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Ecosystem Status and Trends Report for North Coast and Hecate Strait ecozone

Rapport de l'état des écosystèmes et des tendances pour l'écozone de la côte nord et du détroit de Hécate

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ABSTRACT

The status and trends of indicators of the condition of biodiversity of the northern coastal waters of British Columbia are reviewed. Among the notable results it is found that upper-ocean waters show warming and freshening trends, dissolved oxygen levels are decreasing, and dissolved CO_2 levels are increasing in intermediate waters of the NE Pacific basin. These changes are likely to impact marine ecosystems found along the continental shelf off British Columbia.

Organisms may shift their location depending on sea surface temperature SST, moving with the water temperature that suits them best. Marine ecosystems in the North Coast and Hecate Strait ecozone may change, perhaps relatively more rapidly than in the past, due to climate change.

Populations of a number of indigenous species to the North Coast are listed as endangered, threatened, or of special concern under the *Species at Risk Act*, including the northern abalone, (*Haliotis kamtschatkana* - Threatened), sea otters (*Enhydra lutris* – Special Concern) and northern resident killer whales (*Orcinus orca - Threatened*). Stocks of some commercially harvested fish remain depressed, notably the sockeye salmon (*Oncorhynchus nerka*) of Smith and Rivers Inlet, and certain stocks of Pacific herring (*Clupea pallasii*). Populations of most marine mammals that had been commercially harvested or purposefully eradicated in the twentieth century, and have since gained protected status, are recovering. Human activities still pose a threat to many of these animals primarily through over-fishing, contaminants, lost or damaged fishing gear, shipping and decline of prey food items.

RÉSUMÉ

On a examiné l'état et les tendances des indicateurs de la condition de la biodiversité des eaux côtières du nord de la Colombie-Britannique. Parmi les résultats notables, on a découvert que les eaux de la partie supérieure de l'océan affichent une tendance au réchauffement et à la désalinisation, les niveaux d'oxygène dissous diminuent, alors que les niveaux de dioxyde de carbone (CO_2) dissous augmentent dans les eaux intermédiaires du nord-est du bassin du Pacifique. Ces changements risquent d'avoir des répercussions sur les écosystèmes marins établis le long du plateau continental au large de la Colombie-Britannique.

Les organismes pourraient se déplacer suivant la température de surface de la mer (TSM) qui leur convient le mieux. Les écosystèmes marins de l'écozone de la côte nord et du détroit de Hécate pourraient changer, peut-être même relativement plus vite que par le passé, en raison des changements climatiques.

Les populations d'un certain nombre d'espèces indigènes de la côte nord sont menacées, notamment l'ormeau nordique (*Haliotis kamtschatkana)*, la loutre de mer (*Enhydra lutris*) et l'épaulard (*Orcinus orca*). Les stocks de certaines espèces de poissons récoltés par la pêche commerciale demeurent appauvris; c'est particulièrement le cas pour le saumon rouge (*Oncorhynchus nerka*) des bras de mer Smith et Rivers, et certains stocks de hareng du Pacifique (*Clupea pallasii*). Les populations de la plupart des mammifères marins qui faisaient l'objet d'une chasse commerciale ou qui avaient été éradiqués intentionnellement au XX^{e} siècle, et qui ont été désignés depuis espèces protégées, sont en voie de rétablissement. Les activités anthropiques demeurent une menace pour bon nombre de ces animaux, principalement en raison de la surpêche, des contaminants, des engins de pêche perdus ou endommagés, de l'expédition et de la diminution des proies disponibles.

1. BACKGROUND

This report presents trends and the status of indicators that may be used to assess the condition of biodiversity of the northern coastal waters of British Columbia from an ecosystem perspective. These indicators pertain to physical, chemical and biological variables measured within this ecozone, which is comprised of three subregions: the Central Coast, the North Coast and the Queen Charlotte Islands (Figure 1). These waters include Queen Charlotte Strait, Queen Charlotte Sound, Hecate Strait and Dixon Entrance. This ecozone is given the name 'North Coast and Hecate Strait'. Geographically, it largely coincides with the region referred to as the Pacific North Coast Integrated Management Area (PNCIMA).

A quantitative consideration of trends implies, in effect, the utilization of time series data. Thus, wherever possible, use has been made of available time series data. The spectrum of oceanic variability is typically red, that is it is dominated by low-frequency variability (e.g., Wunsch, 1999; Rudnick and Davis, 2003). Pronounced physical variability is known to occur in the northeast Pacific on interannual to decadal time scales. In particular, ENSO events (El Niño/La Niña) and the Pacific Decadal Oscillation (PDO) exert a strong control on the upper ocean physical environment and are also thought to have an influence on fish populations (e.g., Mantua et al., 1997). One consequence of this low frequency variability is that time series data extending for several decades are required typically to acquire a sufficient number of independent observations to identify statistically significant trends. While the status of various species within the study zone is discussed, this report focuses largely on those potentially important indicators for which time series of significant length are available. Ideally, the duration of such time series should be for several decades. However, the northern coast of British Columbia is remote from major population centres and sampling programs have historically not been as complete or sufficiently wide-ranging in this region in comparison to those for the southern coast waters of BC, or the Strait of Georgia.

The available time series on the physical variability include reasonably long and accurate measurements of sea surface temperature, sea surface salinity and sea level and upwelling indices. Regarding the chemical properties, far less data are available. Trends have been reported for dissolved oxygen at depth along the continental margin. However, there appear to be no extended time series of primary marine nutrient concentrations from the coastal waters of the ecozone.

The most complete biological time series appear to be those pertaining to various fish stocks and, to a lesser extent, marine mammals. Some time series data also exist for the lower trophic levels and certain invertebrate species. However, time series providing quantitative measures of the abundance of invasive species do not appear to exist. This may complicate the assessment of the long-term risk that invasive species pose to the indigenous ecosystems.

2. STATUS AND TRENDS OF POTENTIAL KEY INDICATORS

2.1 PHYSICAL VARIABLES

2.1.1 Surface air temperature

Surface air temperature (SAT) is one of the most widely used measures of the state of the environment and it 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 course of the last one hundred years, globally averaged SAT has risen by $0.6 \pm 0.2\ ^{\circ}\mathrm{C}$. Figure 2 shows that the record of global mean SAT, and SAT separately averaged 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 ecosystems trends over the course of the 21st century, both globally and for the coastal and terrestrial environments of British Columbia.

2.1.2 Sea surface temperature

Globally averaged 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 3a). 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 in 2008 of SST anomalies is illustrated in Figure 3b, 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 *below* the long term mean of the region by about 1º C (Crawford and Irvine, 2009). This change from warm to cool status is associated with changes in the Pacific Decadal Oscillation which has switched to its negative 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. The PDO variability is characterized by its long decadal time-scales and 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 immediately within BC coastal waters (Figure 4a). Figure 4b compares long-term annual mean SST records that are representative of three broad regions of coastal British Columbia. The Langara Station is representative the North Coast and Hecate Strait ecozone, while the Departure Bay lighthouse is for the Strait of Georgia, and the Amphitrite Point lighthouse for the west coast of Vancouver Island. Common features are found in all of these records, suggesting that there is considerable spatial coherence in the long-term variability over coastal British Columbia. This is consistent with the finding 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. There is, as well, 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 about that occurred following the 1999 La Niña event (Peterson and Schwing, 2003). The last two years have seen a cool period, as sea surface temperatures have fallen below the long-term average.

2.1.3 Sea surface salinity

Time series of sea surface salinity (SSS) at three representative coastal British Columbia lighthouses are presented in Figure 5, and show the contrasting variability found along the coast. The Langara station, which is within the North Coast and Hecate Strait 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 trend is not known. It may be that the Langara station, which is not in proximity of a major river or other immediate source of fresh water, may be reflecting larger scale changes occurring 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 that is 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. There may be an impact on upper ocean stratification which could reduce the nutrient supply to surface water and oxygen to the deeper waters of the shelf.

2.1.4 Sea Level

Secular 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 at the end of the Pleistocene, 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 6). 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. 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 to be highly sensitive to rising sea level. (The other is the low-lying area of Richmond, south of Vancouver on the Strait of Georgia.)

2.1.5 Coastal Upwelling

Wind driven upwelling can be important to ecosystems by bringing deeper, nutrient rich waters to the surface. Alongshore winds in the North Coast and Hecate Strait ecozone have a marked seasonal variation. Winter is dominated typically by strong downwelling winds. During summer climatological winds display only weak upwelling at the southern end of the region (i.e. the northern tip of Vancouver Island) and essentially neutral conditions (no upwelling or downwelling) at the northern end of the region.

This situation is illustrated in Figure 7, which shows time series of monthly upwelling indices for the period 1946-2008 for locations at the southern (51ºN, 131ºW) and northern (54ºN, 131ºW) end of the North Coast and Hecate Strait ecozone. The figures illustrate the comparatively weak upwelling that occurs in summer and the large and highly variable downwelling during winter. While there is no significant trend at either location, it is evident that there is significant interannual and long period variability, especially in the intensity of winter downwelling.

2.2 CHEMICAL PROPERTIES

2.2.1 Dissolved Oxygen

Trends in dissolved oxygen through the water column have been reported for the west coast of North America (Crawford and Irvine, 2009). Figure 8 presents trends in oxygen concentration for waters below 100 m depth along the North American coast from South California to the Queen Charlotte Islands. The latter is situated within the North Coast and Hecate Strait ecozone. 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, and along the entire coast. The greatest declines are found within the 200-300 depth range. Within this depth range, the rate of decline represents about 1% of the dissolved oxygen per year in BC coastal waters. The decline in dissolved oxygen at these depths may affect the habitat of groundfish. Whitney (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.

2.2.2 Nutrients

Time series data on the primary marine nutrients - nitrate, phosphate and silicic acid – do not appear to be available from the northern coastal waters of British Columbia. It is notable, however, that the terminus of deep ocean currents resulting from global thermohaline circulation is the North Pacific Ocean. Because particulate remineralisation results in the accumulation of nutrients in deep waters, the highest nutrient concentrations found in the world's oceans are found in the deep waters of the North Pacific. For example, at Ocean Weather Station P (145°W, 50°N), bottom water concentrations of phosphate, nitrate and silicic acid are approximately 2.5, 40 and 170 :mole, respectively. One part of the North Coast and Hecate Strait ecozone that is impacted by the high nutrient concentrations of North Pacific deep water is the sponge reef complexes discussed below (Section 2.4.1).

2.2.3 Carbon

Increasing levels of atmospheric carbon dioxide are causing the world's oceans to become more acidic, as a significant fraction of the CO_2 released from burning fossil fuels is dissolved into the ocean, where it reacts to form carbonic acid, carbonate and bicarbonate. The pH of the upper North Pacific Ocean, already the most acidic in the world, is thus lowering, to the point where organisms with calcite or aragonite shells are threatened (e.g., Orr *et al*. 2005; Feely *et al*. 2008). It is thought that the primary groups threatened by ocean acidification include carbonate producing coccolithophorids (phytoplankton including *Emiliana huxleyi*), foraminifera (zooplankton) and pteropods (zooplankton). An additional and unexpected consequence of ocean acidification, associated with enhanced sound propagation, is that it may lead to a 'noisier' ocean which could have detrimental impacts on, for example, cetaceans (Hester *et al*. 2008).

Figure 9 shows the shallowest saturation depths for aragonite over the northeast Pacific, including the North Coast and Hecate Strait ecozone. The saturation depth is defined as the depth at which the mineral dissolves more readily than it can form. With the progressive acidification of the surface waters of the ocean, this saturation depth is believed to have shoaled by 50 -200 m over the course of the last century (Feely *et al*. 2008). For the North Coast ecozone, the ocean below about 300 m depth is now corrosive to aragonite shells. Continued shoaling of the saturation depth of these forms of aragonite and calcite could threaten the long-term presence in the ecozone of certain shelled organisms such as pteropods, with harmful consequences to fishes that feed on pteropods, including Pacific salmon.

2.3 PLANKTON

2.3.1 Phytoplankton

The natural progression of phytoplankton species and abundance in temperate waters, such as those of the North Coast and Hecate Strait ecozone, is described by Margalef (1958) and Guillard and Kilham (1977). In general, the availability of nutrients and increasing light in springtime result in higher rates of primary production and higher phytoplankton biomass. This spring bloom is composed largely of small, fast-growing diatoms such as *Skeletonema costatum*, *Leptocylindrus danicus*, *Chaetoceros* spp. and *Rhizosolenia* spp.. As these species deplete surface nutrients, larger diatoms such as *Thalassiosira* spp., *Thalassionema* spp., and *Eucampia zoodacus* gain in abundance, as do dinoflagellates such as *Prorocentrum micans*, *Dinophysis* spp. and *Ceratium* spp.. While light availability (determined by day length, cloudiness and mixed-layer depth) is the over-riding variable driving the spring bloom, the timing and magnitude of bloom dynamics can be strongly modulated by zooplankton grazing. Throughout the summer and fall, diatom and dinoflagellate populations respond to the physical conditions that control light and nutrient availability, and to grazing by micro- and macro-zooplankton. A brief return to high diatom production often occurs in the late summer/fall as grazing pressure decreases and seasonal winds mix deep nutrients to the surface. During the winter in temperate waters, phytoplankton production and biomass tend to be low, in response to low light conditions.

Available information on phytoplankton abundance, species composition, chlorophyll *a* concentration or primary production is limited for the North Coast and Hecate Strait ecozone. However, the satellite-derived monthly mean chlorophyll concentrations from 1998 to 2005 (Lucas *et al*., 2006) (Figure 10) are consistent with the general phytoplankton dynamics of temperate seas, as described above. These satellite data, furthermore, suggest that the interannual variability of chlorophyll concentrations is small in the North Coast and Hecate Strait ecozone. However, satellite-derived chlorophyll estimates should not be regarded as reliable replacements of *in situ* measurements in coastal regions where land-derived particulates and coloured dissolved organic matter (CDOM) are prevalent, as both of these water-borne substances interfere with the light-absorption spectrum of chlorophyll *a*.

2.3.2 Zooplankton

There are only limited time series observations of zooplankton for the north coast of B.C. Although there are gaps, observations of secondary production for the region of northern Vancouver Island (NVI; 50˚-51.5˚N) that begin in 1990 (standardized methods and locations since 1996) from ongoing study of zooplankton community composition (Mackas *et al*. 2001, 2007) constitute the most useful data available. While the observations extend into southern Queen Charlotte Sound, it is uncertain to what extent they are generally representative of northern coastal waters.

To filter out the strong seasonal cycle, zooplankton biomass data for individual species and sampling periods 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. The anomaly plots are on a $\log_{10}$ scale so that, for example, an anomaly of +1 corresponds to 10x the long term average. Correlations with physical time series indicate that the zooplankton community is significantly affected by global-scale forcing (e.g., ENSO events), basin-scale forcing, (e.g., the Pacific Decadal Oscillation), as well as the local upwelling index, alongshore wind and currents (Mackas *et al*. 2001, 2007). These physical forcing mechanisms are not entirely independent from one another. The zooplankton anomalies are also strongly correlated with several fishery time series (e.g. salmon marine survival, sablefish recruitment, Mackas *et al*. 2007). To date, there is no significant trend of total biomass (Figure 11), although a strong minimum occurred in 2001-2002, coincident with low abundance of euphausiids (see Figure 12 below).

The stronger and more interesting signal is in changing community composition. Note the larger range of these anomaly graphs compared to the plot for the total biomass shown in Figure 12. Southern species of copepods (eg. *Paracalanus parvus*, *Ctenocalanus vanus*, *Mesocalanus tenuicornis*) and the northern, or boreal copepods (eg. *Calanus marshallae*, *Pseudocalanus minimus*, *Acartia longiremis*) tend to vary inversely to one another, each group thriving when conditions are suitable to them, and the southern species have (despite oscillations) shown a long-term upward trend, suggesting that climate change could produce a shift in dominant species. In general, juvenile salmon growth is reduced when southern copepods dominate the plankton community (Peterson and Schwing 2003, Mackas *et al*. 2007), possibly because southern copepods are less energetically favourable for growth (i.e. low lipids).

2.4 INVERTEBRATES

2.4.1 Hexactinellid Sponge Reefs

Until recently, hexactinellid sponge reef complexes were known only in the fossil record, where they are abundant in Upper Jurassic sediments, decrease in Cretaceous deposits and disappear in sediments of the Tertiary (Conway *et al*. 2005). However, in 1987-88, hexactinellid sponge reefs were mapped and photographed during two expeditions of Queen Charlotte Sound and southern Hecate Strait (Conway *et al*. 1991). Since their initial discovery, sponge reef complexes have been found to cover hundreds of square kilometres of the continental shelf of northern British Columbia (Figure 13), at depths between 165 and 230 m (Conway 1999, Cook 2005). These reefs are architecturally similar to coralline reefs, in that living animals grow upon the skeletal framework of previous generations. However, the skeleton of hexactinellid sponges is hydrated amorphous silicon dioxide ($SiO_2 \cdot nH_2O$), also known as opal or biogenic silica, while coral skeletons are made of the carbonate mineral aragonite ($CaCO_3$).

Three primary species form the skeleton framework of sponge reefs: *Chonelasma calyx*, *Aphrocallistes* vastus, and *Farrea* occa. Sponges grow by filtering organic debris settling from surface waters and cascading seaward through the glacially-carved canyons where the sponge reef complexes are found. Reef complexes can take either a sheet or a mound (bioherm) formation, with mound formations reaching heights of 21 m. The sponge reefs of the North Coast and Hecate Strait ecozone present a unique scientific opportunity to gain a first-hand understanding of the ancient reefs that formed the largest bioconstruction in Earth's history (Krautter *et al*. 2001). The reef-building sponges are also an important foundation species (*sensu* Dayton, 1975), as they promote greater biodiversity and abundances through the creation and maintenance of new biological habitat. Cook (2005) found that species richness was higher in live reef habitats than in dead reef or off-reef habitats, and that the abundance of sea stars, boot sponges, squat lobsters, prawns and crabs was also greatest in live reef habitats. She also found that the live reef habitats are important nurseries for juvenile rockfish.

Sponges have a high demand for silicic acid, the building block of its skeleton. The concentration of silicic acid at the depth of sponge reefs in the North Coast and Hecate Strait ecozone is approximately 40-80 .mole (Whitney *et al*. 2005), similar to the concentration at the same depth at OSP. Thus, high silicon acid concentrations in the North Pacific Ocean allow for sponge reef formation. Sediment coatings on the skeletons may further inhibit skeletal dissolution.

Bottom-trawling and other fishing activity are the most serious threats to these globally unique reef complexes (Conway 1999; Jamieson and Chew 2002; Booth *et al*. 2007). Damage from trawling has been documented in multi-beam acoustic and video surveys (Conway 1999), as well as with bycatch rates from the groundfish bottom trawl fishery on-board observer data base (Booth *et al*., 2007). Permanent groundfish and shrimp trawl closures were first implemented in 2002 and 2003, respectively, but due to ongoing “bycatch” of sponges in unprotected areas and with updated multi-beam data on the extent of the sponge reefs themselves, these closures were amended and expanded in 2007 (*pers. comm.* Jamieson, 2006, in Booth *et al*. 2007, DFO 2009) in an effort to fully protect the sponge reef complexes. Long lines and traps also break off portions of the brittle sponge reefs, reducing the recruitment and growth of young sponges and damaging the over-all health of the entire reef ecosystem (Jamieson and Chew 2002). Indeed, because of the slow growth rate of sponges and of the unique conditions of reef formation, it may take decades or centuries for sponge reef complexes to recover from damage caused by trawling, long lines and trapping (Conway 1999).

2.4.2 Northern abalone

Figure 14 presents a time series showing the spatial density of northern abalone (*Haliotis kamtschatkana)* over two subregions of the North Coast and Hecate Strait ecozone. This shows a clear secular trend to lower abundance over the last 30 years. As a result of this decline, Northern abalone was listed as a Threatened species in Canada by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 1999; subsequent review resulted in changing the classification to Endangered in 2009. Northern abalone were listed as Threatened under the Species At Risk Act (SARA) in 2003. Illegal harvesting and low recruitment are considered the most significant threats to this species (http://www.pac.dfo-mpo.gc.ca/fm-gp/commercial/shellfish-mollusques/abalone-ormeau/index-eng.htm).

2.4.3 Geoduck and other clams

Geoduck (*Panopea abrupta*) are large, long-lived hiatellid bivalves that live in un-consolidated substrates in the north Pacific Ocean from California to southern Japan (Coan *et al*. 2000). Geoducks are broadcast spawners; postlarvae settle to the seafloor where they search for a suitable substrate (King 1986) until metamorphosis and the commencement of suspension feeding. These young clams begin to dig, and after 4-5 years reach a final depth of roughly 1 m. Predation of adult geoducks is extremely low, with the exception in regions of the BC coast where sea otters are recovering.

A geoduck fishery takes place in waters < 30 m throughout coastal BC, whereby divers use pressurized water to loosen the substrate to the depth of the clams (~1 m) allowing for live extraction. The fishery is considered the most valuable invertebrate fishery in the North Coast and Hecate Strait ecozone where approximately half of the total geoducks catch of British Columbia occurs (Figure 15). As Figure 15 shows, the geoduck catch peaked in the mid- to late-1980s, then declined and leveled off. There is evidence of renewed declines 2004-2005. Geoduck harvest is managed through a combination of limited entry and individual quotas (Heizer 2000). Annual quotas are set at 1.6% (Haida Gwaii) or 1.8% (North Coast) of the estimated virgin biomass B_0 (http://www.pac.dfo-mpo.gc.ca/fm-gp/commercial/shellfish-mollusques/geoduck-panope/index-eng.htm).

The North Coast and Hecate Strait ecozone includes the largest stock of razor clams (*Siliqua patula*) in British Columbia. This is found in the Queen Charlottes on several beaches near Masset, Haida Gwaii along northern Graham Island. These stocks support commercial, Food, Social and Ceremonial (FSC) and recreational fisheries. The razor clam fishery is managed jointly by the Council of the Haida Nation and Fisheries and Oceans Canada though an agreement reached in 1994 as part of DFO's Aboriginal Fisheries Strategy (DFO 2001). Landings of razor clams from Haida Gwaii are shown in Figure 16. Although landings were sometimes higher in the 1920s and 30s, landings have stabilized over recent decades, largely as a result of active management, and no trend is apparent.

There are also limited intertidal fisheries for butter, Manila, cockles, littleneck and horse clams (*Saxidomus gigantea*, *Venerupis philippinarum*, *Clinocardium nuttallii*, *Protothaca staminea* and *Tresus capax*, respectively). The Heiltsuk First Nation conducts a commercial fishery for Manila clams in the Waglisla area, with assessments conducted by the Heiltsuk Fisheries Program and a joint management plan completed in collaboration with DFO (Gillespie *et al.* 2001). Many First Nations communities conduct FSC harvests, primarily butter clams and cockles. The most common form of harvest for clams is hand digging or picking using garden tools. The high incidence of red tides on the North Coast, combined with limited testing of intertidal clams for sanitary contamination or algal biotoxins, may have restricted the growth of commercial and recreational fisheries.

The Olympia oyster (*Ostrea lurida*) is the only oyster native to the Pacific coast of Canada and was listed as a Special Concern species by COSEWIC in 2000 and the Species At Risk Act (SARA) in 2003 (Gillespie 2009). The species' northern limit is Gale Passage, near Waglisla, and relatively few isolated populations are known in the North Coast (Gale Passage, Ormidale Harbour, Watt Bay, Fish Egg Inlet and Boswell Inlet).

2.4.4 Prawns and Shrimp

A fishery for pink (*Pandalus borealis* and *P. jordani*) and sidestripe (*Pandalopsis dispar*) shrimp utilising beam trawls and small otter trawls, occurs in fjords of the North Coast and in parts of Queen Charlotte Sound, while prawns (*Pandalus platyceros*) are harvested throughout the North Coast and Hecate Strait ecozone using traps. As with geoduck, about half of the total BC harvest of shrimp and prawns occurs in the region. Growth in the shrimp and the prawn fisheries (Figure 17) occurred as a result of fishermen responding to the changes in groundfish and salmon management in the 1990's (MacConnachie *et al.* 2007) (Figure 17).

Shrimp larvae are pelagic, and the fishery must allow females to carry their eggs until hatching in early spring. Prawn populations are more localised, such that many separate stocks occur within the North Coast and Hecate Strait ecozone. Nevertheless, meta-populations defined by shared larvae of both shrimp and prawns may occur in the North Coast and Hecate Strait ecozone (Lucas *et al*. 2006).

2.4.5 Crabs

While red rock crab (*Cancer productus*) and king crab (*Paralithodes camtschaticus*) fisheries exist in the North Coast and Hecate Strait ecozone, the primary crab harvest is of Dungeness (*Cancer magister*). Crabs are caught using traps, and the majority of the BC Dungeness fishery occurs in the PNCIMA region (Figure 18). Dungeness catch in the region shows inter-decadal variability, but no secular trend is evident since 1990 (Figure 18).

Dungeness crabs are particularly abundant on the north and east coasts of Graham Island and in the waters off Prince Rupert, as well as in Naden Harbour, Masset Inlet and Portland Canal. A cyclonic circulation gyre off the north coast of the Queen Charlotte Islands retains larvae in productive areas of McIntyre Bay, Rose Spit and Tow Hill (Lucas *et al*. 2006).

2.4.6 Echinoderms

Commercial echinoderms within the North Coast and Hecate Strait ecozone include sea cucumbers and sea urchins. The California sea cucumber (*Parastichpous californicus*) is pretty much ubiquitous over the region, although they are not all that abundant in eel grass or mussel beds. They are found in sheltered rocky substrates, while sea urchins (*Strongylocentrotus droebachiensis* and *S. franciscanus*) are found along rocky shores.

2.5 FIN FISH

2.5.1 Groundfish

The Hecate Strait assemblage survey is the longest running synoptic survey of marine demersal fish on the BC coast. Sinclair *et al*. (2007) present abundance trends for 47 fish species during the years 1984 to 2003; thereafter, the design of the survey changed. For 39 species that had sufficient annual indices for regression analysis, 23 yielded positive instantaneous rates of change (Figure 19). Fourteen of these positive trends belong to flatfish species, which predominate in shallow (<300 m) Hecate Strait. Arrowtooth flounder (*Atheresthes stomias)* remains ubiquitous and abundant in the North Coast and Hecate Strait ecozone, and until recently, has had limited economic value. Also traditionally abundant in Hecate Strait is the short-lived species Pacific cod (*Gadus macrocephalus)*, which reached an historic low in 2001 (Figure 20) (Sinclair and Starr 2005). Subsequent restrictions on fishing yielded increasing biomass for this dynamic and productive species. Populations have not yet reached the long-term average.

Further south in Queen Charlotte Sound, a diverse mixture of rockfish populate the three main gullies: Moresby, Mitchell's, and Goose Island (Figure 21, CLARA group map). The predominant rockfish species, Pacific Ocean Perch (POP) (*Sebastes alutus*), remains a high-value economic driver for the north coast of British Columbia. As with many important groundfish species, the harvest is managed through a set of transferable individual vessel quotas (IVQs). Goose Island Gully has the longest time series of ageing data, which allows the creation of a population trajectory (Figure 22) using a catch-age model (Schnute *et al*. 2001). Prior to 1970, POP was exploited very heavily, causing a dramatic decline in the population. Subsequent restriction to a smaller domestic fishery, plus a successful recruitment event due to favourable oceanic conditions in the late 1970s, has allowed the population to recover.

Pacific halibut (*Hippoglossus stenolepis*) occurs along the continental shelf from northern California to the Bering Sea. Under the terms of the Canada/US Halibut Treaty, the the International Pacific Halibut Commission (IPHC), is responsible for produceing annual assessments of abundance in various sub-areas, including BC (Figure 23). The following synopsis comes from Hare and Clarke (2009). Between 1997 and 2006, total removals were stable, averaging 13.5 million lbs (6123 t). Removals and commercial effort declined sharply in 2007 and 2008, in response to the revised view of relative halibut abundance. For most of the past decade, removals have exceeded surplus production estimates. Indices of abundance all suggest a steady decline in biomass, with an uptick in 2008. (The survey CPUE declined more than 50% between 1996 and 2007.) The age structure of fish caught in IPHC Area 2 is noticeably younger than in Areas 3 and 4 to the north. Mean age in the North Coast and Hecate Strait ecozone is around 11 years, with little difference between males and females. Taken together, all the diagnostic indices suggest a steadily declining exploitable biomass. The reasons for the decline are likely due to (i) the declining influence of the large year classes 1987 and 1988, and (ii) removals exceeding surplus production.

Sablefish (*Anoplopoma fimbria)* catch rates (assumed to be proportional to trap-vulnerable biomass) were relatively stable from 1979 to 1987, but increased substantially in 1988 and remained high for several years (Figure 24). 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 (like many for rockfish spp.) remains short compared to generation times.

2.5.2 Pacific Salmon

Pacific salmon are highly migratory and can cover thousands of kilometers during their marine life. On the west coast of North America, juvenile Pacific salmon generally undertake a rapid northwestward migration along the continental shelf until they reach the Aleutian Islands, where they migrate offshore in the Gulf of Alaska (Hartt and Dell 1986; Groot and Margolis 1991). As such, the north Coast and Hecate Strait ecozone is not only an important rearing area for local stocks originating from the Central and North Coast of British Columbia, but also for southern stocks, such as Fraser River and Barkley Sound sockeye salmon (*Oncorhynchus nerka*) that are transiting through this region during their northward migration.

The High Seas Salmon Program has been conducting an integrated epipelagic survey in Queen Charlotte Sound, Hecate Strait, and Dixon Entrance during summer and fall, since 1998 to assess the effects of ocean conditions on the distribution, migration, growth, and survival of

Pacific salmon. Overall, the abundance of juvenile salmon nearly doubled in the North Coast and Hecate Strait ecozone during summer, after 2003, for all the species (Figure 25). This may be due to an increase in early marine survival and/or smolt production. No such trend was apparent during fall. Instead, the abundance of juvenile salmon reached a peak in 2000-2002, declined thereafter until 2005, and appears to be on the rise again (Figure 25). Most of this variability appears to be driven by changes in the abundance of juvenile pink salmon. The low abundance of juvenile salmon, in the fall of 1998 and 2005, may be respectively the result of poor ocean survival associated with the 1997-98 El Niño and unusual warm ocean conditions in 2005 (Brodeur *et a*l. 2006; DFO 2006).

Interestingly, prior to 2003, catches of juvenile pink and chum salmon were higher during fall than during summer (Figure 25), indicating that juvenile salmon remained on the continental shelf for longer than had previously been reported by Hartt and Dell (1986). In addition, as the Fraser River is near the southern end of pink salmon distribution, and only produces large numbers of pink salmon smolts in even years (Groot and Margolis 1991), the relatively small year-to-year variability in catches of juvenile pink salmon in the North Coast and Hecate Strait ecozone during fall (Figure 25) suggests that a large number of pink salmon smolts are produced in the Central and North Coast of British Columbia during odd years.

Since 2001, surveys have also been conducted during winter. However, with the exception of February 2003, very few juvenile Pacific salmon have been caught during winter in this region (Figure 25), either because they had migrated out of the region or simply died over winter. Thus the importance of this region as a rearing and transiting area for juvenile salmon varies on a seasonal basis.

Sockeye salmon stocks from Rivers Inlet formed one of the most valuable salmon fisheries in British Columbia, until the late 1970s, with annual catches often exceeding one million fish (Walters *et al*. 1993; McKinnell *et al*. 2001). However, despite considerably reducing harvest rates in the 1980s to increase escapement, these stocks collapsed over a 20 year period to approximately 0.1% of their initial abundance (Figure 23) and have been closed to commercial fishery, since 1996, to protect and rebuild the stocks (Rutherford and Wood 2000; McKinnell *et al*. 2001). Although the specific cause of the collapse has not been established, it would appear to be due to an extended period of poor marine survival (Rutherford and Wood 2000; McKinnell *et al*. 2001). The lack of consistent trend in egg-to-smolt survival since 1960, and the parallel collapses of sockeye salmon stocks from nearby watersheds such as Smith Inlet, further suggest that these declines were due to a common cause in the marine environment (Rutherford and Wood 2000; McKinnell *et a*l. 2001). Yet, Fraser River and west coast of Vancouver Island sockeye salmon migrate up the coast directly past Rivers and Smith Inlets (Groot and Cooke 1987), but do not show the long-term decline in productivity that is evident for the Rivers-Smith Inlet sockeye salmon (Figure 23). DNA analyses performed on juvenile sockeye salmon collected from coastal Washington to Southeast Alaska, during summer and fall, indicate that juvenile Rivers Inlet sockeye salmon remain as local residents of some coastal region, while juvenile Fraser River and west coast of Vancouver Island sockeye quickly migrate past them on their northern migration (Tucker *et al*. 2009). This difference in marine migration behavior may leave Rivers-Smith Inlet sockeye salmon particularly vulnerable to poor ocean conditions, if such developed in the south-central British Columbia coastal region over an extended period of time. In contrast, Fraser River and west coast of Vancouver Island sockeye salmon that migrate through this region are not exposed to these putative poor marine conditions for extended periods. Thus, stock-specific differences in marine migration pathways, coupled with regional variation in ocean conditions, could hypothetically lead to the collapse of central coast sockeye salmon stocks, but not that of sockeye salmon stocks to the south. It is worth emphasizing, however, that it is unknown what actually constitutes 'poor ocean conditions' that may affect growth. Accordingly, direct observational evidence for the occurrence of such conditions does not exist.

2.5.3 Herring

Migratory stocks of Pacific herring (*Clupea pallasii*) from the Queen Charlotte Islands, Prince Rupert and the Central Coast of BC contribute to the overall exploitable biomass of herring in Hecate Strait (Crawford and Irvine, 2009). The distribution of herring in the North Coast and Hecate Strait ecozone is shown in Figure 27, and time series of the abundance of the major stocks is given in Figure 28. Large interannual and decadal variability in the pre-fishery biomass of herring exist in these records. The time series show that, while the Prince Rupert stock remains at moderate levels of abundance, the Queen Charlotte Islands stock has been depressed for the last decade. The Central Coast stocks also have experienced a fairly pronounced decline over the last 15 years. Trends over the last several years indicate that these stocks are approaching near-record low levels of abundance.

2.5.4 Eulachon

The eulachon (*Thaleichthys pacificus)* is an anadromous and lipid-rich member of the smelt family. Historically it spawned in many river systems along most of the Pacific coast of North America, favouring locations where strong spring freshets occurred. Although eulachon have not been officially identified by any conservation agency as currently being "at risk", populations have declined throughout their range, in the last 20 years, with intermittent but unsustained signs of rebounding (Hay and McCarter 2000, Beacham *et al.* 2005). Local knowledge indicates that extirpations have occurred on the Central Coast in the vicinity of Bella Coola and Rivers Inlet and stock weakness is seen more and more from the Nass to the Fraser (Booth *et al*. 2007).

Eulachon can be a significant food source for some marine mammals and avian predators. The diminution of eulachon through much of its range carries potentially significant consequences for both its predators in the North Coast and Hecate Strait ecozone and the First Nations that harvest them. The aggregation of diverse terrestrial and marine birds and mammals during eulachon spawning has been remarked upon by observers as far back as the Lewis and Clark expedition (Butler 2004) up to the present (Marston *et al.* 2002). Recent studies suggest that the short but intense pulse of eulachon availability may be critical to species, such as the Steller sea lion as they prepare for breeding season (Sigler *et al.* 2004).

2.6 MARINE MAMMALS

Marine mammals that inhabit or transit through the North Coast and Hecate Strait ecozone include seven species of baleen whales, 15 species of toothed whales, dolphins and porpoises, and five species of sea lions and seals, as well as the sea otter. A full listing of these species, along with their status under COWESIC, is given in Heise *et al.* (2007). Many of these species are listed as endangered or threatened. Among the endangered groups are the blue whales, the sei whales and North Pacific right whales, and the southern resident population of killer whales. Among the threatened species are fin whales, humpback whales, the northern resident killer whales, the transient killer whales, and the sea otters. Others of special concern are the stellar sea lion, the harbour porpoise, the offshore killer whale, and the gray whale. Time series data exists for killer whales, stellar sea lions and harbour seals and this is presented below.

2.6.1 Killer whales

Killer whales (*Orcinus orca*) are an iconic species of great symbolic, as well as economic, significance for the province of British Columbia. Killer whales are regarded as a key indicator of the health of the marine environment because for their survival they require a large region of clean water and healthy prey (Heise *et al*. (2007). In addition, the environment must be sufficiently quiet to allow the whales to communicate, and to eco-locate their prey. Killer whales are classified according to whether they belong to a resident group coastal group, a transient group, or an offshore group. The resident whales are further divided according to whether they reside in southern or northern BC coastal waters. Figure 29 presents a time series of the number of killer whales belonging to the northern resident ecotype. Because of their size and limited numbers, reasonably accurate estimates of the population can be made. It is clear from Figure 29 that the northern resident population has increased steadily in size from the mid 1970s through the mid 1990s, nearly doubling the population over this time. Since the mid 1990s, the numbers seem to have reached a plateau. Nevertheless, because of their relatively small size and vulnerability to environment disruption, both the northeast Pacific transient population and the northeast Pacific northern resident population of killer whales are currently listed legally as threatened. The northeast Pacific offshore population is listed legally as Special Concern.

2.6.2 Sea Lions and Seals

Steller sea lions (*Eumetopias jubatas*) and harbour seals (*phoca vitulina*) remain in BC waters year-round. BC waters are also a major migration route and provide vital feeding grounds for California sea lions, northern fur seals and northern elephant seals (Johannessen *et al*. 2005). The North Coast and Hecate Strait ecozone includes all of BC's Steller sea lions rookeries, the locations of which are indicated in the map of Figure 30. Cape St. James and the Scott Islands are critical areas for Steller sea lions. A time series of the stellar sea lions counted in the region (Figure 30, bottom panel) shows that a general long term decline through much of the 20^{th} century which occurred, due to an intense killing/eradication program lasting from 1913-1968 (DFO 2003). As a result, by the 1970s, numbers of stellar sea lions were at only 25-33% of levels of the early 1900s (DFO, 2003). There is indication of a recovery in these numbers over the last 20 years. Nevertheless, stellar sea lions are regarded as a species of special concern.

Harbour seal populations, in BC waters, were also subject to eradication and commercial hunting during much of the 20^{th} century. Numbers of seals declined greatly over this time. Since harbour seals were protected in 1970, numbers have recovered markedly. This is illustrated in Figure 31 which shows a time series of numbers of seals in BC waters, outside of the Strait of Georgia. This time series shows the increase in numbers in the 1970-80s, followed by an abrupt stabilization in the number of seals starting in 1990 (Olesiuk, 1999).

2.6.3 Sea otters

Sea otters (*Enhydra lutris*) have a significant impact on nearshore ecology, preying on invertebrates such as sea urchins, which in turn graze kelp forests. Historically, sea otters were abundant along the entire coast of BC. However, sea otters were extirpated from British Columbia by the early 1900's by the Euro-Asian sea otter fur trade, primarily through trade with coastal aboriginal peoples (Watson *et al*. 1997). Between 1969 and 1972, 89 otters were reintroduced to Checleset Bay on the northwest coast of Vancouver Island (Watson *et al*. 1997). Sea otters are not migratory and generally live out their lives in a relatively small area. Thus, populations grow by first reaching the carrying capacity of a specific area, and then by moving en masse to adjacent areas. The population on the west coast of Vancouver Island has advanced north and around to Port Hardy, and south beyond Nootka Sound (Gregr *et al*. 2007). Numerically, this population has increased at a rate of ~15% per year. A total of 4,712 sea otters was counted in British Columbia in 2008: 4,110 on the west coast of Vancouver Island and 602 on the central B.C. coast (Nichol et al. 2009). On the central B.C. coast the population increased at an annual rate of 11.4% from 1990 to 2008. Range expansion, evident to the southeast and north to Aristizabal Island, continues to contribute to population growth The present distribution of sea otters in the North Coast and Hecate Strait ecozone is shown in Figure 32.

Sea otters living along the BC coast are a keystone species because of the large impact they have on the habitat of young and small fishes, and on other marine animals (Estes and Palmisano, 1974; Watson *et al*.1997). Furthermore, in areas where sea otters are established, the production of kelp forests is significantly greater than of barren rocks, resulting in a significant increase of species abundance, productivity and biomass where otters forage (Reisewitz *et al*. 2006).

Sea otters are exceptionally sensitive to oil slicks (Watson *et al*. 1997; Gerber *et al.* 2004). Sea otters have no blubber, but stay warm by a dense coat of fur that traps insulating air against the otter's body. Oil destroys the coat's ability to trap air. Considering the relatively small number of sea otters inhabiting a small portion of the BC coast, the potential for oil spills along the west coast of Canada is a significant threat to this species. This is the case not only to sea otters, but for the near-shore ecosystem they keep in balance (Watson *et al*. 1997). While other threats to individual otters exist, that of exposure to oil is considered the most serious.

2.7 MARINE BIRDS

McFarlane Tranquilla *et al*. (2007) have summarized the marine birds of the North Coast and Hecate Strait ecozone. Provided below are sample of time series data that are being collected in the region for several of the key seabird species. Triangle Island (51* 52* N; 129* 05* W), the outermost of the Scott Islands chain is B.C.s largest seabird colony and has significant time series on for Cassin's Auklet (*Ptychoramphus aleuticus*), Rhinoceros Auklet (*Cerorhinca monocerata)*, Tufted Puffin (*Fratercula cirrhata*) and Common Murres (*Uria aalge*). An example of the time series data are timing of breeding, which are available from historical data in the 1970s and 1980s, and ongoing annual data from 1994-present (Figure 33), where a research and monitoring station have been run jointly by Canadian Wildlife Service and the Centre for Wildlife Ecology at Simon Fraser University.

Estimates of breeding production on Triangle Island are related to spring sea surface temperatures, in an ongoing time series, for the largely planktivorous Cassin's Auklet, and the largely piscivorous, Rhinoceros Auklet (Figure 34). Both of the above time series for Triangle Island seabirds are presented annually in the DFO state of ocean report.

Ancient Murrelets (*Synthliboramphus antiquus*) are colonial seabirds which have a two egg clutch and precocial chicks. The nestlings are not fed in the burrow but, instead, go to sea at two days old with their parents. The time series example shows the median timing of departure of nestlings from 1985 - 2007 at East Limestone Island in Laskeek Bay, in the South East Moresby area of Haida Gwaii (Figure 35). The data represents the longest annual time series available for seabirds in BC (Laskeek Bay Conservation Society; http://www.laskeekbay.org/). Ancient Murrelets are currently listed as Special Concern by the Canadian Species at Risk Act.

Marbled Murrelets (*Brachyramphus marmoratus*) are listed as Threatened under the Species at Risk Act, due to loss rates of old growth forest nesting habitat. To examine population trends a detection program is in place that requires repeated biannual surveys at sample locations within each of the six conservation regions of the Marbled Murrelet over a 10 year period (based upon Arcese *et al*. In review). Within each conservation region, there are 10 - 15 long term survey stations for monitoring birds as they transit between the ocean and the forest in the early morning using marine radar (Manley 2006, Figure 36).

2.8 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 been identified as the second largest threat to biodiversity after habitat lost, and while many species have limited impacts, some cause major changes in ecosystem function and are referred to as ecosystem engineers. If introduced species do not cause measurable damage, from a human point of view, they are known as non-indigenous, rather than invasive, species. A recent summary of marine non-indigenous species reported from the Queen Charlotte Islands included one plant, 14 invertebrate, and two fish species Sloan & Bartier (2004). An extensive survey of intertidal marine non-indigenous species across BC identified one plant and four invertebrates (Gillespie 2007). These rates of invasion are considerably lower than those for the Strait of Georgia or west coast of Vancouver Island.

Some invasive species have been introduced historically, like the Japanese wireweed, *Sargassum muticum*, or Eastern softshell, *Mya arenaria,* and are now common on shores throughout BC they arrived too early to quantify the impact they had on BC's subtidal and intertidal ecosystems. A more recent invasion of great concern is the European green crab (*Carcinus maenas*), which is currently only found on the West Coast of Vancouver Island, but likely to spread further north through human activity or larval drift. A recent DFO risk assessment has identified that this species has potential to cause serious impacts on marine and estuarine biodiversity, in general, and intertidal clams in particular (Klassen & Locke 2007; Therriault *et al.* 2008). Two species of invasive tunicates (*Botryllus schlosseri, Botrylloides violaceus*), which have serious impacts on the shellfish aquaculture industry in Atlantic Canada, and the Asian skeleton shrimp (*Caprella mutica*), have been found in the North Coast and Hecate Strait/Quainnis ecozone (Therriault & Herborg 2007, Frey *et al*. 2009).

While the transport vectors for different non-native species are highly dependent on the life cycle of particular species, the main vectors for the BC coastline based on expert surveys are the following: (Therriault & Herborg 2007; Therriault *et al.* 2008):

- Transportation associated with large commercial vessels in ships ballast water or attached to their hulls;
- Transport as fouling on small coastal vessels such as fishing and recreational vessels;
- Hull fouling on slow moving vessels such as barges;
- Extension of their range in U.S. waters via currents or "hops" along the coast;
- Stock enhancement (e.g. non-indigenous salmon stocks);
- Intentional introduction, either as part of an official governmental introduction attempt, aquaculture venture or as an illegal private release; e.g. the Pacific oyster (*Crassostrea gigas*), imported from Japan for aquaculture, has become a dominant species in the

intertidal areas of much of the southern BC coast, and natural settlement has occurred near aquaculture facilities in Haida Gwaii (Gillespie 2007); and,

- Accidentally introductions associated with intentional introductions; e.g., Manila clam and Japanese wireweed.

The occurrence of species outside of their normal range can also result from oceanographic variability (Booth *et al*. 2007). In particular, El Nino events are associated with the presence of species off coastal British Columbia whose range is normally found further to the south, for example off California. This may be due to both warming of coastal waters during El Nino, and transport processes associated with anomalous northward currents during these events. The occurrence of such species gives an indication of a possible ecosystem response in the coastal waters of British Columbia to global warming.

2.9 CONTAMINANTS

The North Coast and Hecate Strait ecozone is sparsely populated (~80,000 human residents), but significant industrial and marine traffic occurs in the area. According to Johannessen *et al*. (2007), the region is exposed to the following contamination: chronic oil release and other wastes associated with increased shipping traffic; metal contamination from current and past mining activities, especially in Alice Arm and Tasu Sound; historic polycyclic aromatic hydrocarbon (PAH) contamination around the Kitimat aluminium smelter; heavy metals associated with a slag heap in Observatory Inlet left behind by the former Anyox copper smelter; pulp mill effluent and port-related contaminations at Kitimat and Prince Rupert (Figure 37); contaminations related to past military and coast guard activities; bio-accumulating persistent organic pollutants (POPs), which occur globally, but for which little data exist in the North Coast and Hecate Strait ecozone. Three growing or potential sources of contamination include the expanding cruise ship industry, the aquaculture industry and, possibly in the future, oil and gas exploration. The Government of Canada imposed a moratorium, in 1972, on oil and gas activities for offshore British Columbia. Recently, a public review was conducted to consider options for lifting of the moratorium on oil and gas activities in the Queen Charlotte Region of the ecozone (Natural Resources Canada, 2004).

3. DRIVERS OF CHANGE

Identifying drivers of change and establishing a chain of causality is often a difficult matter. This is true not only of the physical environment, but particularly for biological variables such as fish populations whose dynamics are poorly understood. What does appear to be reasonably clear is that the physical environment of this coastal ecozone is subject to episodic climatic fluctuations over long time periods. This refers to variability on multi-year (e.g., El Nino) to multi-decadal time scales (e.g., the Pacific Decadal Oscillation), in upper ocean heat content, salinity, sea level. There is some evidence for secular trends: in particular the surface waters in the NE Pacific appear to be warming, freshening and intermediate waters are becoming depleted in dissolved oxygen and enriched in carbon dioxide. The consequences are uncertain. It is conceivable that surface freshening may inhibit mixing and may reduce surface 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 may adverse affect the marine ecosystem. Warming upper ocean temperatures may lead to changes in the abundance and variety of marine species found in the ecozone.

Secular trends are evident in several of the fish and mammal populations in the ecozone for which time series exist. While the factors driving these long-term changes are often not known, there are notable exceptions that point to the effect of human activity. For example the rebounds seen in stellar sea lion, harbour seal populations and the expansion in sea otter distribution (Figs. 30-32) are due attributable to reduced hunting/extirpation pressures. On the other hand, it is possible that changing ocean conditions may have led to the collapse of the Rivers/Smith Inlet salmon fishery (Fig. 26). However, it is not known what actual changes may have occurred in the ocean that produced the collapse.

Human habitation in the North Coast and Hecate Strait ecozone is sparse and likely to remain so. Consequently, in the future, human pressures driving change in the region are most likely to be, as they are today, those associated with resource extraction (e.g., commercial fishing, aquaculture, offshore oil and gas minng, power generation using tidal and wind turbines).

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5. FIGURES

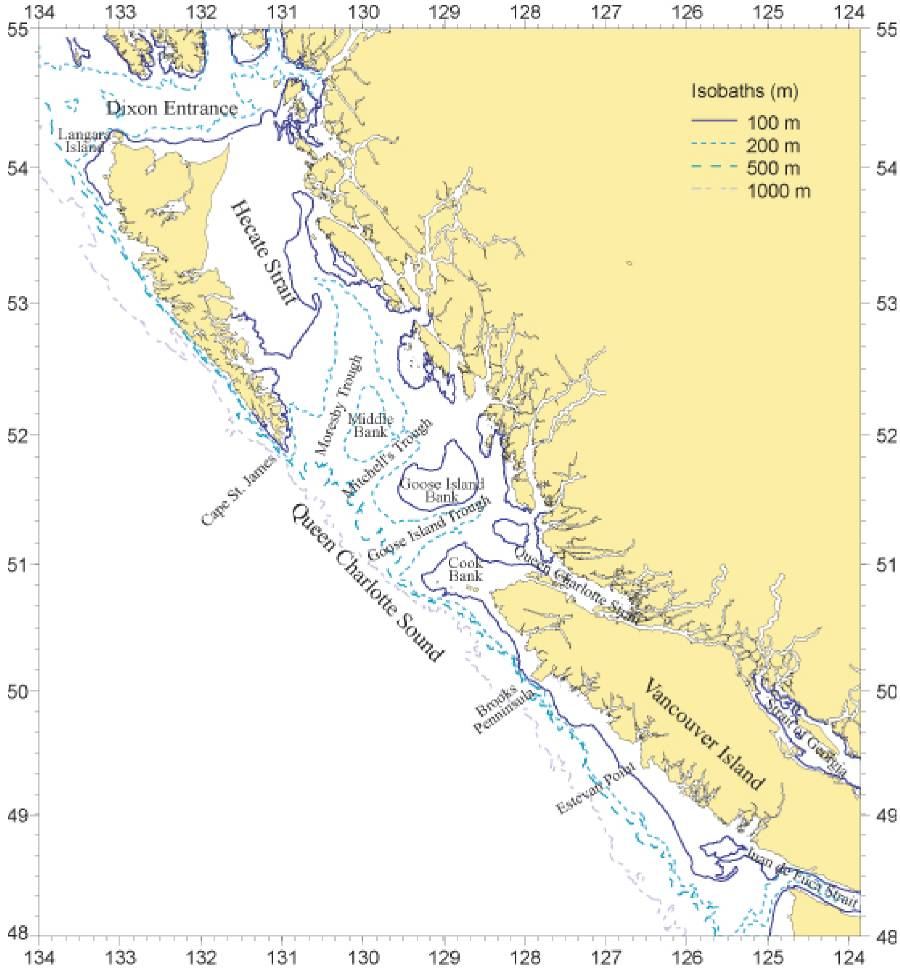


Figure 1. Map of the Pacific North Coast Integrated Management Area (PNCIMA), comprising Queen Charlotte Strait, Queen Charlotte Sound, Hecate Strait and Dixon Entrance. Source: Sinclair et al. (2005).

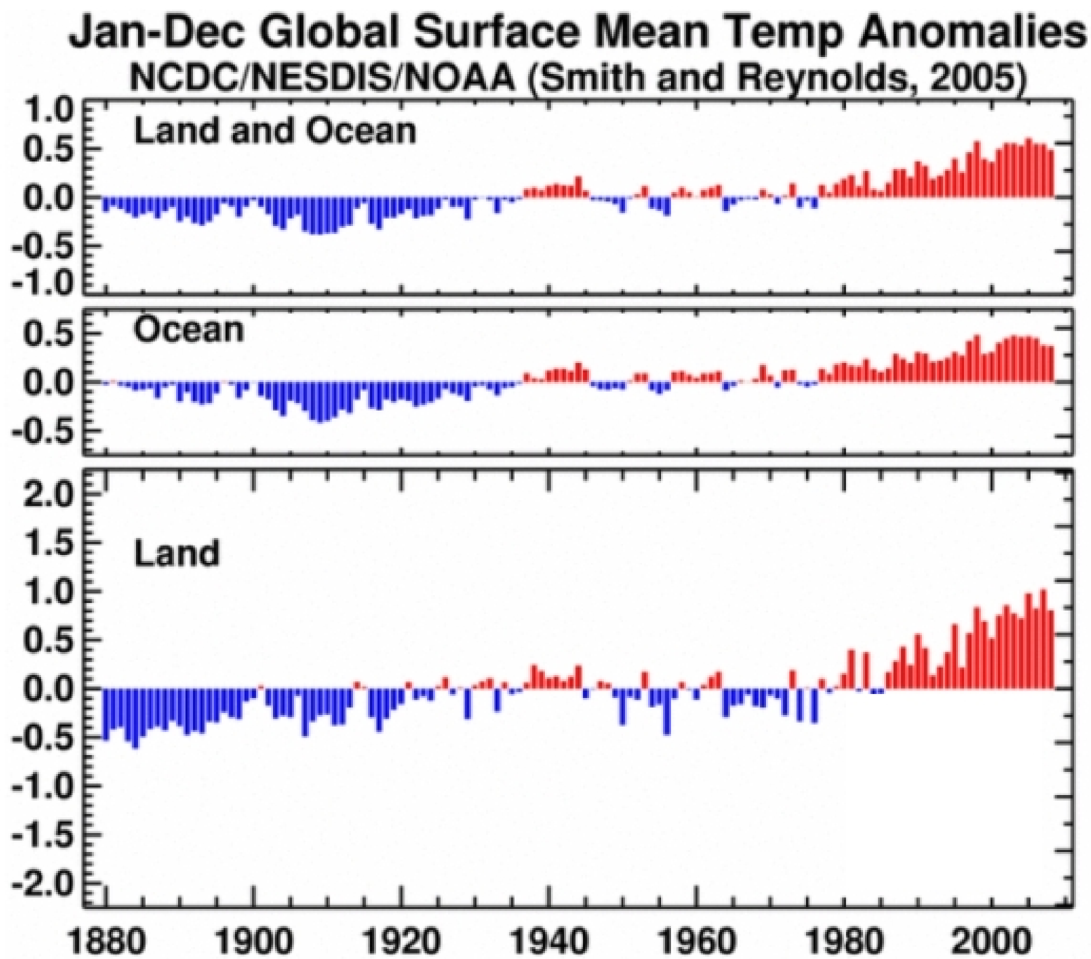


Figure 2: Annual anomalies of surface temperature from 1880 to 2008, over land and ocean (top), ocean alone (middle), and land alone (bottom). Anomalies are reference to the period 1961-1991. Source: Crawford and Irvine (2009).

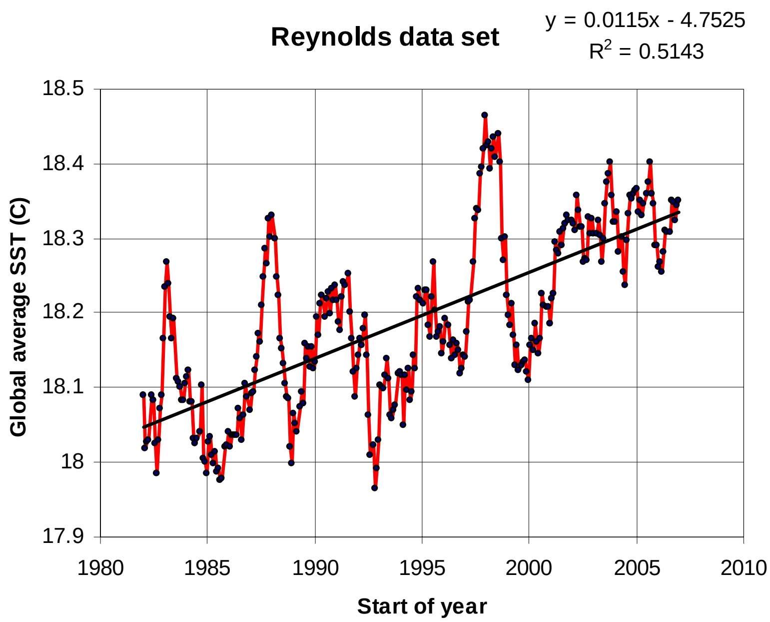


Figure 3a. Monthly average temperatures computed over 1-degree latitude by 1-degree longitude squares of the ocean. The time series above represents the monthly global averages. Source: DFO (2007).

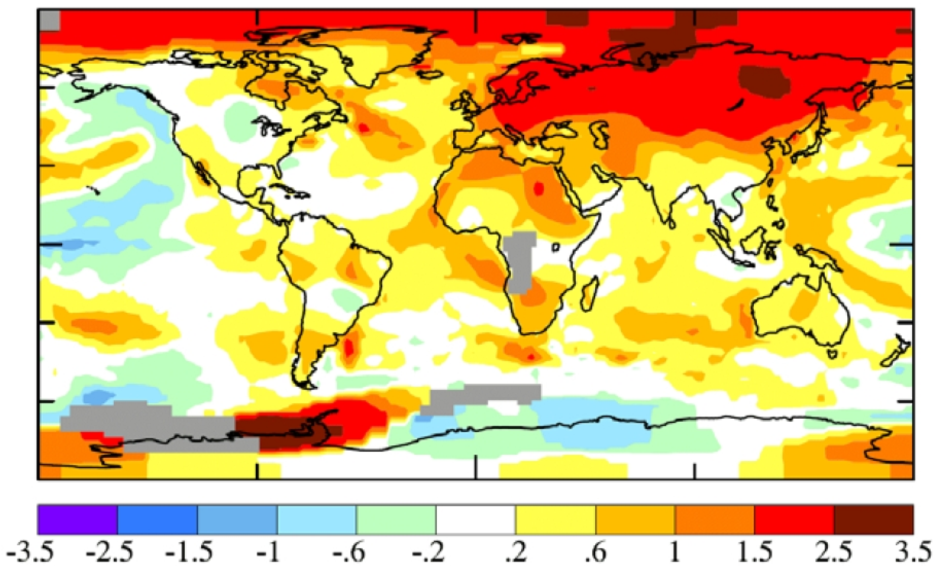


Figure 3b. Annual mean pattern of SST anomalies for 2008. Anomalies are calculated relative to the mean over the period 1961-1991. Note the broad region of negative anomalies extending along the west coast of North America indicating the local prevalence of below-average temperatures in 2008. Source: Crawford and Irvine (2009).

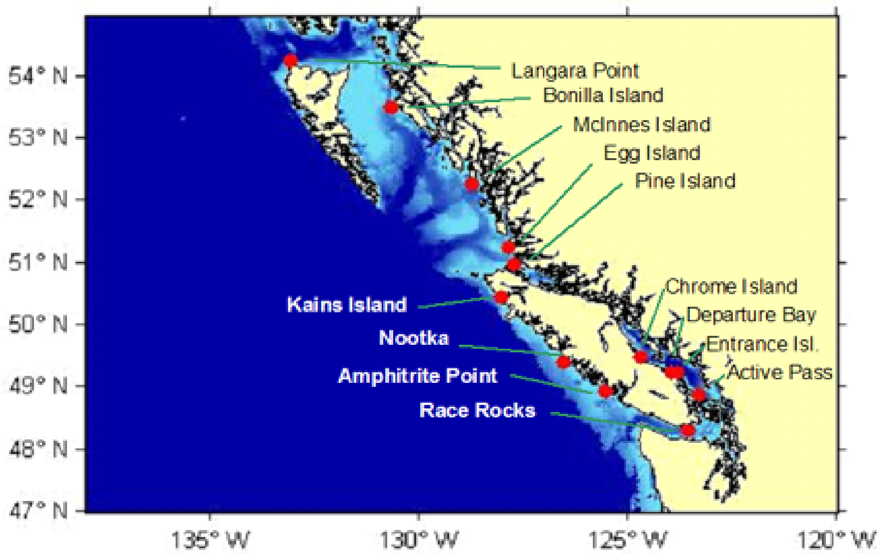


Figure 4a. Locations of British Columbia lighthouse stations for which there exist long-term record of surface water temperature and salinity.

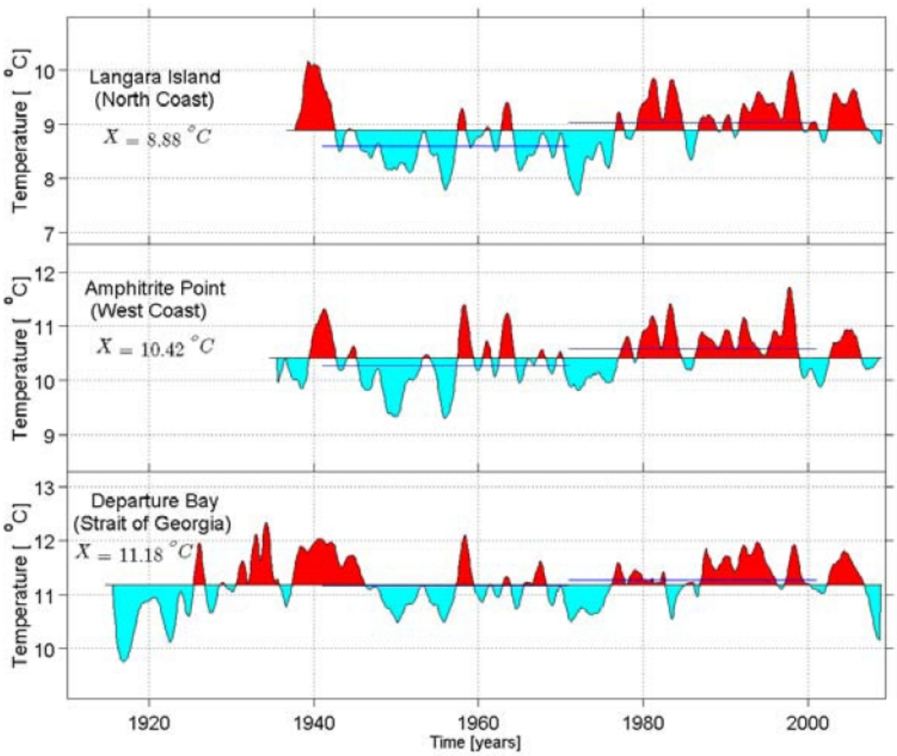


Figure 4b: Long-term time series of annual-average temperature at representative coastal BC lighthouse stations. The Langara lighthouse is within the North Coast and Hecate Strait ecozone. Source: Crawford and Irvine (2009).

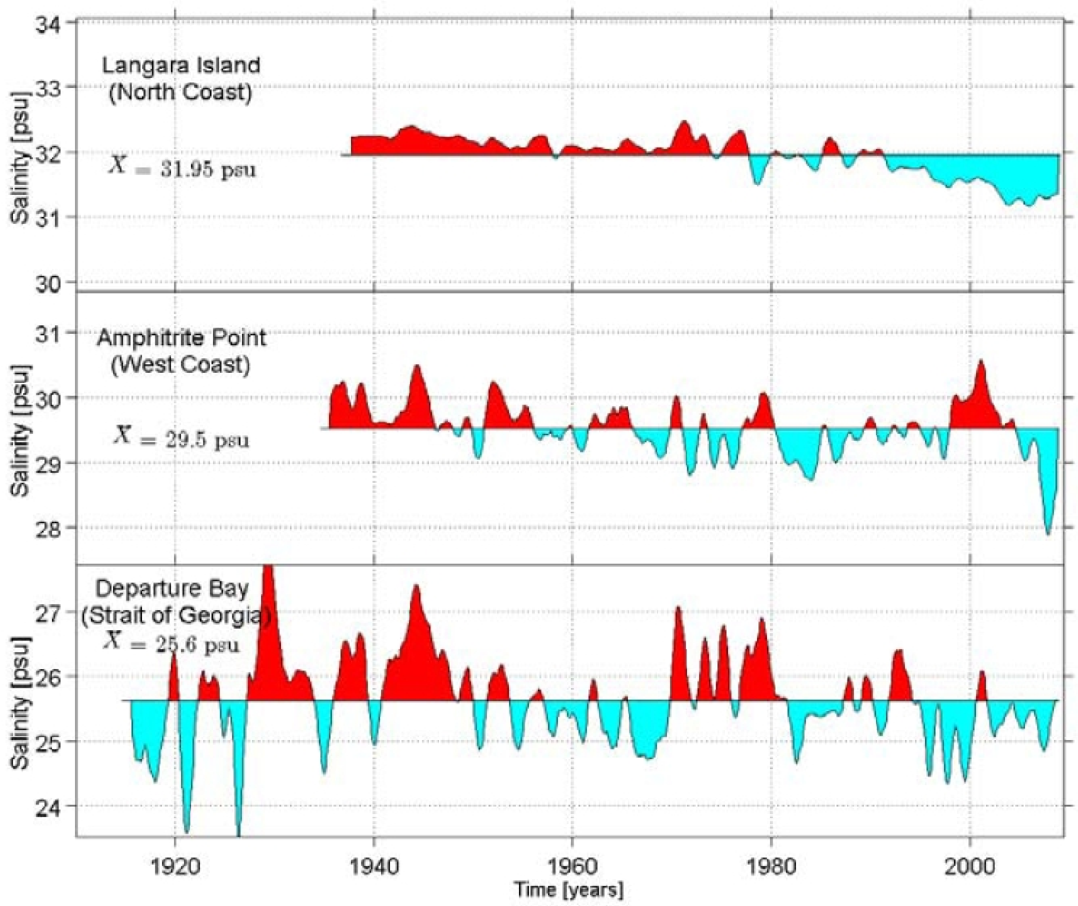


Figure 5: Long-term time series of sea surface salinity at representative BC lighthouse stations. The Langara Island lighthouse is within the North Coast and Hecate Strait ecozone. Source: Crawford and Irvine (2009).

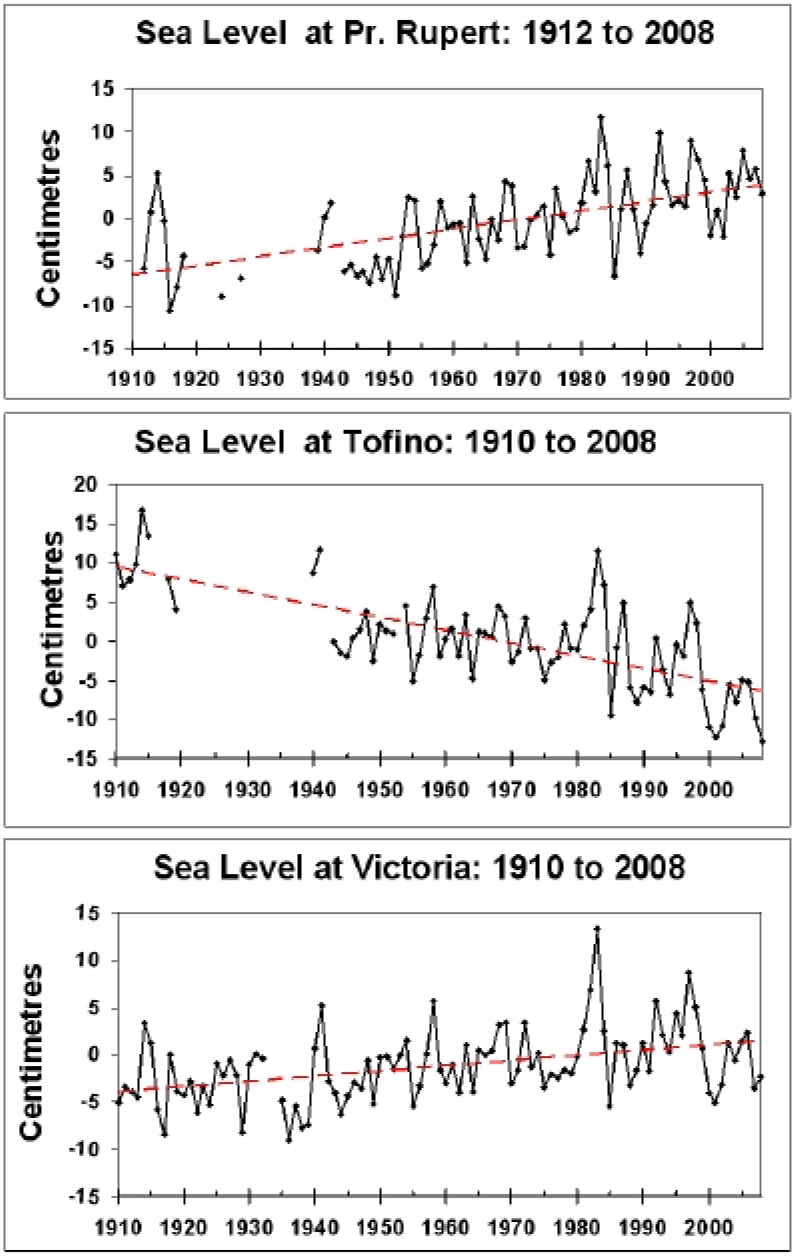
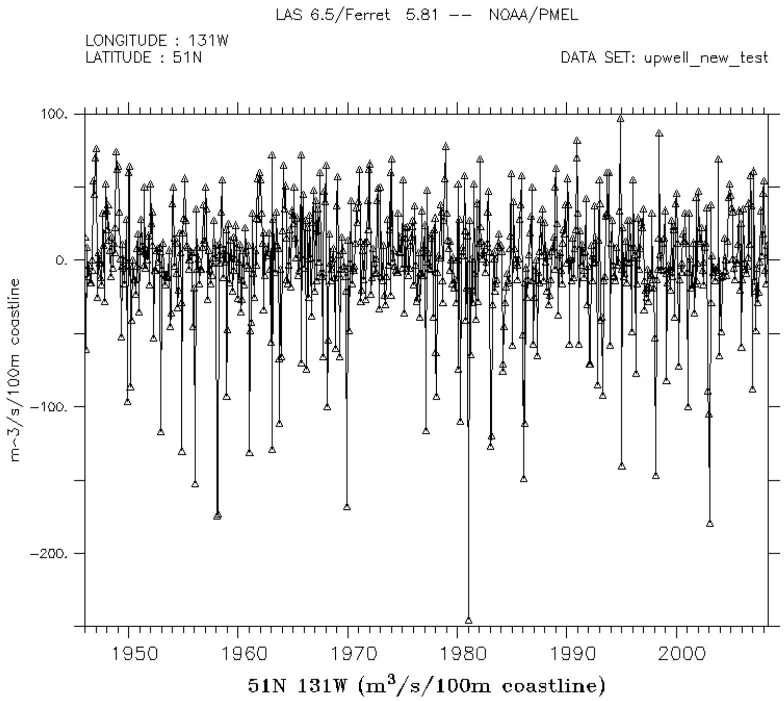


Figure 6: Time series of annual mean sea level and fitted linear trends at three locations on the BC coast. The Prince Rupert time series is from the North Coast and North Coast and Hecate Strait ecozone. Source: Crawford and Irvine (2009).



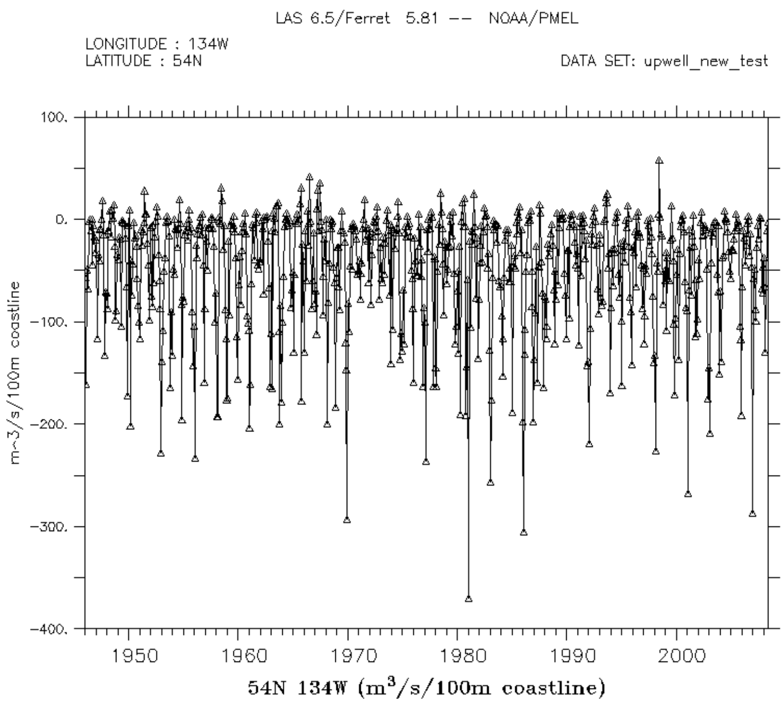


Figure 7. Upwelling indices for (a – upper panel) the southern and (b – lower panel) northern ends of the North Coast and Hecate Strait ecozone. Data were obtained from the web site: http://las.pfeg.noaa.gov/las6_5/servlets/dataset?catitem=1668

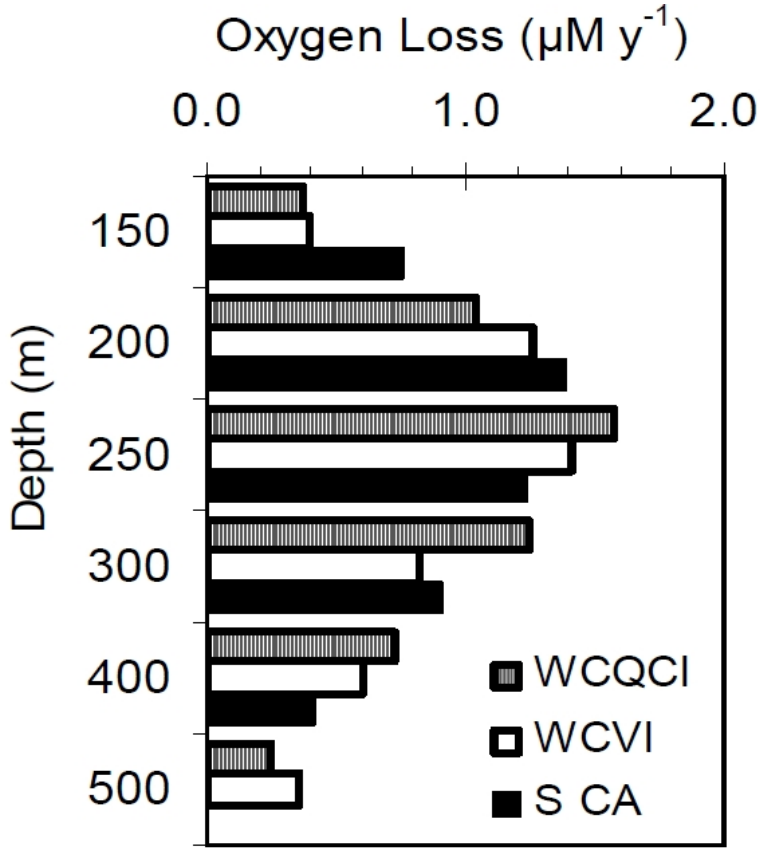


Figure 8: Oxygen trends at different depths along the west coast of North America. 'S CA' refers to Southern California, 'WCVI' refers to the west coast of Vancouver Island, and 'WCQCI' refers to the west coast of the Queen Charlotte Islands. The latter is within the North Coast and Hecate Strait ecozone. Source: Crawford and Irvine (2009).

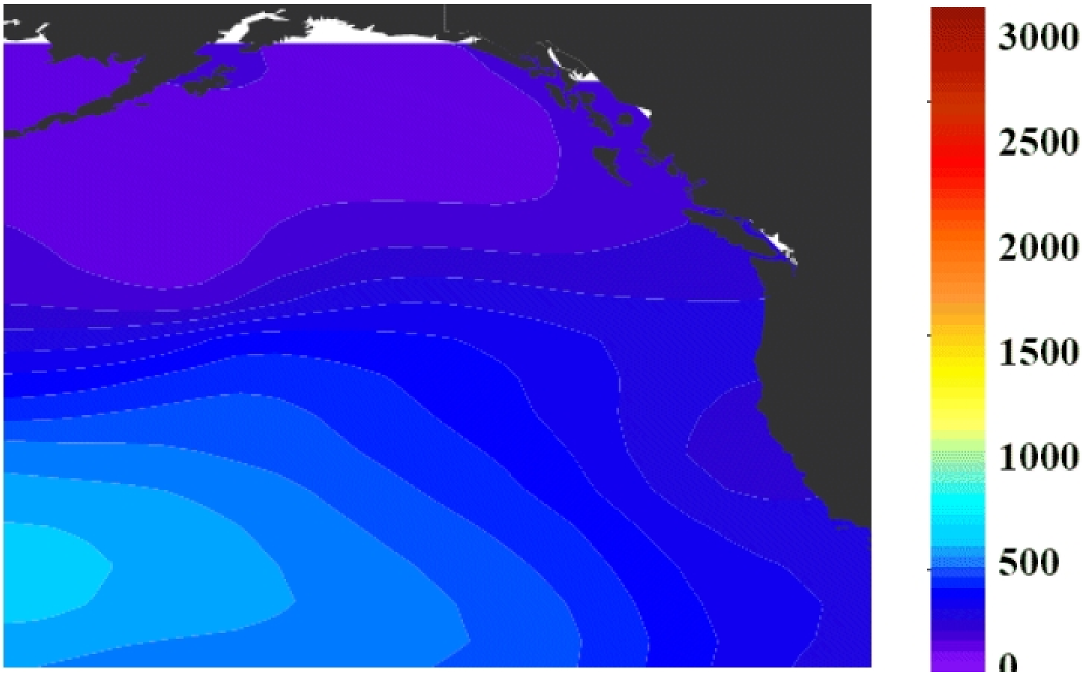


Figure 9: Saturation depth (in metres) for aragonite over the northeast Pacific. White indicates areas with little or no data. Source: Irvine and Crawford (2008).

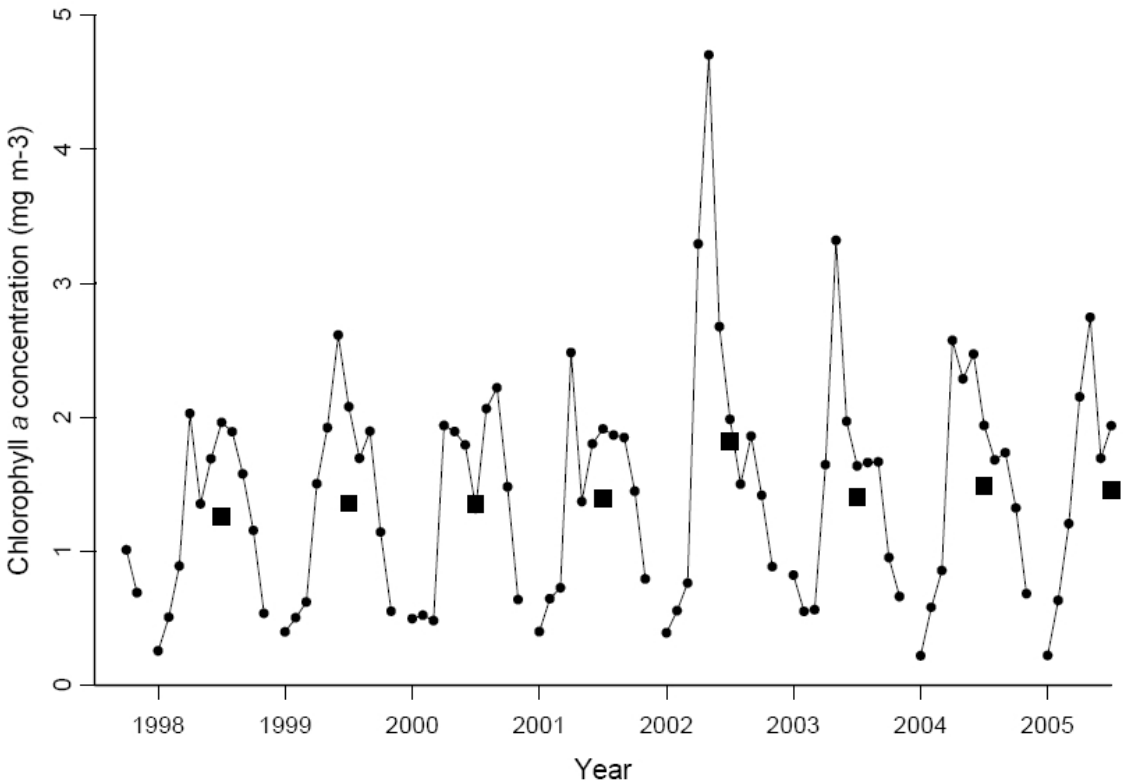


Figure 10: Monthly mean chlorophyll a biomass ($\mathrm{mg\ m^{-3}}$ *) for the North Coast and Hecate Strait ecozone as measured by the SEAWIFS satellite sensor at 9 km resolution. Large squares represent annual (Jan – Nov) means. Source: Lucas el al. (2006).*

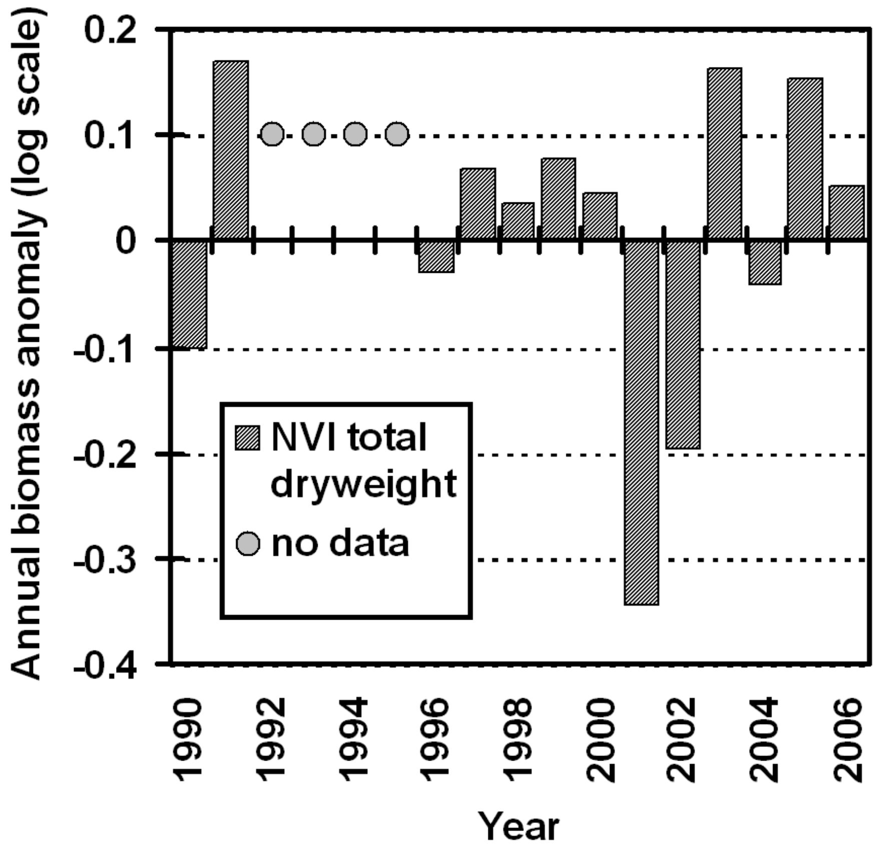


Figure 11. Time series for 1990-2006 of within-year-average anomalies of total dryweight zooplankton biomass. The anomaly index (vertical axis) has a logarithmic scale. Source: Mackas et al. (2007).

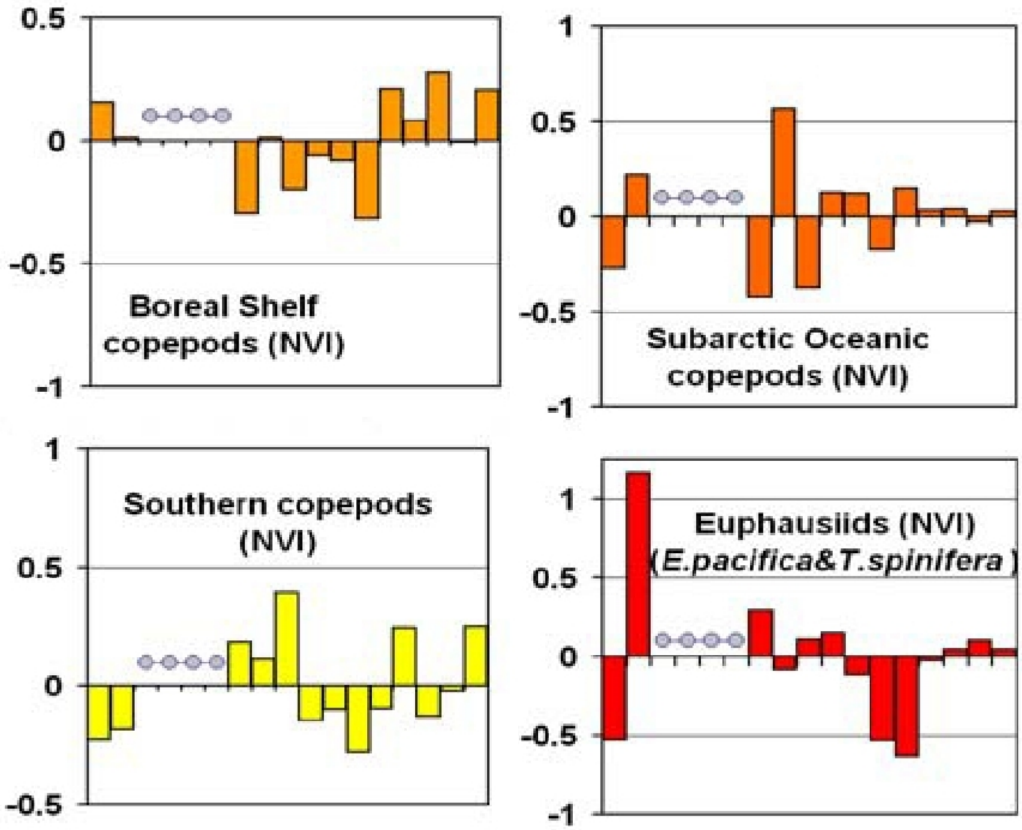


Figure 12. Standardized annual time series for 1990-2006 of biomass anomalies within selected zooplankton taxonomic groups off northern Vancouver Island (NVI). Circles indicate years with no, or too few, data. The anomaly index (vertical axis) has a logarithmic scale. Source: Mackas et al. (2007).

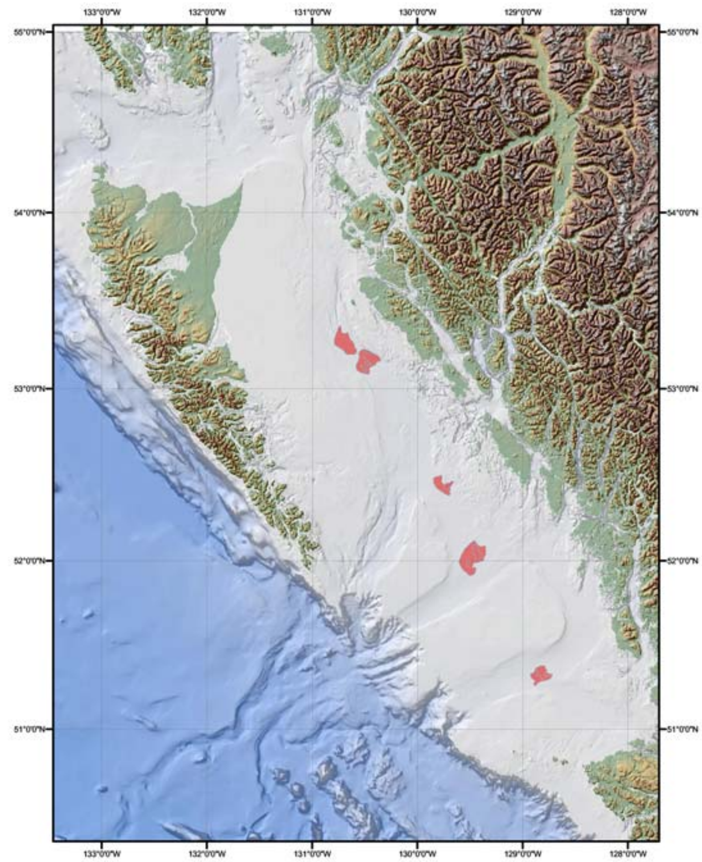


Figure 13: Known location of sponge reef complexes in the North Coast and Hecate Strait ecozone. Source: Lucas et al. (2006).

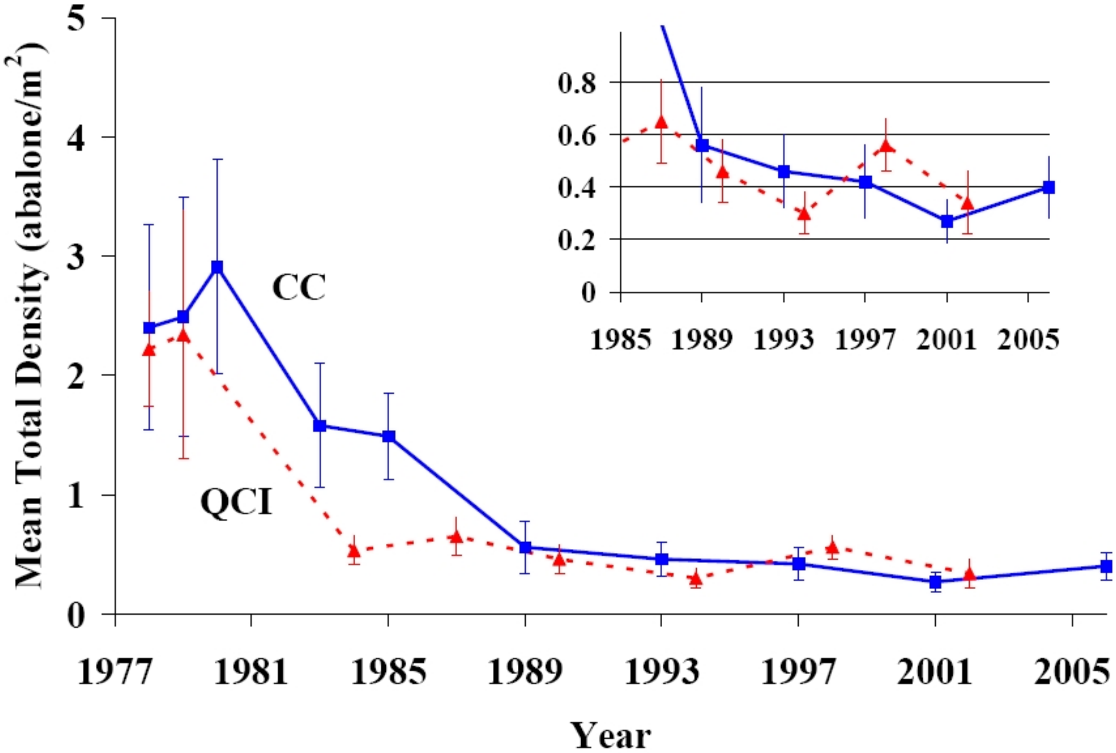


Figure 14: Mean total density of abalone from all surveys in the central coast (CC) (solid blue line) and Queen Charlotte Islands (QCI) (dashed red line). Inset graph displays greater resolution of densities for survey years after 1985. Source: Lessard et al. (2006).

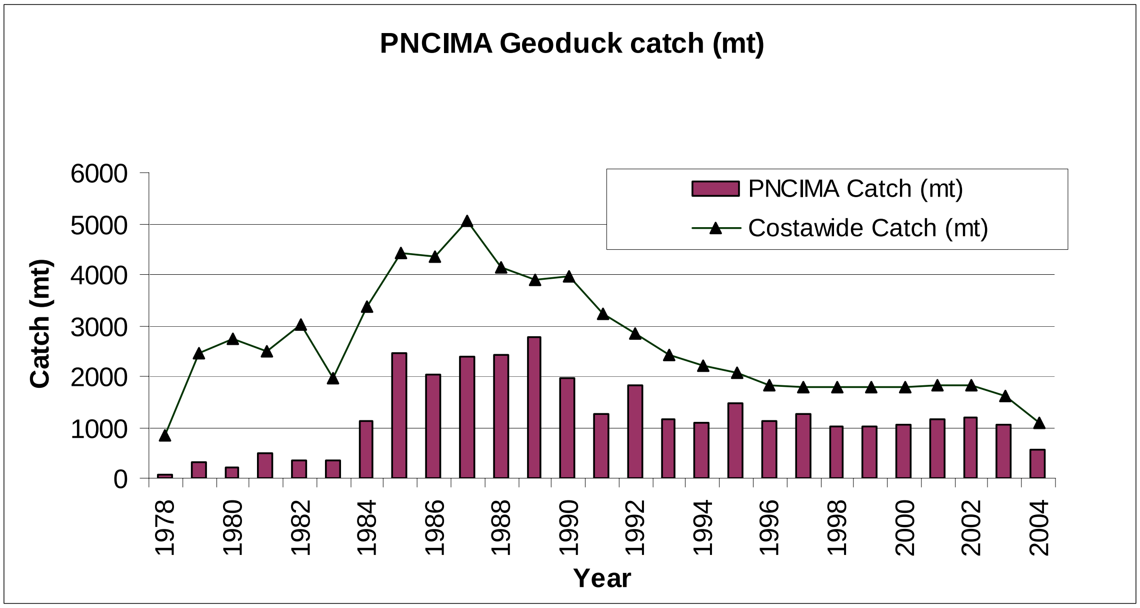


Figure 15: Geoduck catch in the North Coast and Hecate Strait ecozone and the coast-wide catch from 1978 to 2004. Source: MacConnachie et al. (2007).

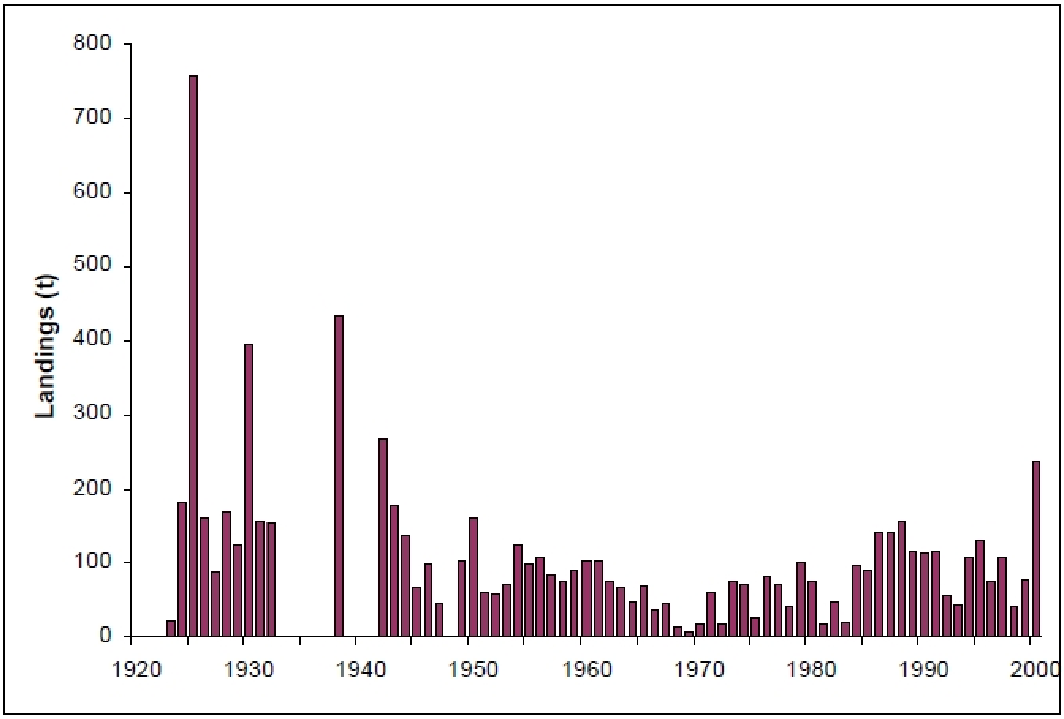


Figure 16: Razor clam landings (tonnes) at North Beach, near Masset, Queen Charlotte Islands. Source: DFO (2001).

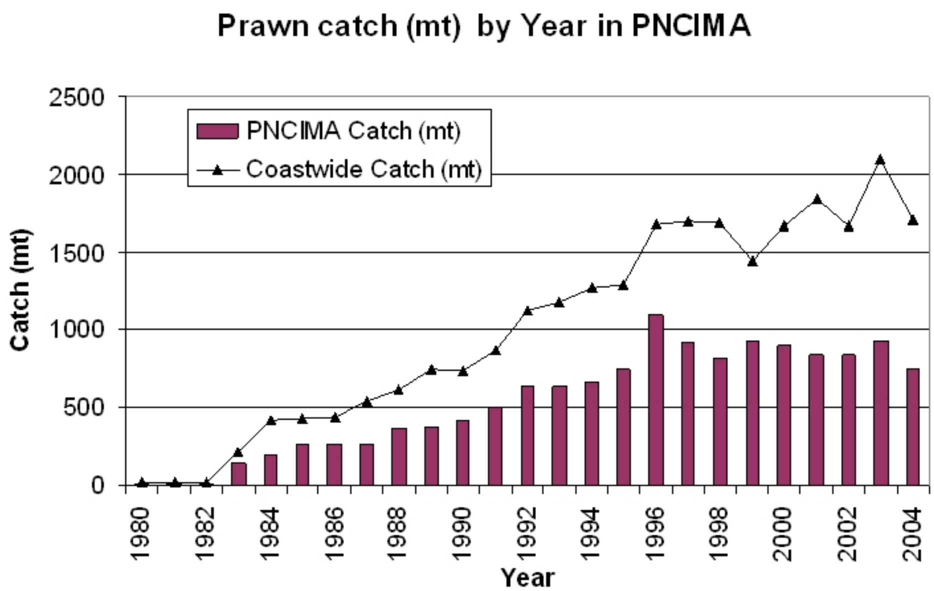


Figure 17: Prawn catch in the North Coast and Hecate Strait ecozone and the coast-wide catch from logbooks. Source: MacConnachie et al. (2007).

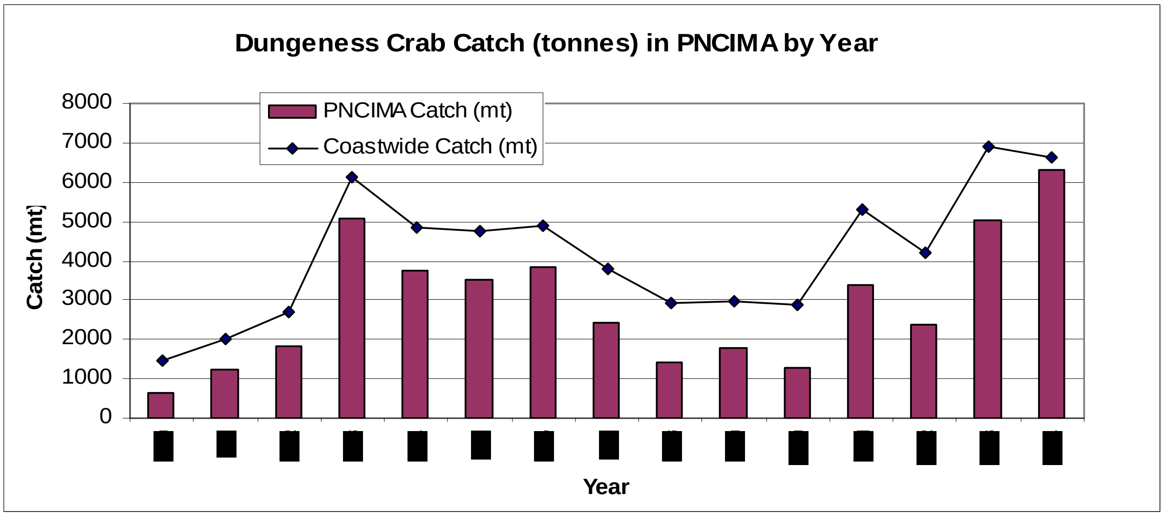


Figure 18: Dungeness crab catch in the North Coast and Hecate Strait ecozone and compared to the coast-wide catch. Source: MacConnachie et al. (2007).

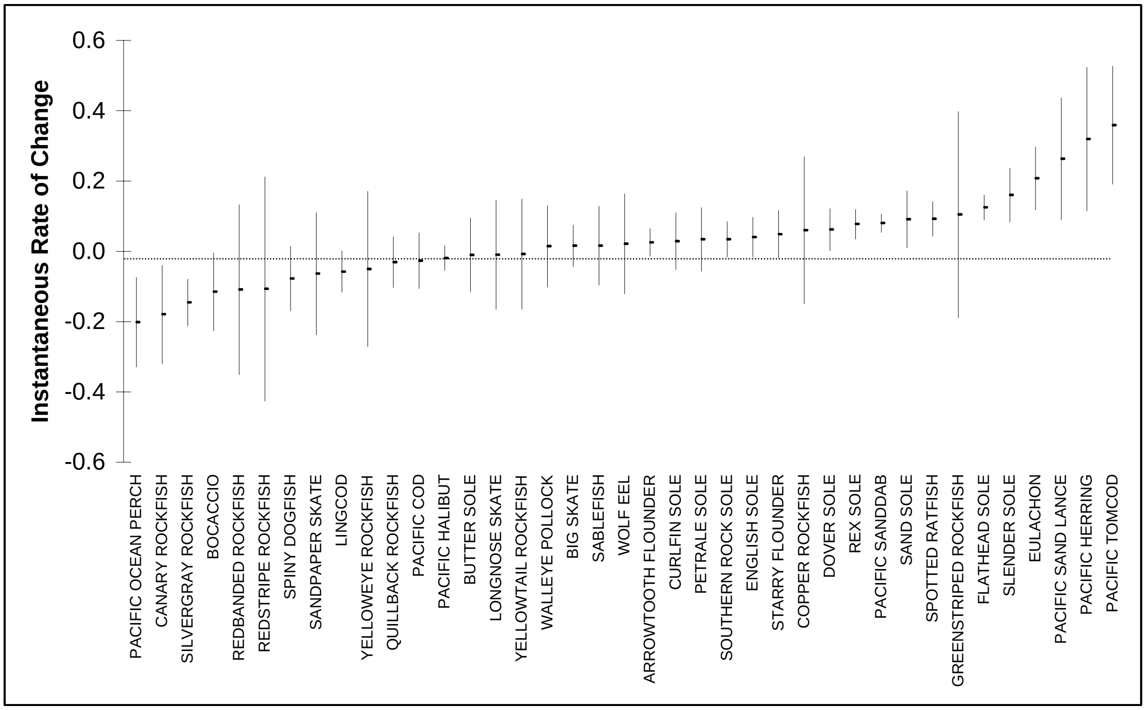


Figure 19: Slopes and 95% confidence intervals for regressions of ln (survey index) vs. year for 39 species from the North Coast and Hecate Strait Assemblage survey. Source: Sinclair et al. (2007).

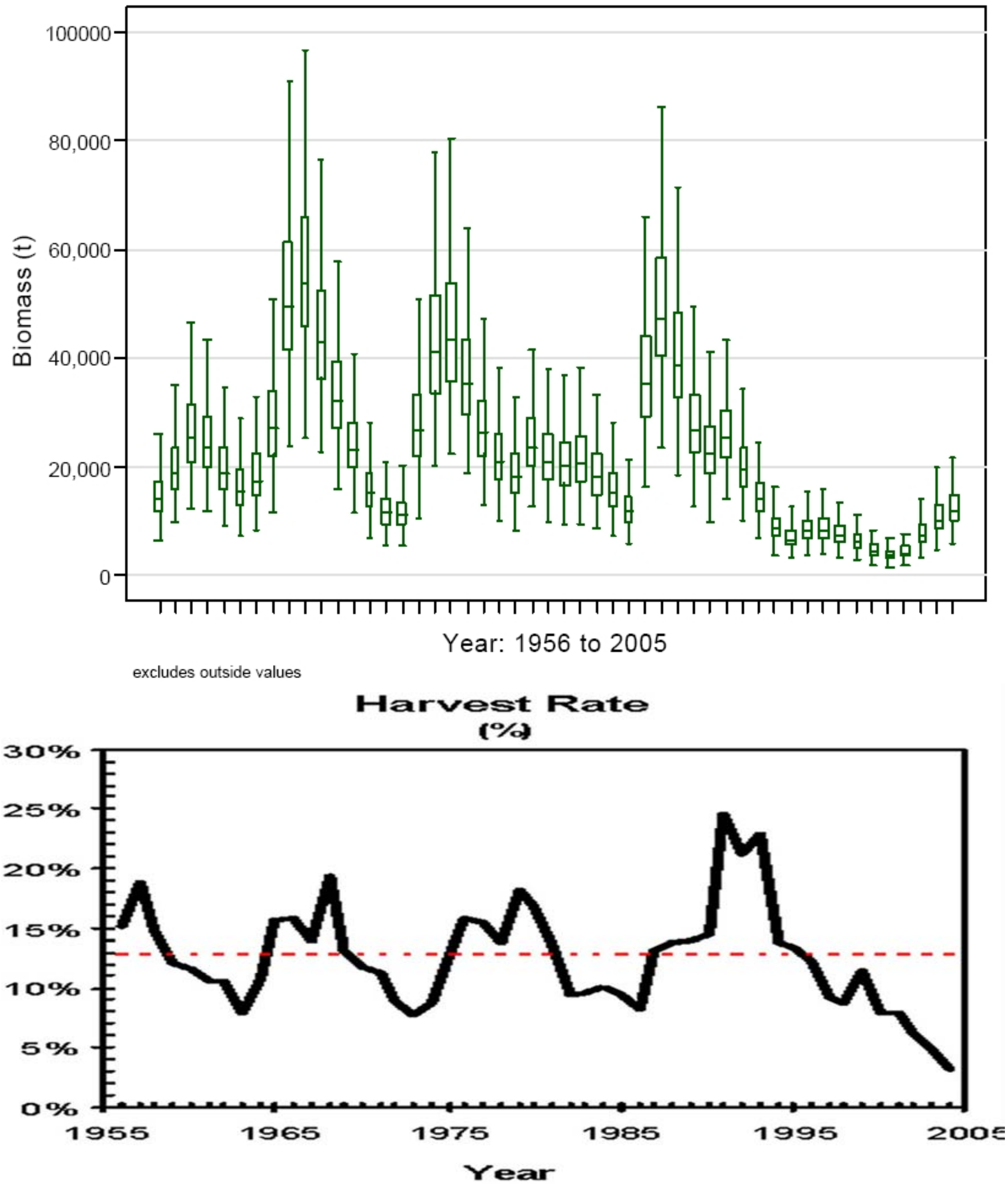


Figure 20: Pacific cod (Gadus macrocephalus) - Upper panel: boxplots of Bayesian posterior estimates of biomass (t) using a delay-difference stock production model. Lower panel: annual harvest rate trend and average harvest rate (red dashed line) over the model period. Source: Sinclair and Starr (2005).

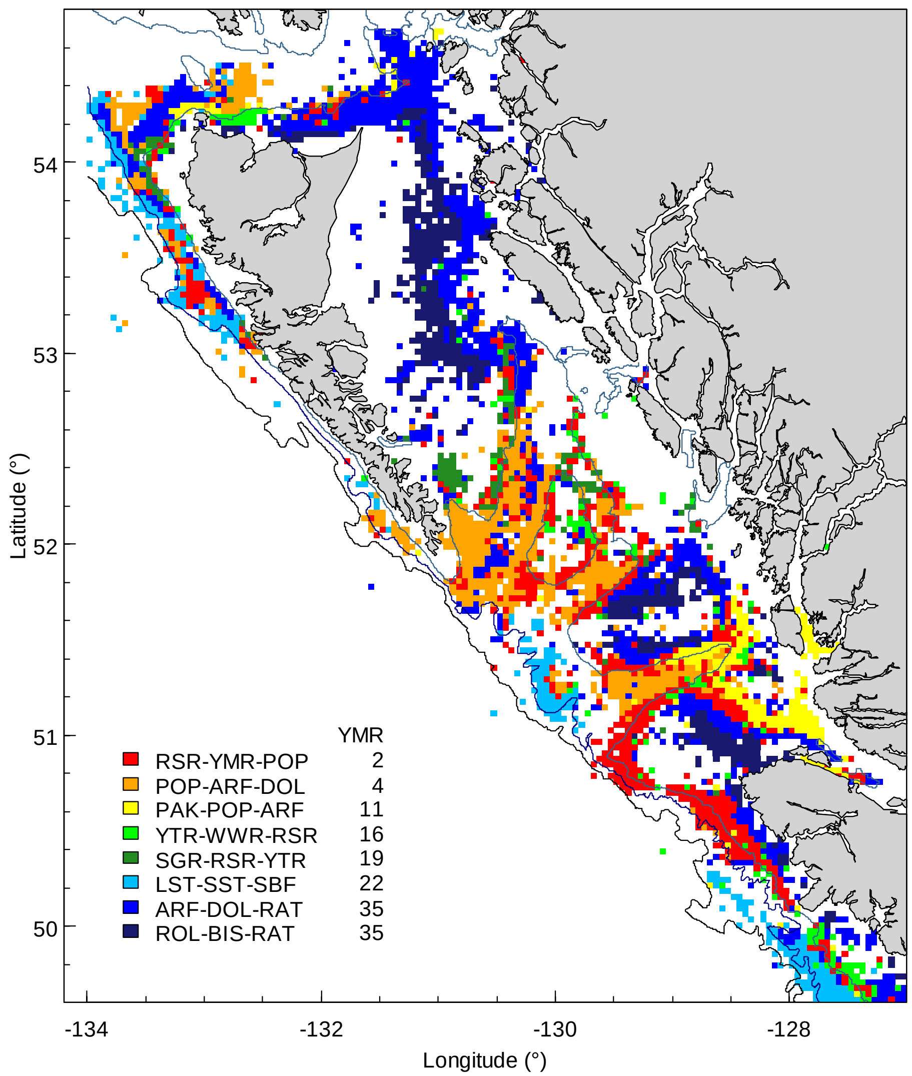


Figure 21: Groundfish groups identified by clustering large datasets (described in Kaufman and Rousseeuw 1990). Isobaths trace the 200, 1000, and 1800 m depth contours. The legend identifies eight clusters ordered by the contribution of yellowmouth rockfish (YMR). Source: Haigh and Starr (2008).

Species codes: ARF arrowtooth flounder Atheresthes stomias, ROL rock sole Lepidopsetta bilineatus, BIS big skate Raja binoculata, RSR redstripe rockfish Sebastes proriger, DOL Dover sole Microstomus pacificus, SBF sablefish Anoplopoma fimbria, LST longspine thornyhead Sebastolobus altivelis, SGR silvergray rockfish Sebastes brevispinis, PAC Pacific cod Gadus macrocephalus, SST shortspine thornyhead Sebastolobus alascanus, PAK Pacific hake Merluccius productus, WWR widow rockfish Sebastes entomelas, POP Pacific ocean perch Sebastes alutus, YMR yellowmouth rockfish Sebastes reedi, RAT spotted ratfish Hydrolagus colliei, YTR yellowtail rockfish Sebastes flavidus.

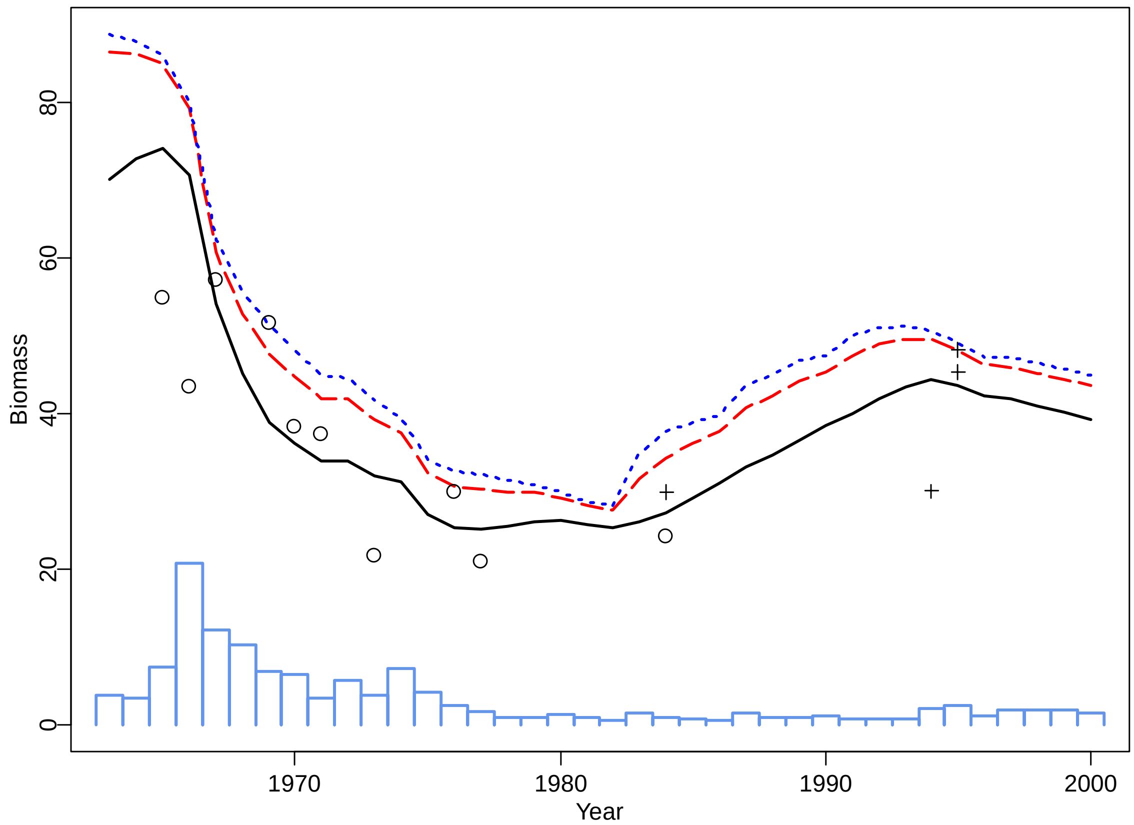


Figure 22: Pacific ocean perch (Sebastes alutus) - Annual biomass estimates (t): available to the fishery (solid black line), mature (dashed red line) and total (dotted blue line). Circles indicate research survey estimates, scaled to available biomass. Plus symbols indicate charter survey estimates, also scaled to biomass. The blue bar plot represents annual catches. Source: Schnute et al. (2001).

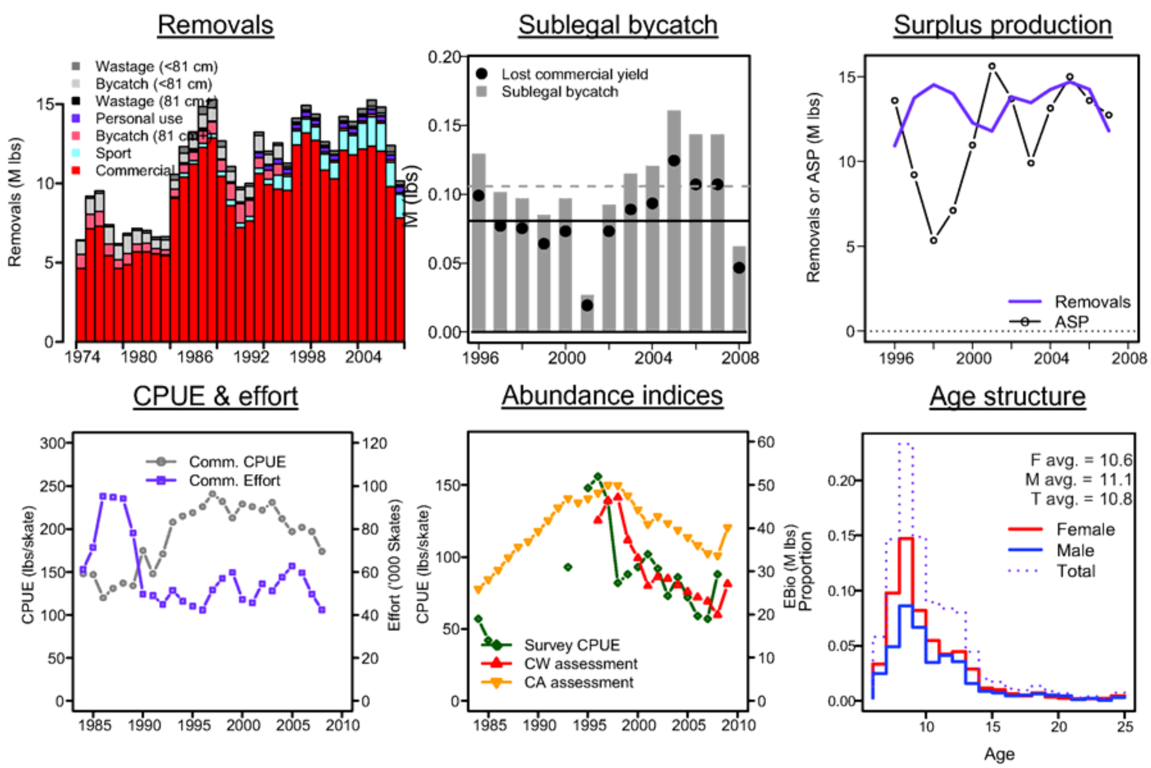


Figure 23: Diagnostic plots for the Area 2B (PNCIMA) halibut (Hippoglossus stenolepis) population. Top left: total removals by category (commercial catch, sport, etc.). Top middle: sublegal bycatch including an estimate of lost commercial yield. Top right: surplus production compared with total removals. Bottom left: commercial CPUE and effort. Bottom middle: abundance indices (survey CPUE, coastwide assessment with survey partitioning, and closed area assessments). Bottom right: 2008 age structure of the population. Source: Hare and Clarke (2009).

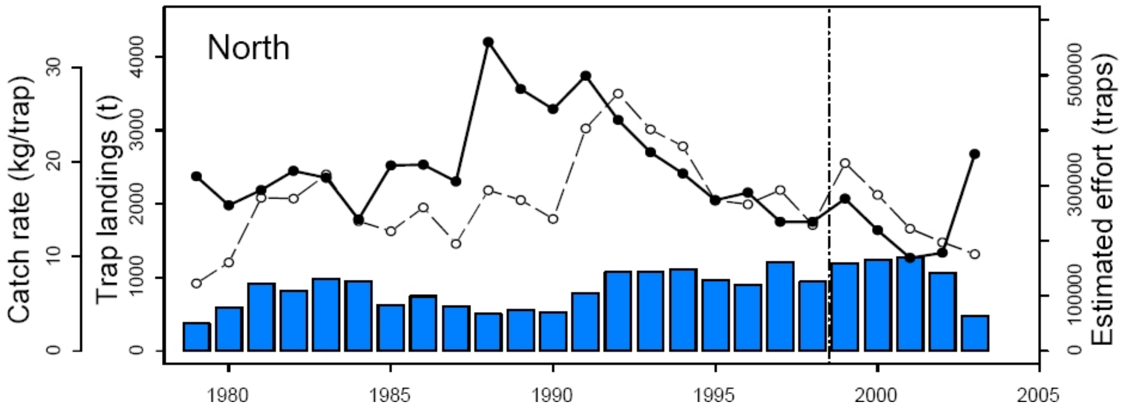


Figure 24. Sablefish Anoplopoma fimbria - Nominal trap fishery CPUE (kg/trap, filled circles, solid line), catch (t) (open circles, dashed line) and estimated effort (traps, vertical bars) for the BC coast north of 50.5°N. The vertical dot-dash line indicates the inception of mandatory escape rings in the commercial trap fishery. Source: Haist et al. (2005).

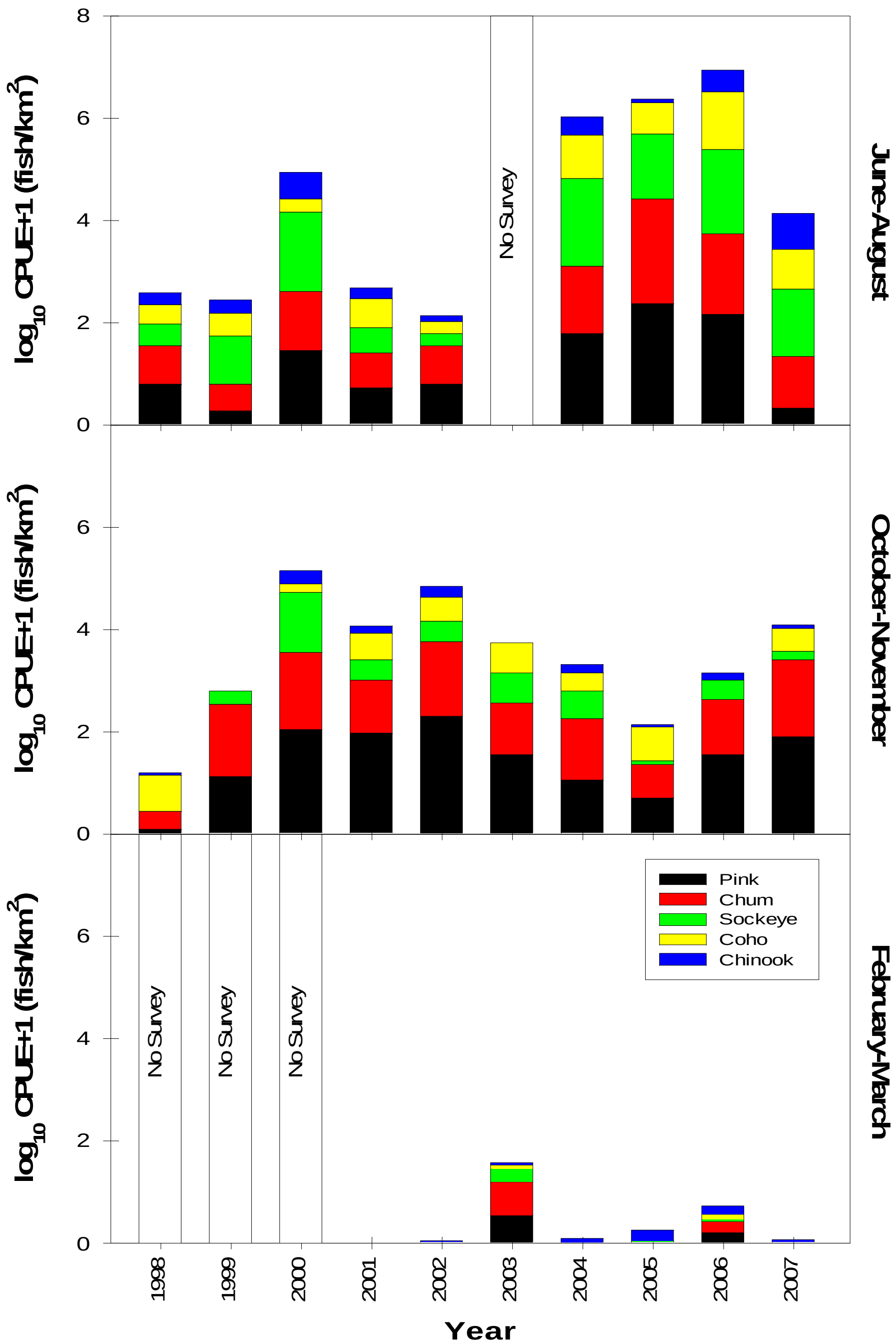


Figure 25: Catch-per-unit effort (CPUE) of juvenile Pacific salmon in the North Coast and Hecate Strait ecozone. No sampling was conducted in this region during summer in 2003 due to a ship malfunction. Source: Marc Trudel, DFO.

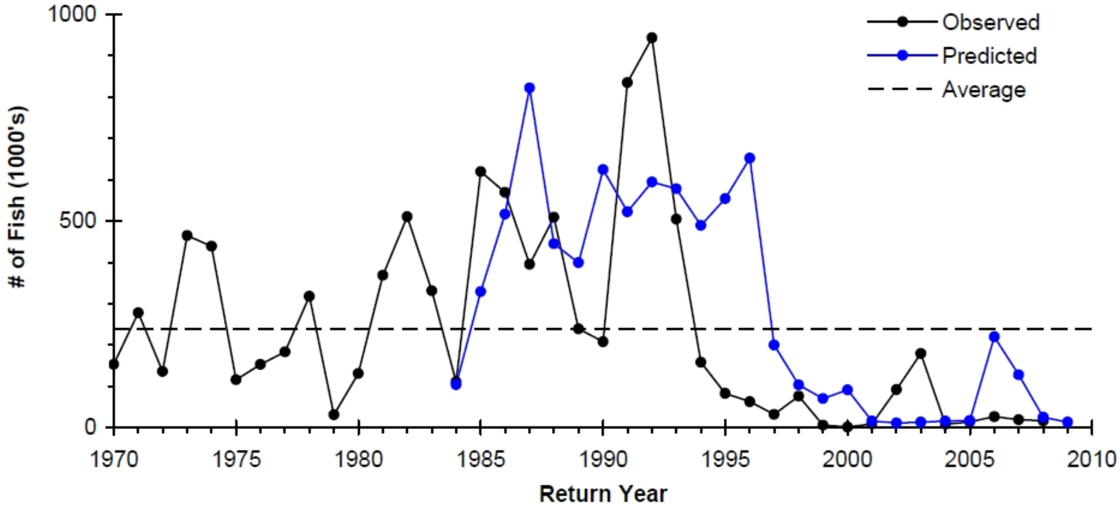


Figure 26: Returns and forecasts of Rivers and Smith Inlet sockeye salmon, 1970-2009. Source: Crawford and Irvine (2009).

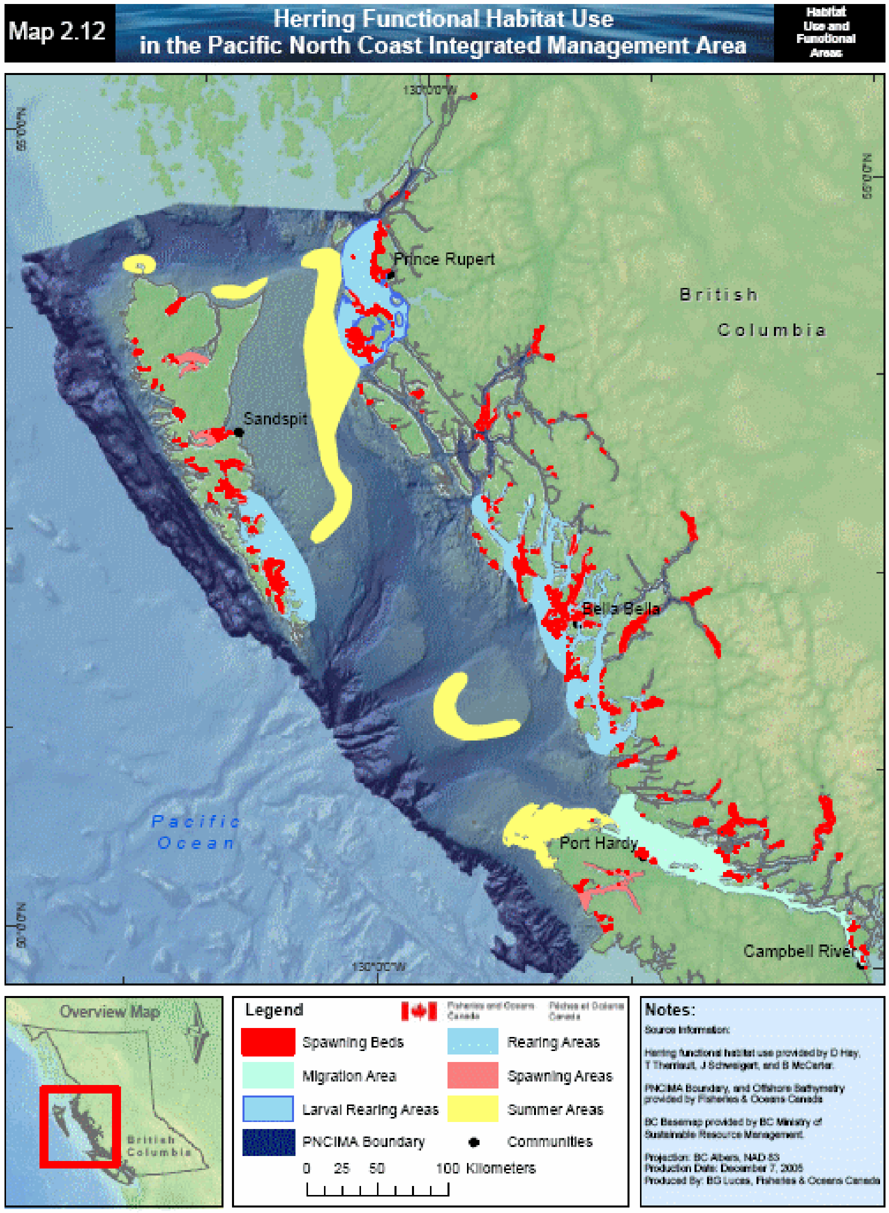


Figure 27: Distribution of herring habitat within the North Coast and Hecate Strait ecozone. Source: Lucas et al. (2006).

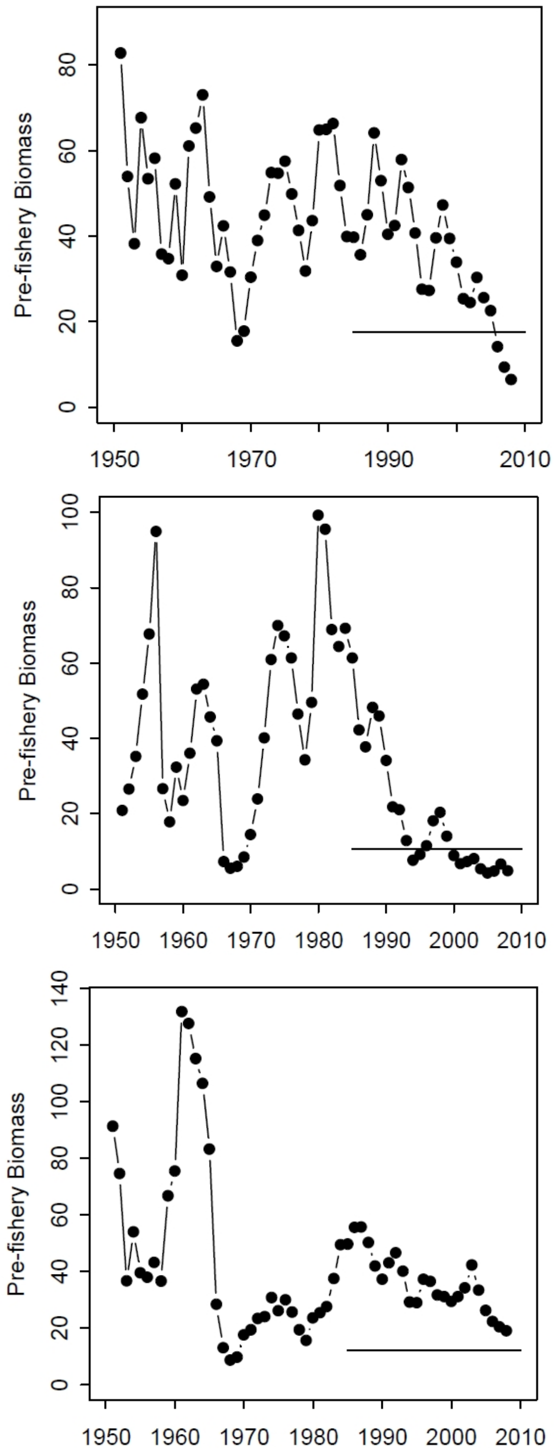


Figure 28. Pre-fishery biomass (in 1000s tonnes) of Pacific herring in three subregions of the North Coast and Hecate Strait ecozone. The top panel is for the Central Coast, the middle panel for the Queen Charlotte Island, and the lower panel for the Prince Rupert District Source: Crawford and Irvine (2009).

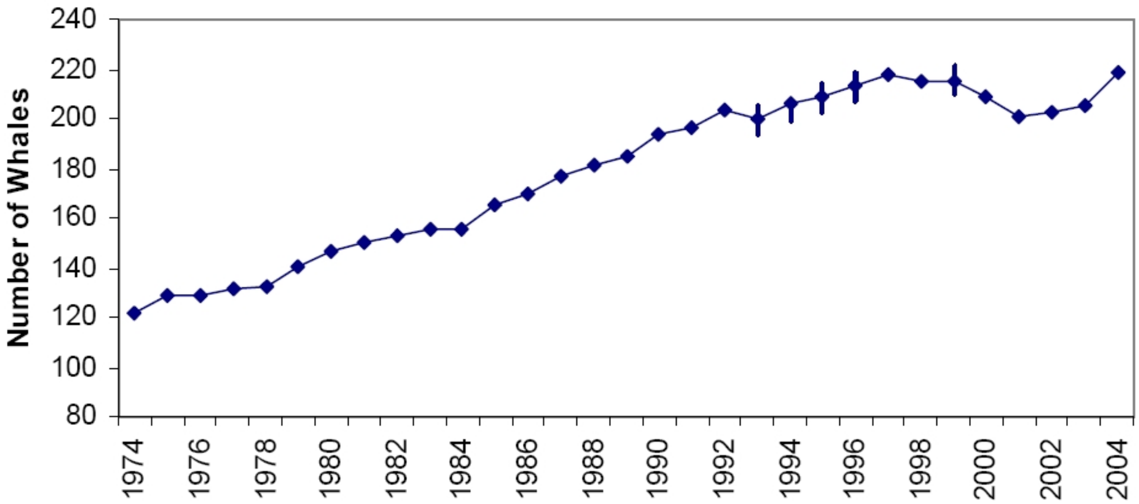


Figure 29. Time series of numbers of resident northern killer whales of the BC coast. From Olesiuk et al. (2005)

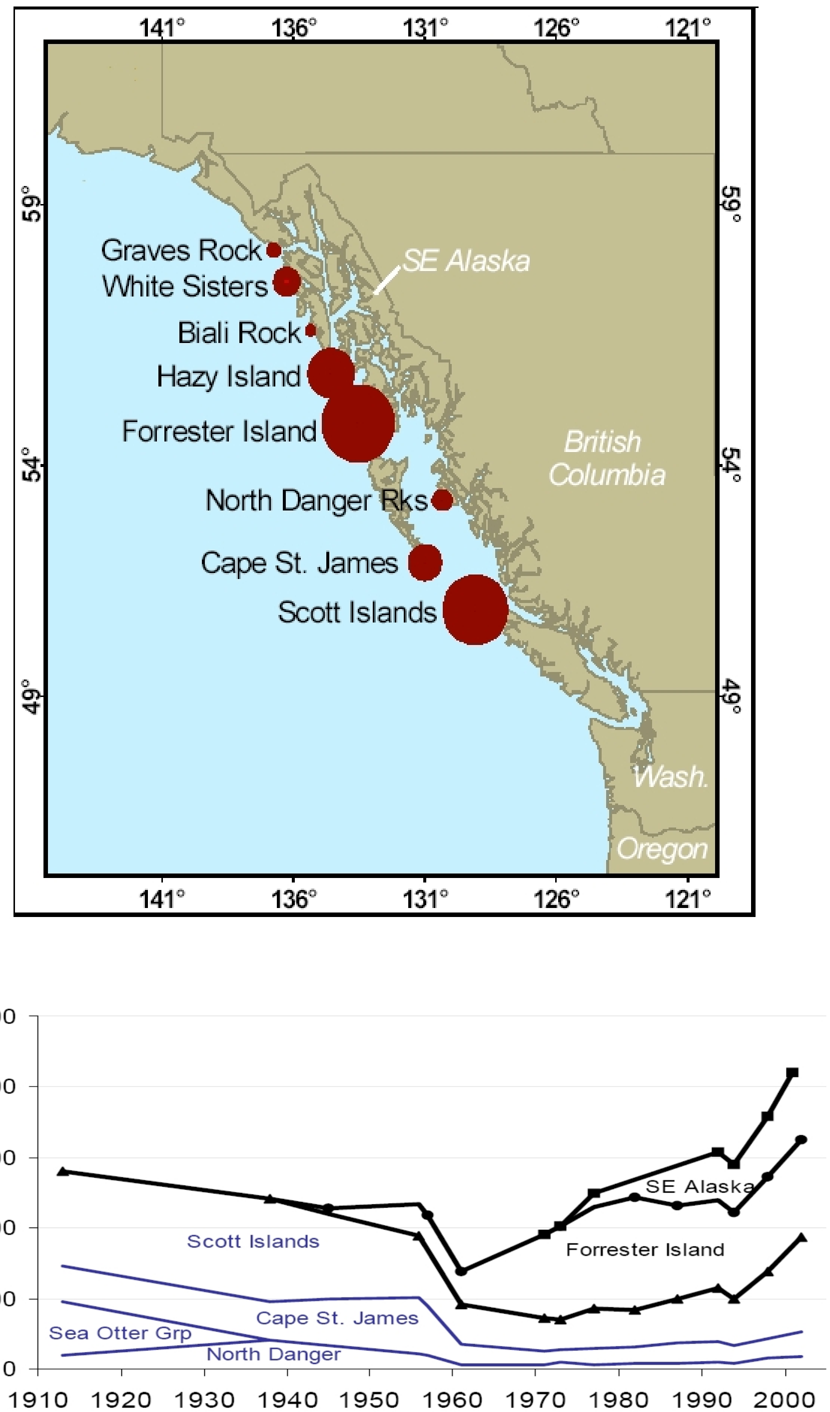


Figure 30: (upper panel) Steller sea lion breeding area with size of symbols proportional to pup production at each rookery in 2002. (lower panel) Time series of numbers of Stellar sea lions at various locations within the North Coast and Hecate Strait ecozone. Source: DFO (2003).

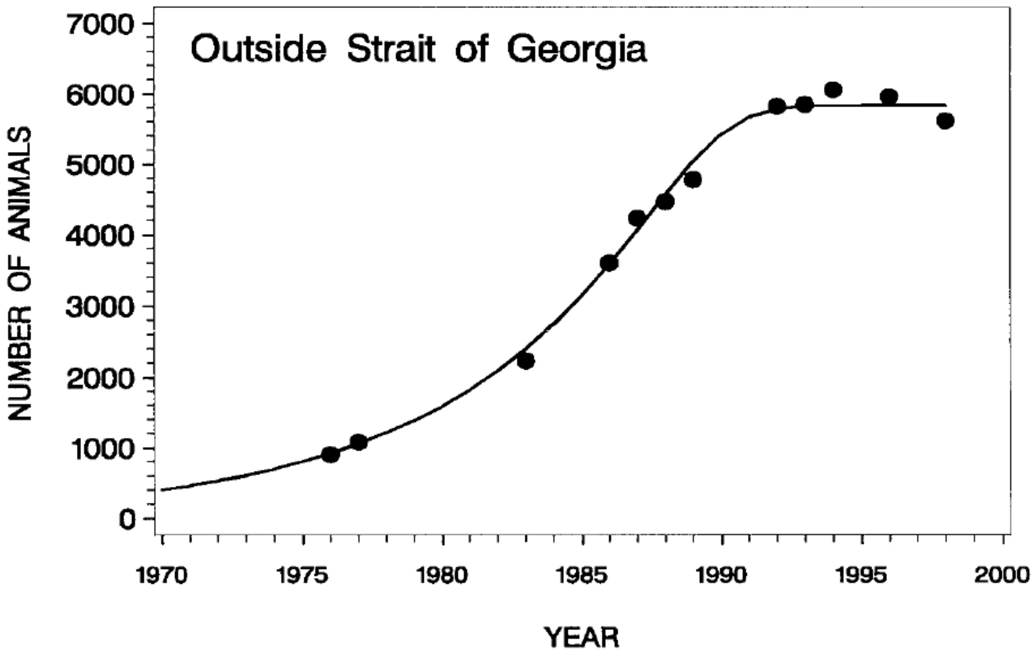


Figure 31: Time series of harbour seals outside the Strait of Georgia. Source: Olesiuk (1999).

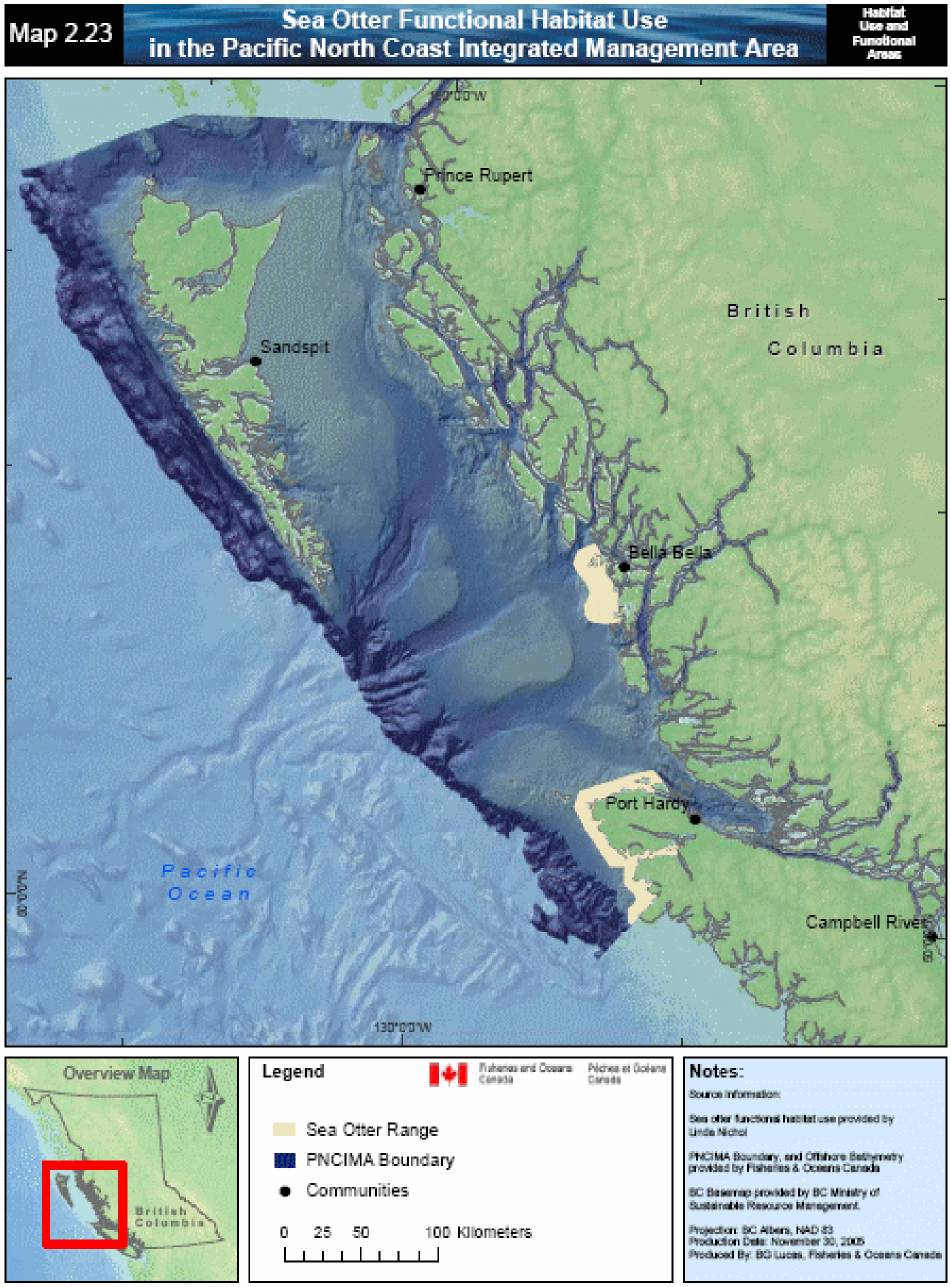


Figure 32: Sea otter habitat within North Coast and Hecate Strait ecozone. From Lucas et al. (2006).

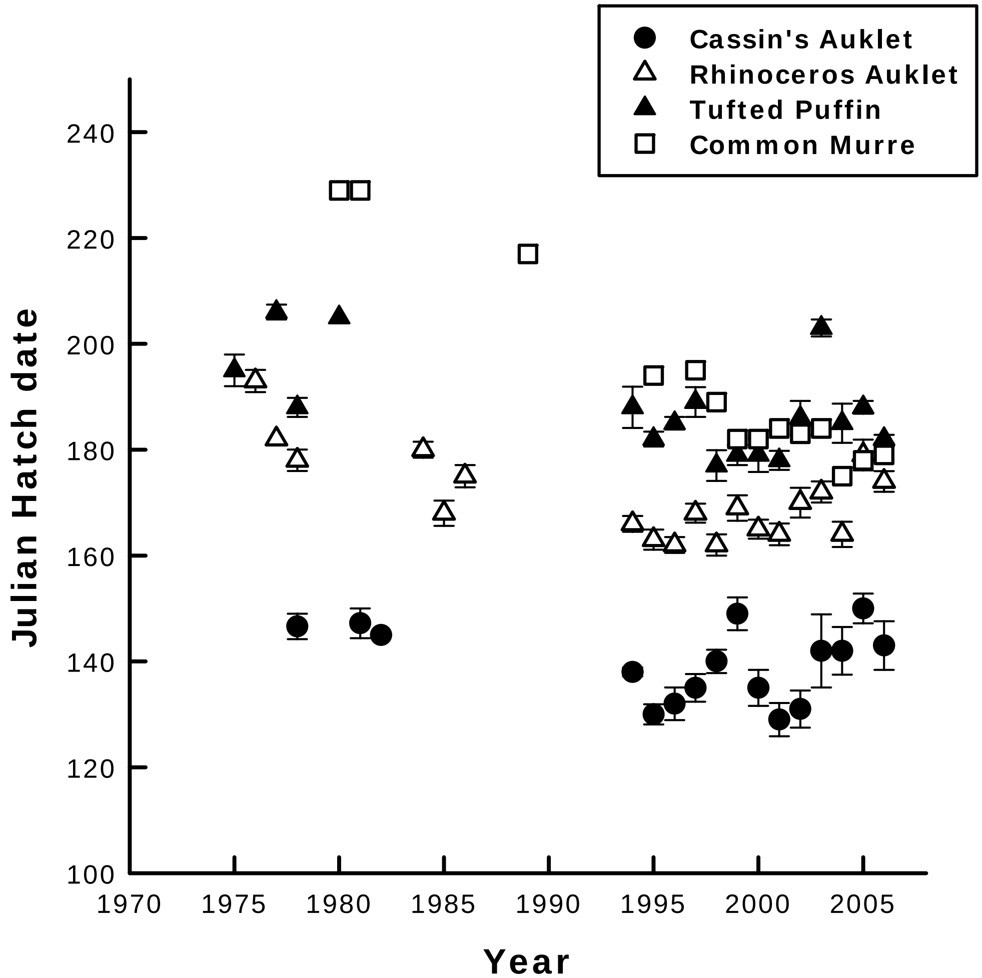


Figure 33: Timing of breeding for seabirds on Triangle Island, British Columbia, 1975-2006. Reported are mean hatching dates, with 95% confidence intervals, for Cassin's Auklets, Rhinoceros Auklets and Tufted Puffins, and dates when nestlings were first seen for Common Murres. Timing of breeding was close to long-term averages for all but Common Murres, which continue to breed early. (DFO 2007, contribution Mark Hipfner, EC/CWS)

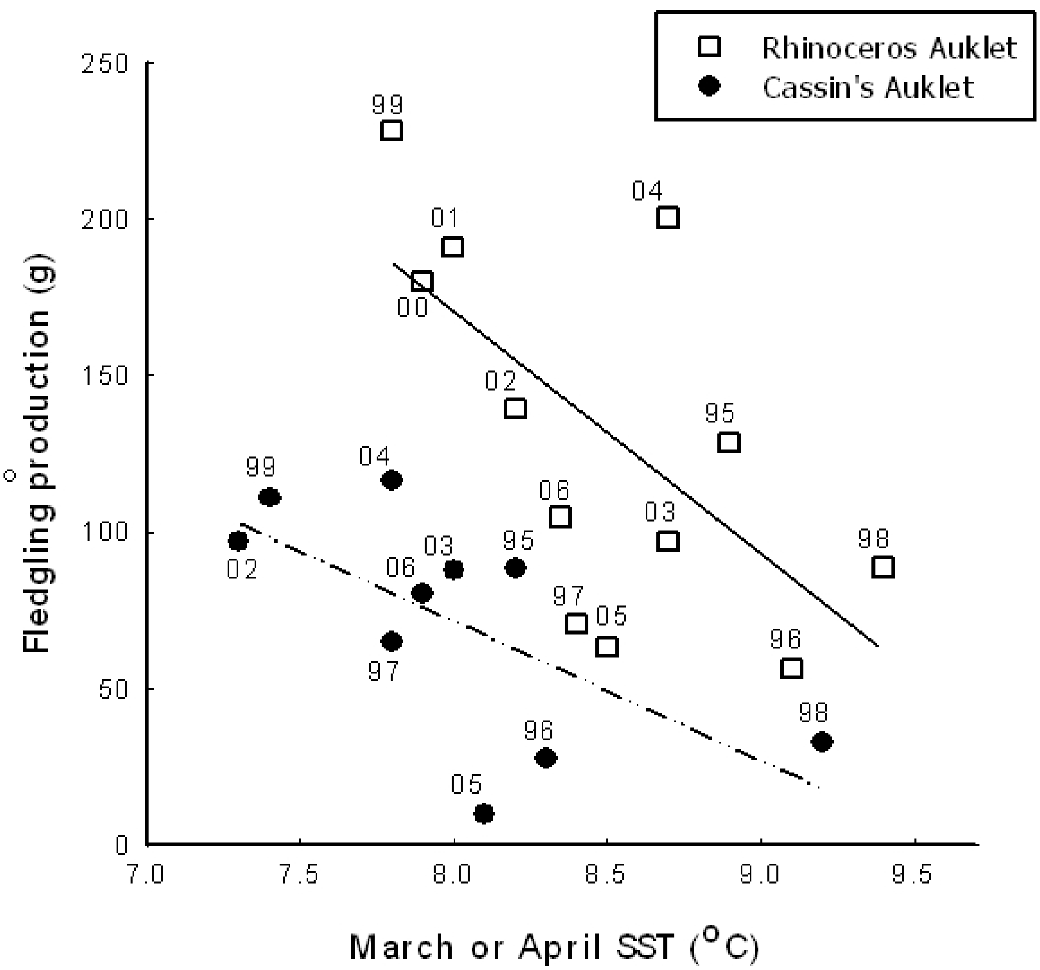


*Figure 34: Consequences of April sea surface temperatures, measured at the Pine Island Lighthouse station (50°35'N 127°26'), for Cassin's and Rhinoceros auklets breeding on Triangle Island, British Columbia, 1994-2006. Fledgling production is calculated as: hatching success * % fledging success * mean fledging mass; or in other words, the mean mass of fledged chick produced per egg laid (DFO 2007, contribution Mark Hipfner, EC/CWS).*

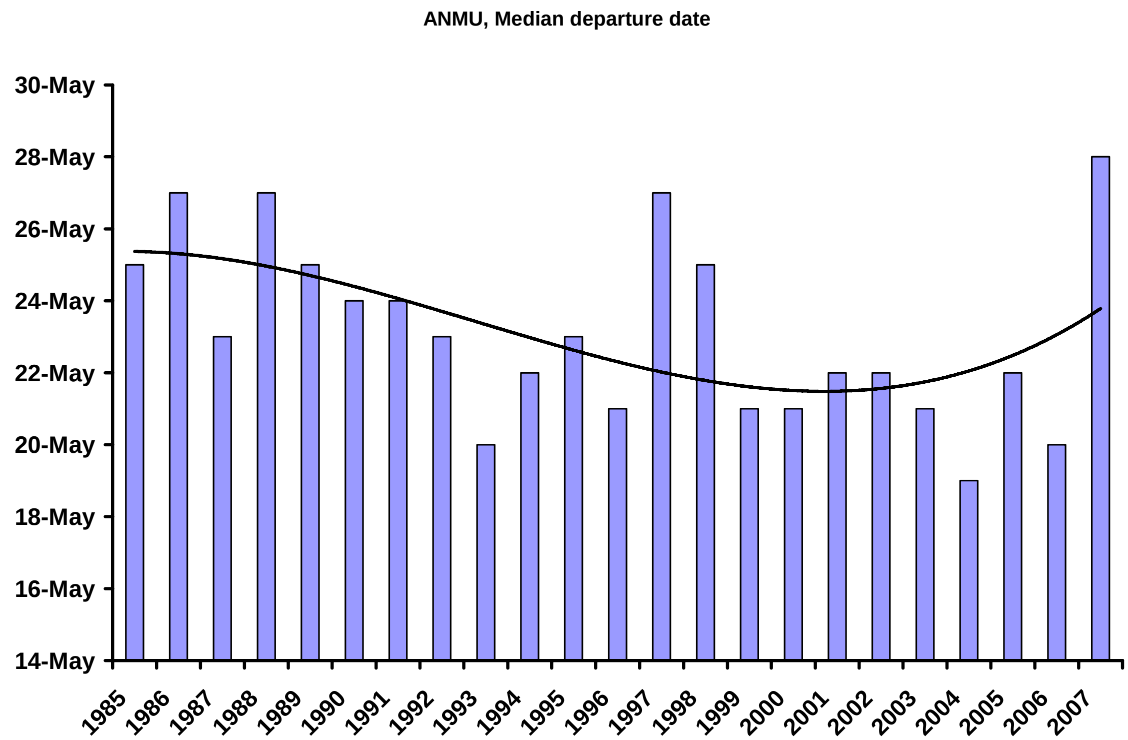


Figure 35: Median departure date of nestling Ancient Murrelets from the breeding colony from Reef Island (1985-1989) and nearby Limestone Island (1990 -2007), South East Moresby, Haida Gwaii. Source: Gaston (2007).

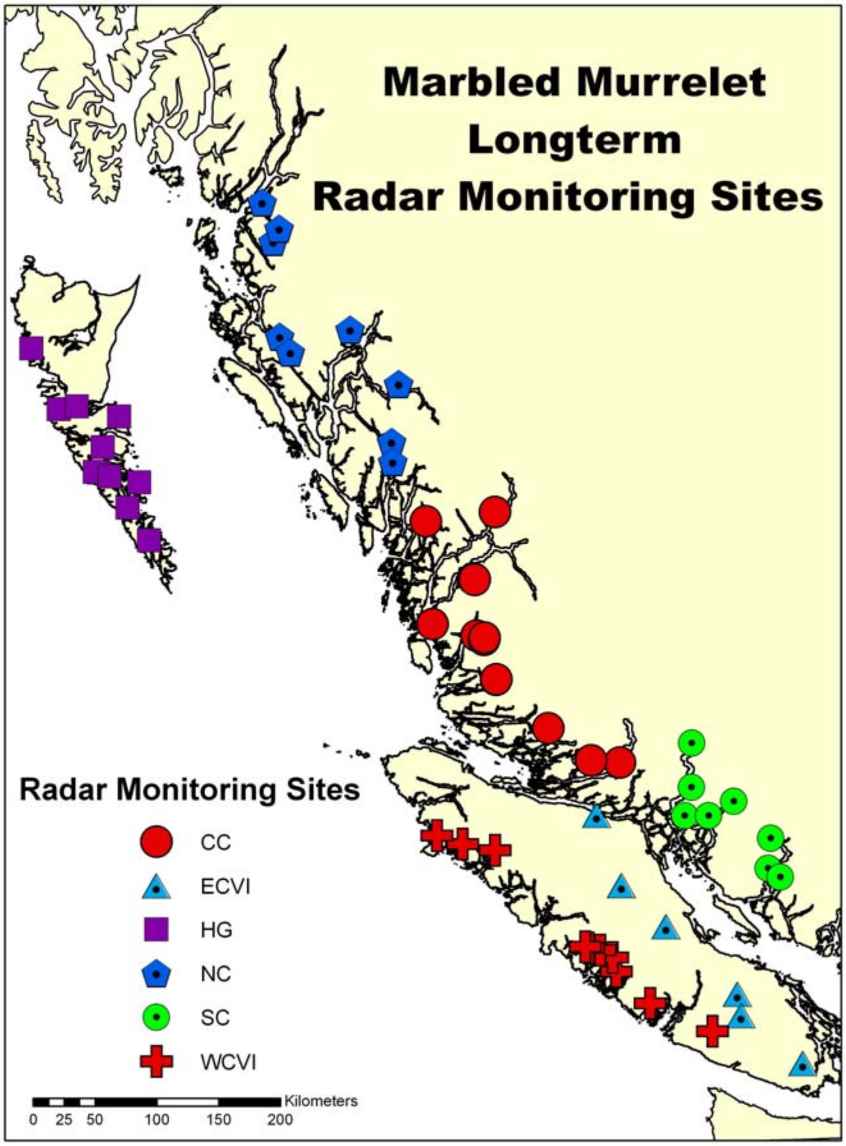


Figure 36: Station locations for monitoring of population trends for Marbled Murrelets in British Columbia in the six conservation regions using marine radar; CC = Central Coast, ECVI = East Coast of Vancouver Island; HG = Haida Gwaii, NC = North Coast, SC= South Coast; WCVI = West Coast Vancouver Island.

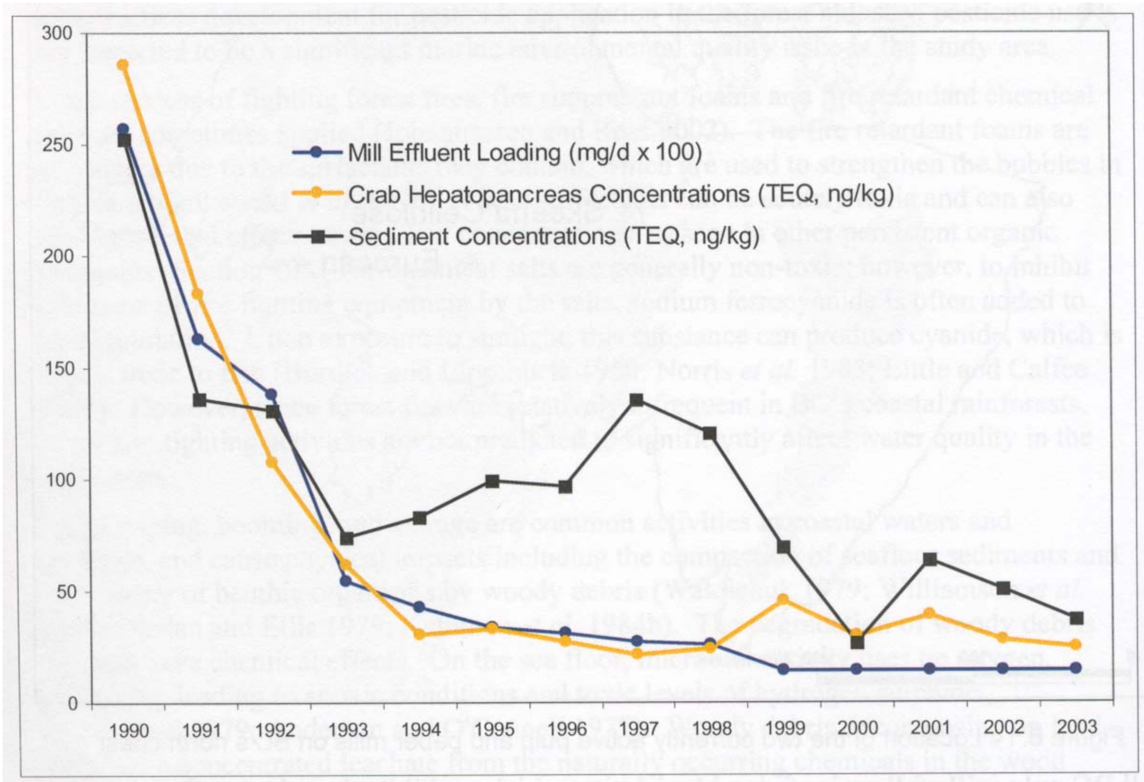


Figure 37: Dioxin and furan loadings in pulp mill effluent and concentrations in crab hepatopancreas and sediment collected near pulp mill outfalls. Data are the mean British Columbia pulp mills and reflect increasing federal regulations. Source: BC Ministry of Environment et al. (2006).