properties (Workman *et al*. 2008; Perry *et al*. 1994). The following text and figures provide some information on a variety of fish species where trends related to WCVI were readily available.

6.1 GROUNDFISH (BY BOTTOM TRAWL)

Trawling, whether for science, commercial or other interests, produces catches that demonstrate aspects of species assemblages and ecosystem linkages. In other words, trawling is highly unselective and damages all aspects of the ecosystem. There has been very little groundfish bottom trawl research conducted, off the WCVI, to generate population time trends for single or multi-species associations. Recent efforts to characterize trends in groundfish species composition include a WCVI fishery independent biennial bottom trawl survey, which started in 2004 (Workman *et al.* 2008).

The WCVI is a major contributor to the Canadian west coast groundfish trawl fishery, with 40,000-140,000 tonnes of mixed species landed annually. Approximately 6,000-9,000 tonnes are taken by bottom trawl. As a result of mandatory reporting and observer records, bottom trawl fishing demonstrates a diverse catch composition. This area contributes significantly to the catches of both longspine and shortspine thornyheads (*Sebastolobus altivelis* and *Seb. alascanus*); Dover and petrale sole *(Microstomus pacificus* and *Eopsetta jordani)*; canary, yellowtail and bocaccio rockfishes (*Sebastes pinniger, S. flavidus* and *S. paucispinis*); lingcod (*Ophiodon elongatus*) and spiny dogfish (*Squalus acanthias*). In most years, 80-90 % of the Pacific hake (*Merluccius productus*), caught off the B.C. coast, is taken in waters off the WCVI; many of the species caught as bycatch in that fishery are also taken in the bottom trawl fishery. Table 1 lists average annual catches for this area comprising 95% of the bottom trawl catch from the WCVI by species between 1996 and 2005 for 27 species.

6.2 PACIFIC SARDINE

Sardines are multiple-batch pelagic spawners. Spawning aggregations, off the coast of North America, are mostly concentrated in central and southern California. Spawning occurs over several months, but peak spawning periods generally occur in March and April. Recruitment to the adult spawning population occurs between 1-3 years of age, which appears to depend on both environmental and population dynamics (Jacobson and MacCall 1995). Adult fish can reach the size of 30cm in total body length and live up to 15 years, but most fish found in BC waters range from 18-25 cm and are 4-8 years old (McFarlane and MacDougall 2001).

In Canadian waters, sardine abundance and its associated fishery collapsed in 1947. After a 45 year absence, sardines reappeared off the south west coast of Vancouver Island in 1992 (Figure 12). Since the late 1990s, sardine distribution has extended into the Hecate Strait and Queen Charlotte Sound, to varying degrees (Schweigert in DFO 2007). In recent years, a purse seine fishery has been developed, and most of the BC catch has been taken from near-shore areas of the WCVI (FOC 2008a). The size distribution of sardines in BC waters is notably larger than that observed off California (Hill *et al.* 2008) The explanation for this discrepancy is that larger (older) fish migrate further north during forage periods and take advantage of the exceptionally high ocean productivity in the northern region.

The ecological role of sardines off the WCVI is linked to their abundance and migratory patterns, which vary considerably over time. There are virtually no published studies quantifying sardine as forage fish in BC waters, but many unpublished observations have been made, since the mid 1990s. Examples of known predators off the WCVI match those of Oregon and California and include humpback whales, sea lions, seals, hake, spiny dogfish, salmon (chinook and coho) and seabirds, such as gulls and cormorants (Hill *et al*. 2008). Many predators that feed on sardine also feed on herring. Species interactions between sardine and herring are likely complex since, in addition to having considerable summer overlap in distribution and predators, they may compete for zooplankton.

6.3 PACIFIC HERRING

Pacific herring (*Clupea pallasi*) is a migratory pelagic species, with dense aggregations occurring near-shore and offshore in the WCVI for spawning and foraging, respectively. Herring are generally less than 23 cm in total length, rarely live beyond 10 years and population sizes fluctuate rapidly (Figure 13A Cleary *et al.* 2009). Herring recruit to the spawning population between the ages of two and five. Since about 1977, their recruitment to the WCVI in-shore spawning grounds has been generally poor, interspersed with a few good year-classes (Figure 13B). In recent years, size at age appears to be decreasing and estimates of natural mortality appear to be increasing (Figure 13), which, along with poor recruitment, partly explains why stock productivity has remained low.

Recent WCVI herring trends representing poor growth and survival are consistent with other herring populations on the BC coast. The cause of these trends is not known. However, it appears that the herring populations are regulated by fluctuations in ecosystem forcing such as decreased food supply (bottom-up) and fluctuations in predation (top-down). Declining trends in size-at-age suggest that food supply has declined over the past two decades. Herring recruitment in this region tends to be negatively correlated with temperature; however, causal mechanisms are not well understood.

Spatial and temporal variability in zooplankton species distribution and abundance as prey are thought to impact herring mortality and growth. Recall that northern species of copepod are lipid-rich while the southern species are not. Juvenile herring feed extensively on copepods and adult Pacific herring feed almost exclusively on euphausiids. Some known potential predators of herring are hake, sablefish, Pacific cod, salmon, spiny dogfish, turbot, Lingcod, Pacific halibut, humpback whales, harbour and northern fur seals, and California and Stellar sea lions. In addition to predation, it is possible that, since the 1990s, sardine, hake and humpback whale summer foraging on zooplankton, in the area, has introduced substantial prey competition with herring (McFarlane and MacDougall 2001, Robinson 2000, Ford *et al.* 2009)

Until the late 1960’s fishing was relatively unregulated and WCVI catch levels (by seining) were some of the highest on the coast, averaging approximately 50,000 tonnes/year from 1950-1967, with a peak in 1964 of approximately 80,000 tonnes (Schweigert and Haist 2007). Fishing was then closed in the late 1960s, until the 1970s, due to extremely low population levels. When fishing was again permitted, in the 1970s, a roe market drove the fishery, utilizing seine and gillnet methods for near-shore spring spawning fishing (Schweigert and Haist 2007).

6.4 PACIFIC SALMON

Similar to herring, there is an apparent positive relationship between cold SST years (La Nina) and strong salmon survival, and a corresponding relation of poor survival during warmer El Nino years (e.g. Hyatt and Luedke 1999). Production trends for major sockeye (*Oncorhynchus nerka)* populations or stock aggregates (i.e. "index stocks") may reflect environmental changes and production trends for several salmon species, originating from areas of the coast, constituting separate production domains (Hyatt *et al.* in DFO 2007). Index stocks entering continental shelf areas, under stronger oceanic influences, (i.e Barkley Sound sockeye in the WCVI) appear more responsive to alternations in La Nina-like and El Nino-like conditions (Hyatt and Luedke 1999).

Since 1970, maximum returns for all sockeye index stocks, on the BC coast, occurred during the early 1990 s, immediately following the strong La Niña event of 1989. In addition to the Central Coast (Smith's Inlet) and the Fraser River (Chilco) index stocks, the Barkley Sound stock declined from peaks in the early-1990s to sub-average returns of the mid-1990s and production has remained poor ever since (Figure 14; Hyatt *et al.* in DFO 2007).

Marine survival of WCVI coho (*O. kisutch*) and chinook (*O. tshawytscha*) salmon varied widely between 1974 and 2005, ranging from nearly 0.1% to 20% for Carnation Creek coho salmon, 0.5% to 11% for Robertson Creek coho salmon, and from 0% to 8% for Robertson Creek chinook salmon (Figure 15A; M. Trudel, unpublished). Marine survival of both coho and chinook salmon declined tremendously during the early to mid-90s. As a result, the commercial fishery for coho salmon was closed in 1997 (Figure 15B), which also reduced chinook exploitation. Recent marine survival data (post-1997) are difficult to compare with previous years, as the approach to estimating marine survival changed following the fishery closure.

Although, sockeye, chinook, coho and chum (*O. keta*) salmon are harvested on the WCVI, there are currently no WCVI pink salmon (*O. gorbuscha)* fisheries. Salmon are harvested by First Nations, commercial, and recreational sectors and methods of estimating catch vary by sector and the presented summary time series information were assembled for this document (DFO unpublished.). Large, multi-sector fisheries for chinook and sockeye occur in Barkley Sound. These combined data are variable, and the time series is not long enough to determine a trend, however, catches are currently the lowest in the record (Figure 16). Similar data combining catches from the whole of WCVI show strong variability and, although catches are not particularly high at present, they are not as low relative to the rest of the record, as in Barkley Sound (Figure 17).

6.5 PACIFIC HAKE

Pacific hake (*Merluccius productus*) ranges throughout the California Current System from Baja California to the Gulf of Alaska. Like many species, its distribution and abundance are closely linked to oceanographic conditions (Beamish and McFarlane, 1985). The most abundant BC hake population is a transboundary, coastal stock that inhabits waters around the continental shelf, but smaller populations also occur in inshore waters, such as the Strait of Georgia, Puget Sound and Gulf of California. The coastal population is distinguished from inshore populations by larger body size, seasonal migratory behaviour and a pattern of low median juvenile recruitment, punctuated by extremely large year classes. The coastal population in U.S. and Canadian waters is modelled as a single stock but catches from the two fishing fleets capture some of the spatial and temporal variability in hake distribution. (Hesler *et al.* 2009)

Migratory Pacific hake generally enter BC waters in the spring and leave in the fall (Beamish and McFarlane, 1985). The number of fish that migrate north is dependent on summer temperatures, with more entering BC waters in warmer summers (Ware and McFarlane 1995). On average, between 250,000 and 500,000 tonnes of hake migrate into Canadian waters off the WCVI, in the late spring and early summer, and feed in the area until October. This large biomass can have dramatic impacts on the resident populations, by competing for food with other species (such as herring, salmon and spiny dogfish), or, preying on species such as herring (Ware and McFarlane 1995; McFarlane *et al*. 2001; Tanasichuk *et al.* 1991).

In recent years, the general temporal and spatial distribution patterns of hake have changed (Figure 18). Prior to 2007, 80-90 % of the Pacific hake caught off the BC coast was taken off the WCVI, but recently the catch has shifted northward. In general, the distribution pattern appears to change with temperature. Hake appear to prefer warmer water so that during colder years they are found further south and during warmer years they are found in the north. Estimates of total hake biomass in U.S. and Canadian waters from 1964 to 2008 show two modes of relatively high abundance, with an extreme peak in the mid 1980s and a recent but smaller peak, from 2003 to 2005 (Figure 19). Recruitment variability is thought to have been the main driver of stock productivity in recent decades (Helser *et al.* 2009). Estimates of historic hake recruitment indicate very large year classes in 1980 and 1984, with secondary recruitment events in 1970, 1973 and 1977. The 1999 year class is the most dominant cohort, since the late 1980s, and has supported fishery catches since 2002 (Helser *et al.* 2009).

6.6 SABLEFISH (BLACKCOD)

Sablefish (*Anoplopoma fimbria),* also known as blackcod, is a highly migratory predatory species that resides in pelagic and demersal realms of shelf and slope waters from Central Baja California to Japan and the Bering Sea. It provides a lucrative fishery on the WCVI. Commercial and survey methods of capturing this species rely primarily on trap gear and, for assessment purposes, catch rates are assumed to be proportional to trap-vulnerable biomass (Haist *et al.* 2005). Estimates of trap-vulnerable biomass show no trend. They were relatively stable from 1979 to 1987, then increased in 1988, and remained high for several years (Figure 20). Catch rates declined from 1991 to an historic low in 2001. A substantial improvement in the nominal catch rate occurred in 2002. Sablefish have relatively long lives (70+ years); therefore, this index series (similar to that of many rockfish species) remains short compared to generation times.

6.7 TURBOT (ARROWTOOTH FLOUNDER)

Turbot (*Atheresthes stomias*), also known as arrowtooth flounder, is a flatfish that inhabits a wide depth range (between 50 and 900 m) and shows a preference for a narrow range of bottom temperature (between 7 and 8 °C) (Perry *et al.* 1994). As adults, they show little preference for bottom type, but juveniles apparently prefer sand and mud bottoms (Perry *et al.* 1994). Juvenile arrowtooth flounder feed on small mobile prey such as shrimp, while adults are more piscivorous and cannibalistic, feeding on herring, juvenile pollock, and Pacific sandlance (Perry *et al.* 1994; Pearsall and Fargo 2007). The population of turbot off the WCVI (denoted by Area 3CD) is thought to be separate from the population in Hecate Strait (Area 5CD), and it is unknown if the west coast Vancouver Island stock is continuous with parts of the Queen Charlotte Sound stock (Area 5AB) (Starr and Fargo 2006). Turbot occupy separate winter spawning and summer feeding areas, undertaking a seasonal bathymetric movement from shallower water in summer to deeper water in winter.

In recent years, turbot has been one of the main catch species in bottom trawl fishing off the WCVI (Table 1. Workman *et al.* 2008). Catch per unit effort and relative abundance survey data from US triennial surveys and a shrimp bottom trawl survey indicate population increases, since the 1990s; this species is presently more abundant in this area than it has been in the previous 20 years (Figures 21 and 22) (Starr and Fargo 2006). Until recently, limited markets for this species kept landings low, and there have been fish quality issues, since its flesh deteriorates relatively quickly after capture. In 2005, some participants in the Canadian groundfish fishery developed markets for turbot and introduced specialist vessels to target this species; part of the attraction of turbot was that it had been primarily managed as a by-catch species and not as part of the individual vessel quota system (Starr and Fargo 2006).

7. BENTHIC AND INFAUNAL INVERTEBRATES

Time series data on most invertebrate populations on the WCVI are lacking. Summary trends on commercially important species such as crabs, prawns, red sea urchin and giant sea cucumber include sporadic observations, limited by remoteness, complex life histories, and the cost of conducting surveys. With the exception of the offshore, multi-species, small-mesh shrimp survey, most other invertebrate populations are not frequently surveyed over a broad area or in association with other species. Only shrimp and geoduck clams are reported herein, as they have contrasting life histories and because information on them was readily available.

7.1 PINK AND SIDESTRIPE SHRIMP

Seven pandalid shrimp species are targeted along the BC coast. Along the WCVI, the dominant shrimp species is smooth pink (*Pandalus jordani*) and, to a lesser extent, sidestripe shrimp (*Pandalopsis dispar*). Fishery independent surveys of shrimp populations have been conducted annually off the WCVI since 1972 (Shrimp bulletin website http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/Shellfish/shrimp/surveys/0501.htm). The long term trend in shrimp biomass estimates determined through these surveys, is highly variable and characterised by high abundance in the late 1970s and in the early 2000s (Figure 23). No single factor, or group of factors, has been identified to account for the observed annual variability in shrimp populations.

Canadian and U.S. commercial shrimp trawl vessels fished for shrimp until the late 1970s, when industry and government reduced fishing fleets and Canada instilled a 200 miles exclusion zone. Recent efforts to manage shrimp fishing apply seasonal constraints and by-catch reduction strategies Total annual shrimp landings varied little during 1997 - 2001 (approximately 1000-1300 tonnes) but in subsequent years, total catches declined below 450t, mainly due to economics of the industry (D. Clarke pers comm.).

7.2 GEODUCK CLAM

The geoduck clam (*Panopea abrupta)*, a North Pacific species, can be extremely long lived (up to168 years) and can grow up to 3 kg (Bureau *et al.* 2002). After approximately 4-5 years of age, they are buried into consolidated substrate (infaunal habitat), which helps them avoid most predation. Their complex life histories have been studied and modeled, but there is still considerable uncertainty associated with many factors such as recruitment and survival (Zhang and Hand 2005).). Populations tend to be patchy and closely located populations may exhibit different dynamics, if they are separated by environmental barriers (Orensanz *et al.* 2004).

Dive surveys for stock assessment purposes on the WCVI have occurred since 1993 over 14 locations, with each location surveyed every 2 to 3 years. Results from survey efforts suggest that geoduck densities range from 0.2 to 2.5 clams/m^2 and that there are few consistent population trends observed for the WCVI as a whole (Zhang and Hand 2005). However, analyses of pooled data for several WCVI populations, compared with pooled data from other coastal regions, suggest that, as a whole, the WCVI has had relatively low to intermediate geoduck production from 1915 to 2005. Results from these analyses suggest that geoduck recruitment (defined to be 6 years of age for stock assessment) had a peak around the year 1965 and a smaller peak in the late 1990s (Zhang and Hand 2005). Figure 24 shows trends of average recruitment estimates grouped together for several WCVI populations compared to other regions of the BC coast and for a Winter Harbour population, taken from (Zhang and Hand 2005).

Mortality of adult geoduck on the WCVI appears to be a primarily a result of commercial harvest and sea otter predation. A lucrative geoduck dive fishery allows a limited number of licenses and limits catches. Divers collect clams using powerful water jets that liquefy substrate around the animals for ease of extraction. The effect of the fishing method on habitat is the subject of on-going study. The sea otter (*Enhydra lutris*) is a notable geoduck predator and, naturally, predation has increased, as the sea otter population has become re-established in the WCVI region.

8. AQUATIC INVASIVE SPECIES

An invasive species is "a non-indigenous species the introduction of which into an ecosystem may cause harm to the economy, environment, human health, recreation, or public welfare" (DFO 2004). Invasive species have the potential to change ecosystems through competition with native species, habitat modification, predation, hybridization and other mechanisms (Levings *et al*. 2002). Introduced species that do not cause measurable damage, from a human point of view, are known as "non-indigenous" rather than invasive. The WCVI harbours numerous non-indigenous species. Our definition of non-indigenous species includes only those introduced to the Pacific from elsewhere, and thus does not include Pacific species that only occasionally enter Canadian waters in warm-water years (e.g. Hart 1973, Mecklenberg *et al*. 2002). Many of these species have established abundance levels on the WCVI in equal to or greater levels than in other BC waters (Gillespie 2007).

The WCVI represents the second most invaded area in British Columbia (based on number of non-indigenous species present) (Gillespie 2007). As many of the introductions occurred at least 50 years ago, impacts on biodiversity and habitat may have occurred without recognition or documentation. The two most widespread species, Pacific oyster and Manila clams, are also of considerable economic value in the area, and this tends to outweigh the concern for potential environmental or biodiversity impacts.

8.1 INVASIVE FISHES

Two known, non-indigenous, marine fish species inhabit waters off WCVI; Atantic salmon (*Salmo salar)* and American shad (*Alosa sapidissima)*. Altantic salmon are raised in net pen aquaculture operations in the inlets of WCVI, and escapes from these facilities have been captured in both marine and fresh water (McKinnell *et al*. 1997, McPhail 2007). American shad was deliberately introduced in the 1800s from Atlantic waters, and is frequently captured in marine waters off WCVI ,(Hart 1973, Mecklenberg *et al*. 2002). American shad have not yet been observed in fresh water systems off the WCVI but they have been found in other freshwater systems on the BC coast (McPhail 2007).

8.2 INVASIVE MOLLUSCS AND OTHER INVERTEBRATES

Non-indigenous molluscs in WCVI are the result of deliberate introduction, such as aquaculture, inadvertent introduction, such as transport by ballast water and hull fouling, and natural distribution from US introductions or combinations of all of the above (Gillespie 2007).

Oyster culture resulted in the establishment of populations of Pacific oyster, *Crassostrea gigas*, in the 1930s (Quayle 1988), and recent introductions have resulted in small local populations of European flat oysters, *Ostrea edulis*, in Barkley Sound (Gillespie, unpub. data). Pacific oysters support significant aquaculture and recreational fisheries in WCVI, as well as a small commercial fishery. Oyster transfers also likely resulted in the establishment of the Manila clam, *Venerupis philippinarum* (Bourne 1979). Manila clams now support significant aquaculture, commercial and recreational fisheries on the WCVI.

Two species of mussel, the Atlantic blue mussel, *Mytilus edulis*, and the Mediterranean mussel, *Mytilus galloprovincialis*, were established on the WCVI through aquaculture trials, although the Mediterranean mussel may also have arrived through ship hull fouling. Both species are difficult to distinguish from native blue mussels, *Mytilus trossulus*, and all can hybridize (Heath *et al*. 1995).

Other molluscs likely introduced to WCVI through aquaculture include the Japanese oyster drill, *Ocinebrellus inornata*, and the European mouse-ear snail, *Myosotella myosotis*. Non-molluscan invasive species carried along with these species include the red alga *Lomentaria hakodatensis*, wireweed, *Sargassum muticum*; dwarf eelgrass, *Zostera japonica*; orange-striped green anemone, *Diadumene lineata*; an endoparasitic copepod, *Mytilicola orientalis*; and three amphipods, *Caprella mutica*, *Jassa marmorata* and *Monocorophium acherusicum*. Two more species, varnish clams, *Nuttallia obscurata*, and Japanese mussels, *Musculista senhousia*, may have arrived in ballast water from international shipping. Eastern softshells, *Mya arenaria*, dispersed north from introduced populations in the US in the late 1800s (Carlton 1979).

The invasive freshwater New Zealand mudsnail, *Potamopyrgus antipodarum*, is known from a single location in the Somass River estuary near Port Alberni. Although it is somewhat unusual to encounter this species in euryhaline environments, there are a number of recent records from the Pacific coast of the United States (Davidson *et al*. 2008). The vector of introduction to British Columbia is not known, but may include transport on boat trailers, waders and fishing gear or transport on migratory waterfowl.

8.3 GREEN CRAB

The European green crab, *Carcinus maenas*, was first collected in BC in 1999, after dispersing north from US populations in the El Niño of 1998/99 (Jamieson *et al*. 2002, Gillespie *et al*. 2007). The green crab is a well-documented invasive species, with a reputation as both a competitor to native crab species and a predator on clams, mussels, juvenile fishes and other species (Jamieson *et al*. 1998). With the exception of a single specimen taken in 1999 at Esquimalt, all records have been from WCVI; surveys in Queen Charlotte and Johnstone Straits and limited sampling in the Strait of Georgia have not recovered any green crabs (Gillespie *et al*. 2007). Surveys in 2006 and 2007 found green crabs present in all sounds and inlets sampled in WCVI (Figure 25), with particularly high catch rates at Pipestem Inlet (Barkley Sound), Pretty Girl Cove (Clayoquot Sound), Queen Cove (Esperanza Inlet) and Winter Harbour (Quatsino Sound)(Gillespie *et al*. 2007; unpub. data). Although it was hoped that populations would decline with the senescence of initial immigrants, the presence of multiple size classes and increased abundance of yearling crabs indicates that populations have persisted in WCVI despite the absence of oceanographic conditions that would continue to transport larvae from southern populations, indicating successful local recruitment (Gillespie *et al*. 2007; Behrens *et al.)*.

8.4 INVASIVE TUNICATES

There are several species of tunicates that may be native or invasive. There are difficulties distinguishing species. Invasive species that have been identified in the WCVI are: *Botryllus schlosseri, Ciona savignyi, Didemnum vexillum, Molgula manhattensis and Styela clava* (Therriault, pers. com.). Some tunicate examples associated with invasive species monitoring are *Ciona savigny, Ciona intestinalis* (although *C. intestinalis* has not been yet been found in the region, only in Puget Sound), and *Didemnum* sp. Tunicates can be highly productive and can quickly foul marine surfaces, such that they have detrimental impacts to vessel surfaces and aquaculture structures.

8.5 HUMBOLDT SQUID

Because they are native to the Pacific Basin, Humboldt squid (*Dosidicus gigas*) are not formally considered an invasive species, but are mentioned here as in the 2000s they expanded their distribution northward and began to regularly appear in increasing abundance in Canadian waters (Cosgove and Sendall, 2004; Trudel *et al*., 2006). The squid are usually found only as far North as California (Field *et al*., 2007; Zeidberg and Robinson, 2007).

In 2009, Humboldt squid were widespread and abundant in British Columbia waters. They were recorded in both commercial and research catches, from early July to October, throughout British Columbia waters. They were very densely aggregated; a three minute research tow yielded nearly 120 individuals and commercial bycatches were occasionally estimated in the tens of tons. In addition to catches and numerous sightings, there were 10 significant stranding events reported throughout the exposed coast (Ucluelet to Massett) between August and October, as well as individuals washed onshore in Campbell River and Puget Sound in December.

Humboldt squid are seasonally-migrant, high metabolism predators that can function as keystone predators in offshore and nearshore ecosystems. They prey primarily on pelagic species such as hake, myctophids, anchovies, sardines, pelagic rockfish and other squid (Field *et al.*, 2007). Their diet could shift in northern waters depending on prey abundance, in particular depending upon the degree of overlap in time and space with salmon and herring.

9. MARINE MAMMALS AND SEABIRDS

The population size of marine mammals and sea birds can provide some indication of the overall health of the ecosystem because they tend to aggregate together and feed at a variety of trophic levels (e.g. DFO 2007).

The trend in many populations of marine mammals is increasing simply because, in the past, (roughly 100 years prior) so many species (e.g. whales and sea otters) were hunted with no regard for conservation. In contrast, the success of seabird reproduction appears to be declining (e.g. DFO 2008).

9.1 CETACEANS

Many marine mammals frequent the waters off WCVI. The three most commonly reported are Killer Whales (*Orcinus orca*), Grey Whales (*Eschrichtius robustus)* and Humpback Whales (*Megaptera novaeangliae*) (reference).

There are three distinct ecotypes of killer whales in B.C.; the 'transients', 'residents', and 'offshore' killer whales. The resident killer whales are further divided into two unique populations; the northern residents and southern residents. All ecotypes are listed under Canada's Species *at Risk Act* (SARA). Transients and northern residents are listed as threatened, southern residents are endangered and offshore killer whales are a species of special concern[1].

The 2008 COSEWIC status report for killer whales in Canada presents the 2006 killer whale census data; 244 northern resident killer whales, 87 southern resident killer whales, and approximately 243 transients. Research efforts from 1988 to 2008 recorded a total of 288 offshore killer whales in B.C., which is considered a conservative estimate (COSEWIC 2008). All three ecotypes utilize coastal waters off WCVI, however sightings of offshore killer whales have been rare. Threats to killer whales include limited food availability, bioaccumulation of toxins (e.g. PCBs), and disturbance (DFO 2007, 2008a, 2009a). Each ecotype is a prey-specialist. Resident killer whales (northern and southern) feed exclusively on Chinook and Chum salmon, while transients feed on marine mammal species. The feeding ecology of offshore killer whales is less well understood, but preliminary information suggests they may specialize in predation on elasmobranchs.

Eastern Pacific grey whales' spring migration from subtropical Mexican breeding grounds to their primary feeding grounds in the Bering, Chukchi and Alaskan Beaufort Sea includes the coastal waters off WCVI. A small proportion of this population (approximately 80, Calambokidis, et al., 2002) remains in areas off WCVI to feed throughout the summer and early fall (Calambokidis et al 2002). These 'summer residents' show fairly high site fidelity to feeding locations (e.g. Barkley Sound), and many individuals revisit the same feeding location year after year. In B.C., summer resident grey whales are known to feed on herring spawn, crab larvae, amphipods, and mysid and ghost shrimp (DFO 2010a). Given their wide variety of prey species, summer resident grey whales exploit almost all types of near-shore marine habitats and are found along the entire WCVI.

Grey whales were severely depleted during 19th century commercial whaling. In 2005, they were listed as a species of special concern under SARA. However, grey whales appear to be making major comeback. In 1994, the Eastern Pacific grey whale was de-listed from the U.S. *Endangered Species Act* based on evidence the population was nearing its estimated historic population numbers. The most recent best estimate for this population's size suggests it is approaching its estimated current environmental carrying capacity (Rugh et al. 2005; 2008 in DFO 2010a).

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[1] COSEWIC recently re-assessed offshore killer whales as threatened (COSEWIC 2008) and a change in legal SARA designation is under consideration.

There is increasing evidence that grey whales can be limited by fluctuations in both benthic and pelagic productivity (Perryman et al. 2002 in DFO 2010a). From 1998-2002, about 1/3 of the total Eastern Pacific grey whale population died from lack of food due to changing conditions on primary Arctic feeding grounds (COSEWIC 2004). Other threats to grey whales off WCVI include; environmental variability/ climate change, negative impacts on benthic feeding habitat, underwater noise, and toxic spills (DFO 2010a).

North Pacific humpback whales are listed as a threatened species under SARA. Despite being hunted to near extinction early in the previous century, the number of North Pacific humpback whales in B.C. waters has been gradually increasing over the past decade (annual B.C. population growth rates estimated to be 3-6%) and conservative estimates of humpbacks off the WCVI in foraging periods between May and October are 200-250 animals (Ford *et al.* 2009). Humpback whales use coastal waters off WCVI to feed and as migration routes to higher latitude feeding areas in northern B.C and Alaska. Humpbacks are known to feed on sardine, herring and euphausiids while in B.C. Several long-term critical feeding habitats in B.C. have been identified for humpbacks, including a 6,188.3 km^2 area off WCVI which extends from shore out to the continental shelf (Nichol et al. 2010, DFO 2010b). As with killer and grey whales, food limitation is considered a threat to humpback whales, as are entanglement and vessel collision (DFO 2010b).

Other large baleen whales sometimes visit the waters off WCVI; blue, fin, sei, and the extremely rare North Pacific right whale. These whales feed on a variety of euphausiids, copepods and forage fishes. These large whales are vulnerable to collisions with boats, noise, pollution and entanglement in lost or active fishing equipment (Gregr *et al.* 2006), and paucity in food as the climate changes (COSEWIC 2002). All species are listed under SARA. Blue, sei and North Pacific right whales are endangered species, while fin whales are listed as a threatened species.

Smaller cetaceans are also present in WCVI waters, but there are few dataon abundance and none show trends in populations. Examples are Dall’s porpoises, Pacific white-sided dolphin and Pacific harbour porpoises. Harbour porpoises are a species of special concern under SARA and a management plan has been developed to address knowledge gaps and threats to this species (DFO 2009).

9.2 PINNIPEDS

A number of pinniped species reside in B.C. waters, including Steller sea lions, California sea lions and Harbour seals. Steller sea lions and harbour seals reside year round in Canadian waters, while California sea lions are found in B.C. primarily in winter months. There are several seasonal and year-round pinniped haulout sites along the entire WCVI.

Between 1913 and 1968, Steller sea lions were culled to reduce their perceived impact on commercially valuable salmon fisheries, and there was also a small commercial harvest for hides and meat of Steller sea lions . A breeding rookery in the Sea Otter Island Group was completely wiped out, and Steller sea lions were reduced to approximately ¼ of their historic total population size (Bigg 1985; DFO 2008b). As a result the total numbers of Steller sea lions on the WCVI showed an overall decreasing trend until 1970. Since 1970, the population has been protected under the *Fisheries Act* and has been increasing (Figure 27) (Olesiuk in DFO 2003). In 2005, Steller sea lions were designated a species of special concern under SARA. Steller sea lion have several rookeries in B.C., one of which is in the Scott Islands off northwest

VI. Steller sea lion in B.C. are known to feed on small to medium-sized schooling fishes, including; herring, hake, sandlance, salmon, dogfish, eulachon, sardine, as well as bottom fish such as rockfish, flounder and skate (Pike 1958; Spalding 1964; Olesiuk and Bigg 1988, Trites and Olesiuk, unpublished data cited in DFO 2009b). Threats to Steller sea lion in B.C include environmental variability limiting prey availability, competition with fisheries, bioaccumulating toxins, and disturbance (DFO 2009b).

Harbour seals are common throughout all of B.C and do not migrate to specific rookeries to breed. This species was also subject to predator control programs and commercial harvest. As a result their numbers were depressed before they were protected under the *Fisheries Act* in 1970 (Olesiuk 1999). Since the early 1970s, when a monitoring program was begun, populations increased at an annual rate of 11.5% (95% CI; 10.9-12.6%) during the 1970s and 1980s (Olesiuk 2010), and the population appears to have now stablized (Figure 28). Harbour seals have similar diet to Steller seal lions.

California sea lions are found in B.C. primarily in winter months and are not year-round residents, as they migrate south to breeding areas in California and Mexico. Expansion of California sea lion into B.C. waters is likely a result of recovery in southern portions of their range as well as changing ocean conditions (e.g. el Nino) and fluctuations in local prey abundance (Olesiuk and Bigg 1988). California sea lions have similar diet to both harbour seals and Steller sea lion, and herring may comprise 35% of their diet (Olesiuk and Bigg 1988).

9.3 SEA OTTERS

The sea otter (*Enhydra lutris)* historically occupied the coastal zone of the North Pacific from Northern Japan to Baja California Mexico, but was hunted intensively for its fur (from about the 1700s to the 1900s) and extirpated throughout much of it’s global range by 1911. 89 sea otters were reintroduced to Checleset Bay, WCVI from Alaska between 1969 and 1972 and, following successful re-establishment, the population has increased (Figure 29) and re-established some of it’s range, so that it covers the northern coast of Vancouver Island extending southward to approximately Tofino, currently occupying about 25-33% of their historical range (COSEWIC 2007).

Sea otters forage primarily on invertebrates, which they obtain by diving to the sea floor. The seaward extent of their habitat is, therefore, limited by their diving ability. Most foraging dives are in depths of less than 40m, thus, sea otters seldom range beyond 1-2km of shore (COSEWIC 2007). In coastal B.C., sea otters generally occur along stretches of exposed coastline characterized by complex rocky shorelines with small islets and offshore reefs.

Most foraging takes place in subtidal areas, but foraging also occurs in the intertidal zone at high tide (Sea Otter Recovery Team 2007). In recently re-occupied rocky habitats, where sea urchins are abundant, urchins are consumed preferentially, probably because of ease of capture. As the quantities of their most readily obtainable (and preferred) prey items decline, the diet of sea otters diversifies to include a larger array of invertebrates, such as bivalve clams, snails, chitons, crabs and sea stars (Estes et al 1981). In soft sediment habitats, sea otters forage on clam species such as butter clams, horse clams and geoduck clams through excavation (Sea Otter Recovery Team 2007). As the re-colonization of sea otters persists and expands, concern regarding competition with humans for shellfish resources is likely to continue (DFO 2009).

Sea otters are relatively sedentary, occupying small overlapping home ranges on the order of 10s of kilometres of coastline. Sea otters form resting aggregations called rafts that can number over a hundred individuals. Rafts often form habitually, in the same locations over periods of years. Males and females occupy spatially distinct areas, so that there are male rafts and female and pup rafts occupying different areas (Nichol *et al* 2005).

In Canada, sea otters were down-listed to *Special Concern* under the Species at Risk Act in 2008. The species is protected under the Fisheries Act and by provisions in the British Columbia Wildlife Act.

9.4. MARINE BIRDS

Seabird species are generally long-lived, with very low-reproductive output (usually one egg) per year, and late onset of sexual maturity. The population dynamics of seabird species are particularly sensitive to changes in adult mortality because of their life history strategies, which are remarkably similar among species, and because population recovery is relatively slow following a decline, even under ideal breeding conditions. Severe weather and climate change are common natural threats. Ship-source oil pollution (Butler, Harfenist, Leighton, Peakall, 1988; Camphysen, Heubeck, 2001; Wiese, Robertson, 2004), fisheries bycatch (Smith, Morgan, 2005) and introduced predators to breeding colonies (Moors, Atkinson, 1984) are probably the largest anthropogenic threats to seabird populations worldwide. Seabird breeding success is tied closely to the availability of key prey species and can vary widely between years (DFO 2007). Since 1994, researchers from the Centre for Wildlife Ecology have visited Triangle Island (northern tip of Vancouver Island) to collect time-series data on seabirds.

In general, breeding success has declined for many seabirds, reaching an all-time low in 2007 (e.g. Cassin's Auklet and Rhinoceros Auklet, Figure 30). This poor success was contrary to predictions based on the cool sea surface temperatures. The preferred prey species for Rhinoceros Auklets nestlings (Pacific sandlance) was extremely low in 2007. It made up > 10% of the birds diets that year (Hipfner in DFO 2008). The Common Murre also had the lowest measured success rate in 2007, but that time series only started in 2003 (*ibid.*).

10. HYDROTHERMAL VENTS

The WCVI also includes a hydrothermal vent system, Endeavour Ridge (ER), that supports a unique and diverse ecosystem (Tunnicliffe 1988). ER is located about 300 km seaward of British Columbia and Washington State in about 2500 m of water. The active venting occurs in a valley in an area of roughly 1 km X 10 km (Thomson *et al.* 2003). In this region benthic and pelagic fauna are more abundant and species-rich, as they derive nourishment from chemosynthetic bacteria in vent plumes.

The benthic fauna described for the Endeavour Ridge venting area is typical of its kind, showing high populations of deep-sea species, as well as species specifically adapted to venting conditions. Long-term biological trends in benthic faunal composition have not been studied, but some theoretical papers discuss benthic diversity relative to properties of the vent habitat (Juniper and Tunnicliffe 1997, Tsurumi et al. 2003). However, when the underwater cable system NEPTUNE comes on line (URL: http://neptunecanada.ca/sensors-instruments/locations/endeavour.dot or www.neptunecanada.com/dotAsset/7196.pdf), scientists will be able to observe long-term population shifts relative to venting conditions and unusual events, such as mega-plume eruptions.

The area surrounding the vent system is a ‘hot spot’ for many pelagic organisms (e.g. copepods, Skebo *et al*. 2006). Pelagic zooplankton have shown consistent biomass enrichment (Burd and Thomson 1994, 1995) in a deep layer overlying (2000 m deep) the spreading vent plume near ER. This layer includes primarily typical mid-depth migratory (200-800 m) fauna, as well as typical deep-sea fauna, and extends from 2-10 km away from active vents (Burd and Thomson 1995). In addition, the biomass of zooplankton is enhanced throughout the water column (Burd and Thomson 1994), in part, because the deeper fauna overlying the vents contribute reproductive by-products (eggs, larvae) to near-surface waters, thus feeding upper water column organisms. Furthermore, jellyfish contribute an abnormally high abundance and biomass throughout the water column within 10 km of the ER vents, presumably taking advantage of the higher biomass of zooplankton in this region (Burd and Thomson 2000).

11. CORALS AND SPONGES

Although little is known about the seafloor on the WCVI (note that the Canadian Geologic Survey has not collected any data there in 25 years – K. Conway, pers. com.), 39 species of corals have been recorded and verified by voucher specimen from the WCVI. These species represent six orders and 21 families, including sea pens and sea whips (Pennatulacea), cup corals (Scleractinia), black corals (Antipatharia) and the gorgonian corals (Alcyonacea) including large charismatic species such as *Primnoa pacifica willeyi* and *Paragorgia arborea*. Several species of hydrozoan coarls have also been recorded. Many of these corals grow in shallower water and many provide important habitat for fish (e.g. Brodeur 2001).

It is also possible that the cold water coral *Lophelia pertusa* is found in this region. This coral has only really been discovered (at any location) in the last 20 years, because of its depth range (> 200 m), however, it forms reefs that provides extensive fish habitat, perhaps more than tropical reefs globally, towering to up to 50 m in some locations (Friewald *et al.* 2004). Some remnants of this species have been found in the Strait of Georgia (Conway *et al.* 2007) and it has also been found on the American side of Juan de Fuca Strait (Ed Bowlby, pers. com.) and in Alberni Inlet in the 1980 s, although it was misidentified at the time (Conway *et al*. 2007). These corals are especially vulnerable to increased acidification, as their skeletons are built of aragonite (Guinotte and Fabry 2008).

It is likely that corals were relatively common on the shelf and continental slope prior to the inception of the foreign fleet bottom trawl fishery which operated off the WCVI during the 1950s and 1960s. Given the slow growth and long generation time of most temperate deep water corals, and the persistence of a domestic bottom trawl fishery in the region, it is unlikely significant aggregations of these species will reappear in trawlable habitat in the foreseeable future.

Similarly, it is possible that sponge reefs, common on the north coast (north of WCVI) and covering 100s of square km (e.g. Conway *et al.* 2001; Whitney *et al.* 2005) could be found on the WCVI as concentrations of silicic acid are also high (a requirement of these reefs), particularly in the northern section of this region. Note that both corals and sponges are highly susceptible to damage by trawling and siltation by activities such as oil exploration.

12. CONTAMINANTS

Despite its rugged and often difficult access, the WCVI is not immune to contamination. Since the 1850s, mining for copper, gold and other metals has released metals and acid mine drainage into adjacent coastal waters. In Quatsino Sound, the Island Copper Mine operated until 1995, having released 358 million tonnes of tailings into Rupert Inlet (Poling *et al.* 2002).

Natural sources of metals have also generated some concern along the coast, with significant upwelling (intermediate depth waters that are upwelled are rich in Cd, especially in the North Pacific) causing high concentrations of cadmium in bivalves such as oysters (Kruzynski 2004; Lekhi *et al.* 2008). This concern prompted bans of imports of Canadian oysters by some other nations.

Until the early 1990s, most BC pulp mills represented significant sources of polychlorinated dibenzo-p-dioxins (PCDDs or dioxins) and polychlorinated dibenzofurans (PCDFs or furans). The use of elemental chlorine (Cl) during the pulp bleaching process led to a by-production of dioxins and furans in effluent.

Two mills were located on the WCVI: Port Alberni and Port Alice (Quatsino Sound). The Port Alice facility, however, employed a process that did not lead to the formation of these compounds. The extent of dioxin and furan contamination here is unclear, although some data exist for harbour seals (Addison *et al.* 1996). The implementation of source control and regulations led to rapid declines in environmental concentrations of these two inadvertently produced contaminants throughout BC (Hagen *et al.* 1997). Despite this improvement, 1200 hectares of seabed in BC remain closed for commercial crab and prawn fishing, underscoring the lasting socio-economic impact of this issue.

While small point sources of polychlorinated biphenyls (PCBs) likely existed along the coast, as a result of electrical transformer use in industrial-scale pulp mills and mining, the extent of its influence is unclear. It is a legacy contaminant, as its use was banned in the late 1970's, causing emissions throughout North America to rapidly decline (Johannessen *et al*. 2008 and references therein). PCBs have been detected in harbour seals, salmon, and in samples of shellfish and invertebrates collected as part of a study on the levelso of contaminants in First Nations diets (Krümmel *et al.* 2003 DeBruyn *et al.* 2004; P.S. Ross, pers. comm.). It is more likely that these PCBs arrived from distant sources, through long-range atmospheric transport from North America and Asia (Wilkening *et al.* 2000) , ocean currents (Iwata *et al.* 1993) and/or biological importation (Ewald *et al.* 1998). Studies of the largely-salmon eating northern and southern resident killer whales, which frequent the waters off the WCVI for part of the year, increasingly suggest that Asian air pollution is partly to blame for the very high PCB levels in their tissues (Ross *et al.* 2000).

Organochlorine (OC) pesticides were used widely until catastrophic DDT-associated eggshell thinning led to regulatory disfavour for this category of persistent and bioaccumulative pesticide (Hickey and Anderson 1968). Little information exists for OC pesticides along the west coast of Vancouver Island, but as with the PCBs, long-range transport, ocean currents and biological importation likely deliver these contaminants to food webs in this region.

Flame retardant chemicals, including the polybrominated diphenyl ethers (PBDEs), have come under increased regulatory scrutiny during recent years. While some forms have been banned others are still in use (Johannessen *et al*., 2008). PBDEs are structurally-related to PCBs, but are less stable and more lipophilic. Recent research suggests that PBDE concentrations are doubling in the aquatic environment every 3.5 years (Rayne *et al.* 2003), a phenomenon that likely holds for the WCVI. This emerging concern has implications for high trophic level wildlife, such as killer whales (Rayne *et al.* 2004), and for First Nations, consumers of traditional seafoods. Detailed studies within marine sediments have been conducted in the Strait of Georgia (See Strait of Georgia Chapter, this document) and it is likely that WCVI sediments contain a similar record.

Numerous additional contaminant sources along the WCVI may present localized problems to the aquatic environment, although these are likely limited in scope by the small human population. An annotated review published elsewhere for parts of the WCVI and the central coast of BC provides an overview of some of the more salient concerns (Haggarty *et al.* 2003). Harbours and marinas are a source for hydrocarbons related to the use and loss of boat fuels, as well as runoff from land-based sources. Aquaculture installations and marinas were a source of organotins prior to the implementation of regulations. Residential communities are potential sources for 'biological pollution', as well as the release of small quantities of pharmaceutical and personal care products, phthalate esthers, and other domestic products. Low-temperature combustion and incineration from industry, dumpsites or households can create dioxins, furans and other compounds, and/or release these into the atmosphere.

Ultimately, however, almost any human activity along the coast has the potential to release contaminants into the aquatic environment. The fate of the myriad contaminants released depends on the physico-chemical properties of the chemical, the extent and amount of its use or release, and the nature of the receiving environment. These factors, together with the toxicity of the contaminant in question, dictate the extent to which aquatic biota will be impacted.

13. SPECIES AT RISK

Some of the marine species found off the WCVI are already protected under the *Species at Risk Act* (SARA) as either endangered, threatened or species of special concern. Others have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and are awaiting a listing decision under SARA by the Minister of the Environment. Species found in the marine waters off of the WCVI that have been classified as at risk are summarized in Table 2. All summary information listed below can be found on the SARA Public Registry: http://www.sararegistry.gc.ca/default_e.cfm

14. DRIVERS OF CHANGE

It appears that the primary driver of change on the shelf west of Vancouver Island is the changing climate. Basin-scale changes are translated onto the coast through physical circulation, most significantly upwelling during the summer. This circulation, in conjunction with tidal mixing and nutrient supply from the Juan de Fuca Strait, drive high primary production in the region (Hickey and Banas, 2008), and is ultimately responsible for the traditionally strong commercial fisheries and abundance of marine mammals. The surface waters in the NE Pacific are freshening and intermediate waters are becoming depleted in dissolved oxygen (Whitney *et al.* 2007; DFO, 2009) and enriched in carbon dioxide (Feely *et al.* 2004). Surface freshening inhibits mixing and may reduce the transport of nutrients into the surface and so primary production may decrease. As intermediate depth waters are brought onto the shelf through upwelling, both the decreased oxygen levels and the increased carbon-dioxide levels are likely to cause negative effects to the marine ecosystem (Feely *et al.* 2008). In addition, sea surface temperatures (SSTs) are increasing as a direct result of increased heating at the surface and increased incidence of El Nino events (that are associated with higher SST) (DFO, 2007). Many marine organisms travel with their preferred temperature (e.g. zooplankton, hake) (e.g. Mackas *et al.* 2007; Ware and McFarlane, 1995) and this movement in turn affects other members of the ecosystem. As coastal waters warm, hypoxia is spreading (DFO, 2009). This spreading will likely cause the displacement of some organisms and increase competition for nutrition and habitat (Whitney and Sinclair, in prep.).

The secondary driver of change is human practices in general, primarily through harvest of fish and shellfish. Many stocks of fish are decreasing to the point where the commercial fishery is closed due in part to climate change, as well as over-harvest depending on the species (e.g. Schweigert and Haist 2007, DFO 2007). In addition, human practices have led to increased contaminants in the ocean. Some of these contaminants bioaccumulate and concentrations are increasing to dangerous levels in marine organisms higher in the food chain, such as salmon and killer whales (e.g Ross *et al.* 2000). This issue persists in the marine environment even though at least some of the toxins have become regulated (e. g. Johannessen *et al.* 2008). On the other hand, protection of species, most notably marine mammals, and regulation of harvest or control by humans has allowed increases in populations of previously endangered or even extirpated organisms (e.g. Olesiuk 1999, Olesiuk in DFO 2003, COSEWIC 2007, Ford *et al.* 2009).

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16. FIGURES

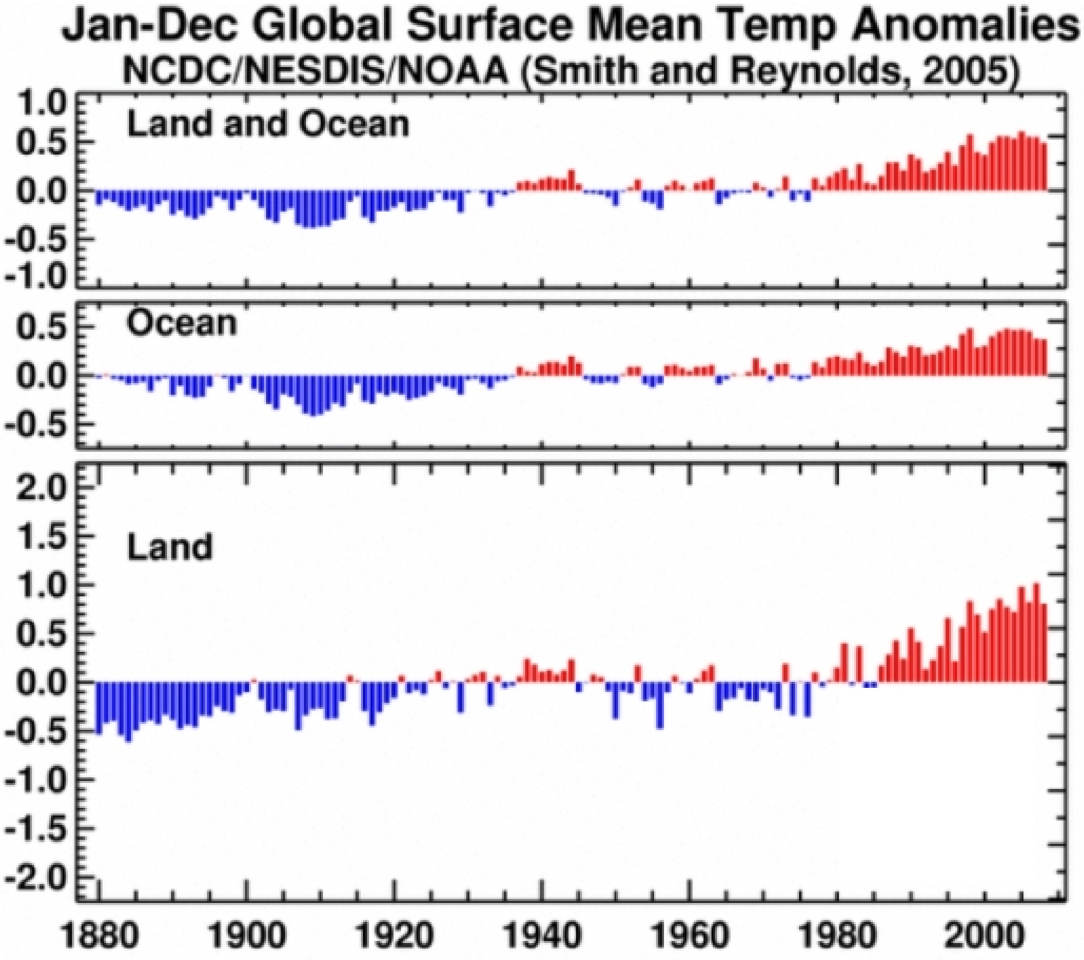


Figure 1. Global annual average air temperatures over land and ocean from 1880 to 2006, over land and ocean (top), ocean alone (middle), and land alone (bottom). Anomalies are relative to the mean over the 20th century (1901-2000). Source: DFO (2009).

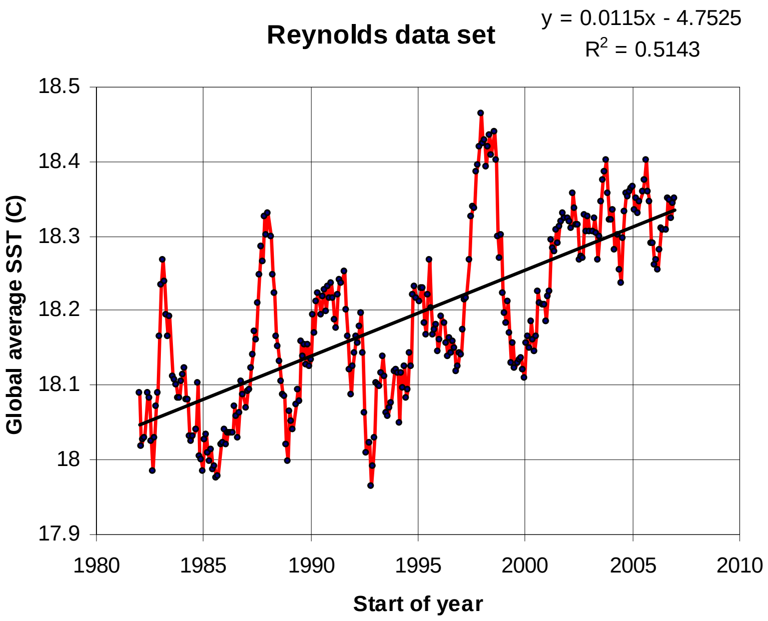


Figure 2a. Monthly average temperatures computed over 1-degree latitude by 1-degree longitude squares of the ocean. The time series above represents the monthly global averages. Source: DFO (2007).

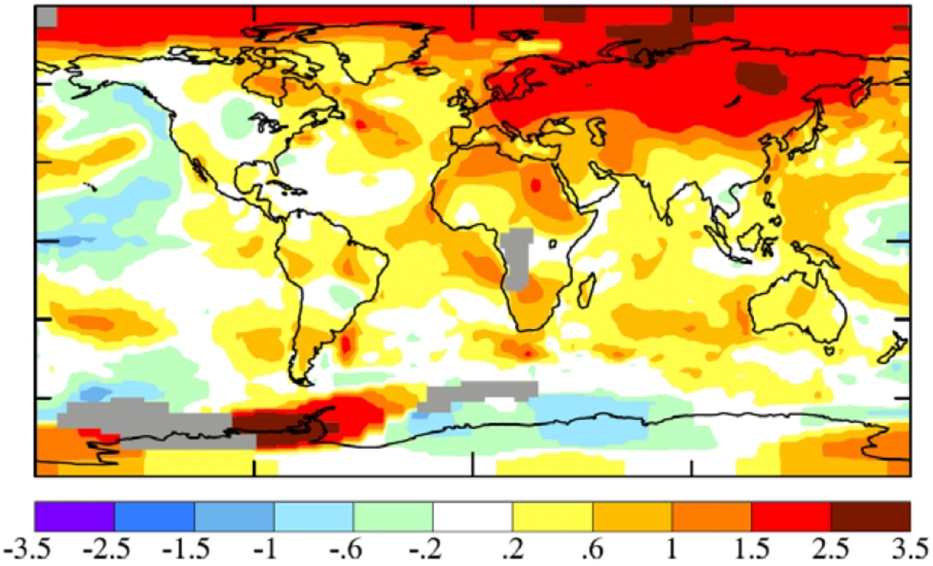


Figure 2b. Annual mean pattern of SST anomalies for 2008. Anomalies are calculated relative to the mean over the period 1961-1991. Note the broad region of negative anomalies extending along the west coast of North America indicating the local prevalence of below-average temperatures in 2008. Source: DFO (2009).

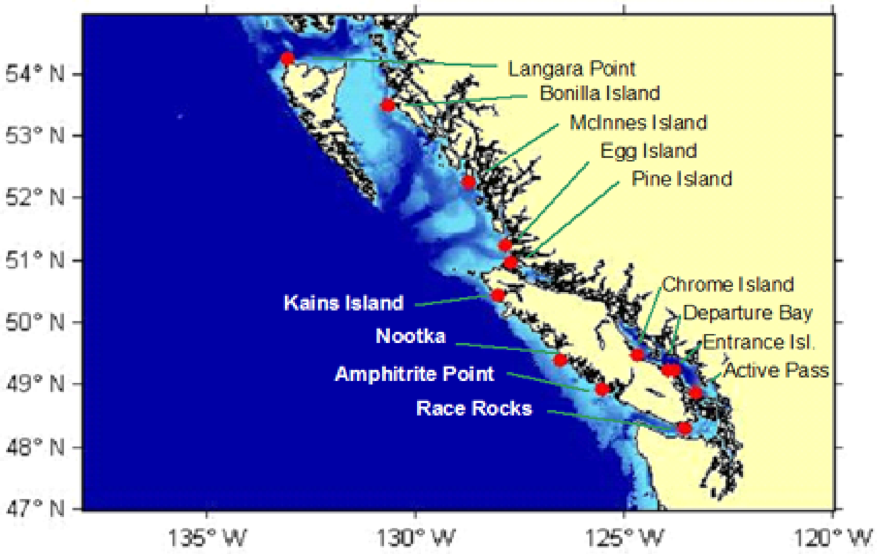


Figure 3a. Locations of British Columbia lighthouse stations for which there exist long-term record of surface water temperature and salinity. DFO (2007).

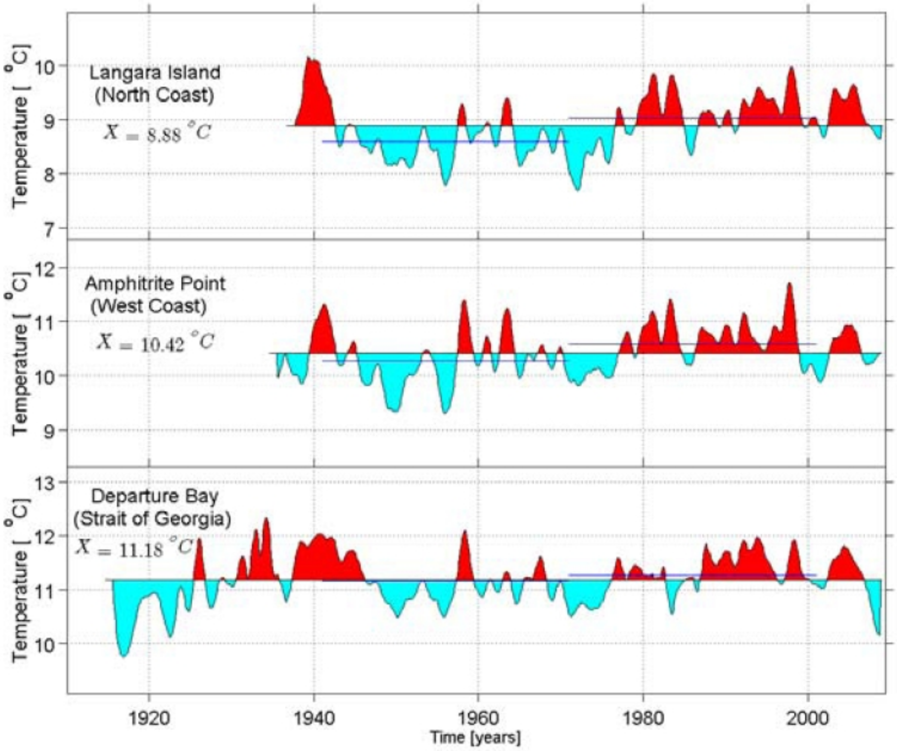


Figure 3b. Long-term time series of annual-average temperature at three representative coastal BC lighthouse stations. Source: DFO (2009).

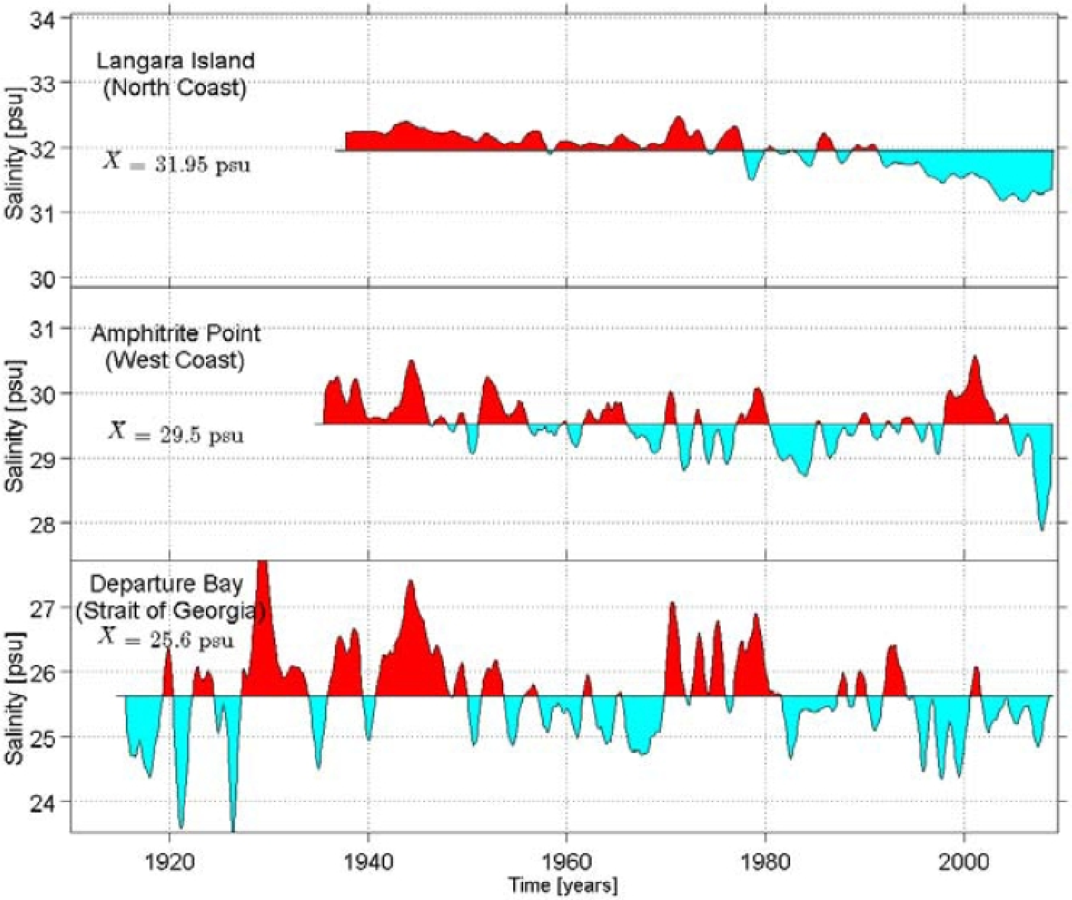


Figure 4: Long-term time series of sea surface salinity at representative BC lighthouse stations. Source: DFO (2009).

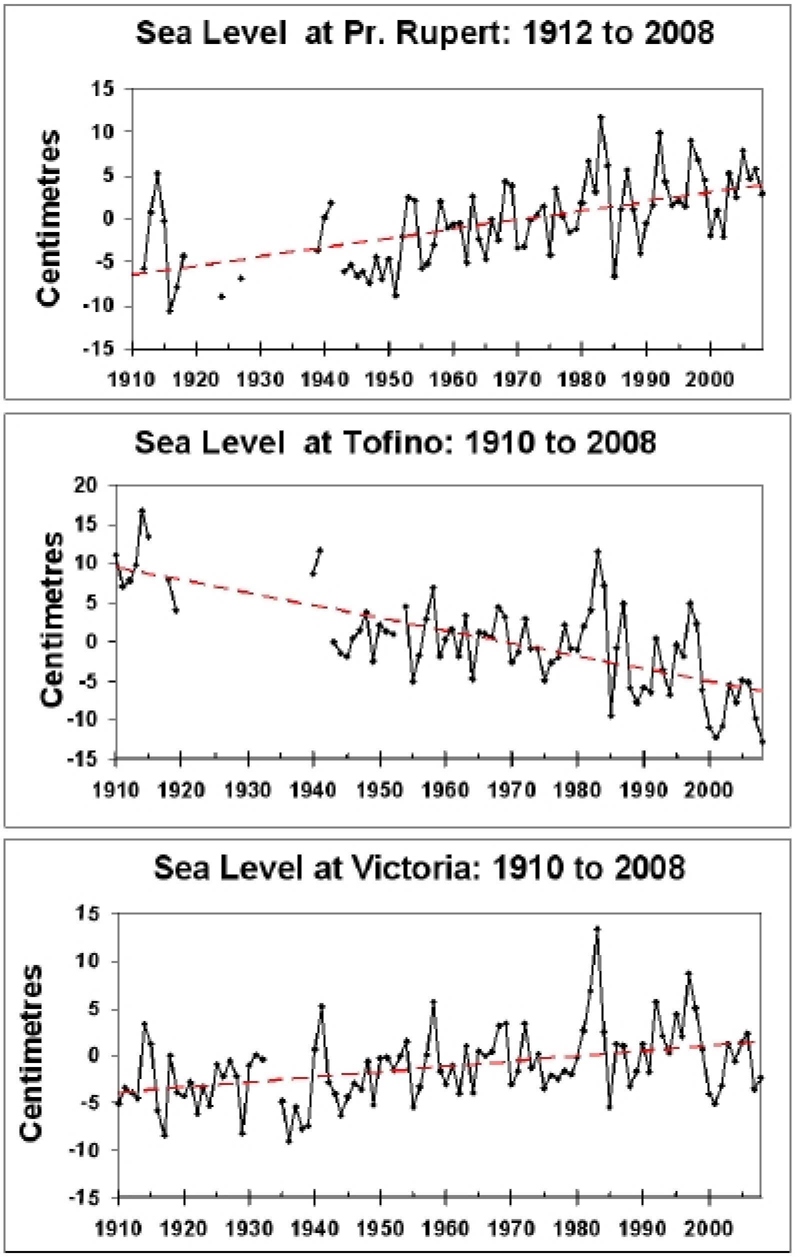
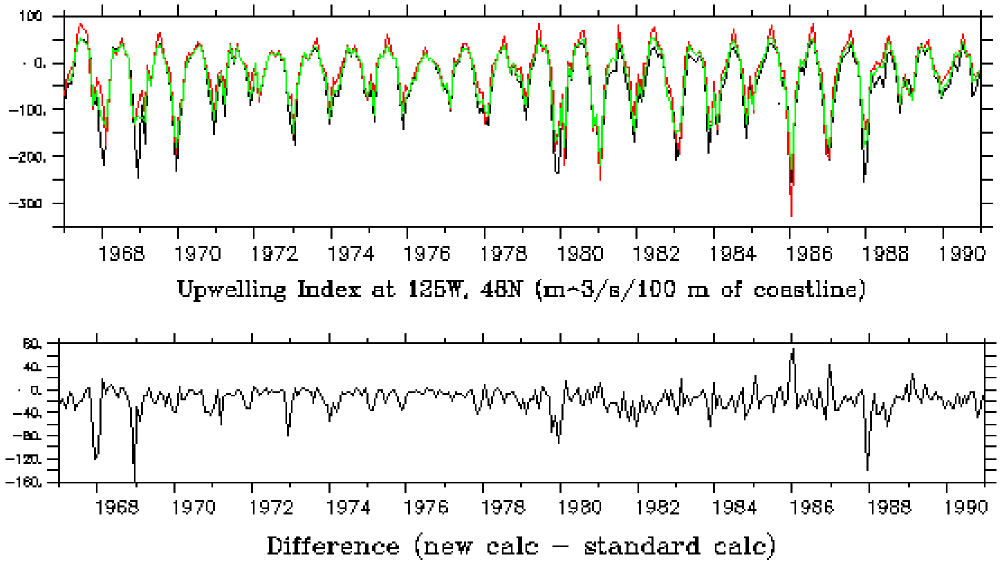


Figure 5: Time series of annual mean sea level and fitted linear trends at three locations on the BC coast. Source: DFO (2009).

A



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B

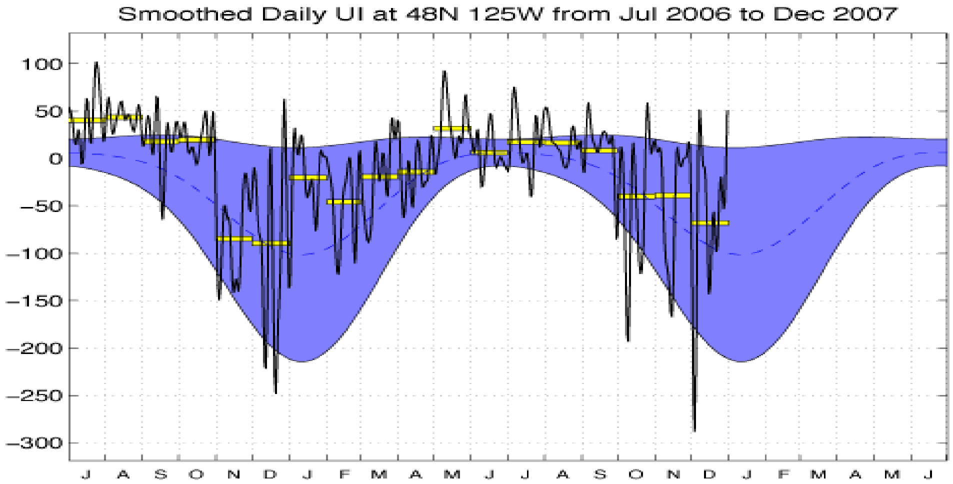


Figure 6 A) Time series of the local upwelling index (units m3/s/100 m coastline) estimated from local winds at the southern boundary of the study region (the green and red curve are from different methods to estimate the index) and B) The most recent annual cycle (2006) of the upwelling. The dashed curve is a biharmonic fit to the daily upwelling indices for the period 1967-1991. The shaded area around the biharmonic curve denotes one standard error, calculated for each Julian day. The yellow bars denote monthly mean of the Upwelling Indices based on the daily values. from: http://www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/upwelling.html

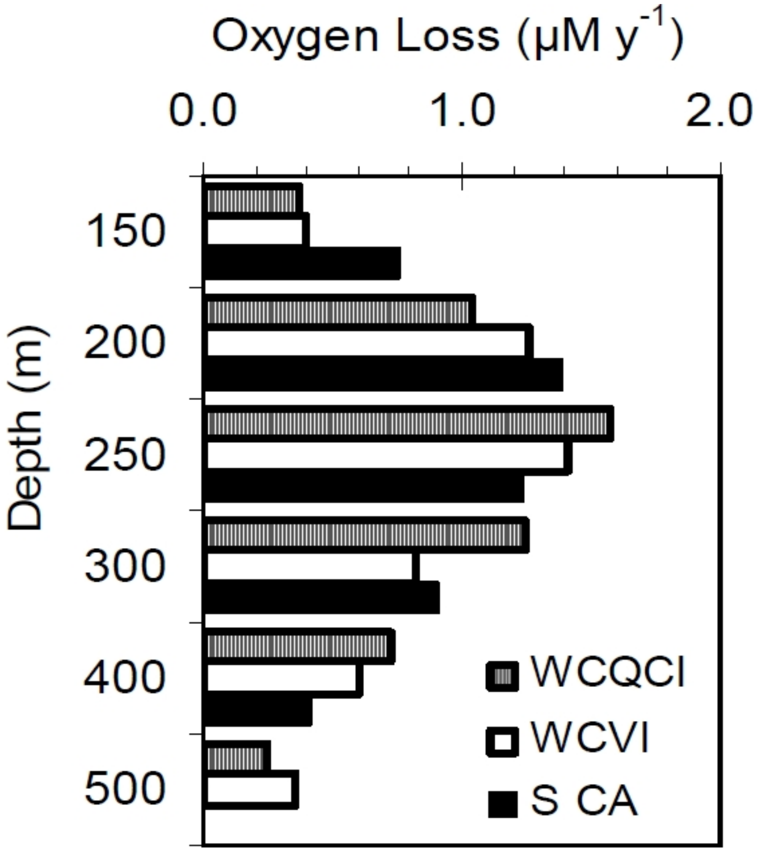


Figure 7. Oxygen trends at different depths along the west coast of North America. 'S CA' refers to Southern California, 'WCVI' refers to the west coast of Vancouver Island, and 'WCQCI' refers to the west coast of the Queen Charlotte Islands. Source: DFO (2009).

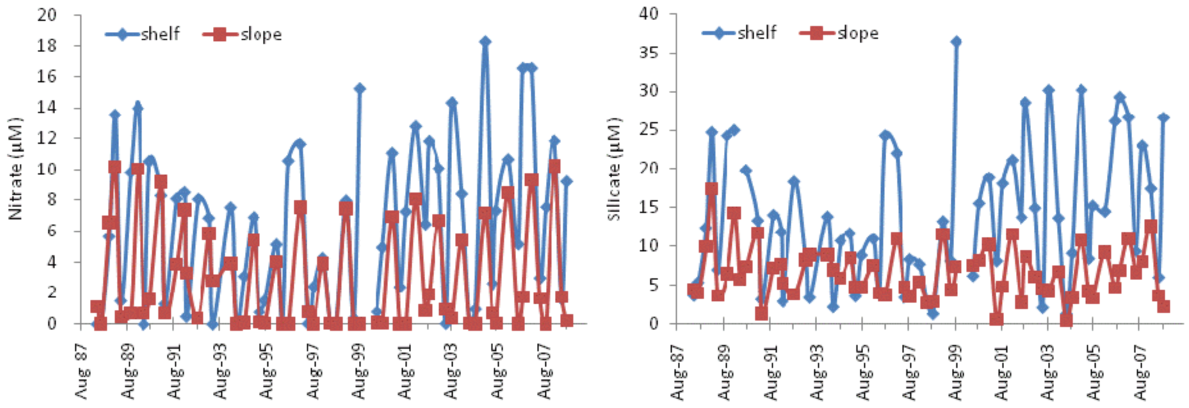


Figure 8. Surface Nitrate and Silicate concentrations in shelf (here defined as the continental shelf and just beyond the shelf break) and slope waters (here defined as the region beyond the 1000m depth contour between the slope and Alaskan Gyre) off southern Vancouver Island from May 1988 to August 2008.

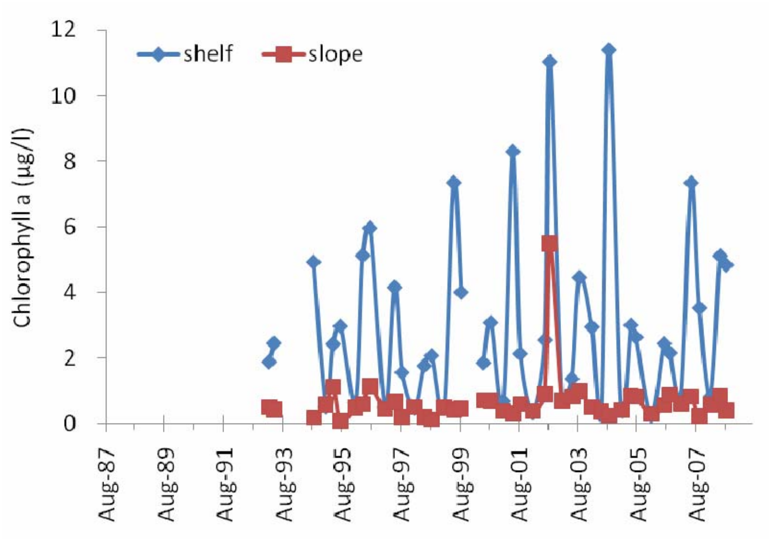


Figure 9. Surface chlorophyll a concentration in shelf (here defined as the continental shelf and just beyond the shelf break) and slope waters (here defined as the region beyond the 1000m depth contour between the slope and Alaskan Gyre) off southern Vancouver Island from May 1993 to August 2008.

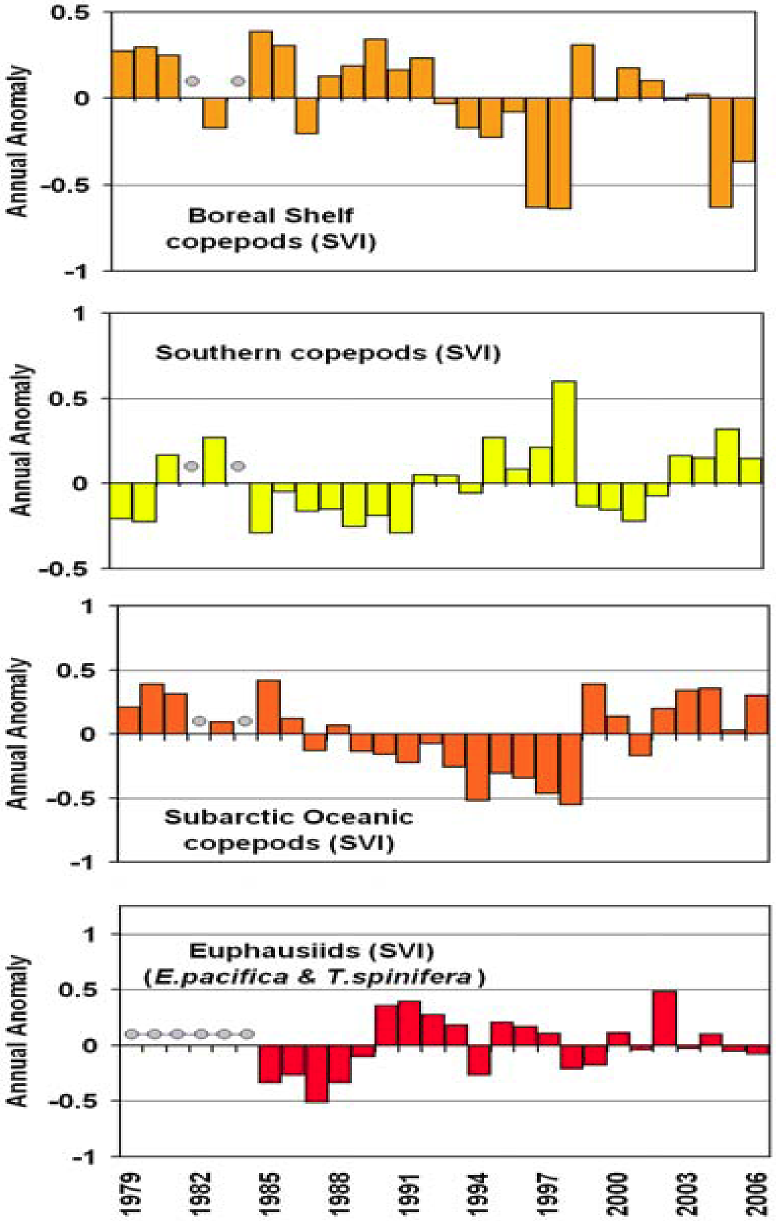


Figure 10. Annual anomaly in zooplankton biomass (see text for explanation) as a function of time. Grey dots indicate no data are available DFO (2007).

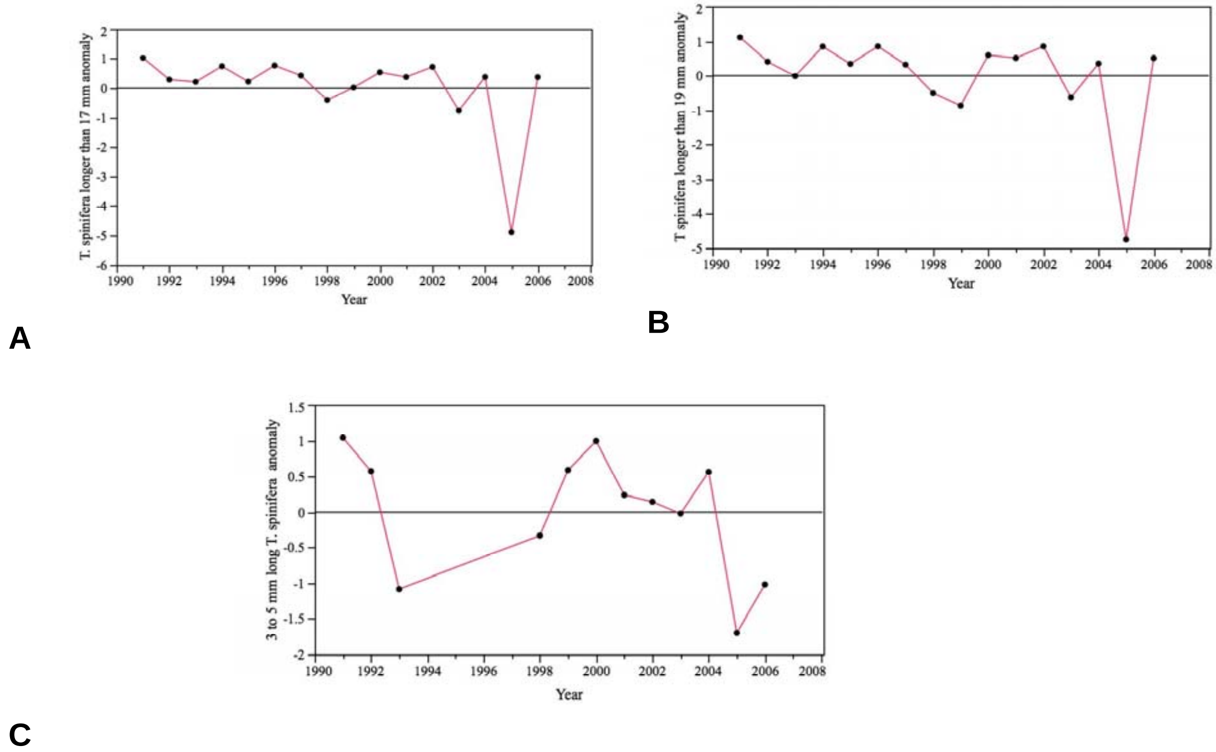


Figure 11. Size classes of euphasiid (T. spinifera) as prey item for A) Pacific herring (Clupea pallasi) longer than 17 mm; B) Pacific hake (Merluccius productus) longer than 19 mm and C) coho salmon (Oncorhynchus kisutch), and sockeye salmon (O. nerka) 3 – 5 mm long (R. Tanasichuk, unpublished data).

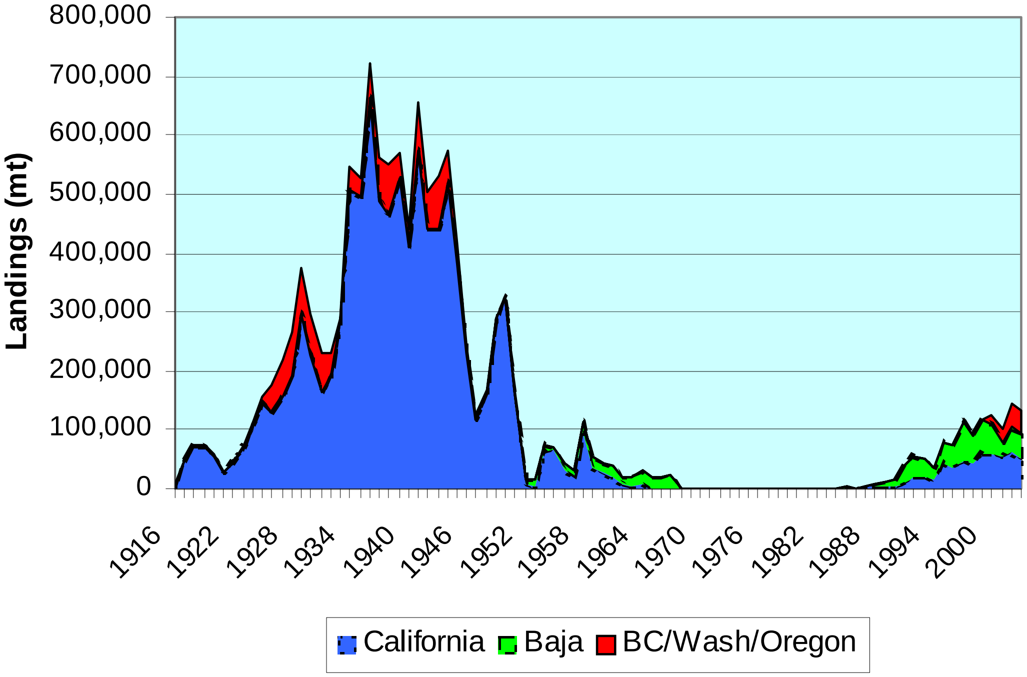
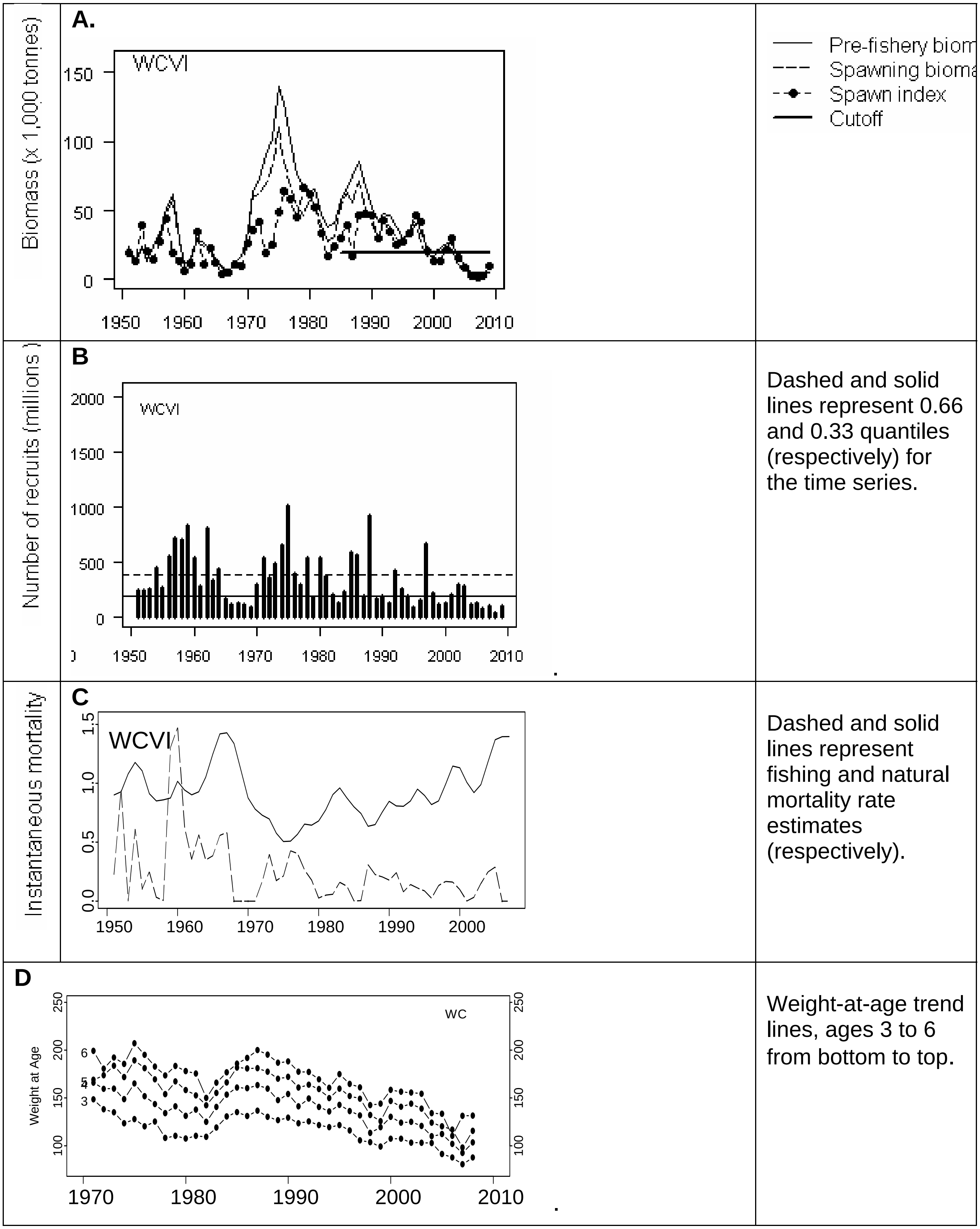


Figure 12. Time series of sardine landings along the west coast of North America (COSEWIC 2002). Most fish caught in BC were from the WCVI.



Dashed and solid lines represent 0.66 and 0.33 quantiles (respectively) for the time series.

Dashed and solid lines represent fishing and natural mortality rate estimates (respectively).

Weight-at-age trend lines, ages 3 to 6 from bottom to top.

Figure 13. Stock assessment estimates and trends for WCVI Pacific herring for 1951-2009 taken from Cleary et al. (2009). A) biomass, B) age 3 fish recruiting to spawning stock, C) instantaneous annual fishing and natural mortality rates, and D) weight-at-spawning 3 to 6 (grams) for 1970-2008.

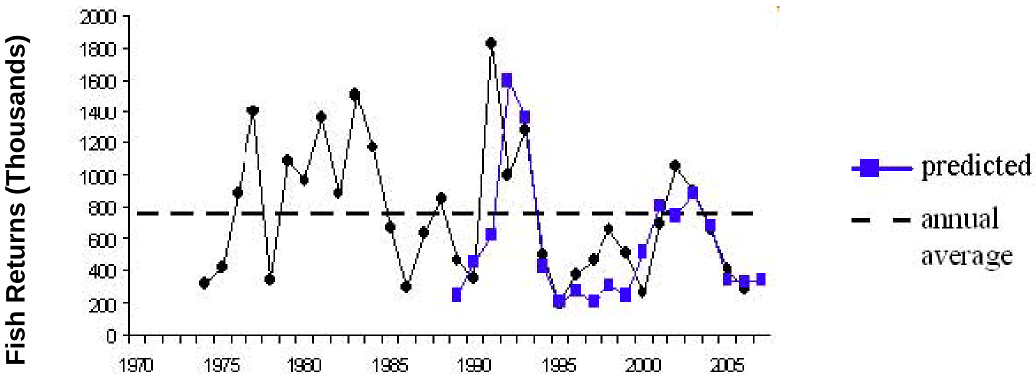


Figure 14. Trends in total returns and forecasts for the Barkley Sound sockeye index stock, 1970 – 2006; the vertical axis represents returns in thousands of fish DFO (2007).

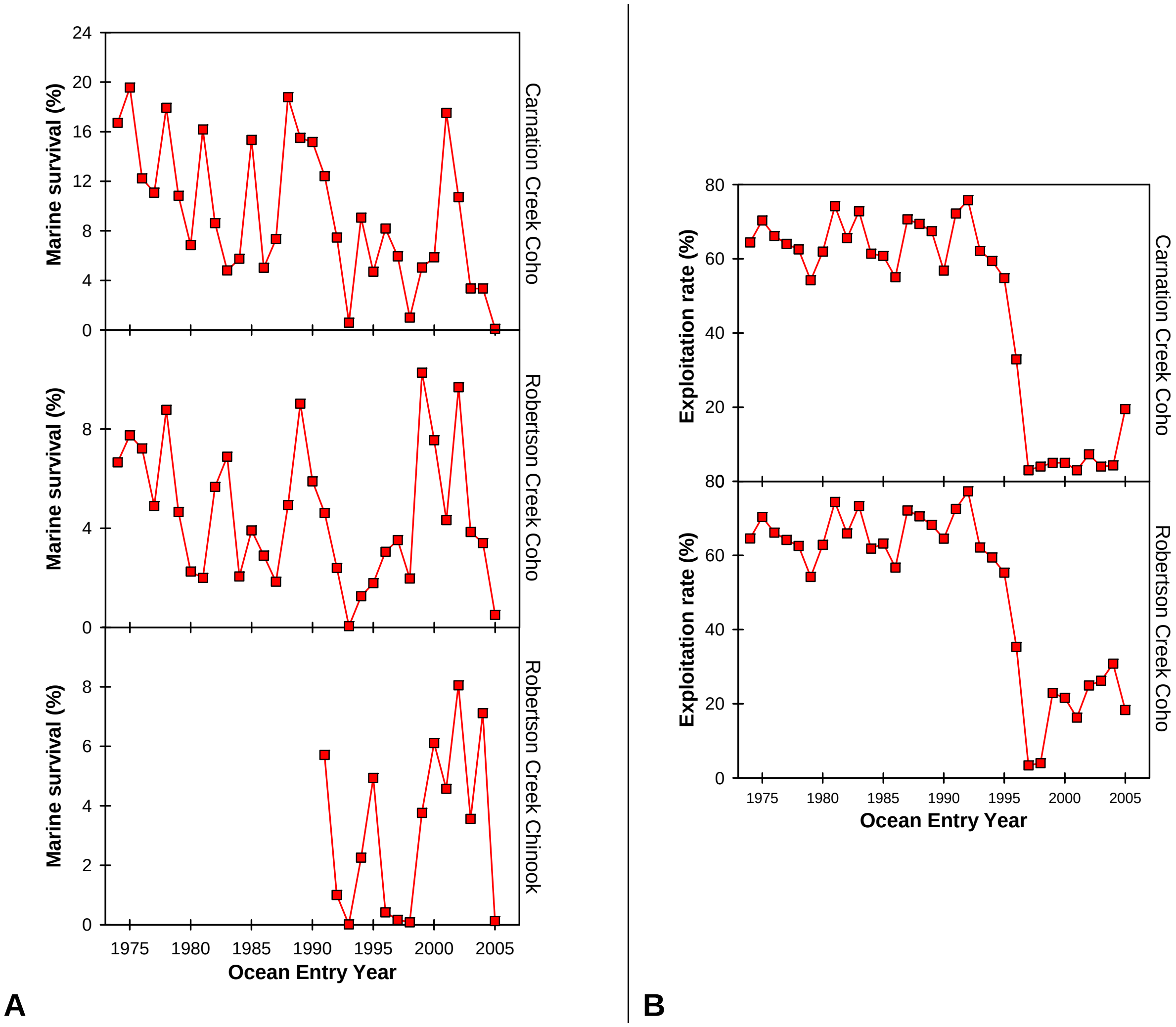


Figure 15. Summary trends from 1995 to 2005 showing estimated (A) marine survival of key west coast of Vancouver island coho and chinook stocks and (B) corresponding estimates of coho exploitation rates (Trudel et al. unpublished).

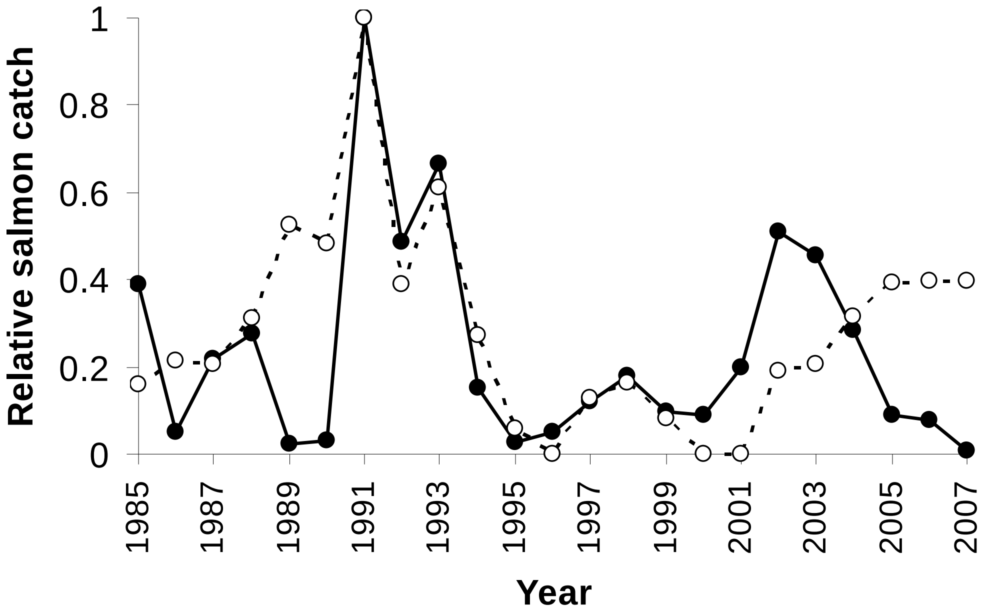


Figure 16. Combined First Nations, commercial and recreational catch of sockeye (filled circles, solid line) and chinook (open circles, dotted line) in Barkley Sound (Statistical Area 23), 1984 – 2007 (O'Brien (DFO) unpublished.). Catches are scaled to the maximum catch over the period: approximately 1,170,000 sockeye and 160,000 chinook.

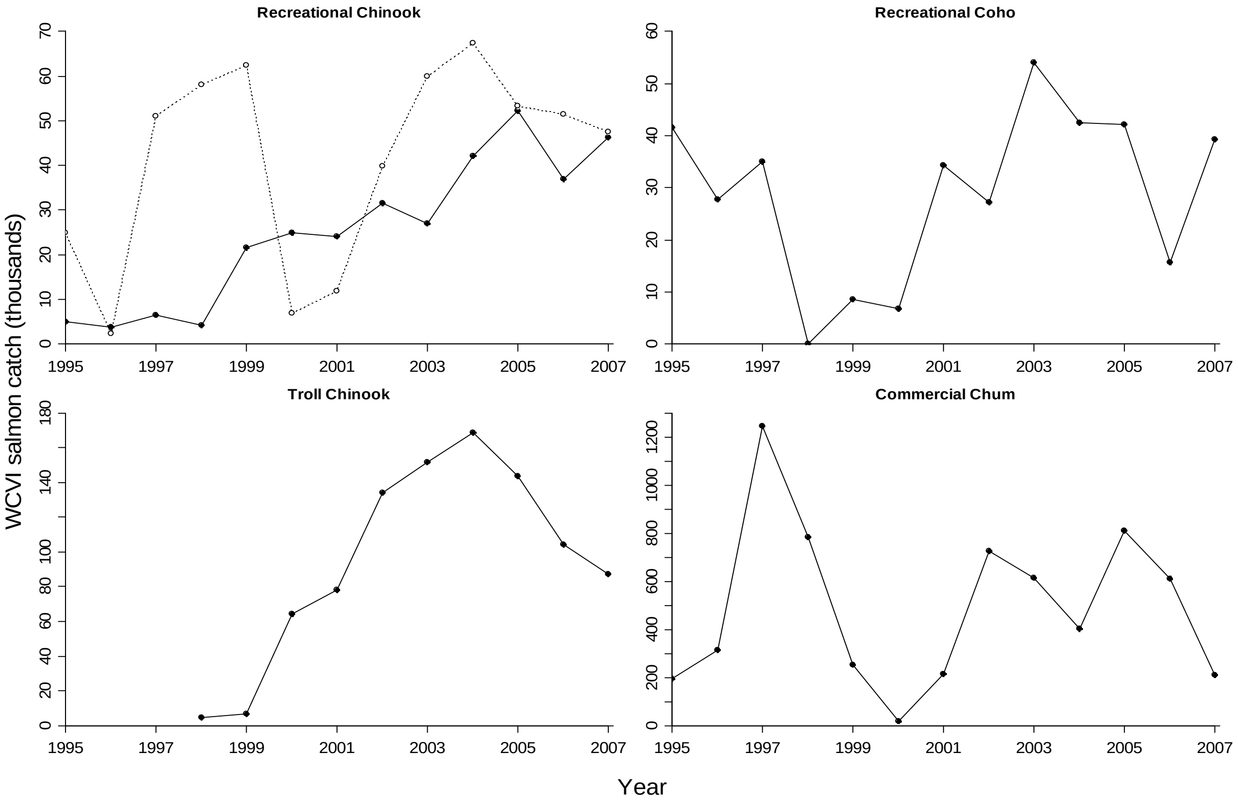


Figure 17. Time series of recreational chinook, commercial troll chinook, recreational coho and combined commercial chum catch estimates across WCVI waters, including Barkley Sound data above (O'Brien unpublished). Recreational chinook catch estimates are partitioned to AABM (solid line) and ISBM (dotted line). Commercial troll chinook catch estimates (AABM) are kept catch only and annual estimates include catch from October of the previous year to the end of September of the estimate year. Coho are captured primarily in directed recreational fisheries. Commercial and First Nations Food Social Ceremonial (FSC) fisheries target chum, while recreational catch of this species is negligible.

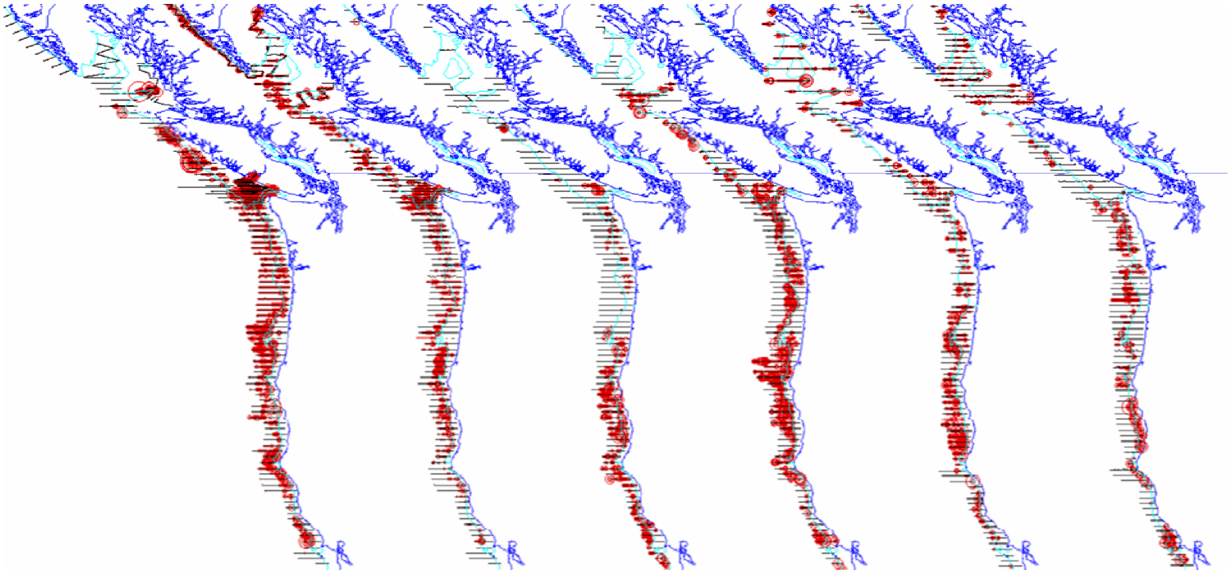


Figure 18. Pacific hake summary distribution and relative catch intensity observations in the Northeast Pacific from a hake acoustic survey time series for years 1995, 1998, 2001, 2003, 2005 and 2007 from left to right. Red indicates Hake acoustic backscatter along transects with size proportional to the maximum among years. The 2007 survey suggests a large drop in hake biomass. (Holmes et al. in DFO 2008)

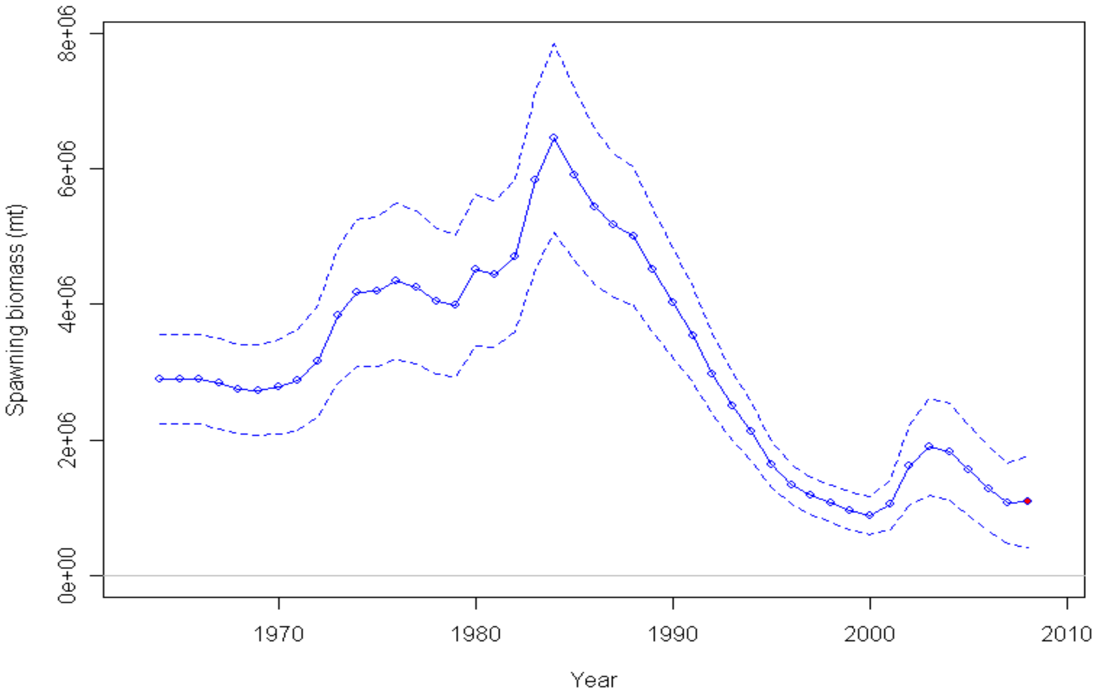


Figure 19. Abundance estimates (mean and 95% confidence intervals) of Pacific hake biomass in U.S and Canadian waters combined for 1964-2008 (Helser et al. 2008).

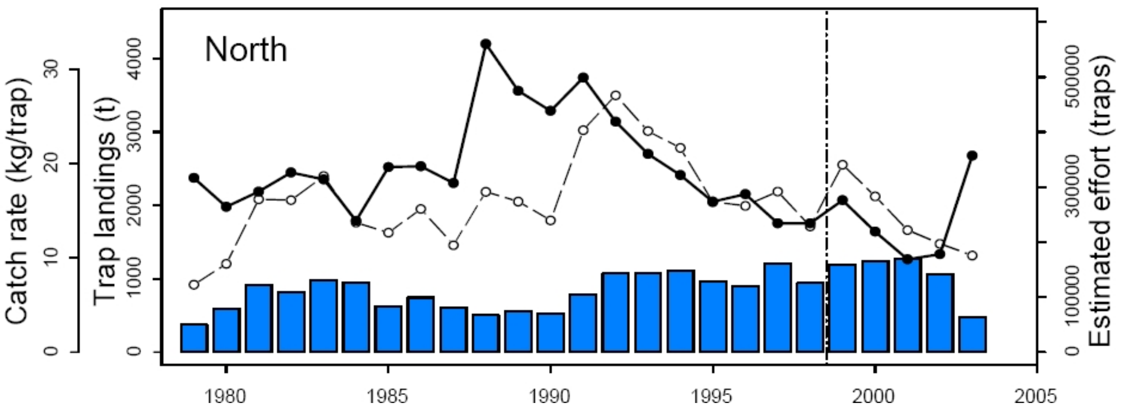


Figure 20. Sablefish nominal trap fishery Catch per unit effoft--CPUE (kg/trap, filled circles, solid line), catch (t) (open circles, dashed line) and estimated effort (traps, vertical bars) for the BC coast north of 50.5°N. The vertical dot-dash line indicates the inception of mandatory escape rings in the commercial trap fishery. (Haist et al. 2005).

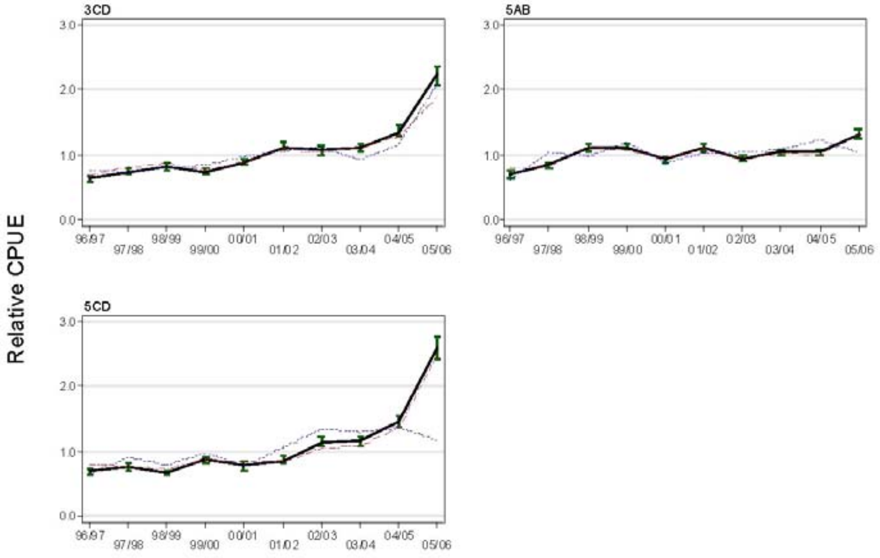


Figure 21: Plots three standardised turbot catch per unit effort (CPUE) series (each is a different model; lognormal, binomial and combined) 1996 to 2006 in each of the three major DFO groundfish fishing regions (WCVI=3CD, Queen Charlotte Sound=5AB and Hecate Strait=5CD. The solid curve represents the combined model; from Starr and Fargo 2006).

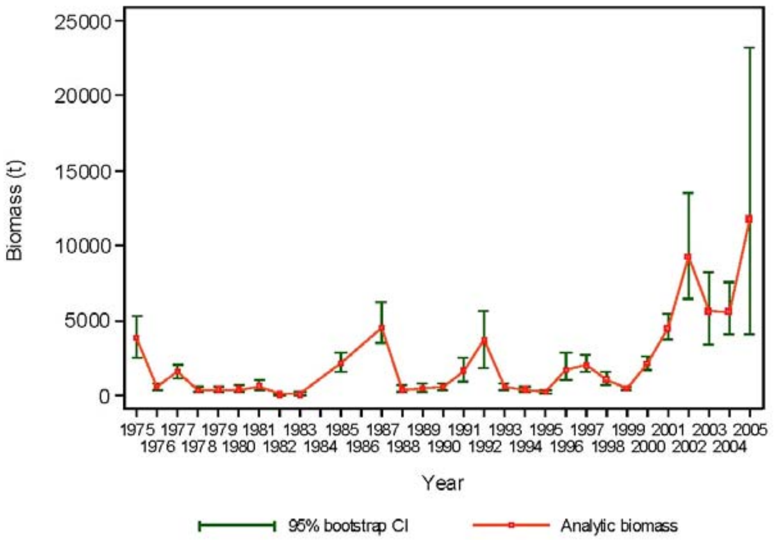


Figure 22; Plot of turbot biomass estimates using data from the WCVI shrimp trawl survey for the period from 1975 to 2005 (Starr and Fargo 2006).

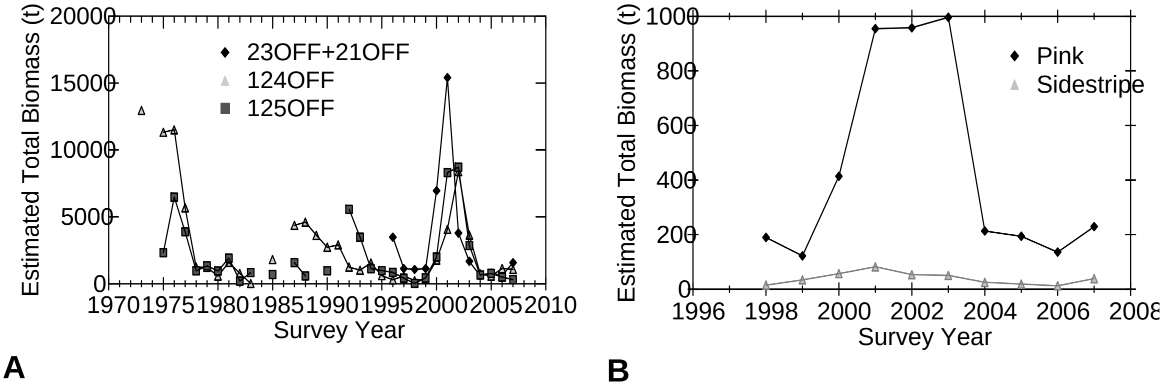


Figure 23: Trends in: (A) smooth pink shrimp biomass from 1973 to 2007 as determined from west coast of Vancouver Island shrimp trawl survey results for individual shrimp fishing areas (denoted as 23OFF, 21OFF, 124OFF, and 125OFF). (B) in pink and sidestripe shrimp biomass as determined from 1998 to 2007 for all west coast of Vancouver Island shrimp trawl surveys areas combined (Perry and Boutillier DFO 2007) same information on bulletin website: http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/Shellfish/shrimp/surveys/0501.htm).

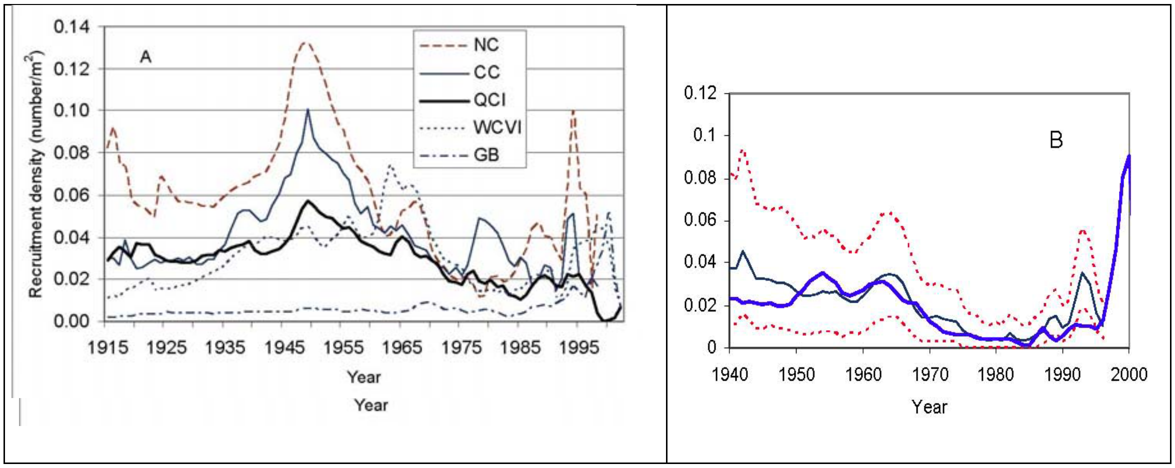


Figure 24. Estimated average historic recruitment rates of goeduck clam (Panopea abrupta) from stock assessment modelling work that applied a constant instantaneous natural mortality rate of 0.016 to the time series (Zhang and Hand 2005): A) for five coastal areas for 1915-2005: North Coast (NC), Central Coast (CC), Queen Charlotte Island (QCI), West Coast of Vancouver Island (WCVI), and Georgia Basin (GB); and, B) for a Winter Harbour study site for 1940-2000, where the solid line represents estimates based on a survey conducted in 1996 and the bold line represents estimates based on a survey conducted in 2002. The broken lines denote the 95% confidence limits for combined estimates.

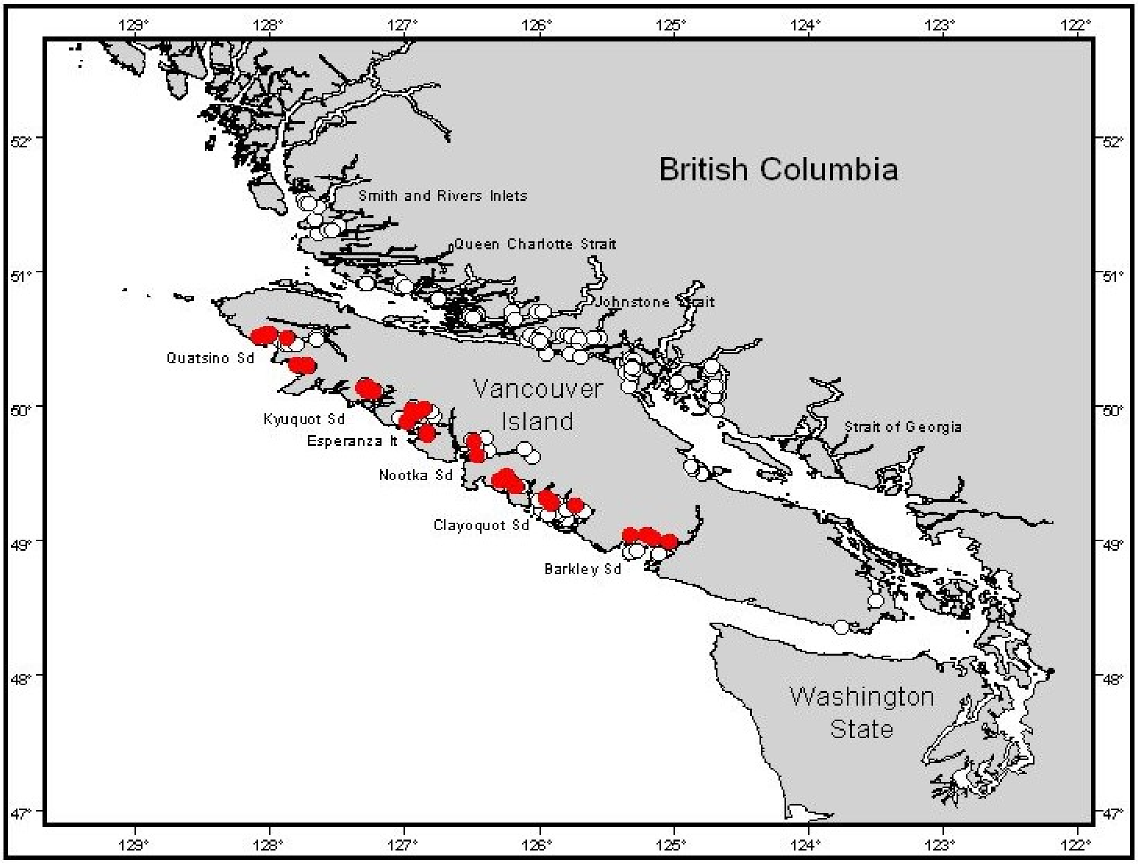


Figure 25. Distribution of European green crab, Carcinus maenas, in British Columbia (Gillespie, unpublished data). Filled circles are beaches with green crab present, open circles are beaches that were surveyed but did not yield green crabs.

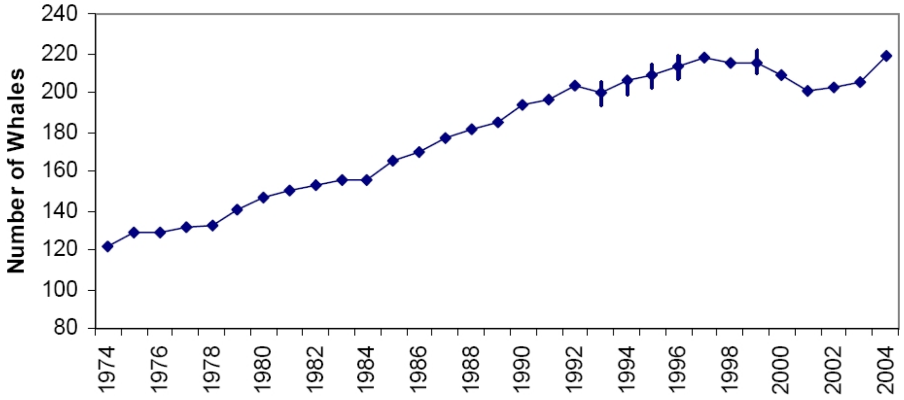


Figure 26. Number of northern resident Orca whales (Source: BC report on Biodiversity – data from Cetacean research program- DFO Nanaimo)

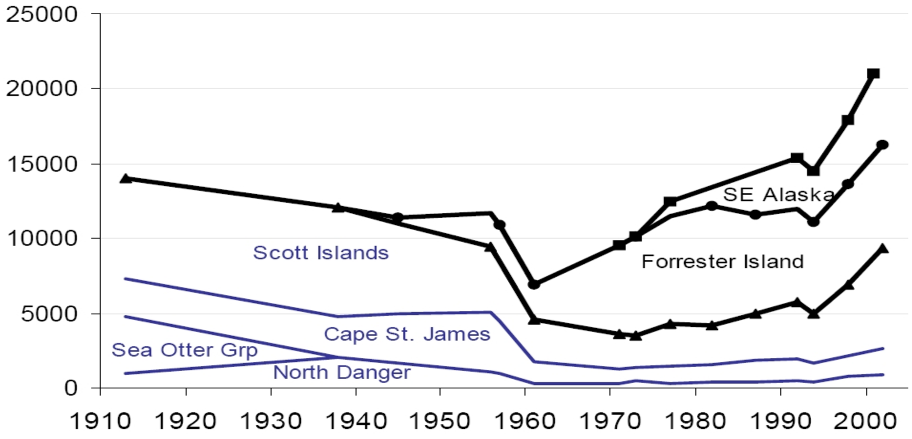


Figure 27. Total number of Steller Sea Lions (pups, juveniles and adults) counted on breeding rookeries, labelled on the plot. Only the Scott Islands are on the WCVI (upper blue curve). DFO (2003).

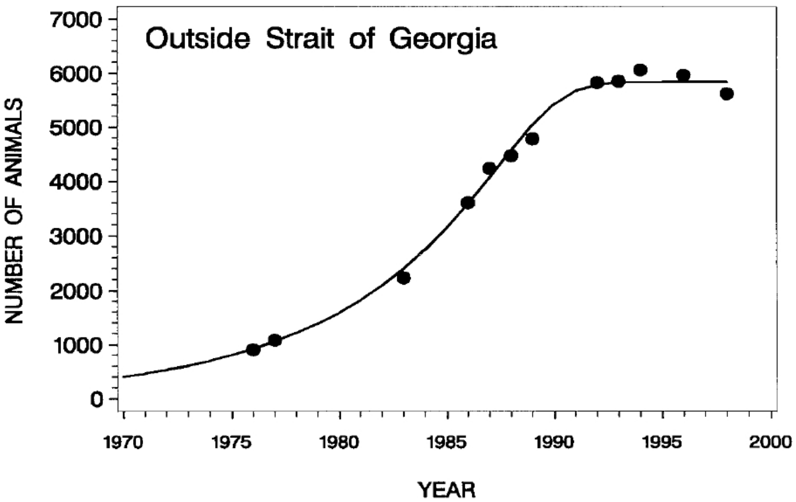


Figure 28. Total number of Harbour seals counted in survey regions outside of the Strait of Georgia and including the WCVI. The curve is from a logistic model fit to the data (Olesiuk 1999).

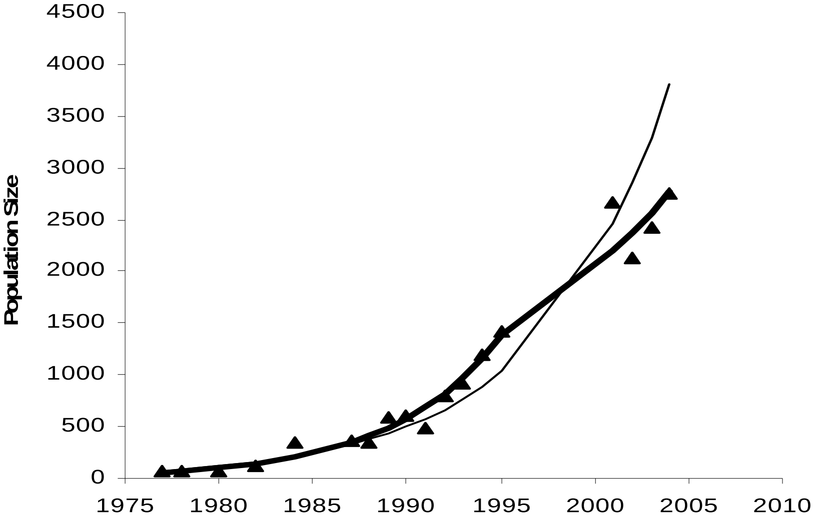


Figure 29. Annual sea otter abundance estimates (triangles) off Vancouver Island for 1977 to 2008 (Nichol et al. 2009). Population growth models estimate annual growth rates of approximately 15% (thin line) for the entire time series or approximately 19% for 1977 to 1995 and approximately 8% for 1995 to 2008 (thick line).

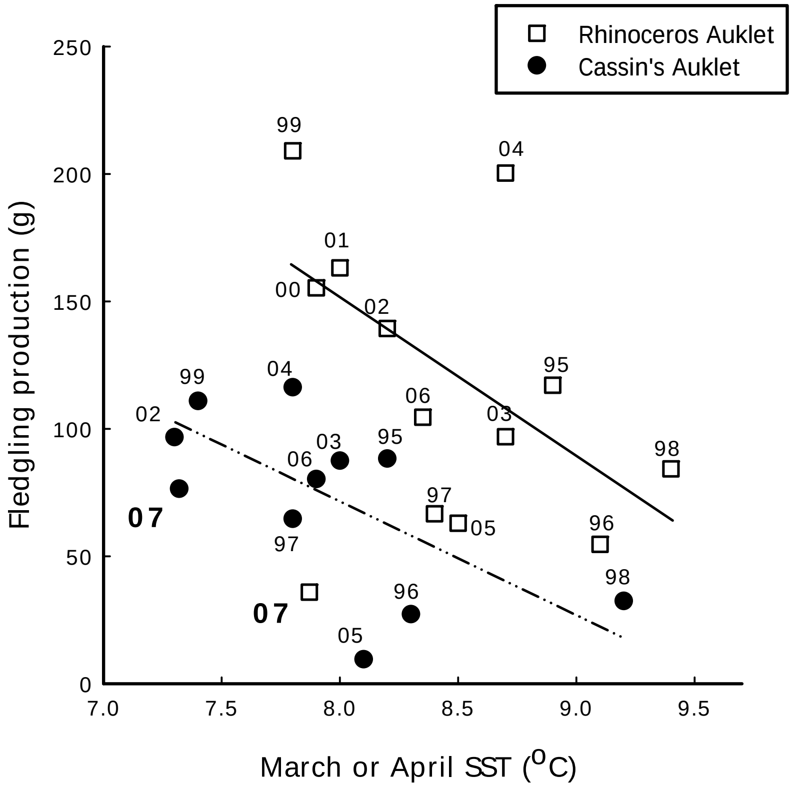


*Figure 30. Fledgling production as a function of April sea surface temperatures, measured at the Pine Island Lightstation (50°35'N 127°26'), for Cassin's and Rhinoceros auklets breeding on Triangle Island, in 2007, compared to the trend for 1994-2006. Fledgling production is calculated as: hatching success * % fledging success * mean fledging mass; or in other words, the mean mass of fledged chick produced per egg laid. Courtesy M. Hipfner (Environment Canada).*

17. TABLES

Table 1. Mean annual bottom trawl catch (tonnes) from the WCVI as well as the entire B.C. coast between 1996 and 2005 for 27 species which comprised 95% of the catch (Workman et al. 2008).

Common Name	**BC Coast wide**	**WCVI**	**Proportion from WCVI**
Arrowtooth flounder	8611	3436	40%
Dover sole	3060	1351	44%
Yellowtail rockfish	1982	859	43%
Lingcod	1552	705	45%
Spiny dogfish	1294	651	50%
Longspine thornyhead	672	580	86%
Pacific ocean perch	5752	503	9%
Canary rockfish	714	425	60%
Pacific hake	514	398	77%
Sablefish	657	392	60%
Shortspine thornyhead	616	349	57%
Petrale sole	445	252	57%
Redstripe rockfish	883	231	26%
Silvergray rockfish	1139	229	20%
Yellowmouth rockfish	2047	216	11%
Pacific cod	972	203	21%
Rougheye rockfish	561	141	25%
Rex sole	589	131	22%
Sharpchin rockfish	370	128	35%
Longnose skate	314	123	39%
Grenadiers	152	96	63%
Pacific halibut	474	94	20%
Spotted ratfish	724	93	13%
English sole	958	80	8%
Tanner crabs	83	79	95%
Bocaccio	175	57	33%
Widow rockfish	242	52	21%

Table 2. A list of marine invertebrates, fishes and mammals found in WCVI waters that have received a status classification under SARA and COSEWIC as of October 2009.

Grouping	Common name	Species	SARA status	COSEWIC status
Invertebrate	Northern abalone	*Haliotis kamtschatkana*	Threatened	Endangered
Invertebrate	Olympia oyster	*Ostrea conchaphila*	Special concern	Special concern
Fish	Canary Rockfish	*Sebastes pinniger*	Listing decision pending	Threatened
Fish	Basking Shark (Pacific)	*Cetorhinus maximus*	Listing decision pending	Endangered
Fish	Bluntnose Sixgill Shark	*Hexanchus griseus*	Special concern	Special Concern (2007)
Fish	Bocaccio rockfish	*Sebastes paucispinis*	Listing decision pending	Threatened
Fish	Chinook salmon (Okanagan population)	*Oncorhynchus tshawytscha*	Listing decision pending	Threatened
Fish	Coho salmon (Interior Fraser population)	*Oncorhynchus kisutch*	Not listed	Endangered
Fish	Green sturgeon	*Acipenser medirostris*	Special concern	Special concern
Fish	Longspine thornyhead	*Sebastolobus altivelis*	Special concern	Special Concern (2007)
	Yelloweye Rockfish	*Sebastes reberrimus*	Listing decision pending	Special conercern
Fish	Rougheye rockfish	*Sebastes aleutianus*	Special Concern	Special Concern (2007)
Fish	Sockeye salmon (Cultus and Sakinaw Lakes)	*Oncorhynchus nerka*	Not listed	Endangered
Fish	Tope soupfin shark	*Galeorhinus galeus*	Special Concern	Special Concern (2007)
Mammal	Blue whale (Pacific)	*Balaenoptera musculus*	Endangered	Endangered
Mammal	Fin whale	*Balaenoptera physalus*	Threatened	Threatened
Mammal	Grey whale	*Eschirichtius robustus*	Special concern	Special concern
Mammal	Harbour porpoise	*Phocoena phocoena*	Special concern	Special concern
Mammal	Humpback whale	*Megaptera novaeangliae*	Threatened	Threatened
Mammal	Sei whale	*Balaenoptera borealis*	Endangered	Endangered
Mammal	Killer whale, northern NE Pacific resident	*Orcinus orca*	Threatened	Threatened
Mammal	Killer whale, southern NE Pacific resident	*Orcinus orca*	Endangered	Endangered
Mammal	Killer whale, offshore NE Pacific population	*Orcinus orca*	Special concern	Threatened
Mammal	Killer whale, transient NE Pacific population	*Orcinus orca*	Threatened	Threatened
Mammal	North Pacific right whale	*Eubalaena japonica*	Endangered	Endangered
Mammal	Steller Sea Lion	*Eumetopias jubatus*	Special concern	Special concern
Mammal	Sea otter	*Enhydra lutris*	Special concern	Special concern