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Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2011/054 | **Document de recherche 2011/054**

State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2010

État des ressources physiques et biologiques et de certaines ressources halieutiques des écosystèmes des eaux canadiennes du Pacifique en 2010

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

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Correct citation for this publication:
La présente publication doit être citée comme suit :

Crawford, W.R. and J.R. Irvine. 2011. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/054. x + 163 p.

ABSTRACT

The near-record high number of returning Sockeye Salmon to the Fraser River was the good news story for 2010. Approximately 30 million adults returned, and of these about 17 million were headed for Shuswap Lake. These returns contrast with 2009 when fewer than 2 million sockeye migrated back to the Fraser. With such wide changes between years it is difficult to predict returns for 2011 with high certainty. The DFO prediction for 2011 is between 1.0 and 12 million (10% and 90% probabilities) if the low recent productivity persists. If on the other hand salmon have the long-term average productivity seen last year and in previous decades, between 1.7 and 15 million sockeye are predicted to return.

The story was reversed for Humboldt squid. Squid were found in record-high numbers in summer 2009 along the west coast, but in 2010 not even one was observed in British Columbia waters. Several causes have been proposed, but none proven.

The year 2010 started with extreme El Niño weather along the west coast, with strong southerly winds bringing warm, fresh ocean waters to the Oregon and British Columbia coast. These winds weakened in April and by summer the winds blew much more strongly than normal from the north, upwelling cool salty water along the outer coast. Waters of the Strait of Georgia shifted from cool to normal or even warm in 2010. La Niña conditions of late 2010 and early 2011 were linked to stronger westerly winds in the Pacific Ocean and cooler ocean waters along the coast. Overall the cool conditions prevailed in 2010, and this year was the third consecutive year with cooler than normal ocean temperatures along the Pacific Canadian coast.

Over the past decade and a half both the Pacific Decadal Oscillation and ENSO (El Niño – La Niña) have shifted phase together and reinforced the impact of each one on west coast ocean temperature. Whereas in the 1990s scientists would attribute changes in ocean temperatures and species compositions to changes in PDO or ENSO, they have recently been able to use these indices almost interchangeably in local waters to link physical changes in the ocean to shifts in abundance of one or several marine species.

Scientists monitor abundance and species of plankton in local waters to determine the quantity and quality of prey for larger species. Phytoplankton can be tracked by measuring chlorophyll in the ocean. Summer 2010 chlorophyll concentrations were often low in the southern Strait of Georgia and Juan de Fuca Strait, while fall chlorophyll concentrations were higher in Juan de Fuca Strait and slightly lower in the Strait of Georgia compared with previous years. The timing of the spring bloom in the Strait of Georgia is considered important for juvenile herring and salmon survival. Numerical models suggest that this bloom occurred in mid-April in 2010, compared to March to early April for most years. Bloom timing depends on local winds and cloud cover. A study of Rivers Inlet of Central BC discovered the spring bloom could be blown completely out of this short inlet by outflow winds. Its late development in 2009 could have been due to these winds. Studies of impacts of this outflow on local sockeye juveniles are ongoing.

Zooplankton species tend to shift from cold-water to warm-water types with corresponding shifts in local ocean temperature. Monthly surveys found the 2010 composition of cold-water copepods (a type of zooplankton) off Oregon was 4th highest in 15 years of observations. However, the species richness, which usually correlates with ocean temperature, was also high in 2010. These contrasting observations might be attributed to a warm ocean waters in winter

and cool summer of 2010. Similar surveys in British Columbia observed more cold-water copepods species.

Recent surveys found the that biomass of *Pandalus jordani* shrimp off central west coast Vancouver Island had increased in 2008, 2009, and 2010 from very low levels during 2004-2007. Such increases appear related to colder waters in 2006, 2007, and 2008 during the larval stages of the shrimp (this species has a 2-yr time lag from hatch to recruitment at age 2) and to low abundances of Pacific hake (a potential shrimp predator) in May surveys in 2008, 2009, and 2010. This survey in May also provides insight into populations of resident flatfish, such as sole, Pacific cod, halibut, and arrowtooth flounder. Biomass trends of key flatfish indicator species all increased in 2010, as did the biomass of the “cold water indicator” species walleye pollock.

Offshore Pacific hake (*Merluccius productus*) is a trans-boundary stock that exhibits seasonal migratory behavior, ranging from offshore and generally southern waters during the winter spawning season to coastal areas between northern California and northern British Columbia from spring to fall. In 2011, spawning biomass is estimated to have rebounded rapidly from a low in 2007 based on the strength of recent year classes (2005, 2006 and particularly 2008). However, estimates of spawning biomass are highly uncertain. The most recent coast-wide survey in 2009, using ship-based sonar sampling, was difficult to interpret due to large numbers of Humboldt squid among the hake.

Coastwide, herring adult biomass is generally low in all areas except the Strait of Georgia, where the stock remains somewhat high due to its near-record high biomass several years ago and indications of strong returns in 2011. Sardine numbers went from zero to many thousands of tonnes in the 1990s, but have declined since 2006. Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. Indices of eulachon abundance in central and southern British Columbia rivers remain at low levels. COSEWIC recently assessed eulachon, and designated stock from some BC rivers as Threatened and in others as Endangered.

The abundance of albacore tuna in BC coastal waters in 2010 was the second highest since 1990, and those caught were in cooler water than in previous years.

Counts of seabirds in Pacific Rim Marine Reserve on the west coast of Vancouver Island revealed many species increased in number over the past five years. However, on Triangle Island where seabird breeding depends critically on ocean conditions in April, the mean growth rate for chicks of Cassin’s auklet was extremely low in 2010 – in fact, the lowest in the 15-year time series by quite a wide margin. This poor growth is linked to late arrival of spring weather.

A Pacific North Coast Integrated Management Area (PNCIMA) Groundfish overview revealed several general trends. Gadoid (Pacific Cod, Walleye Pollock, Pacific Hake) stocks are stable or increasing. Most rockfish species are at low abundance with some being listed as Special Concern or Threatened by COSEWIC. Flatfish stocks appear to be stable. Sablefish stocks appear to be stable at low abundance. Lingcod and Elasmobranch (e.g. Spiny Dogfish) stocks appear stable.

Sockeye ocean survival was high for stocks in Barkley Sound on the west coast of Vancouver Island, attributed to cool ocean waters when they entered the ocean two years earlier. An assessment of ~60 years of escapement and catch data of five salmon species to the central and north coast suggests that Pink Salmon, with significant increases in escapements, are doing relatively well. Coho and Chinook Salmon are doing relatively poorly - declines over the time series were significant for Coho Salmon catches, escapements, and returns; and for Chinook Salmon catches and returns. A different picture can emerge from shorter-term studies. For example, the Chinook Abundance Index for stocks between SE Alaska and Oregon has increased and declined over 10 to 15 year cycles since 1979, and this index is presently increasing from a low in 2008.

The numbers of some baleen whales have increased following the end of whaling in the 1960s. Humpback whales are now most frequently sighted. Fin, blue and sei whales are observed much less frequently.

Oxygen concentrations in bottom waters at 150 metres depth in late summer dropped to lowest observed values in 2006 and 2009 off southwest Vancouver Island. Normal concentrations were observed in 2010. Lower oxygen concentrations were observed off the coast of Oregon and Washington in most summers since 2002, perhaps due to stronger upwelling winds there in summer.

Finally, biophysical features and human uses on the BC coast are illustrated by 260 new maps prepared by the BC Marine Conservation Analysis Project Team.

RÉSUMÉ

Un nombre quasi-record de saumons rouges retournant frayer dans le fleuve Fraser fut la bonne nouvelle de 2010. Environ 30 millions de saumons adultes ont remonté le fleuve dont 17 millions vers le lac Shuswap. Cette grande remontée se démarque fortement de 2009 ou moins de deux millions de saumons rouges sont retournés au fleuve Fraser. Étant donné la forte variabilité observée au cours des deux dernières années, il s'avère difficile de faire une prévision des retours pour 2011. La prévision du MPO pour 2011 est de 1.0 à 12 millions (probabilité de 10% et 90%) si la faiblesse de la production récente persiste. Dans le cas où la productivité moyenne à long terme du saumon observée l'année dernière et dans les décennies précédentes demeure, ces limites seraient de 1.7 à 15 millions.

Par ailleurs, un nombre record de calmars de Humboldt est apparu le long de la côte ouest durant l'été 2009 mais, en 2010, pas un seul n'a été observé dans les eaux de la Colombie-Britannique. Quelques explications ont été avancées, mais sans preuve à l'appui.

Au début de l'année 2010, des conditions météorologiques extrêmes associées à El Niño associées avec de forts vents du sud ont apporté de l'eau chaude et fraîche sur les côtes de l'Orégon et de la Colombie-Britannique. Ces vents diminuèrent en avril et, à l'été, de forts vents du nord provoquèrent une remontée d'eau froide et salée le long de la côte extérieure. La température des eaux intérieures du détroit de Géorgie passa de froide à normale ou même chaude en 2010. Les conditions associées à La Niña de la fin 2010 et du début 2011 ont amené des vents de l'ouest plus forts sur l'océan Pacifique et des eaux plus froides le long de la côte. Dans l'ensemble, les conditions froides ont dominé en 2010, et cette année fut la troisième année consécutive de température océanique plus froide que la normale le long de la côte canadienne du Pacifique.

Au cours de la dernière décennie et demie, l'oscillation décennale du Pacifique et ENSO (El Niño – La Niña) ont varié en phase en accentuant l'influence de l'un et l'autre sur la température océanique de la côte ouest. Tandis que durant les années 1990, les scientifiques attribuaient les changements de température océanique et la composition des espèces soit à l'ODP ou à l'ENSO, ils ont récemment pu utiliser ces indices presque indifféremment pour relier les changements physiques des eaux locales de l'océan aux variations de l'abondance d'une ou plusieurs espèces marines.

Les chercheurs surveillent l'abondance et les espèces de plancton des eaux locales afin de déterminer la quantité et la qualité de proie pour les plus grosses espèces. Le phytoplancton peut être suivi en mesurant les concentrations de chlorophylle dans l'océan. En 2010, des valeurs généralement faibles de chlorophylle furent observées durant l'été dans la partie sud du détroit de Géorgie et dans le détroit de Juan de Fuca, alors que les concentrations de chlorophylle en automne étaient plus élevées dans le détroit de Juan de Fuca et moindrement plus faibles dans le détroit de Géorgie en comparaison de la moyenne des années précédentes.

On s’attend à ce que le moment de la prolifération printanière dans le détroit de Géorgie soit important pour la survie des saumons et harengs juvéniles. Les résultats des modèles numériques de ce détroit donnent à penser que cette prolifération s’est produite à la mi-avril en 2010, par rapport au mois de mars et début avril pour la plupart des années. Le moment dépend des vents locaux et de la couverture nuageuse. Une étude du bras de mer Rivers dans la partie centrale de la C.-B. a démontré que la prolifération printanière peut être poussée hors de ce court bras de mer par des vents de terre. Il se peut que ces vents soient responsables de la prolifération tardive en 2009. Une étude de l’effet de ces vents de terre sur le saumon rouge juvénile local est en cours.

Les espèces de zooplancton ont tendance à alterner entre les espèces d’eau froide et d’eau chaude selon les variations de la température océanique locale. Des relevés mensuels ont révélé que la composition de copépodes d’eau froide (un type de zooplancton) au large de l’Orégon arrive au quatrième rang de 15 années d’observations. Cependant, la diversité des espèces de copépodes, ce qui est habituellement en corrélation avec la température océanique, était également élevée en 2010. Ces différentes observations peuvent être attribuées aux eaux océaniques chaudes durant l’hiver et froide durant l’été de 2010. Des relevés semblables en Colombie-Britannique ont révélé plus d’espèces de copépodes d’eau froide.

Des relevés récents ont indiqué une augmentation de la biomasse de crevettes Pandalus jordani au large de la partie centrale de la côte ouest de l’île de Vancouver en 2008, 2009 et 2010 par rapport aux très faibles quantités de 2004 à 2007. Il semble que ces augmentations correspondent à la présence d’eau froide en 2006, 2007 et 2008 durant le stade larvaire des crevettes (il y a 2 ans entre l’éclosion de cette espèce et son recrutement) et à la faible abondance du merlu du Pacifique (un prédateur potentiel de la crevette) observée en mai 2008, 2009 et 2010. Ce relevé en mai nous permet aussi de mieux comprendre les populations de poisson plat résident tel que plie rouge, morue du Pacifique, flétan et plie à grande bouche. Les tendances de biomasse des espèces indicatrices clés de poisson plat ont toutes augmenté en 2010, de même que la biomasse de l’espèce «indicatrice d’eau froide», la goberge de l'Alaska.

Le merlu du Pacifique du large (Merluccius productus) est un stock transfrontalier qui exhibe un comportement migratoire saisonnier, allant des eaux du large et surtout au sud durant la saison de fraye d’hiver jusqu’aux régions côtières entre le nord de la Californie et le nord de la Colombie-Britannique du printemps à l’automne. De fortes classes d’âge récentes (2005, 2006 et surtout 2008) semblent indiquer que la biomasse de géniteurs a rebondi rapidement en 2011 du faible niveau de 2007. Cependant, une grande incertitude entoure l’estimation de la biomasse de géniteurs. Il a été difficile d’évaluer le relevé le plus récent de 2009 sur l’ensemble de la côte, utilisant un sonar pour effectuer l’échantillonnage à bord du navire**,** en raison de l’abondance du calmar de Humboldt parmi les merlus.

En règle générale, la biomasse du hareng adulte sur l’ensemble de la côte est faible dans tous les secteurs sauf le détroit de Géorgie ou le stock demeure assez abondant par suite d’un niveau quasi record il y a quelques années et des indications d’une forte remontée en 2011. Le nombre de sardines est allé de zéro à plusieurs milliers de tonnes durant les années 1990, mais a sensiblement diminué depuis 2006. On observe un déclin à long terme des populations d'eulakane dans plusieurs rivières à l'intérieur de son aire de répartition qui s’étend de la Californie jusqu'à l’Alaska. Les indices de l’abondance d'eulakane dans les rivières des parties centrale et sud de la Colombie-Britannique demeurent à des niveaux faibles. COSEPAC a récemment évalué l’eulakane et des stocks désignés de certaines rivières de la C.-B. comme étant «menacé» tandis que les populations de certaines autres rivières ont été désignées «en voie de disparition».

L’abondance du thon blanc dans les eaux côtières de la C.-B. en 2010 fut la deuxième plus élevée depuis 1990, et ils ont été capturés dans des eaux plus froides que les années précédentes.

Le décompte des oiseaux marins dans la réserve naturelle Pacific Rim de la côte ouest de l'île de Vancouver révèle une augmentation du nombre de plusieurs espèces au cours des cinq dernières années. Cependant, sur l'île Triangle où le succès de la reproduction des oiseaux marins repose principalement sur les conditions océaniques en avril, le taux de croissance moyen des poussins du starique de Cassin était extrêmement faible en 2010 – en fait, nettement le plus faible de la série chronologique de 15 ans. Cette faible croissance est liée à l'arrivée tardive du printemps.

Plusieurs tendances générales furent mises en évidence par un sommaire des divers stocks de poissons de fond du ZGICNP. Les stocks de gadidés (morue du Pacifique, goberge de l'Alaska, merlu du Pacifique) sont stables ou augmentent. La plupart des espèces de sébaste sont à un faible niveau d'abondance et certains sont désignées préoccupantes ou menacées par COSEPAC. Les stocks de poissons plats semblent stables. Les stocks de morue charbonnière semblent être stables mais à un niveau d'abondance faible et les stocks de la morue-lingue et d'élasmobranche (par ex. aiguillat commun) semblent également stables.

Le saumon rouge du détroit de Barkley sur la côte ouest de l'île de Vancouver a connu un taux de survie en mer élevé, une conséquence des eaux océaniques froides lors de leur entrée dans l'océan deux ans plus tôt. Une évaluation des données sur 60 années de l'échappée et des retours vers la côte centrale et la côte ouest de cinq espèces de saumon nous donne à penser que le saumon rose, qui affiche une augmentation importante de l'echappee, prospère dans cette région. Le saumon coho et quinnat sont en plus ou moins mauvais état – la série chronologique indique un déclin important des prises, des retours et de l'échappée du saumon coho et des prises et des retours du saumon quinnat. Des études à plus court terme nous présentent un tableau différent. Par exemple, l'indice d'abondance du saumon quinnat pour les stocks entre la partie sud est de l'Alaska et l'Orégon a augmenté et diminué durant des cycles de 10 à 15 années depuis 1979, et cet indice augmente actuellement par rapport à son niveau bas de 2008.

Le nombre de certains cétacés à fanons a augmenté depuis le moratoire contre la chasse à la baleine implémenté dans les années 1960. On observe maintenant plus souvent le rorqual à bosse. Les rorquals bleus, communs et boréaux sont observés moins fréquemment.

Les valeurs de la concentration d'oxygène de la fin d'été dans les eaux de fond à une profondeur de 150 mètres étaient les plus faibles jamais observées en 2006 et 2009 au large du sud-est de l'île de Vancouver. Des concentrations normales ont été observées en 2010. Par contre, les concentrations d'oxygène sont plus basses au large de l'Orégon et de Washington durant la plupart des étés depuis 2002 probablement suite à la remontée d'eau froide provoquée par les vents d'été dans cette région.

Finalement, les caractéristiques biophysiques et les utilisations anthropiques de la côte de la C.-B. sont illustrées par 260 nouvelles cartes préparées par la Marine Conservation Analysis Project Team de la C.-B.

INTRODUCTION

This report is the twelfth in an annual series on the state of physical, biological, and selected fishery resources of Canadian Pacific marine ecosystems. The region supports important resident and migratory populations of invertebrates, groundfish and pelagic fishes, marine mammals and seabirds. Monitoring the physical and biological oceanographic conditions and fishery resources of the Pacific Region is done semi-regularly by scientific staff in several government departments, to understand the natural variability of these ecosystems and how they respond to both natural and anthropogenic stresses. Support for these programs is provided by Fisheries and Oceans Canada, Environment Canada, Parks Canada and various other agencies. Additional information is provided by the US National Oceanographic and Atmospheric Administration (NOAA), University of Victoria, Simon Fraser University, and the University of British Columbia.

Information for this report was presented at the annual meeting of the Fisheries Oceanography Working Group (FOWG) at the Institute of Ocean Sciences, Sidney, BC, on Feb. 24 to 25, 2011 chaired by Jim Irvine and Bill Crawford, both of Fisheries and Oceans Canada. This summary report is based on contributions by participants.

This report is to be referenced as:

Crawford, W.R. and J.R. Irvine. 2011. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/054. x + 163 p. available at: http://www.pac.dfo-mpo.gc.ca/science/psarc-ceesp/osrs/index-eng.htm.

ASSESSMENT HIGHLIGHTS

2010 – Warm and Fresh, then Cool and Salty

After a cool ocean year in 2009, Coastal Pacific Canadian waters were warmer and fresher than normal in the first three to four months of 2010, due to stronger southerly winds of the El Niño winter. Conditions shifted to cool and salty at Langara and Kains Islands (Fig. 1 below) and at other outer coast stations in April through September 2010, due to strong winds from the north along the west coast. Temperatures at Race Rocks and Departure Bay in the Salish Sea in summer 2010 were warmer than average (Chandler RD2011, p127). Temperatures at Langara and Kains warmed somewhat through autumn, then turned cool in late 2010 and into 2011.

Waters of the nearby Strait of Georgia warmed at most depths through the first half of 2010, from relatively cool temperatures of previous years. (Masson RD2011, p111, p110; Dewey RD2011, p107).

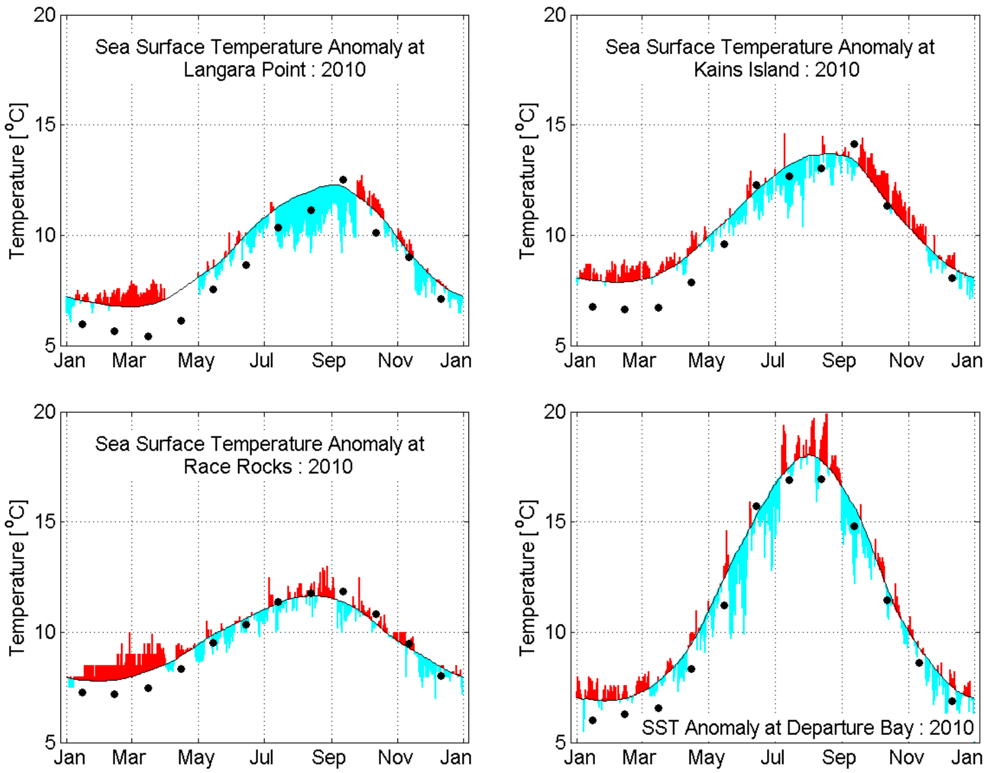
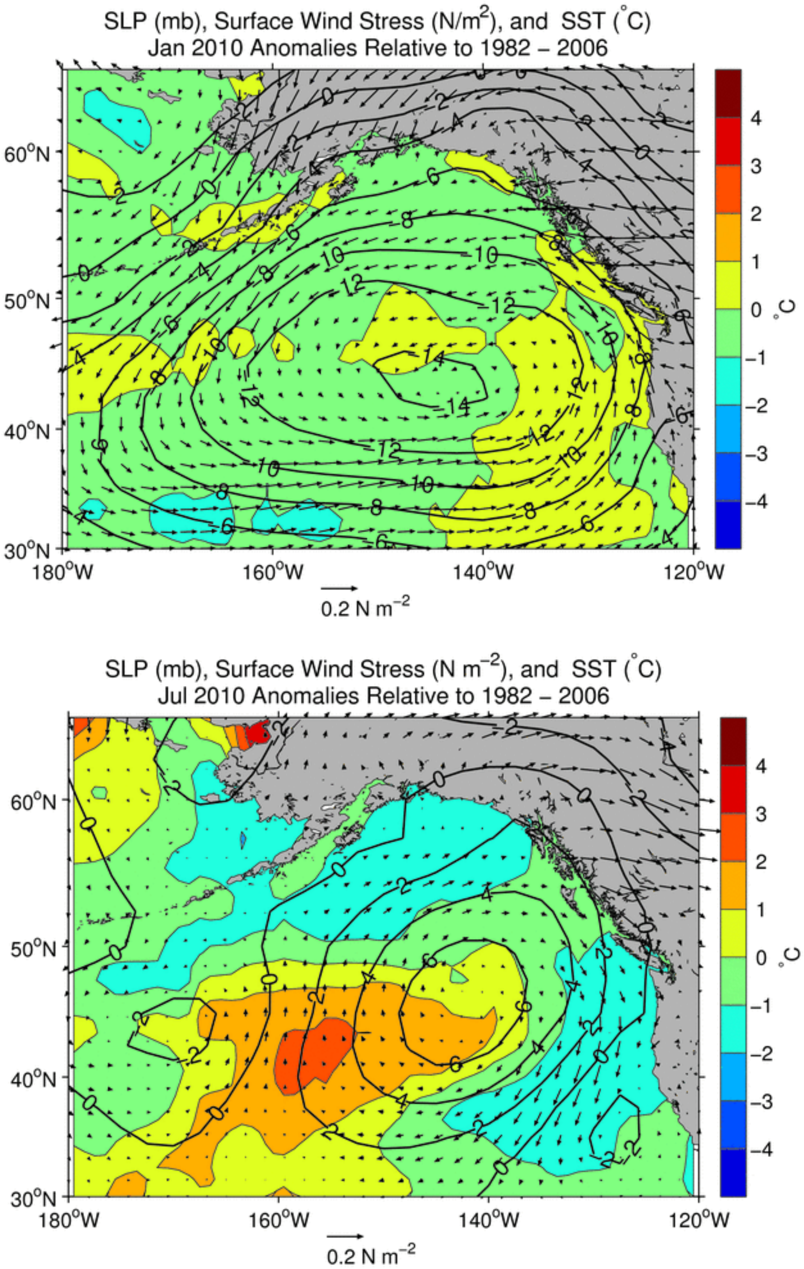


Figure 1. Sea surface temperature measured at lighthouses and shore stations (Chandler RD2011, p127). Langara Island is off the northwest tip of Haida Gwaii; Kains Island is off northwest Vancouver Island; Race Rocks is on the north side of Juan de Fuca Strait; and Departure Bay is in Nanaimo in the Strait of Georgia. Red denotes temperature above normal for the time of year; blue denotes temperature below normal while black dots represent the monthly temperature anomalies observed in 2009.

The 2010 winter and summer weather patterns (Fig. 2) included formation of a very intense Aleutian Low Pressure system in January and February (Hourston and Thomson RD2011, p40). The lowest air pressure in its centre was almost 14 millibars lower than typical for January. Because winds flow counter-clockwise around this low pressure system, coastal winds were much stronger than normal, and pushed relatively warm fresh water toward shore.
It was the warm air of this weather system that melted so much snow in January and February, just before the 2010 Winter Olympics in Vancouver.



The stronger, counter-clockwise rotating winds in winter in the centre of the Aleutian Low drew cold and salty waters closer to the ocean surface of the centre of the Gulf of Alaska. These formed a layer of salty water between 90 and 150 metres depth across this gulf (Freeland RD2011, p28; Robert et al. RD2011, p31).

Figure 2. (from Hourston and Thomson RD2011, p40) Anomalies of air pressure, winds and ocean temperature in Jan. 2010 (top) and July 2010 (bottom). Black contours denote air pressure anomalies in millibars. Arrows show wind stress anomalies in Nm^{-2}. Colours show sea surface temperature anomalies in °C.

The opposite weather system took over in July 2010. Normally the North Pacific High Pressure System extends northward into the Gulf of Alaska in summer. In July this system moved even farther northward than normal, and strengthened, so that the normally gentle winds from the north were much stronger along the BC and northern USA coast, as can be seen in Fig. 2, bottom panel. By early 2011 the winds had shifted into a typical La Niña weather pattern, with much stronger winds from the west in the Gulf of Alaska, and cooler coastal ocean temperatures.

2010 – Some Biological Surprises

Fraser River Sockeye Salmon

The biggest event in 2010 was the large return of Sockeye Salmon to the Columbia/Okanagan and Fraser rivers. The Fraser Sockeye Salmon return was amongst the largest observed in the past 100 years, bringing a bonanza Sockeye fishery to southern British Columbia in summer and early autumn 2010, with commercial, sports and First Nations all benefiting. Preliminary estimates indicate 30 million Fraser Sockeye Salmon returned (i.e. catch plus escapement) in 2010, with 17 million of these from the Shuswap Lake populations alone. The 2010 Fraser Sockeye returns contrasted significantly with the previous year's (2009) near-record low (~1.3 million) returns that fell at the extreme low end of the forecast distribution.

Fraser Sockeye productivity in 2009 had been amongst the lowest on record, following over a decade of systematic decreases in productivity exhibited by most stocks. Most Fraser Sockeye

Salmon take four years from egg to their return as adults to spawn. During these years there are very few observations of these fish as they hatch, grow in fresh water, enter the ocean and circle the Northeast Pacific Ocean. Scientists typically use the number of spawners four years earlier to predict the numbers returning. The uncertainty surrounding predictions would be reduced if the ratio of adult returns to their previous (parental) generation spawners (i.e. productivity) remained constant over the years. However, starting as early as the 1950's and 60's, this ratio has systematically decreased for many stocks and was particularly low in 2009.

Given the systematic decreases in productivity over time and the particularly low productivity in 2009, DFO recommended a forecast that assumed recent lower stock productivity for 2010; a forecast that assumed long-term average productivity for 2010 returns was also presented but had a lower degree of belief. The 2010 Fraser Sockeye returns fell at the high end of the recommended forecast distribution. Most stocks were in the middle of the forecast distribution that assumed long-term average productivity. Notable exceptions included Shuswap Lake stocks that had exceptionally high productivity in 2010 (Grant RD2011, p125).

The recommended forecast for Fraser Sockeye Salmon returns in 2011 again assumes that recent lower productivity conditions will persist. Under this scenario there is a one in ten chance (10% probability) that returns will be at or below 1.0 million, and a nine in ten chance they will be at or below 12.1 million. The mid-point of this distribution is 3.2 million (one in two chance returns will be above or below this value). Under the alternate, and presumably less likely, assumption that long-term average productivity conditions will persist, there is a 10% probability returns will be at or below 1.7 million, a 90% probability they will be at or below 15.1 million and a 50% probability they will be at or below 4.6 million (Fig. 3).

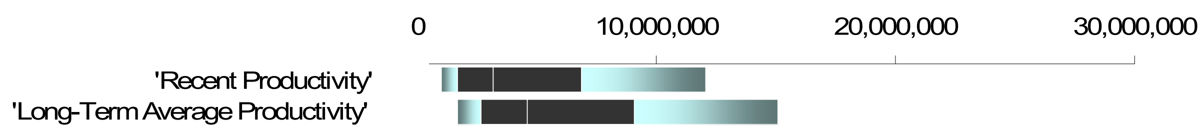


Figure 3. (from Grant RD2011, p125) 2011 forecast probability distributions for all Fraser Sockeye Salmon stocks. Black horizontal bars represent the 25% to 75% probability distribution range, the 50% probability level is indicated by the white vertical line and the blue (lighter) horizontal bars represent the 10% to 90% probability distribution range. Separate distributions are provided for the two forecast scenarios: 'Recent Productivity' and 'Long-Term Average Productivity.'

Clearly we are in an era of very uncertain times for predicting Sockeye Salmon returns to the Fraser River. The Cohen Commission is investigating all aspects of Fraser River Sockeye Salmon health, especially the low returns of 2009 and high returns of 2010.

Humboldt Squid

The second major surprise was the complete absence of Humboldt Squid in BC (Forrest et al. RD2011, p89). These invaders arrived from the south in summer in the early 2000s and reached maximum numbers in the summer of 2009, extending all along the continental shelf of BC, where they were caught by the tonne in many of the test trawls of the summer hake survey. In previous decades they were confined mostly to Central American and Mexican waters. Their sightings in 2010 were confined to waters south of Oregon, and ocean features such as ocean oxygen concentrations and temperatures are considered as factors in their distribution.

Biological Linkages between Spring Bloom Timing and Fish and Bird Production

Phytoplankton are a major source of food for zooplankton, which in turn are fed upon by many species in the ecosystem including salmon and birds. In some coastal areas of BC a spring phytoplankton bloom is closely followed by a zooplankton bloom (Allen et al. RD2011, p116). The relative role of nutrients, temperature, light, and wind in determining the timing and intensity of spring blooms and linkages further up the food chain are areas of active research reported on at this year's State of Ocean Workshop.

Chlorophyll concentrations can be measured from research ships and provide a reliable estimate of the concentration of phytoplankton in the ocean. Peña (RD2011, p113) reports that chlorophyll concentrations in the Strait of Georgia are generally high and variable in spring, low during the summer and fall, and lowest during winter. Spring concentrations in Juan de Fuca Strait are usually lower than in the Strait of Georgia, perhaps due to strong vertical mixing, but are similar at other times of the year. In 2010 chlorophyll concentrations were generally close to the average from 2004-2009. However, summer chlorophyll concentrations were often low in the southern Strait of Georgia and Juan de Fuca Strait while fall chlorophyll concentrations were higher in Juan de Fuca Strait and slightly lower in the Strait of Georgia compared with those observed in previous years. Ship-based sampling reveals that diatoms tend to dominate the phytoplankton populations in the Strait of Georgia in spring and dinoflagelates in summer.

Allen et al. (RD2011, p116) used a biophysical model to predict spring blooms in the Strait of Georgia. They defined the spring bloom to be the time of the peak of the bloom, which occurs as the nitrate at the surface drops to zero, which in 2010 was 16 April (Fig. 4). This figure is instructive as it shows that chlorophyll concentrations over time can be multi-modal, and bloom timing dates can vary depending on how one defines the bloom and collects data. On several occasions during 2010, strong winds deepened the mixed water layer, postponing the development of the bloom.

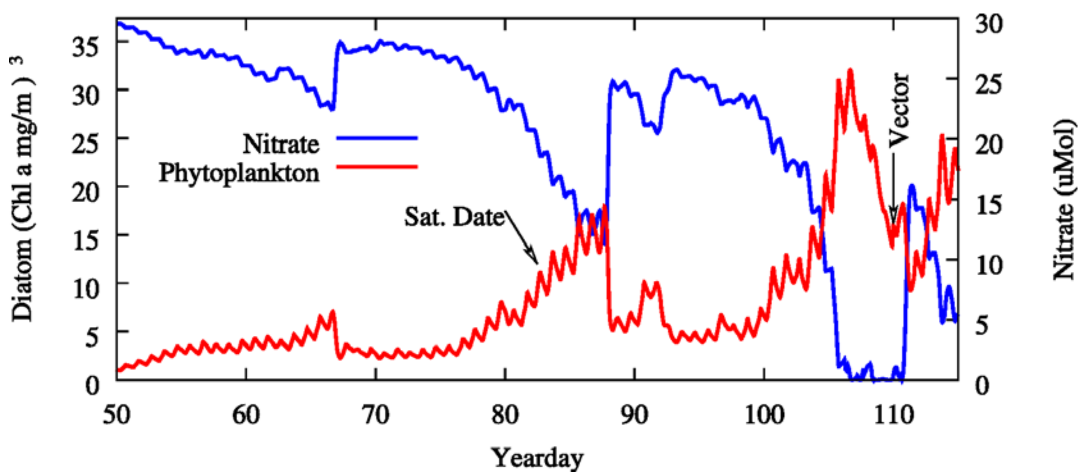


Figure 4 (from Allen et al. RD2011, p116): Modelled time series for spring 2010 in Strait of Georgia showing phytoplankton chlorophyll a (in red) and nitrate (in blue). The spring bloom peaked on day 106, April 16. Marked are day 82, March 23, the date that satellite data show the start of the spring bloom, and day 110, April 20, when, sampling from the Vector (Peña RD2011, p113), showed that the spring bloom was over.

Pawlowicz et al. (RD2011, p137) applied the same model further north in Rivers Inlet. Here the timing of the spring bloom is less governed by variations in available light, and can be inhibited by wind-driven mixing and advection. For instance, the 2009 spring bloom was two weeks later than 2008, apparently the result of strong late outflow winds moving surface currents containing phytoplankton out of the fjord, delaying the onset of the bloom within the inlet. In 2010, lower than normal spring and summer river flows in the area (Morrison RD011, p131) may have been partly responsible for the early large spring bloom reported by Pawlowicz et al. (RD2011, p137).

Interestingly, advection of plankton-rich water from Rivers Inlet might provide needed prey for seabirds and salmon in Queen Charlotte Sound. Hipfner (RD2011, p142) found the mean growth rate for the zooplanktivorous Cassin's auklet on Triangle Island was extremely low in 2010 – in fact, the lowest in the 15-year time series by quite a wide margin. In general, the auklets' offspring grow more quickly and fledge at heavier masses in cold-water years, because timing of their hatching is strongly temporally matched with the phenology of an important prey species, the copepod *Neocalanus cristatus*.

Using chlorophyll measurements from SeaWiFS satellite, Borstad et al. (2011) linked the survival of Rhinoceros auklets on Triangle Island and Sockeye Salmon from nearby Smith Inlet to spring chlorophyll concentrations measured by satellite. Irvine et al. (2010) predicted marine survivals for Chilko Lake Sockeye Salmon returning in 2010 and 2011 using a strong correlation between spring chlorophyll concentrations and marine survivals of Chilko Lake Sockeye Salmon from previous years. Measured survivals for fish that returned in 2010 were within the prediction interval; predicted survivals for fish returning in 2011 are low (~2%).

Gower (RD2011, p26) tracked the phytoplankton concentrations in surface waters of the Gulf of Alaska with satellite imagery of chlorophyll. Measurements over the past 13 years revealed a massive bloom in phytoplankton in late summer 2008. Growth of phytoplankton in the Gulf is normally limited by availability of iron, and an Alaskan volcano whose iron-carrying dust spread over the gulf is believed to have triggered this bloom in 2008 (Hamme et al. 2010). This bloom did not return in the summers of 2009 or 2010.

In conclusion, the timing of the spring bloom plays a major role in our coastal marine ecosystem, although the relative importance of light, wind, and discharge can vary among regions.

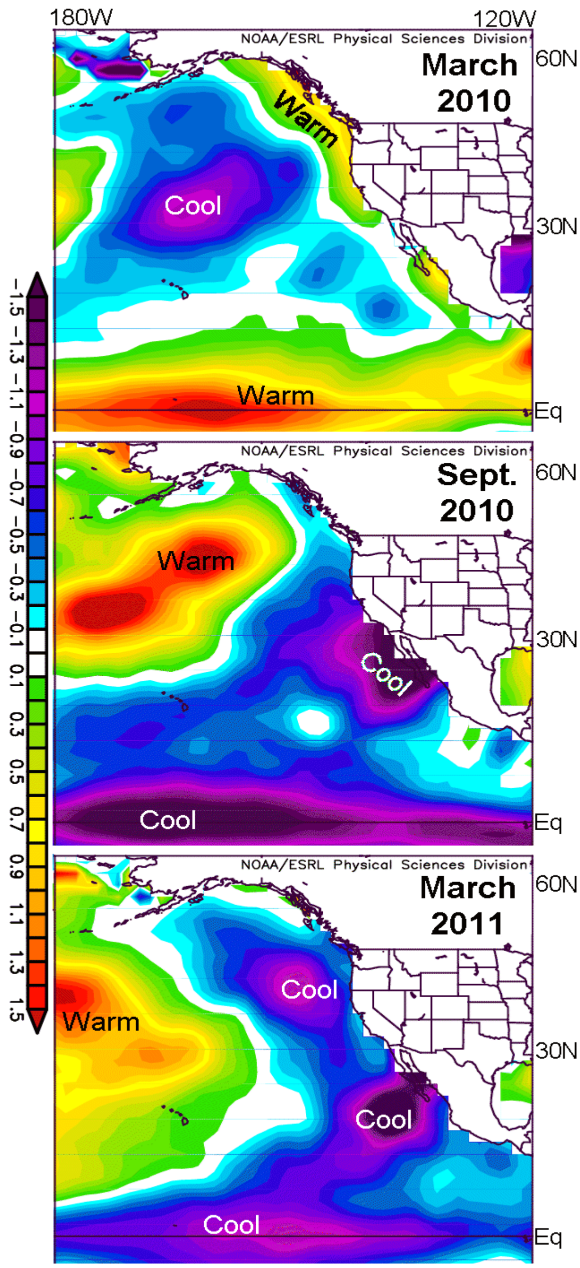
Linking Climate Changes to Lower Trophic Levels

Rapid shifts in Pacific Ocean Temperature

Recent ocean temperature changes in the eastern Pacific Ocean can be seen in the three panels of Fig. 5. The colour shading indicates the temperature relative to the 1971-to-2000 average of that month. Note that the absolute surface temperature of BC waters in a warm March is still cooler than the ocean temperature in a cool September. The relatively warm oceans west of North America in March 2010 were part of the coastal warming due to stronger southerly winds of this El Niño winter. The warm anomalies gave way to cooler anomalies in September 2010, due to persistent and strong northerly winds along the west coast in summer. By March 2011 relatively cool waters were present all along the west coast and Equator, in response to La Niña winds (Crawford, et al. RD2011, p18).

El Niño is part of a Pacific-wide pattern of winds and temperatures. It is formally defined by the ocean temperature along the Equator in the Pacific Ocean and is present when these temperatures exceed 0.5°C above normal for several seasons. This warming is present in the top panel of Fig. 5, showing temperature anomalies of March 2010. La Niña events take place when temperatures fall to more than 0.5°C below normal, as in September 2010 and March 2011 in the bottom two panels of Fig. 5.

Temperatures along the Equator and west coast in March 2011 were similar to those of March 2008 and 2009, and were typical of La Niña winters. These ocean temperatures are usually set up by stronger northeast trade winds over the tropical North Pacific Ocean and stronger westerly winds in the subarctic Pacific. Similarly, Pacific Ocean temperatures of early 2010 were typical of El Niño winters, with warm oceans along the North American west coast. As of early April 2011 the existing La Niña was predicted to continue into late spring 2011. Readers can track future La Niña conditions and predictions at this site: NOAA ENSO News.



The link between ENSO events (a term that includes both El Niño and La Niña) and winds and temperatures in the Gulf of Alaska has become stronger in the past decade. Another index of North Pacific climate is the Pacific Decadal Oscillation (PDO), which is a measure of changes in temperature all across this ocean. Both ENSO and the PDO have varied together in the past decade, allowing use of either index to relate ocean changes to changes in marine resources in west coast waters. Time series of these indices are presented in Fig. 6.

Figure 5. (Crawford, et al. RD2011, p18) Ocean temperature anomalies in the Pacific Ocean for March 2010 (top), September 2010 (middle), and March 2011 (bottom). The map extends from North America westward to 180°West, and from 5° South to 65° North. The Equator is marked by the horizontal black line near the bottom of each panel. The temperature anomaly scale in °C is at left. Positive and negative temperature anomalies are labelled warm and cool, respectively. Images provided by NOAA.

Zooplankton

Juvenile Barkley Sound Sockeye Salmon can consume euphausiids 3 to 5 mm long in May when these Sockeye enter the ocean. Low biomass of 3 to 5 mm *Thysanoessa spinifera* in May 2010 could result in low returns of age 4 Sockeye Salmon in 2012 and age 5 fish in 2013 relative to the time series (Tanasichuk RD2011, p65).

The Oregon coast saw an increase through the middle of 2010 in the total number of copepod species (a type of zooplankton), in response to the warming in early 2010 (Peterson RD2011, p61). These warm waters, in turn, were set up by El Niño winds of winter 2010. This increase in copepod species richness in 2010 is seen in Fig. 6, which also reveals the past 15 years of changes as measured by monthly ocean surveys.

The PDO of Fig. 6 is the Pacific Decadal Oscillation, and MEI is an index of El Niño intensity in the tropical Pacific. Copepod Species Anomaly is based on the number of copepod species in monthly net surveys. These graphs reveal that the anomaly of ocean temperature at NOAA

Buoy 46050 tends to change with changes in both PDO and MEI. The number of copepod species on the Oregon shelf increases with local ocean temperature, which in turn changes with both PDO and MEI.

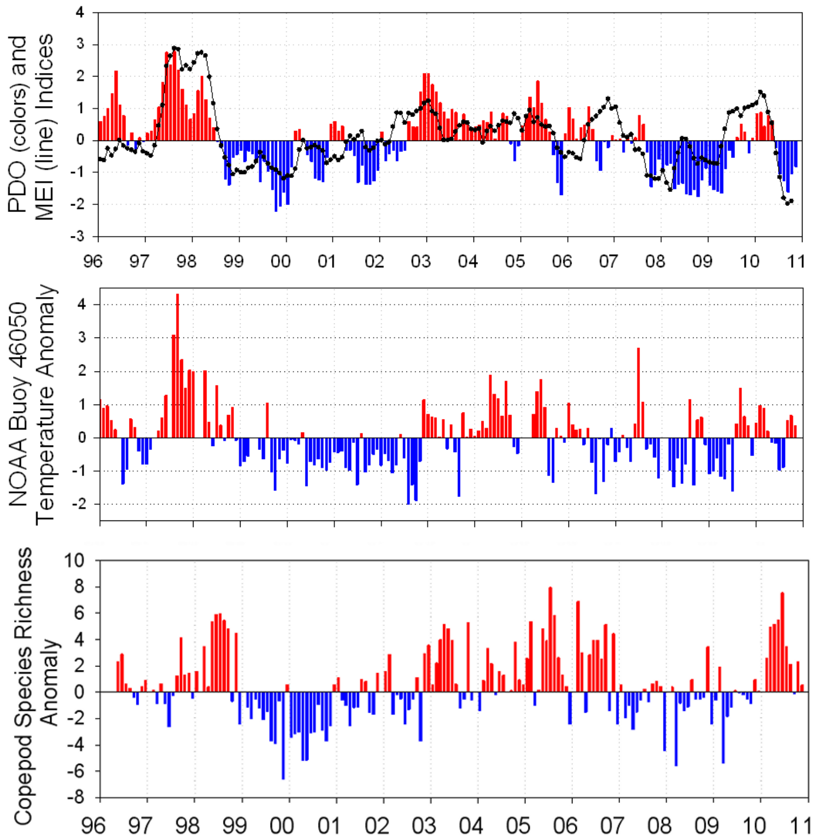


Figure 6. Indices of the ocean and copepods on the Oregon continental shelf (from Peterson RD2011, p61).

Oddly, despite a warm spring and high copepod species richness, the biomass of cold water, (or northern) species was high, ranking 4th out of 15 years (1996-2010). Much of the high biomass was due to the copepod *Pseudocalanus mimus*.

Zooplankton survey data from the outer coast of Vancouver Island and in the Pacific North Coast Integrated Management Area (PNCIMA) region (Mackas, et al. RD2011, p57) also reveal temperature as an ongoing cause of species changes. The positive anomalies of the cool-water zooplankton community off the west coast of Vancouver Island are associated with good local survival and growth of juvenile salmon, sablefish, and some seabirds. Annual-average anomalies of the cool-water copepod and chaetognath species groups on the Vancouver Island continental shelf remained positive in 2010, following generally warmer waters of the previous three seasons, but trended downward from their higher levels in the colder years 2007 and 2008. Conversely, the warm-water, southern-origin copepods and chaetognaths shifted to positive anomalies, continuing an upward trend that began midway through 2009 with the onset of El Niño related warming. Another strong and ongoing signal in the zooplankton time series since about 2000 has been increasing incidence of strongly positive annual anomalies of one or more gelatinous zooplankton taxa. In 2010, the gelatinous zooplankton were dominated by salps (herbivores) in spring, and by medusae (predators on crustacean zooplankton) in mid-late summer.

The open ocean zooplankton community in the Gulf of Alaska, sampled by a Continuous Plankton Recorder towed behind commercial ships, had a relatively normal year of species composition and timing of their spring bloom in 2010 (Batten RD2011, p55). However, preliminary results indicate that 2010 was a year of low biomass of zooplankton.

Zooplankton time series from the Strait of Georgia are being reconstructed from samples collected by various shorter-term research programs. Sampling methods and spatial coverage have been relatively consistent since about 1990. Analyses reveal responses that are surprisingly different from those off the outer coast (Mackas, et al. RD2011, p118), although they appear to maintain a close relationship to subsurface water temperatures. In particular, there is less evidence of recent rapid alternations between warm- and cool-water, shelf-resident copepod communities. Instead, the dominant signals in the Strait of Georgia have been the declines, after about 1999, in the biomass of large deep-migrating copepods and of euphausiids. Both taxa had a prolonged minimum from about 2003-2008, but also show a partial recovery in 2009 and 2010.

Shrimp on the Vancouver Island Shelf

An annual DFO survey in May samples for *Pandalus jordani* shrimp (Perry et al. RD2011, p69). Recent surveys found their biomass off central Vancouver Island had increased in 2008, 2009, and 2010 from very low levels during 2004-2007. Such increases appear related to colder waters in 2006, 2007, and 2008 during the larval stages of the shrimp (this species has a 2-yr time lag from hatch to recruitment at age 2) and to low abundances of Pacific hake (a potential shrimp predator) in May surveys in 2008, 2009, and 2010.

Clams and oysters in Pacific Rim National Park Reserve

All clam species in Pacific Rim Park displayed globally and/or recently declining trends for at least some size cohorts (Zharikov et al. RD2011, p95). 2010 in particular, and the last 4 to 5 years in general, have had very low stock abundances for all three species. The introduced Japanese oyster remained stable through the past 6 years and 2010 was about average. Native Olympia oyster abundance hasddeclined precipitously but during the past 5 years numbers fluctuated at low levels and in 2010 were about average.

Abundance Variations of Fish, Birds and Mammals

Pacific Hake

Offshore Pacific hake form the largest biomass of any groundfish species on the continental shelf of BC (Forrest et al. RD2011, p89). The 2009 acoustic survey data were re-analyzed in 2010 due to problems caused by the record incursion of Humboldt squid into BC waters and these revised estimates were included in 2011 stock assessment. The stock reconstruction indicates that offshore Pacific hake experienced a long period of decline from the late 1980s to a low in 2000, followed by a brief increase to a peak in 2003 as the exceptionally large 1999 year class matured. The stock again declined from 2003 to 2007, but in 2011 spawning biomass is estimated to be rebounding rapidly based on the strength of recent year classes (2005, 2006 and particularly 2008). Hake spawned during the cool La Niña winter of 2008 is now estimated to form the largest year-class along the entire west coast. However, this assessment is quite uncertain, particularly with respect to the size of the 2008 year-class.

Pacific Herring

Pacific herring comprise an important component of commercial fisheries in British Columbia (Schweigert et al. RD2011, p78). Projected biomass estimates of the Strait of Georgia and Prince Rupert herring stocks were above the fishery threshold or cutoff values and were therefore open to commercial fishing in the 2010/2011 fishing season. Biomass estimates for the Haida Gwaii, Central Coast, and West Coast Vancouver Island herring stocks were projected to be below 2011 fishery cutoff values; therefore these three areas were not open during the 2011 roe herring fishery.

Off the west coast of Vancouver Island (WCVI), fish predator abundance has decreased in recent years, while the abundance of most marine mammal predators has increased. This has resulted in a relatively stable or slightly decreasing trend in the amount of herring consumed by predators since 1973 (Schweigert et al. RD2011, p78). In the shorter term, WCVI herring recruitment should remain low in 2011 because, although the biomass of hake which prey on fishes was low in 2008, *T. spinifera* prey biomass was low during the first three years of life; lower *T. spinifera* prey biomass in 2010 could continue to depress recruit and adult growth; adult survival rates in 2010 could decline because of lower *T. spinifera* biomass (Tanasichuk RD2011, p65).

The biomass of herring in the Strait of Georgia reached near historic high levels in 2002 to 2004 at over 100,000 tonnes (Schweigert et al. RD2011, p78). They feed in summer along the southwest coast of Vancouver Island. The summer off-shore trawl survey and the juvenile herring survey indicated good recruitment for 2011, and initial indications from the 2011 test fishery suggest recruitment was very high. However, their weight-at-age has declined since the mid-1970s.

Sardine

In 1992, after a 45 year absence, sardine returned to southern Vancouver Island from their southern base off California and expanded their distribution northward throughout the west coast of Vancouver Island, Hecate Strait and Dixon Entrance by 1998 (Flostrand et al. RD2011, p84). The most recent U.S. sardine assessment suggests that coast-wide abundance off Canada and the U.S. peaked in 2000 and has declined since, decreasing to approximately 700,000 tonnes in 2010. The estimated migration rate into Canadian waters has also decreased since 2006.

Eulachon

Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska (McCarter et al. RD2011, p87). Abundance indices in central and southern British Columbia rivers remain at low levels. The estimated eulachon spawning stock biomass in the Fraser River decreased in 1994 and has consistently been below the 150-tonne fishing reference point since 2004. COSEWIC recently designated eulachon as Threatened in some BC rivers, and others as Endangered. The biomass in the Fraser River will be estimated by an egg and larval survey in April-May 2011.

Albacore Tuna

Albacore tuna, like Pacific hake, sardines, and most recently Humboldt squid, migrate into BC waters in summer. Annual albacore Catch Per Unit Effort (CPUE) in BC coastal waters averaged 87 fish per vessel-day for 2000-2009 and in 2010 was well above average at 113 fish per vessel-day (Holmes RD2011, p76). The 2010 CPUE was the second highest since 1990; the highest was in 2006 at 129 fish per vessel-day. Temperature does not appear to be the major driver of this recent increase. Coastal BC waters in 2010 were 0.1 to 0.45 C° cooler than normal (based on Amphitrite Point data) during the fishing season (July-Oct) and more than 80% of the catch was made at temperatures of 14 to 16 °C, in contrast to temperatures between 16 and 18 °C in previous years.

Flatfish along the West Coast of Vancouver Island

The annual shrimp survey in May also provides insight into populations of resident flatfish, such as sole, Pacific cod, halibut, arrowtooth flounder, and of midwater species such as Pacific hake

(Perry et al. RD2011, p69). Biomass trends of key flatfish indicator species all increased in 2010, as did the biomass of the "cold water indicator" species walleye pollock.

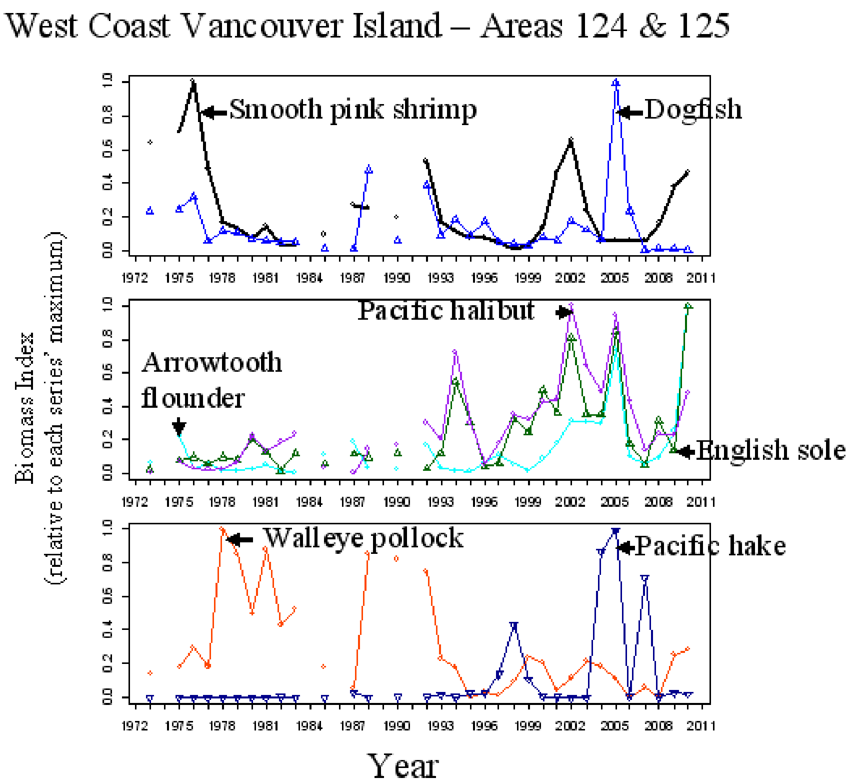


Figure 7. (from Perry et al. RD2011, p69) Time series of normalized (to maximum biomass) survey catches of smooth pink shrimp, dogfish, Pacific halibut, Arrowtooth flounder, English sole, Pacific hake and walleye pollock. Sampling was conducted in May of each year.

Seabirds in Pacific Rim National Park Reserve

Parks Canada scientists discovered that 2010 experienced one of the highest abundances of most seabirds in this reserve (Zharikov et al. RD2011, p95). Most species responded positively to the cooler local oceanic conditions observed during 2007 to 2009. Cooler coastal waters in BC are generally thought to result in increased energy flows through phyto- and zooplankton to juvenile fish to seabirds. The steep increases in abundance in the past few years and 2010 in particular suggest that we are mostly observing aggregative responses – birds congregate in areas with abundant food sources.

Groundfish

During the last 4 years roughly 51% of BC's trawl and 67% of BC's non-trawl catch has come from PNCIMA, which includes all waters in Canada north of Brooks Peninsula and Campbell River in northern Strait of Georgia. Recent groundfish catches, stock status and trends in abundance within the PNCIMA region were summarized by Workman and Rutherford (RD2011, 144). Gadoid (Pacific Cod, Walleye Pollock, Pacific Hake) stocks are stable or increasing. Most rockfish species are at low abundance with some being listed as Special Concern or Threatened by COSEWIC. Flatfish stocks appear to be stable. Sablefish stocks appear to be stable at low abundance. Lingcod and Elasmobranch (e.g. Spiny Dogfish) stocks appear stable.

The following statements can be made about species group status for British Columbia as a whole. Where possible, stock status for groundfish species are now characterized relative to fishery reference points usually related to the target biomass at maximum sustained yield, BMSY. For BMSY-based reference points, Critical, Cautious and Healthy Zones of stock abundance are delimited by a limit reference point (e.g. 0.4BMSY) and upper stock reference point (e.g., 0.8BMSY) based on the DFO Sustainable Fisheries Framework (DFO 2009). Recent stock assessments for inside and outside populations of Spiny Dogfish (*Squalus acanthius*) (DFO 2010) and Sablefish (*Anoplopoma fimbria*) (DFO 2011) are available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm. Those pertaining to Pacific Ocean Perch (*S. alutus*), the inside population of Yelloweye rockfish, and four outside stocks of Lingcod (*Ophiodon elongatus*) will be posted shortly.

The status of the inside Yelloweye rockfish population in 2010 was estimated to be well below the limit reference point of 0.2 of the unfished biomass following a long period of decline since the mid-1980s, and therefore very likely to be in the Critical Zone. The 2010 abundances of four offshore Lingcod stocks were estimated to be above the target reference point of BMSY, and therefore likely to be in the Healthy Zone. Stock assessment model fitting to historical data suggests that the sablefish spawning stock biomass is currently estimated to be below BMSY, and in the mid- to upper-Cautious Zone to low-Healthy Zone. The harvest rate of legal-size sablefish is close to the harvest rate at maximum sustained yield, UMSY, due to the series of quota reductions from 4,600 t to 2,300 t between 2007 and 2010 in response to declining abundance. The spawning biomass of Pacific Ocean Perch has increased modestly from a historical low in 2006; spawning biomass at the start of 2011 has a high probability being above the limit reference point of 0.4BMSY and is likely in the Cautious to low - Healthy zone. No immediate conservation concerns were identified for the inside and outside populations of Spiny Dogfish; proxy reference points based on historical catches were applied rather than BMSY-based reference points.

Basking shark is the only Groundfish species listed by COSEWIC as Endangered. Species listed as Threatened include Bocaccio rockfish (*Sebastes paucispinous*), Canary rockfish (*S. pinniger*), Quillback rockfish (*S. maliger*) and Yellowmouth rockfish (*S. reedi*). Species listed as Special Concern include Darkblotched rockfish (*S. crameri*), the inside and outside populations of Yelloweye rockfish (*S. ruberrimus*), Longspine thornyhead (*Sebastolobus altivelis*), and the sibling species Rougheye (*S. aleutianus*) and Blackspotted rockfish (*S. melanostictus)* (COSEWIC 2011).

Indicator Stocks of Sockeye Salmon

Fraser River Sockeye Salmon returns were the big event of 2010 and are discussed at the beginning of this report. Hyatt et al. (RD2011, 157) provide information on non-Fraser Sockeye Salmon. Each of five regions of British Columbia has at least one Sockeye stock that has been closely monitored over many decades and serves as an indicator for that region. Two of these regions lie on the outer coast of British Columbia in Eastern Queen Charlotte Sound and along the west coast of Vancouver Island, and in both regions the ocean survival tends to be best when La Niña conditions and cool ocean waters are present in the first months that juveniles enter the ocean.

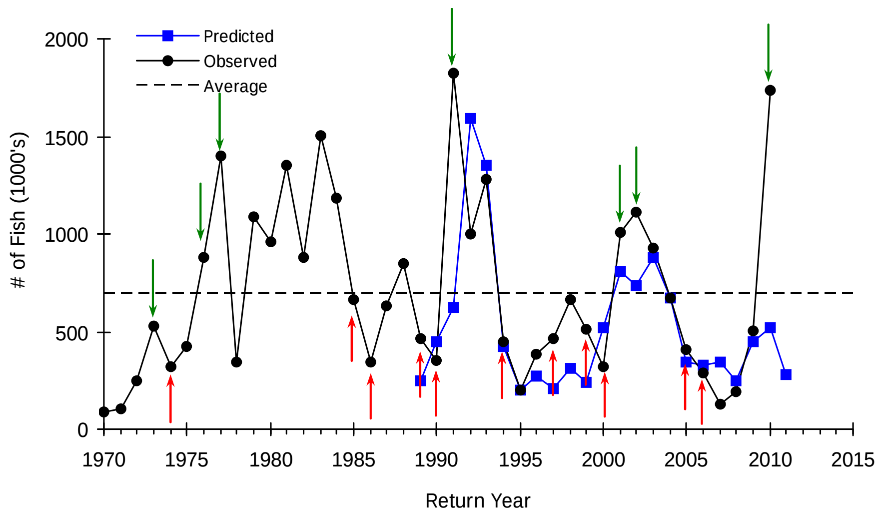


Figure 8 (from [Hyatt et al. RD2011, 157](#)). Observed and predicted returns of Barkley Sound Sockeye Salmon 1970-2011. Arrows indicate La Niña (green, cool ocean) or El Niño (red, warm ocean) events classified by NOAA as moderate to strong ([www.ggweather.com/enso/oni.htm](#)). Arrows are aligned with adult returns two years after the sea entry year in which juvenile salmon experienced a given ENSO event.

The sockeye indicator stock of Barkley Sound in Vancouver Island reveals this response in Figure 8, where returns were high two years after La Niña events and extremely high following the strong 1989 and 2008 La Niña events. The prediction formula might need to be adjusted for strong La Niña years when local waters are especially cool. Smith Inlet Sockeye are the indicator stock in Queen Charlotte Sound. Their numbers crashed in the early 1990s, and although the fresh water survival has been much higher since 1995 than in the twenty years before, the marine survival dropped in the early 1990s, has remained low, and this stock has not rebounded.

Salmon in the Central and North Coast (PNCIMA)

Temporal abundance patterns and status were examined for PNCIMA salmon ([Irvine et al. RD2011, p154](#)). To reduce the influence that non-PNCMIA salmon migrating through PNCIMA might have on the analyses, catch data were excluded from areas known to include large portions of migrating salmon. Escapement data were from all watersheds within PNCIMA. Analysis of data for salmon returning to PNCIMA revealed interesting differences in total returns (i.e. sum of catches and escapements scaled for missing streams and years) among species (Fig. 9).

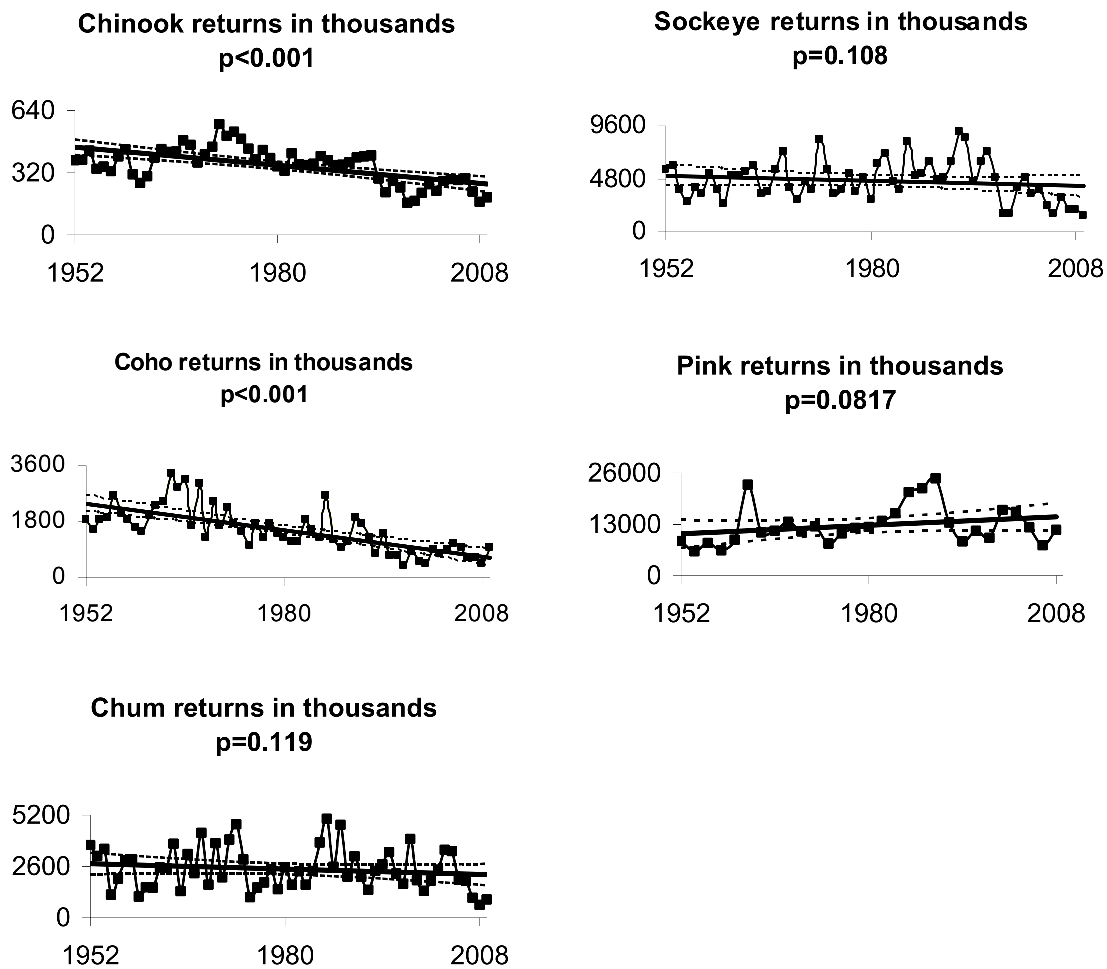


Figure 9. (from [Irvine et al. RD2011, p154]) Return estimates (i.e. catch plus escapement) for Chinook, Sockeye, Coho, Chum, and Pink Salmon in PNCIMA. Solid lines are linear regression lines (time series slopes) with probability that slope is 0 and dashed lines are 95% confidence limits for these lines.

It appears that Pink Salmon are doing relatively well in this area, and Coho and Chinook Salmon relatively poorly. Pink Salmon was the only species with significant increases since 1952 (spawner numbers only). When scientists compared mean values during the most recent decade with historical means, recent catches and returns were lower for each species except Pink Salmon. Pink Salmon was also the only species with significantly higher escapements during the most recent decade compared to earlier. Declines since 1952 were significant for Coho Salmon catches, spawning escapements, and returns, Chinook Salmon catches and returns, and Chum Salmon escapements (Irvine et al. RD2011, p154).

Chinook Salmon

Under the jurisdiction of the Pacific Salmon Treaty (PST), 30 Chinook Salmon stock aggregates and 25 fisheries distributed between southeast Alaska and northern Oregon are managed annually to either projected landed catch targets or are limited by maximum allowed exploitation rates. Estimates of escapements or terminal runs of mature fish for each of the stock aggregates and estimates of numbers of Chinook landed or released in the PST fisheries are assembled annually and provide some of the crucial inputs to the calibration of the Coast-wide Chinook Model (CM). The Chinook stocks (consisting of both wild- and hatchery-origin fish) and fisheries represent nearly all Chinook and fishing-related impacts known to occur within the PST jurisdiction (Brown et al. RD2011, p92). Time series of abundance indices are annually derived and reported to the Pacific Salmon Commission in technical reports available at http://www.psc.org/publications_tech_techcommitteereport.htm#TCCHINOOK).

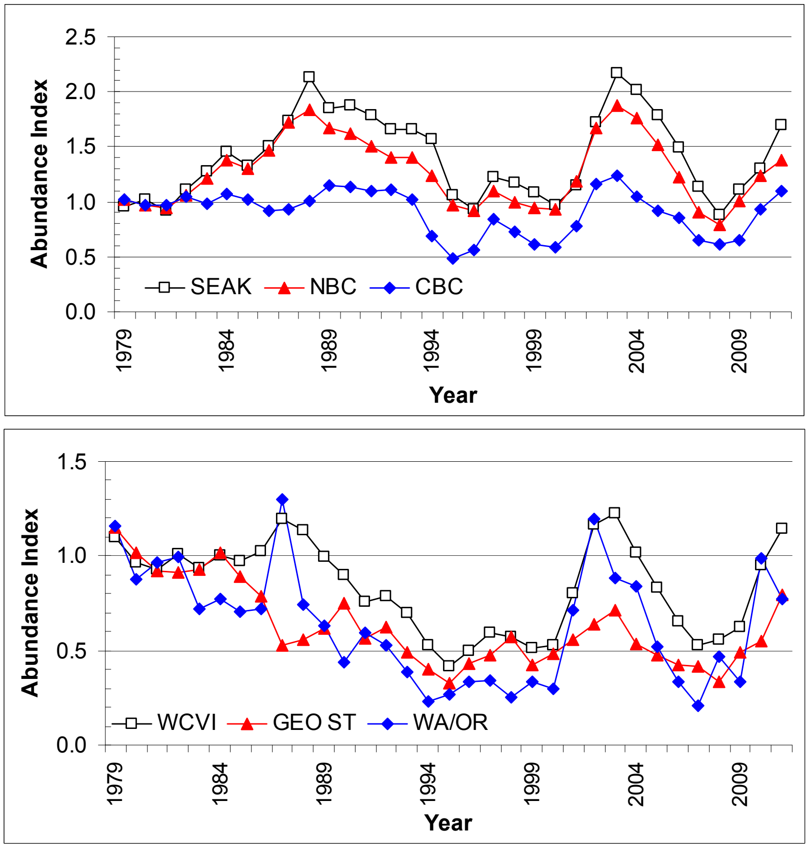


Figure 10. (from Brown et al. RD2011, p92) Time series of Chinook Salmon abundance indices. Top panel: Three major northerly PST fisheries, 1979-2011. These are southeast Alaska troll (SEAK), northern BC troll in statistical areas 1-5 (NBC) and central BC troll in statistical areas 6-12 (CBC). Bottom panel: Three southerly PST fisheries, 1979-2011. These are west coast Vancouver Island troll (WCVI), Georgia Strait and Juan de Fuca Sport (GEO ST), and Washington and northern Oregon ocean troll (WA/OR). Values for 2011 are forecasts resulting from the March 2011 calibration of the coast-wide Chinook model.

The abundance indices are derived by dividing the annual estimated Chinook abundance in any one fishery by the average from the 1979-1982 'base period'. These provide a means to assess temporal and spatial trends in the relative abundance of Chinook stocks contributing to regional fisheries. The 2011 report projects increases in Chinook abundance for most fisheries but a modest decrease for the Washington/Oregon troll fishery. The modest increases are due to expectations for large abundances of Lower Fraser River and most Columbia River stocks that entered the sea in 2008 and produced record high, or nearly so, returns of jack Chinook (the youngest age class maturing which has spent time in the ocean) to spawning grounds in 2009 and age-3 Chinook to spawning grounds in 2010.

Long-Term Trends

Many features of the ocean change slowly over several years or decades. Although they need not be reported annually, they do need updates from time to time. The status of some of these features is reported below.

Recovery of Populations of Large Baleen Whales

Seven species of baleen whales (blue, fin, sei, humpback, North Pacific right, minke and grey) inhabit Canadian Pacific waters and the Northeast Pacific. Shore-based whaling in BC (1905 to 1967) focused on the blue, fin, sei and humpback whale (as well as sperm whales), killing at least 18,316 baleen whales during this period (Gregr *et al.* 2000) and greatly reducing their numbers (Nichol et al. RD2011, p100).

Presently, the humpback whale is the most frequently encountered baleen whale in BC, with a population of about 2,100 whales estimated in 2006 (by photo-identification and mark recapture analysis) and a growth rate of 4% per year (Ford *et al.* 2009). Fin whales remain relatively uncommon in BC waters, at least when compared to sighting rates obtained for humpback whales during DFO ship surveys.

Blue whales remain relatively rare in BC even with the cessation of whaling, but there is evidence of recovery of this Northeast Pacific population with movements of individuals between California/Mexico and historic feeding grounds in the waters of BC/Alaska in late summer (Burtenshaw *et al.* 2004; Calambokidis *et al.* 2009).

There have been only two recent sightings of sei whales in BC, both since 2004, yet during the BC whaling era 3,779 sei whales were taken offshore of west coast Vancouver Island, mostly during the 1960's (Gregr *et al.* 2000).

The North Pacific right whale is an endangered species and there have been no sightings in Canadian Pacific waters since 1951, although there have been a few sightings in areas adjacent to Canadian waters.

Ocean Oxygen Concentrations

Scientists have reported alarmingly low oxygen concentrations in near-shore waters of the Oregon coast in summer, beginning in 2002 and most severely in 2006. High crab mortalities on the ocean bottom took place in these summers. Low oxygen concentrations (less than 1 ml/L) have also been observed on the continental shelf of southwest Vancouver Island since 2002, with concentrations of 0.7 ml/L at 150 metres depth recorded in 2006 and 2009, the lowest in the 50 year record (Crawford RD2011, p47). Although the frequency of observations of low oxygen concentrations has increased since 2002, hypoxia on the Canadian shelf is much less severe than off Oregon and Washington, and mortality of bottom life has not been reported.

Ocean Acidification

Ocean acidification is an alarming ocean feature of global climate change. It is expected to become a major problem impacting our local waters in the latter half of this century (Ianson 2008).

Global oceans are becoming more acidic due to increasing carbon dioxide. Much of the extra CO_2 released by burning fossil fuels ends up in the oceans, increasing the dissolved inorganic carbon concentration (DIC). The North Pacific Ocean already has the most acidic water in the Pacific, Atlantic and Indian Oceans, due to its relatively cool and fresh waters. At present the pH of seawater has decreased by about 0.1 due to oceanic uptake of anthropogenic carbon dioxide and is projected to decrease by 0.4 by the year 2050 (Orr et al. 2005). The decrease in pH (and concurrent decrease in carbonate ion concentration) is a great threat to organisms that produce calcite and aragonite shells or structures, such as pteropods, corals and shellfish. The Royal Society (2005) provides more information on this disturbing trend.

Mapping of the BC coast.

Over the past few years a project team has undertaken a thorough analysis of British Columbia's marine regions, including adjacent lands (Bodtker RD2011, p134). Products include an online marine atlas and data library (www.bcmca.ca/data) and various workshop reports generated during data collation and review (www.bcmca.ca/document-library/.

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All references cited as (Name RD2011, pxxx) are in the appendix of the following research document as separate reports:

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Irvine, J.R. et al. 2010. Do marine conditions in Queen Charlotte Sound limit the marine survival of Chilko Sockeye Salmon? Pg 132 in State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2009, edited by W. R. Crawford and J.R. Irvine. DFO Can. Sci. Advis. Sec. Res. Doc. 2010-053.

The Royal Society. 2005. Ocean Acidification due to Increasing Atmospheric Carbon Dioxide. http://royalsociety.org/Ocean-acidification-due-to-increasing-atmospheric-carbon-dioxide/

APPENDIX 1 – INDIVIDUAL REPORTS

OUTER COAST OF VANCOUVER ISLAND

TEMPERATURES IN 2010: GLOBALLY WARM, BUT COOL IN THE EASTERN PACIFIC

Bill Crawford, Roy Hourston, Richard Thomson, Fisheries & Oceans Canada

The temperature in 2010 was warmer than average almost everywhere, except in the eastern Pacific Ocean and in parts of Siberia. The map below in Fig. 1 shows the extent to which temperatures were warmer (red) or cooler (blue) than in past years. Local cooling in the eastern Pacific Ocean was present in every year since 2007, part of a Pacific-wide weather pattern associated with La Niña conditions of these years. El Niño of late 2009 to early 2010 did bring warmer waters to the eastern Pacific Ocean, including British Columbia, but not enough heat to overpower the cool conditions of the past four years.

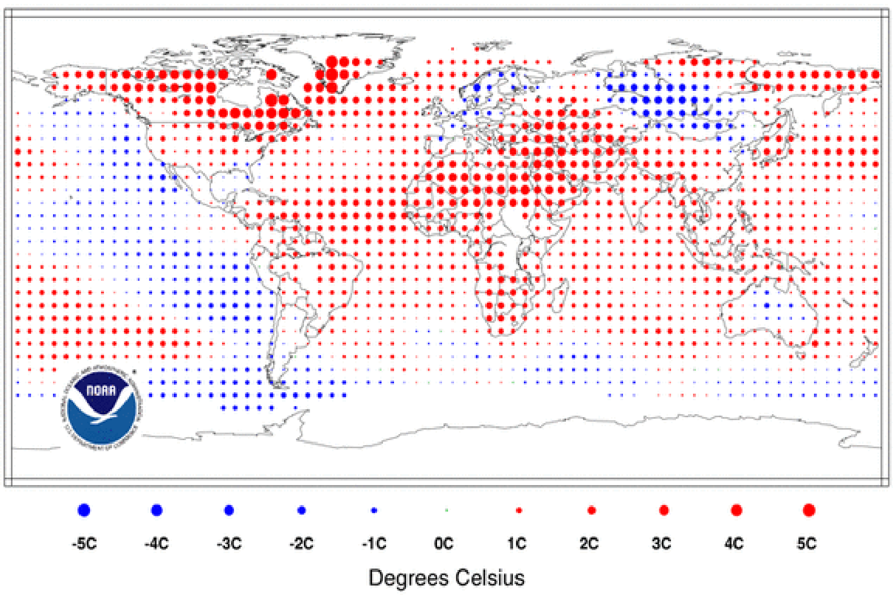

Figure 1. Annual surface temperature anomaly for 2010 (°C). relative to 1971 to 2000. Image provided by the National Climate Data Center of NOAA of the US National Oceanic and Atmospheric Administration.

The long term global temperature trend is shown below in Fig 2. NOAA says that temperature in 2010 tied with 2005 for warmest since 1880, based on preliminary data for 2010 available at the beginning of 2011.

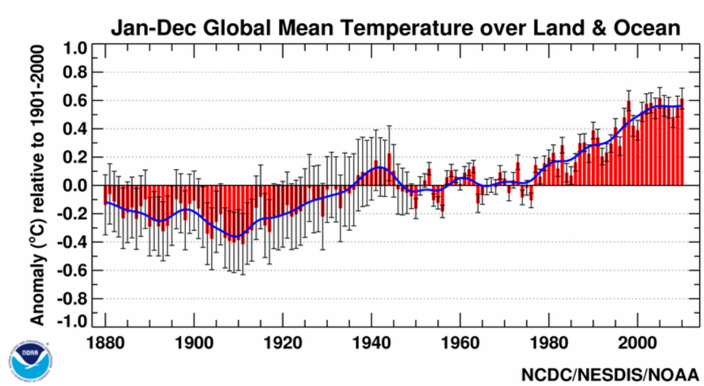

Figure 2. Global temperature anomalies since 1880, relative to the 20th century average. Image provided by NOAA: http://www.ncdc.noaa.gov/cmb-faq/anomalies.html.

From 2008 to 2011, both El Niño and La Niña determined our winter weather, with La Niña dominating in three of these four winters, bringing cooler ocean temperatures to British Columbia. Pacific Canadian and USA waters are vulnerable to these two tropical events. Generally, El Niño shifts the winds over the Pacific Ocean to increase the strength of winds flowing counter-clockwise around the Aleutian Low Pressure System, labelled **L** in Fig. 3 below, whereas La Niña increases the westerly winds over the North Pacific Ocean. Ironically, the 2010 Winter Olympics needed the cool weather of La Niña for optimum snow. Instead an intense El Niño brought high temperatures that melted much of the snow.

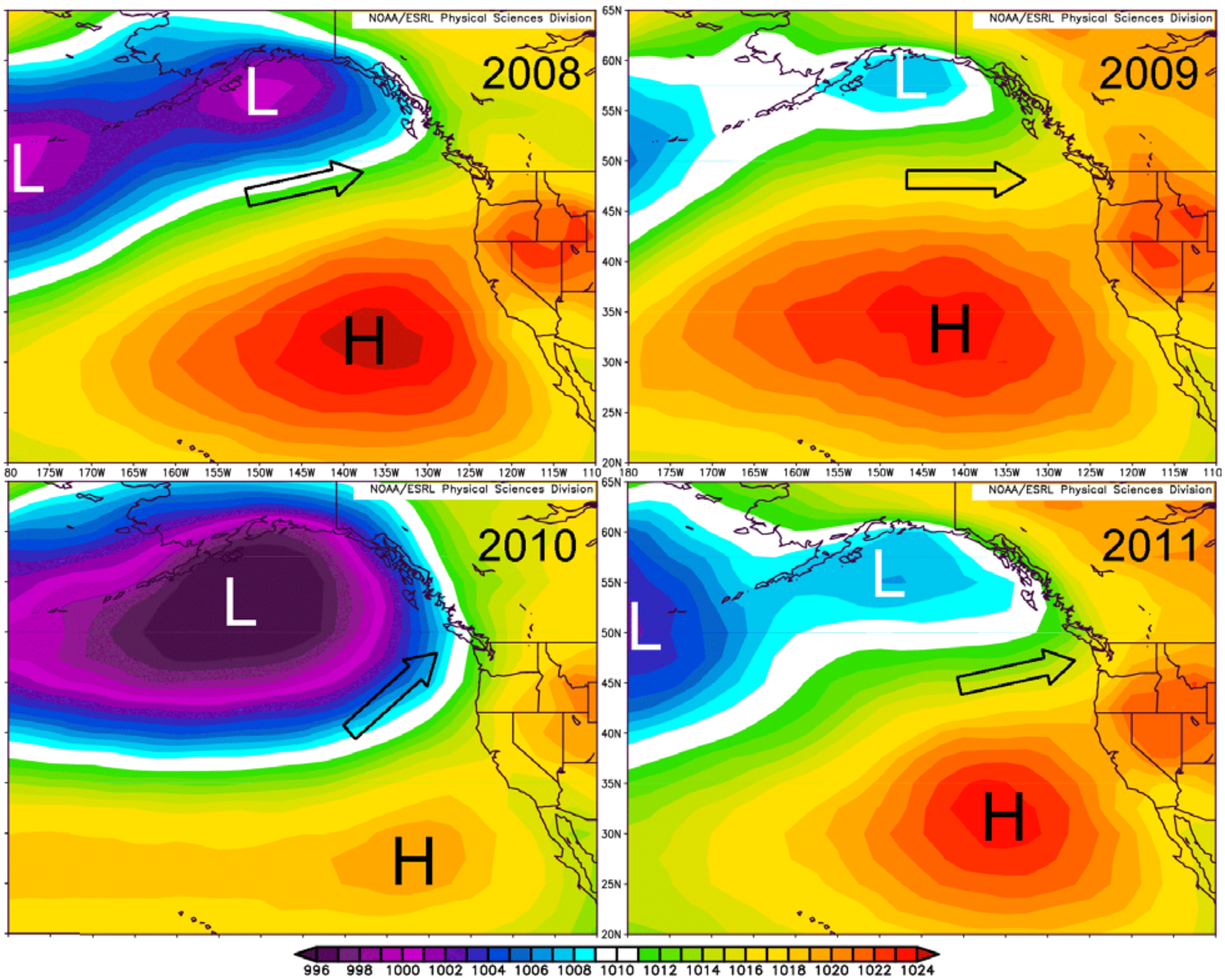

Figure 3. ***Sea surface air pressure*** *in the Northeast Pacific Ocean and western North America, averaged over the winter months of January to March for each of the years 2008 to 2011. Contours are at intervals of 1 millibar, with colour scale at bottom. The letter* **H** *denotes the North Pacific High Pressure System;* **L** *denotes the Aleutian Low Pressure System. The relative strength and position of these systems determines the direction and strength of average winds in these winters, with the black arrow showing prevailing winds off the southern BC coast in each winter. El Niño in the 2010 winter brought warm winds from the southwest, pushing warm waters toward the British Columbia coast. La Niña conditions of the other three winters brought cool westerly winds and cool ocean surface waters to BC. Note the very intense Aleutian Low in winter 2010, one of the lowest of the past 50 years.*

Images on the next two pages show another view of extreme weather in the Pacific Ocean off British Columbia in 2010. In the severe Aleutian Low in January 2010 (Fig. 4) the average air pressure dropped to 987 millibars, one of the lowest ever. By contrast, the North Pacific High of BC in July 2011 (Fig. 5) was one of the highest in recent years.

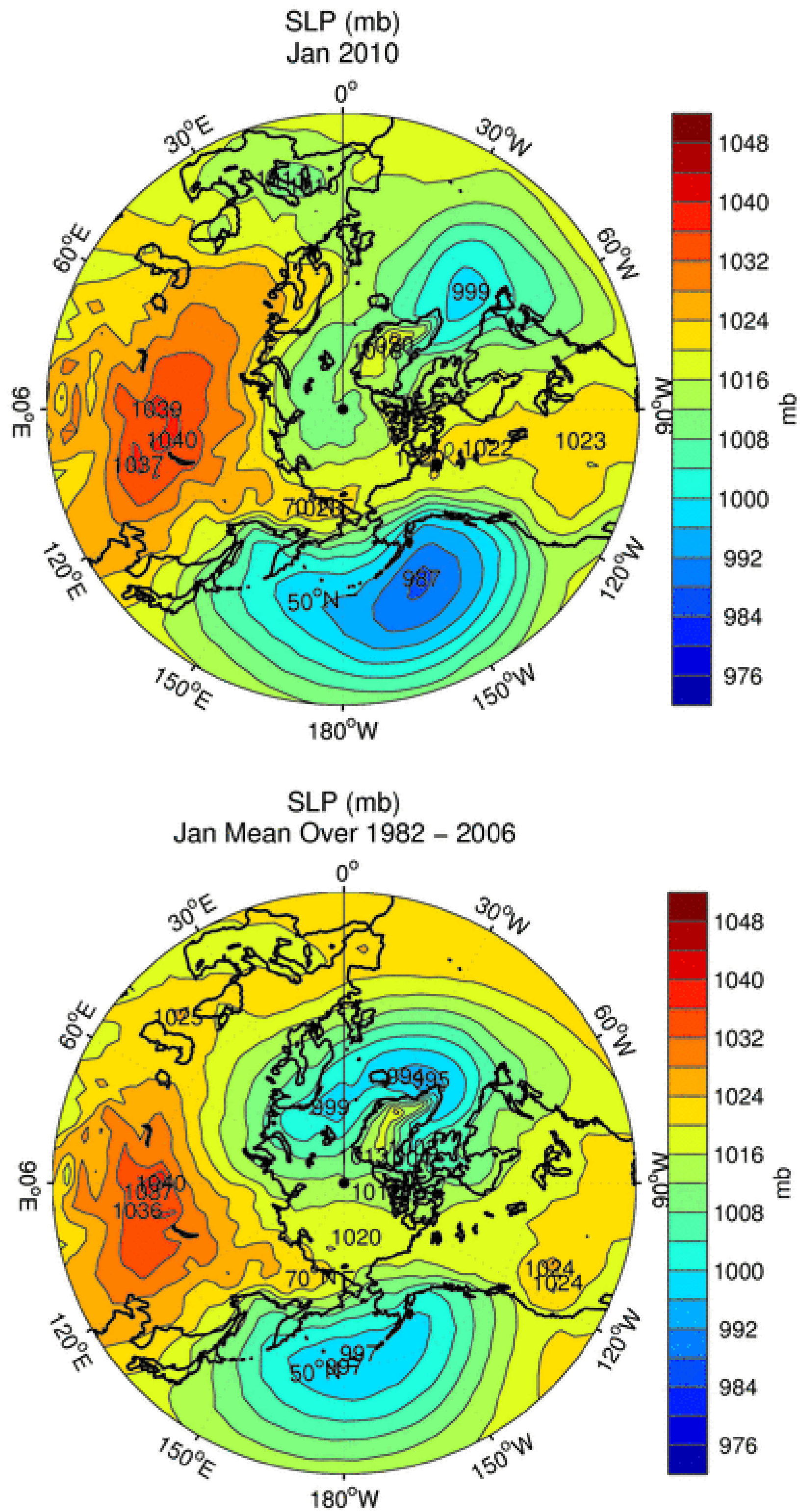

Figure 4. ***Isobars of air pressure*** *for January 2010 (top panel), and January averaged over 1982-2006 (bottom panel). Winds generally blow along these isobars, with low pressure on their left in the Northern Hemisphere. Isobars along the BC coast were closely spaced and aligned north-south in Jan. 2010 with low pressure to the west, indicating strong winds from the south pushing warm water to the BC coast*

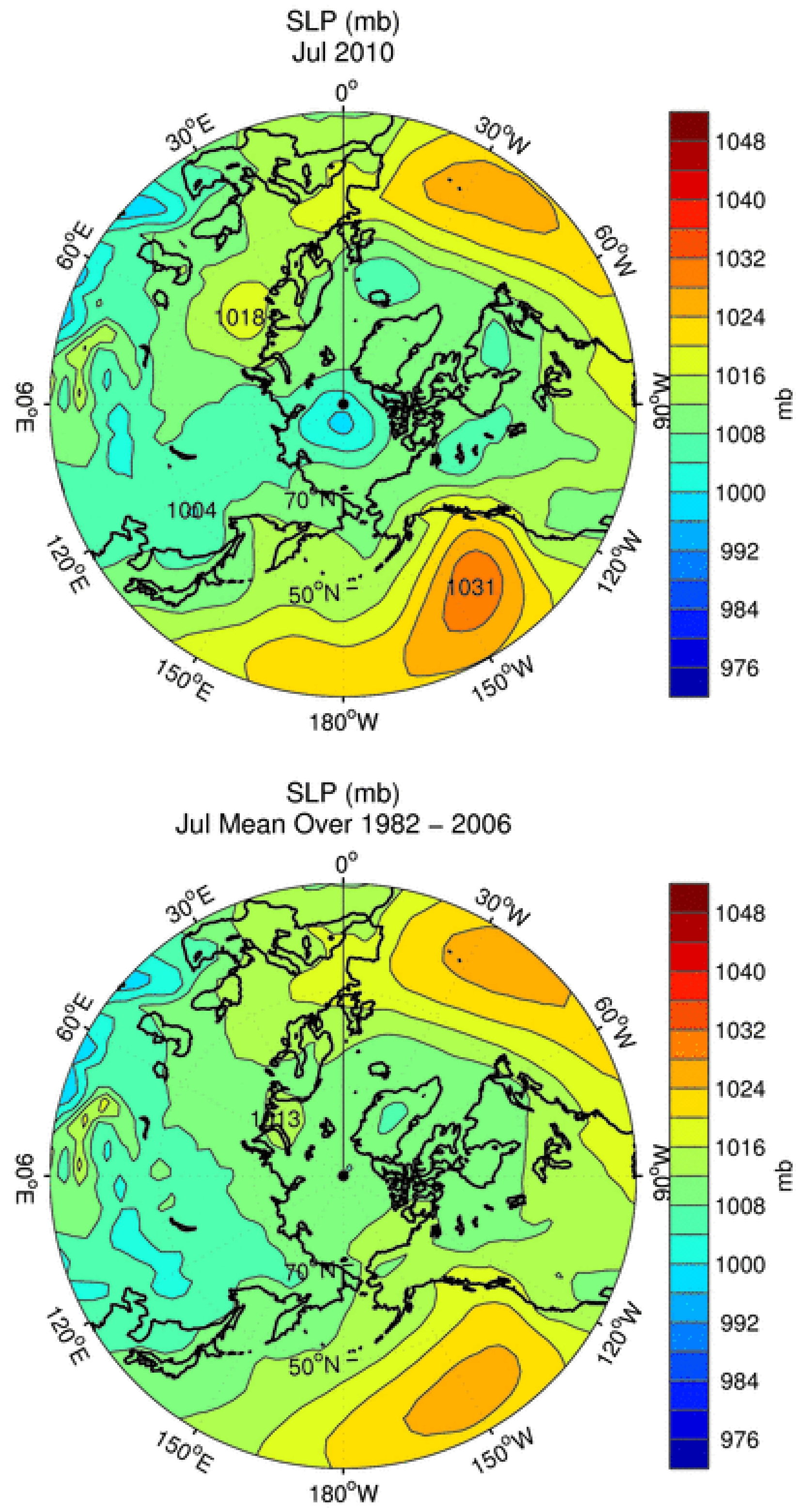

Figure 5. ***Isobars of air pressure*** *for July 2010 (top panel), and July averaged over 1982-2006 (bottom panel). Winds generally blow along these isobars, with low pressure on their left in the Northern Hemisphere. Isobars along the BC coast were aligned north-south in July 2010 with lower pressure to the east, indicating winds from the north pushing cool water to the BC coast*

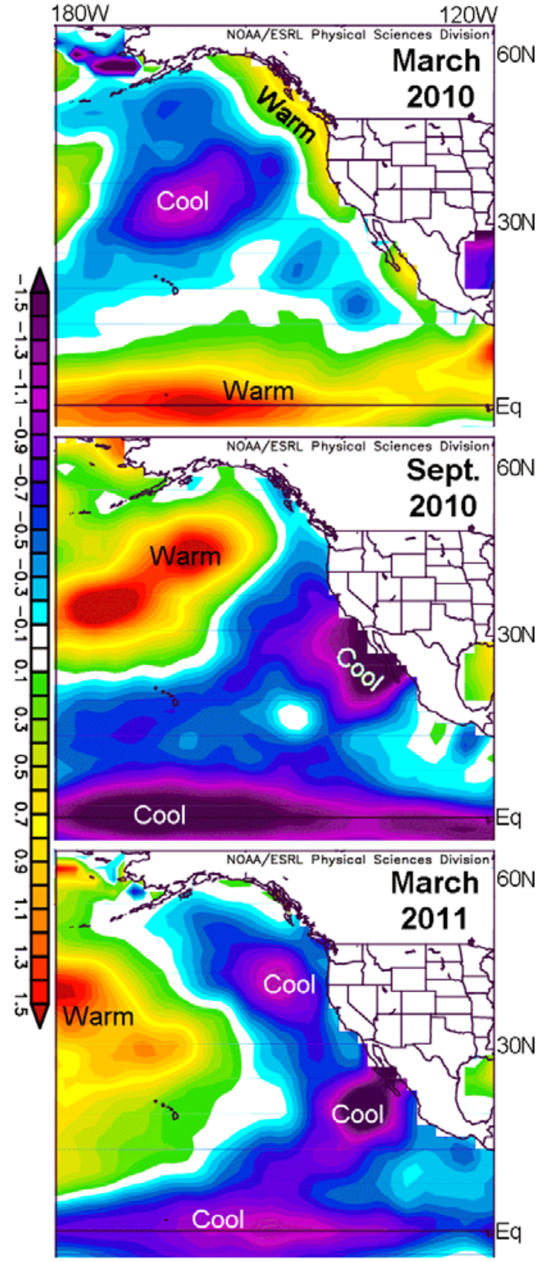

Figure 6. ***Ocean temperature anomalies*** *in the Pacific Ocean for March 2010 (top), September 2010 (middle), and March 2011 (bottom). The map extends from North America to 180°W, and from 5° South to 65° North. The Equator is marked by the horizontal black line near bottom of each panel. The temperature anomaly scale in °C is at left. Positive and negative temperature anomalies are labelled* warm *and* cool*, respectively. Images provided by NOAA.*

The recent changes of ocean temperatures in the eastern Pacific Ocean can be seen in the three panels of Fig. 6 at right. These maps present temperature anomalies of March 2010, September 2010 and March 2011. The colour shading indicates the temperature relative to the 1971-to-2000 average of that month. Note that the absolute surface temperature of BC waters in a warm March is still cooler than the ocean temperature in a cool September.

The relatively warm oceans west of North America in March 2010 were part of the coastal warming due to stronger southerly winds of this El Niño winter. The warm anomalies gave way to cooler anomalies in September 2010, due to persistent and strong northerly winds along the west coast in summer. By March 2011 relatively cool waters were present all along the west coast and Equator, in response to La Niña winds.

El Niño is part of a Pacific-wide pattern of winds and temperatures. It is formally defined by the ocean temperature along the Equator in the Pacific Ocean and is present when these temperatures exceed 0.5°C above normal for several seasons. This warming is present in the top panel of Fig. 6, showing temperature anomalies of March 2010. La Niña events take place when temperatures fall to more than 0.5°C below normal, as in September 2010 and March 2011 in the bottom two panels of Fig. 6.

Temperatures along the Equator and west coast in March 2011 were similar to those of March 2008 and 2009, and were typical of winters with La Niña conditions in the Pacific Ocean. These ocean temperatures are usually set up by stronger northeast trade winds over the tropical North Pacific Ocean and stronger westerly winds in the subarctic Pacific. Similarly, Pacific Ocean temperatures of early 2010 were typical of El Niño winters, with warm oceans along the North American west coast. As of early April 2011 the existing La Niña was predicted to continue into late spring 2011. Readers can track future La Niña conditions and predictions at this site: NOAA ENSO News.

The link between ENSO events (a term that includes both El Niño and La Niña) and winds and temperatures in western North America was noticed several decades ago, and has become stronger in the past 10 years or so, allowing more reliable predictions in winter weather.

LINKING PACIFIC-WIDE CLIMATE VARIATIONS TO LOCAL TEMPERATURE

Bill Crawford, Fisheries and Oceans Canada

How will El Niño affect our weather this year? What happens in the North Pacific Ocean to bring a cool winter? Or a warm summer? To try to answer these questions in a simple manner, scientists look at ocean temperature or air pressure in specific regions of the Pacific Ocean to develop indices whose changes in time will impact other areas far away. El Niño is the most famous, the Southern Oscillation is another. I have prepared a figure of six of these Pacific–wide indices in Figure 1 below, as well as one graph of local ocean temperature anomaly at Amphitrite Point on southwest Vancouver Island and another of temperature anomaly along Line P in the Gulf of Alaska. A large, positive Oceanic Niño Index indicates El Niño; large, negative indicates La Niña.

See the next page for descriptions of what other indices represent and how they are computed.

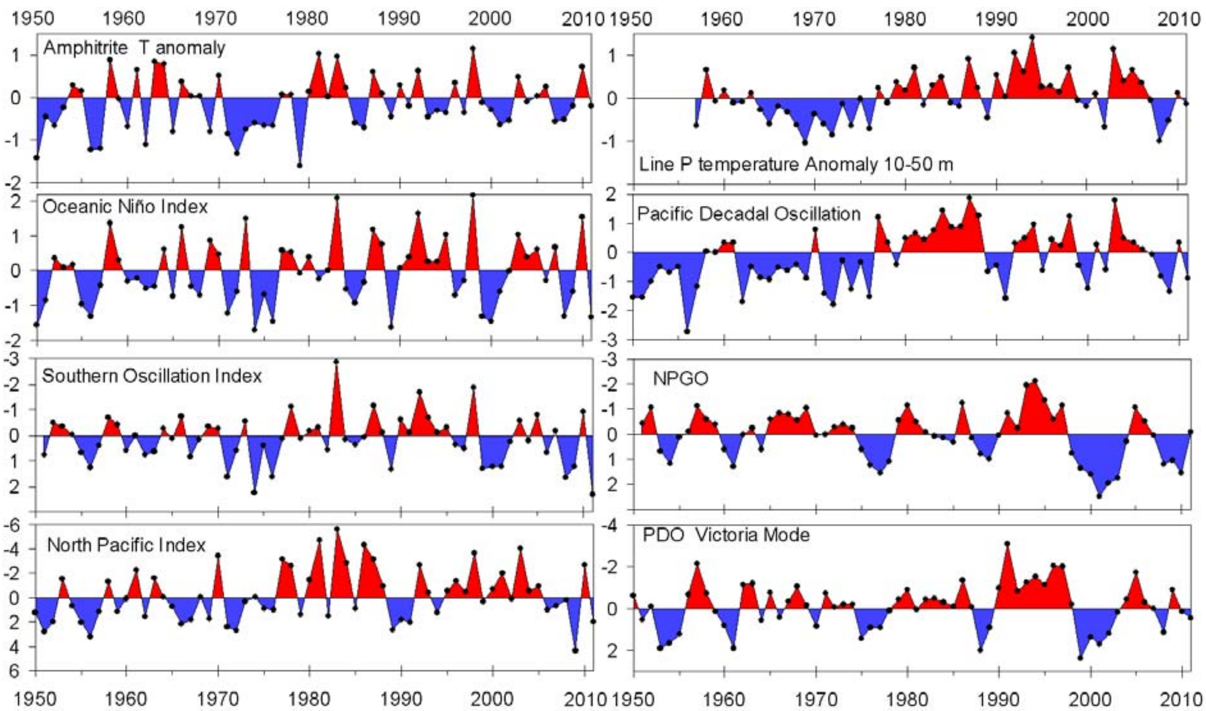

Figure 1. Indices of Pacific Ocean climate plus temperature anomalies (°C) of the Oceanic Niño Index and at Amphitrite Point and along Line P. Each point is an average over the months of November to March, and plotted for the calendar year of March. For example, an average of November 2010 to March 2011 is plotted as a data point for 2011. Several time series are inverted so their variability is in phase with other series.

It is remarkable how the series on the left side of Fig. 1 shift from blue to red to blue in the past three winters, generally showing changes from cold to warm to cold. The Pacific Decadal Oscillation (PDO) on the right side of Fig. 1 also oscillates from blue to red to blue in this same period. Few other years display such rapid and large changes in only two to three years. The rapid warming in the winter of 2009-2010 followed by rapid cooling from summer 2010 to early 2011 caused some of the quick shifts in zooplankton communities reported elsewhere in this State of the Ocean Report.

We attribute this cold-warm-cold signal to the El Niño – Southern Oscillation (ENSO) cycle in the tropical Pacific Ocean in 2009 to 2011, together with similar rapid changes in the PDO. These impacted the weather all over the North Pacific Ocean.

Over the past decade and a half both the Pacific Decadal Oscillation and ENSO (El Niño – La Niña) have shifted phase together and reinforced the impact of each one on west coast ocean temperature. Whereas in the 1990s scientists would attribute changes in ocean temperatures and species compositions to changes in PDO or ENSO, they have recently been able to use these indices almost interchangeably in local waters to link physical changes in the ocean to shifts in abundance of one or several marine species.

Many of these series in Fig. 1 display common variability in other years as well, with blue regions prevailing prior to 1977, and red regions after then for about two decades until 1998. The PDO shows this pattern the best. Most time series shift from blue toward red for several years centred on 2000 and again in 2007-2008. Note the extreme cooling along Line P from 2005 to 2008. These shifts indicate actual cooling in the eastern Gulf of Alaska (Line P) and along the west coast of Vancouver Island (Amphitrite Point), and in Niño 3.4 (Oceanic Niño Index). In general, cooling aligns with La Niña, negative PDO and Aleutian Low Pressure Index, positive Victoria Mode, and Southern Oscillation Index.

Warming along Line P and at Amphitrite Point in mid-2000s coincides with positive Oceanic Niño Index, with Positive PDO and with negative Victoria Mode. Cooling in the past three years accompanies negative Oceanic Niño Index and negative PDO, and usually positive PDO-Victoria mode. Although the PDO-Victoria Mode was "blue" for much of 2008, it shifted in summer 2008 and its overall annual average was close to zero.

Details of each index and time series:

Amphitrite temperature anomaly time series are based ocean surface temperatures measured daily at the Amphitrite Lighthouse on the southwest coast of Vancouver Island. Reference years are 1981 to 2010. Monthly time series are provided by Fisheries and Oceans Canada: http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm

Oceanic Niño Index (ONI) is a measure of the anomaly of ocean surface temperature in the central tropical Pacific Ocean that serves as the official index of the El Niño and La Niña. It is provided by the NOAA/ National Weather Service National Centers for Environmental Prediction Climate Prediction Center, Camp Springs, Maryland : http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Southern Oscillation Index is available at: http://www.cpc.ncep.noaa.gov/data/indices/soi. It represents the atmospheric pressure gradient, as measured between Easter Island and Darwin Australia, that usually sets up the El Niño and La Niña ocean resp.onses.

North Pacific Index (NPI) is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W. It serves as an index of the impact of ENSO over the North Pacific Ocean. Monthly time series of this index are provided by the Climate Analysis Section, NCAR, Boulder, USA, http://www.cgd.ucar.edu/cas/jhurrell/npindex.html based on Trenberth and Hurrell (1994). This index is a useful indicator of the intensity of the Aleutian Low Pressure system. Both monthly and winter-only values are available.

Line P temperature anomaly is based on Crawford *et al*. (2007) and is updated annually. Line P is a set of sampling stations in the North Pacific sampled regularly by Fisheries and Oceans Canada since the 1950s. Reference years are 1956 to 2006. http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/line-p/index-eng.htm

Pacific Decadal Oscillation (PDO) is based on analysis of Mantua *et al*. (1997) and Zhang *et al*. (1997). The time series was provided at this Internet site of the Joint Institute for Studies of Atmosphere and Ocean of NOAA in Seattle: http://jisao.washington.edu/pdo/PDO.latest

PDO – Victoria Mode is first described by Bond *et al*. (2003). The time series was provided by Muyin Wang of JISAO/NOAA, in Seattle. For this analysis she computed the EOF patterns based on 1950-99 SST and then regressed the SST to the spatial patterns to get the entire time series. The advantage of doing this is that from now on, the old numbers won't change, and each year one can simply add one more new number at the end. The SST data used is the HadCRUT3v.

North Pacific Gyre Oscillation (NPGO) is a climate pattern that emerges as the 2nd dominant mode of sea surface height variability (2nd EOF SSH) in the Northeast Pacific Ocean. (Di Lorenzo *et al*; 2008, 2009) http://www.o3d.org/npgo/ It is the sea level signal that corresponds to the surface temperature of the Victoria Mode.

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This article has not been formally peer-reviewed, but represents the expert opinion of its authors. It does not necessarily reflect the official views of DFO Science or the Canadian Science Advisory Secretariat

SATELLITE AND WEATHER BUOY OBSERVATIONS

Jim Gower, Fisheries and Oceans Canada

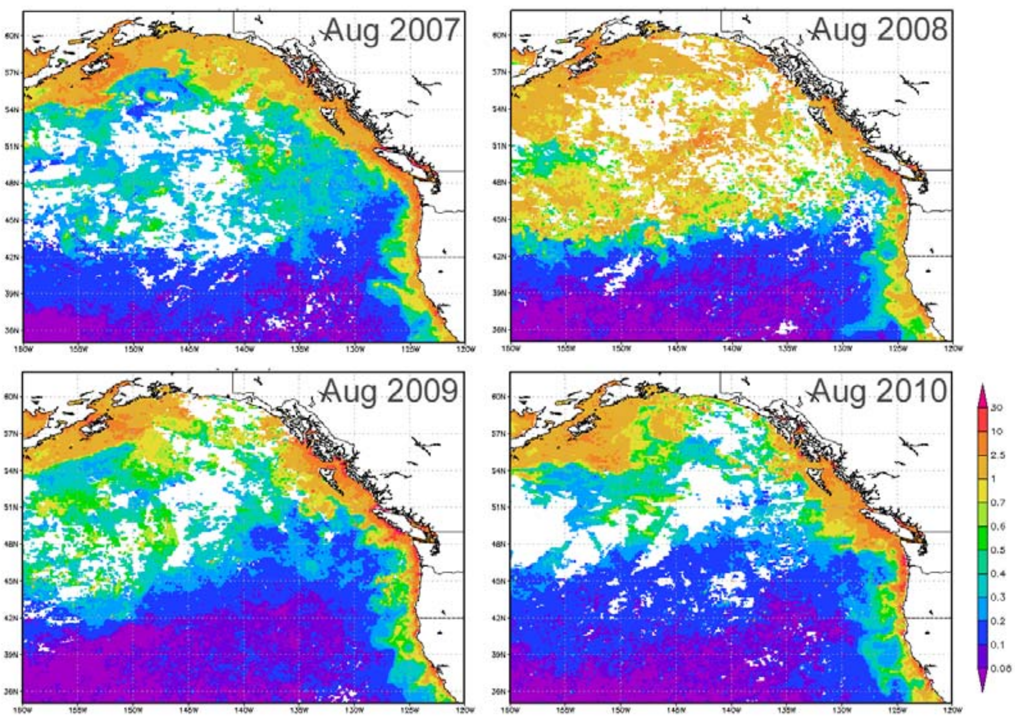

Figure 1. SeaWiFS monthly composite images of August 2007 to 2010 chlorophyll available from the NASA Giovanni system. Chlorophyll is an indicator of phytoplankton in ocean surface waters. The colour bar at right shows relatively low concentrations in purple; high concentrations in red.

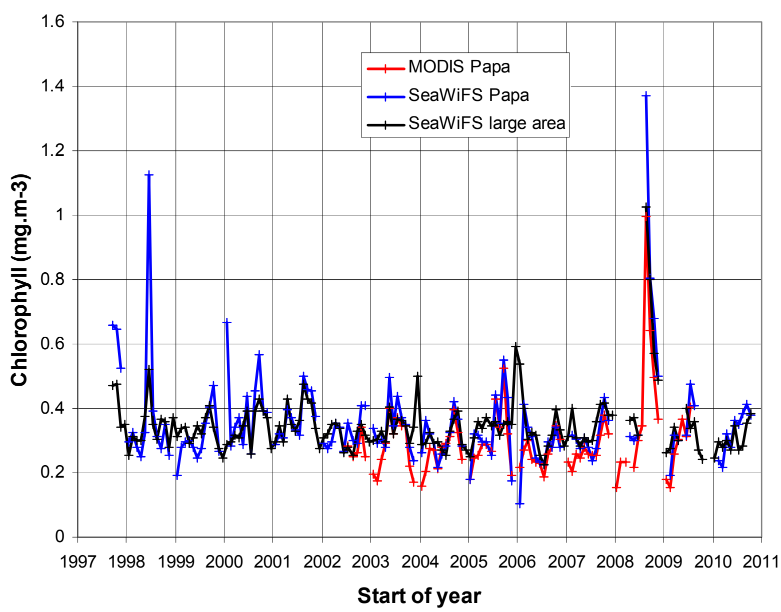

Figure 2. Time series of SeaWiFS and MODIS measurements of chlorophyll for a 2X3 degree area centred on Station Papa, at 50°N, 145°W in the Gulf of Alaska The maximum in 2008 has been attributed to iron input from volcanic dust. Iron is normally the limiting nutrient for phytoplankton in mid-Gulf of Alaska in summer (Hamme et al., 2010).

SeaWiFS sensors on the Orbcom satellite have now stopped working after 12 years of operation. Chlorophyll observations now rely on MODIS or MERIS satellites. The time series of Figure 2 was computed by NASA's Giovanni system over the area 49°N to 51°N, 143.5°W to 146.5°W, surrounding Ocean Station Papa in the Gulf of Alaska. Both SeaWiFS and MODIS show a significant peak in August 2008. In July 2008, SeaWiFS gives no data while MODIS shows an average level. MODIS shows values of 0.34, 1.00, 0.64, 0.50 and 0.37 milligrams/m^3 for months from July to November 2008, while SeaWiFS shows 1.37, 0.81, 0.68 and 0.50 for these same months. The August peak appears to start suddenly, and decay slowly by a factor of about 0.7 per month. SeaWIFS also shows a peak in June 1998, before MODIS data are available, but this is due to a small area of high chlorophyll in a very cloudy month.

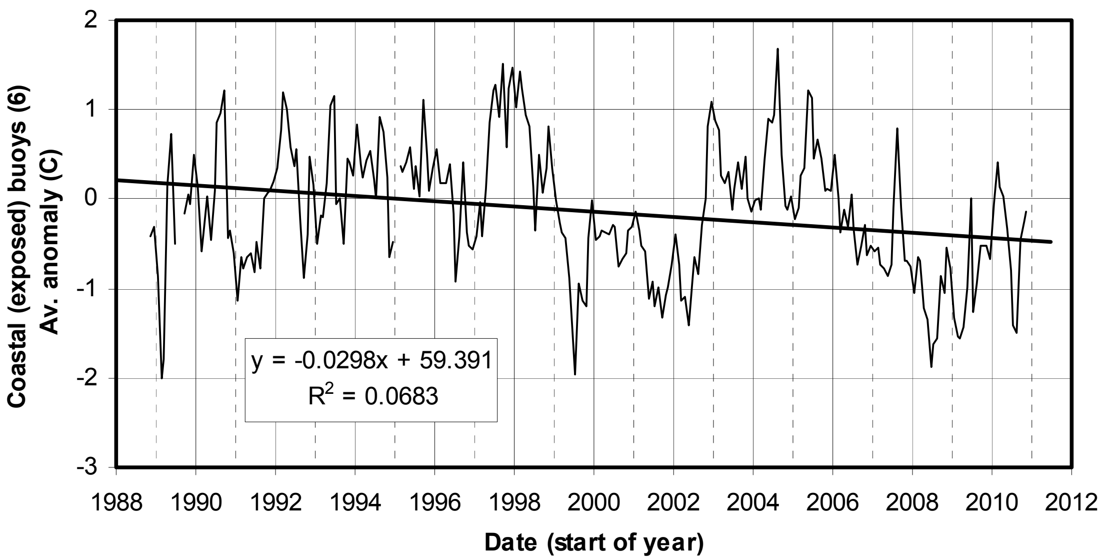

Figure 3. Time series of monthly sea surface temperature anomaly measured by west coast weather buoys along the exposed coast of BC. Anomalies are referenced to the years shown in this figure.

Weather buoy data show 2010 with -0.7°C average temperature anomaly, as part of a cool period that began in 2007. The year 2010 had a relatively warm start, followed by a cool summer. Earlier years 2003 to 2005 were relatively warm (+0.4 anomaly), 1999 to 2002 were relatively cool (-0.75 anomaly) and previous years were relatively warm (+0.15 anomaly). The overall trend is negative (cooling) for the west coast SST time series from these buoys that started measurements in about 1990. A warming trend is seen only in series that start before about 1980. Satellite thermal data show a similar interannual pattern at Station Papa.

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Hamme, Roberta C., Peter W. Webley, William R. Crawford, Frank A. Whitney, Michael D. DeGrandpre, Steven R. Emerson, Charles C. Eriksen, Karina E. Giesbrecht, Jim F. R. Gower, Maria T. Kavanaugh, M. Angelica Peña, Christopher L. Sabine, Sonia D. Batten, Laurence A. Coogan, Damian S. Grundle, and Deirdre Lockwood, 2010, Volcanic ash fuels anomalous plankton bloom in subarctic northeast Pacific, *Geophysical Research Letters*, Vol 37, L19604, doi:10.1029/2010GL044629

AN ARGO VIEW OF THE GULF OF ALASKA

Howard Freeland, Fisheries & Oceans Canada

Argo is a global array of 3000 free-drifting, profiling floats that measures the temperature and salinity of the upper 2000 m of the ocean, and for a few of the floats, dissolved oxygen profiles are also available. The number of floats supplying profiles at 10-day intervals in the Gulf of Alaska is sufficient to provide continuous information at Ocean Station Papa at 50°N, 145°W. A contour plot of water density anomaly (specifically σ_t) is shown in Fig. 1.

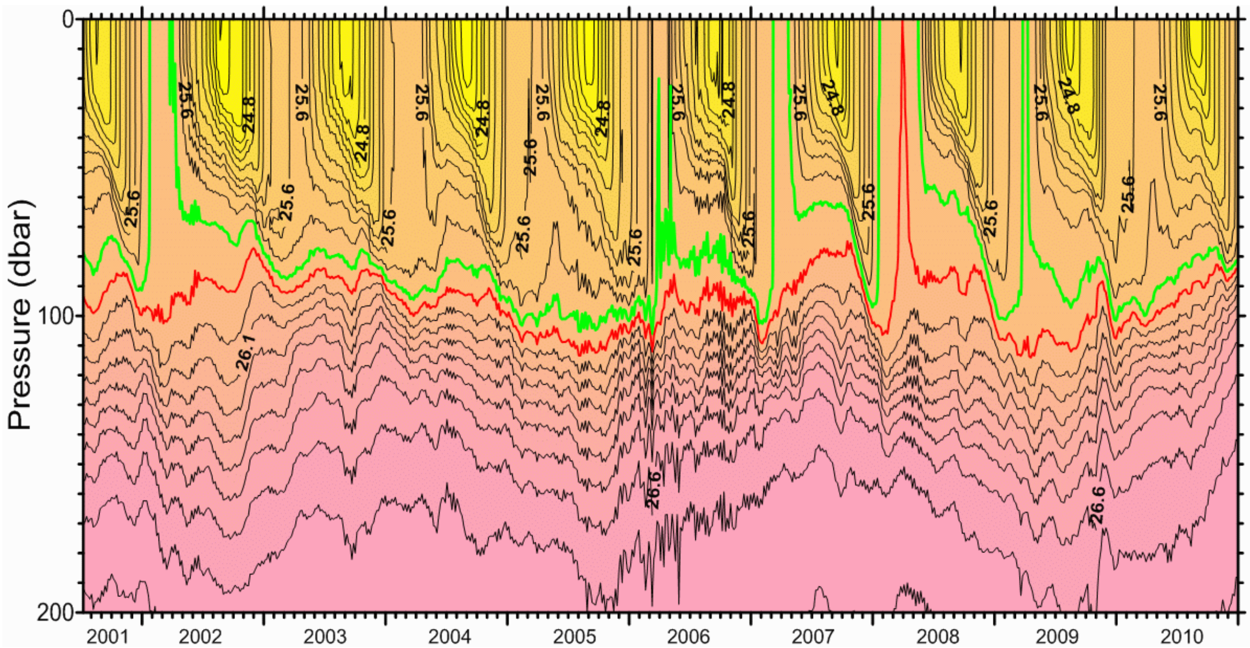

Figure 1. A plot versus time on the x-axis and water pressure on the y axis of density anomaly at Ocean Station Papa. The green contour marks a σ_t of 25.8 and the red line a σ_t of 25.9. (water densities of 1025.8 and 1025.9 kg/m^3, respectively). A pressure of 100 dbar lies very close to 100 metres depth.

Fig. 1 shows that at the end of 2010 the density contours were very close together at pressures of 90 to 100 dbar, indicating stronger than normal stratification, but rather more impressively the dense contours are very shallow, much shallower than normal. This shallowness of the area of strong stratification has a direct impact on the depth to which winter mixing can penetrate, it was likely that the near-surface mid-winter mixed layers were shallower than normal.

Fig. 2 shows the distribution of mixed-layer depth in the NE Pacific in January 2010 and January 2011. The blue line indicates Line-P and the red dots indicate the locations of Argo floats providing observations for computations of mixed-layer depth. Mid-winter mixing to great depth supplies nutrients to precondition the NE Pacific for the productive period in the following spring. In Fig. 1 we can see that the density contours were closer together at the beginning of 2011 compared with contours in 2010, but also, the area of strongest gradient was much shallower at the beginning of 2011. Hence we see in Fig. 2 that the mixed layers were at about 90 metres depth, compared to 100 metres in January 2010. Typical depths were 100 to 110 metres over the previous decade.

The shallowness of the deep contours in Fig. 1 also has implications for the distribution of salt in the Gulf of Alaska. In Fig. 3 we show the salt anomaly along Line-P in January 2010 and January 2011, as computed using data from Argo floats. It is not hard to use the process called objective analysis to take observations from Argo floats surrounding Line-P and interpolate temperature and salinity onto individual Line-P stations. That done we can compare the resulting Line-P reconstruction with the history of observations of salinity along Line-P and compute anomalies, or differences from normal, which are shown in Fig. 3.

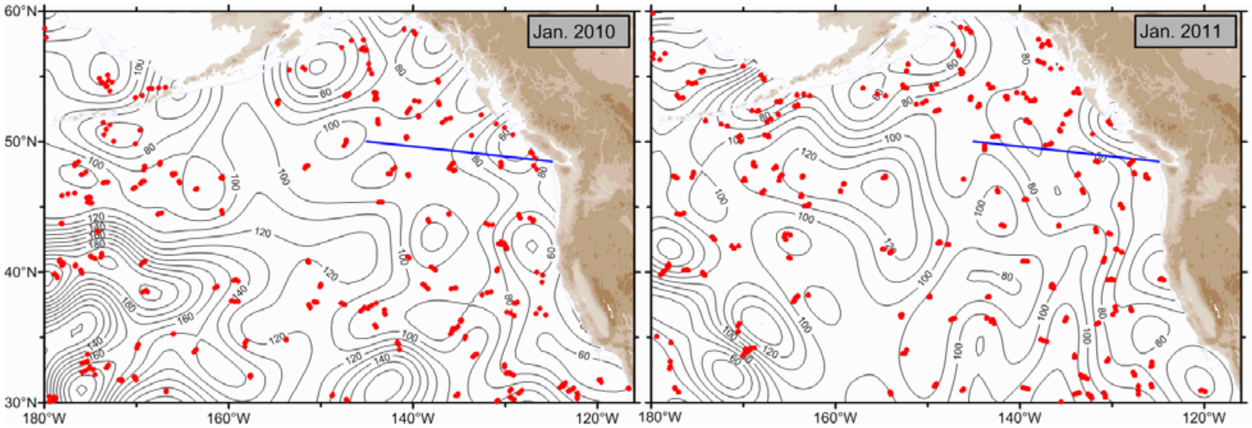

Figure 2. Two maps of January mixed-layer depth distribution in metres in the Northeast Pacific. At left is the distribution for a relatively normal January (2010) and at right the distribution for January 2011 with the mixed layer about 10 metres shallower. Observations are at the locations indicated by the red dots.

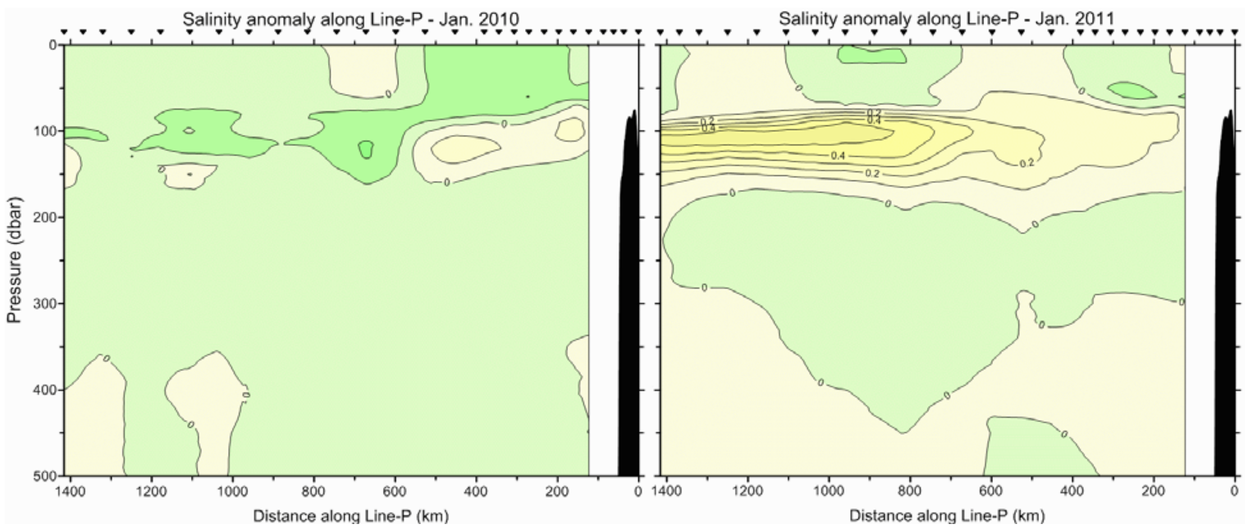

Figure 3. Anomaly of salinity measured along Line-P for January 2010 and January 2011. These images are derived by interpolation of observations from the Argo array.

Fig. 2 shows the influence of the anomalously shallow density surfaces on the formation of a deep mixed layer. The extent of this impact along Line-P can easily be seen in Fig. 3 where again we contrast the distribution in January 2011 with that we observed precisely one year earlier. The contrast could hardly be more marked. The shallow density surfaces have made salinity surfaces shallower and this layer of dense and saline water forms a very effective barrier to deep mixing.

Fig. 4 contrasts the broad and diffuse North Pacific Current in January 2011 with the narrow and intense current in June 2008. It is this North Pacific Current than might deliver debris from the Japan tsunami of March 2011. The decrease in its speed since 2008 might retard arrive of material to west coast beaches. (A typical time to drift across the Pacific is 2 to 3 years.)

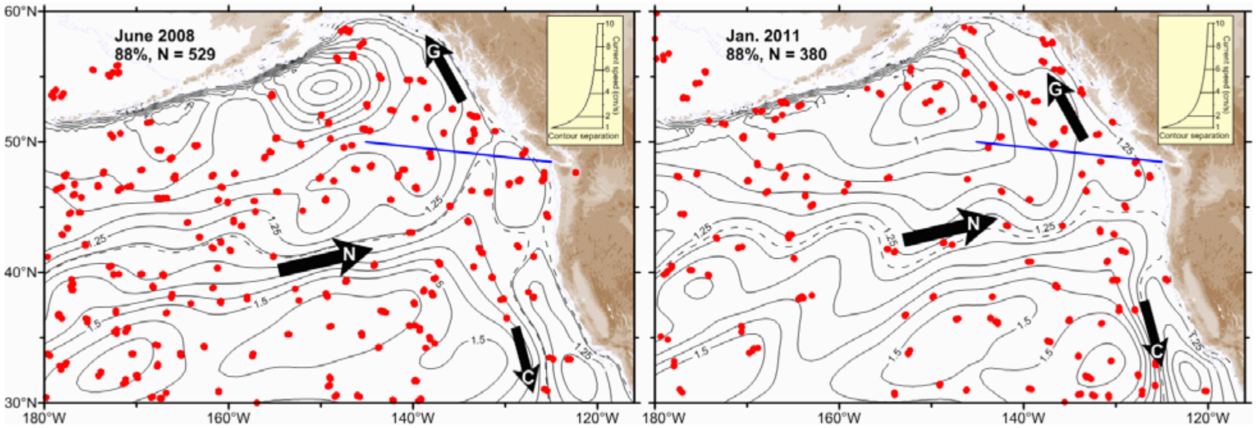

Figure 4: Two maps of the circulation of the NE Pacific. Streamlines of ocean surface currents are plotted in solid black lines. Closely spaced streamlines indicate stronger currents. The arrows labelled N, C and G identify the North Pacific, California and Alaska Currents, respectively. On the left a map for June 2008 when the North Pacific Current was narrow and strong. Currently, as seen in January 2011, the North Pacific Current is broad and weak.

Fig. 5 shows a time series of the strengths of the three major currents, and the ratio in red showing the fraction of water in the North Pacific Current that eventually heads into the Gulf of Alaska. Between 2004 and 2008 the amount of water carried in the North Pacific Current steadily increased and since mid-2008 has been steadily decreasing.

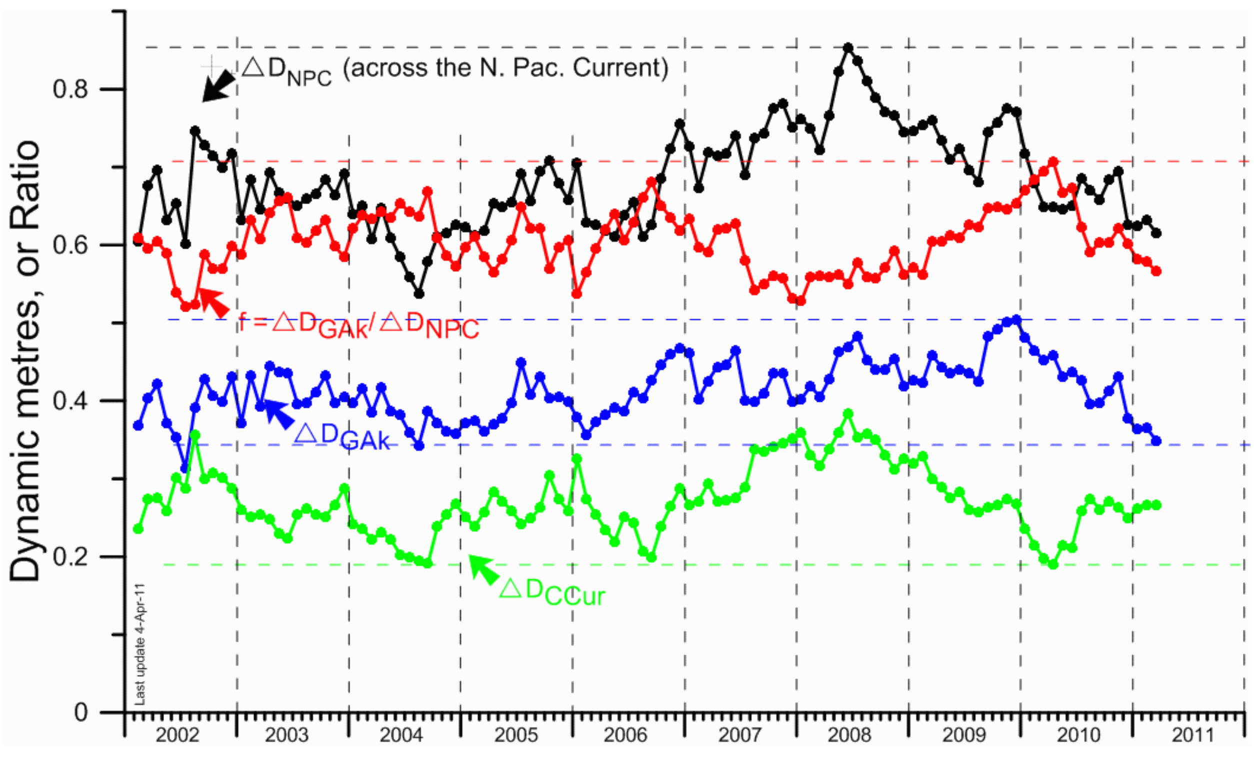

Figure 5. The difference in dynamic height between two points is a good surrogate for the strength of the current between those two points and flowing perpendicular to the line joining them. The black, blue and green lines indicate the relative strength of flow in the three major currents in the Northeast Pacific Ocean. The red line is the ratio of the blue line divided by the black line and so represents the fraction of North Pacific Current water that flows northward into the Gulf of Alaska. The remaining water is carried to the south in the California Current.

OCEAN CONDITIONS IN BC WATERS AND GULF OF ALASKA

Marie Robert, Bill Crawford, Nick Bolingbroke Fisheries & Oceans Canada

The surface ocean west of Canada was hit by extremes in 2010 and early 2011. In January to March 2010 the entire region was much warmer than the 75-year average, likely due to the strong Aleutian Low Pressure system of this winter (Fig. 1). Only in a few inlets of the north coast of British Columbia did average temperature fall below average seasonal values.

Salinity all along the coast was much below normal, but only slightly below normal in deep-sea regions. Warmer and fresher waters along the coast were more buoyant than in average winters, and warmer water extended down to several hundred metres depth. Anomalies of both temperature and salinity shifted sign from winter to summer of 2010, a rare event for BC waters.

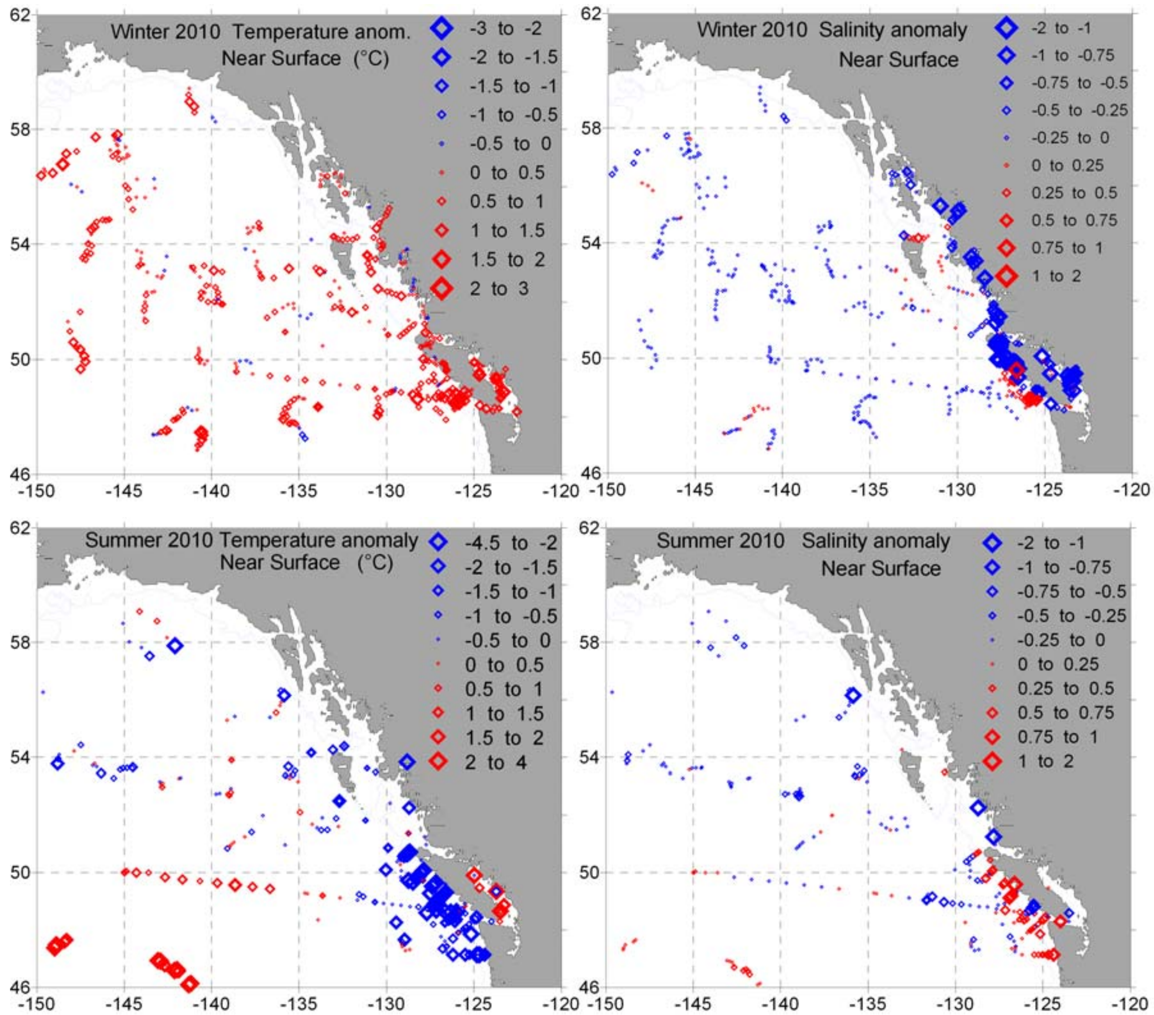

Figure 1. Anomalies of ocean temperature (°C) and salinity in January to March 2010 (top panel) and in August to September 2010 (bottom panel). Each symbol represents a single measurement of temperature by Argo profilers, Fisheries and Oceans research cruises, weather buoys and at lighthouses. The colour of each symbol denotes positive anomaly (red) or negative (blue). Size of each symbol denotes magnitude of the anomaly according to the scale in each panel. Most observations were in the upper 10 metres of the ocean and referenced to a seasonal average of the years 1929 to 2005. Lighthouse observations were from the ocean surface at shore.

We believe the strong northerly coastal winds in July-August set up the relatively cool and salty waters near the ocean surface along the west coast in summer 2010. Such winds upwell deep waters to the surface on the continental shelf. These cool and salty anomalies extended down to at least 100 metres depth. However, near-surface temperature remained above normal in the Strait of Georgia in summer 2010. It is common for ocean temperature in the Strait of Georgia to take as much as a year to respond to changes in offshore temperatures.

Cool temperature persisted off the west coast of Vancouver Island into early 2011, and the Strait of Georgia remained cool. Salinity shifted from relatively salty in summer 2010 to relatively fresher in winter 2011 off the Vancouver Island west coast, yet relatively salty water covered the Strait of Georgia. All these anomalies were present down to at least 100 metres depth. The fresh anomaly along the Vancouver Island west coast is rather curious. It was present in both winters, despite strong southerly winds in 2010 and strong westerly winds in 2011.

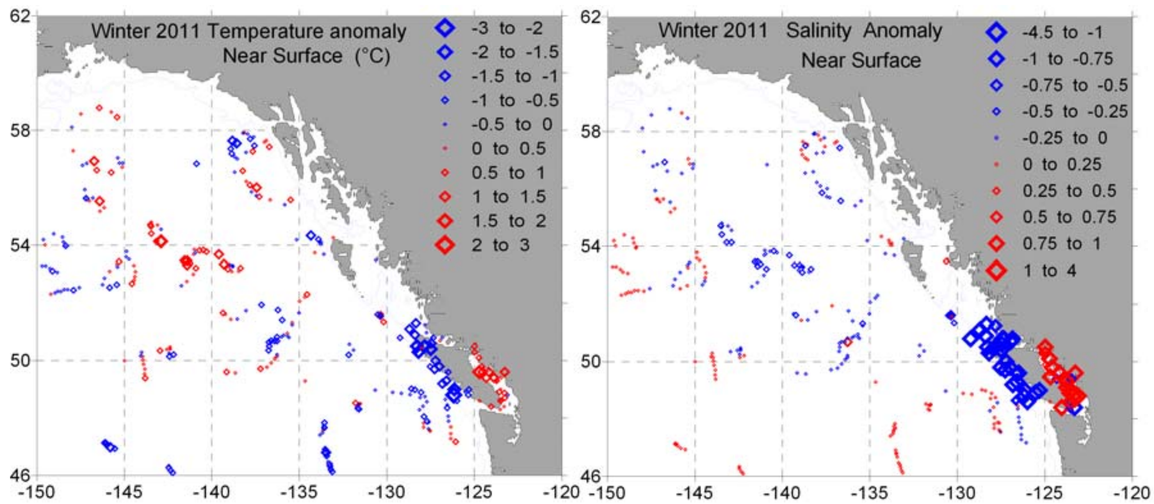

Figure 2. Anomalies of ocean temperature (°C) and salinity in January to March 2011. Each symbol represents a single measurement of temperature by Argo profilers, Fisheries and Oceans research cruises, and at lighthouses. The colour of each symbol denotes positive anomaly (red) or negative (blue). Size of each symbol denotes magnitude of the anomaly according to the scale in each panel. Most observations were in the upper 10 metres of the ocean and referenced to a seasonal average of the years 1929 to 2005. Lighthouse observations were from the ocean surface at shore.

We next show more details of how these anomalies extended to deep waters in the Gulf of Alaska along Line P, a set of ocean sampling stations extending almost 1500 km west of Vancouver Island. This program began in the 1950s by collecting data while weatherships were in transit to Ocean Station Papa at 50N, 145W. Fisheries and Oceans Canada has managed this program since the Weathership Program ended in 1981.

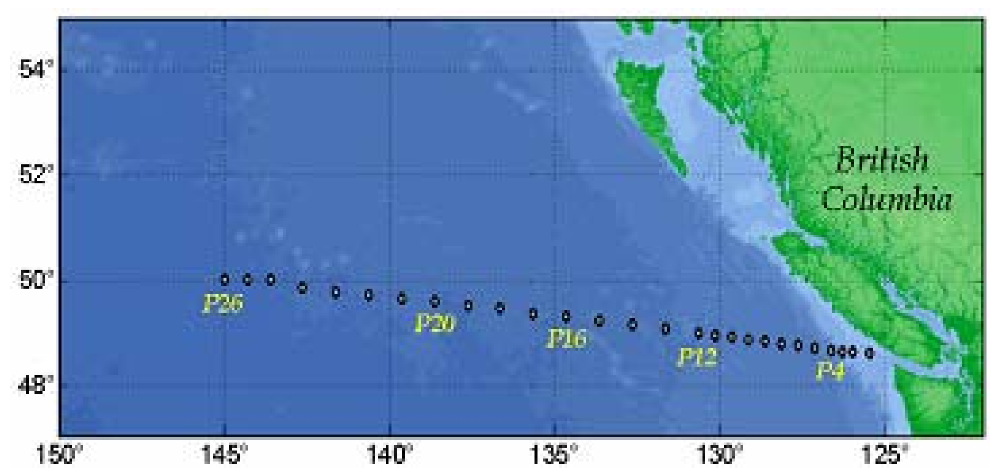

Figure 3.

Line P stations in the Gulf of Alaska. Ocean Station Papa is at P26. Although all stations are sampled, more extensive water samples are collected and analysed at the numbered stations.

Warming along Line P began in 2008, and by February 2010 these waters were above seasonal average temperature near the coast and in the top 100 metres (Fig. 4b). During this month, an intense low pressure system was situated over the Gulf of Alaska. One of the storms in this system (Fig. 4a) prevented the CCGS *J.P. Tully* from reaching Ocean Station Papa. Salinity along Line P was very near the average for this month but waters on the continental shelf were saltier at the surface and fresher at shelf bottom than normal (Fig. 4c). Oxygen concentrations above 6 millilitres per litre (ml/L) extended right to the bottom of the continental shelf, indicating strong downwelling and mixing due to the southerly winds of this winter. (Fig. 4d).

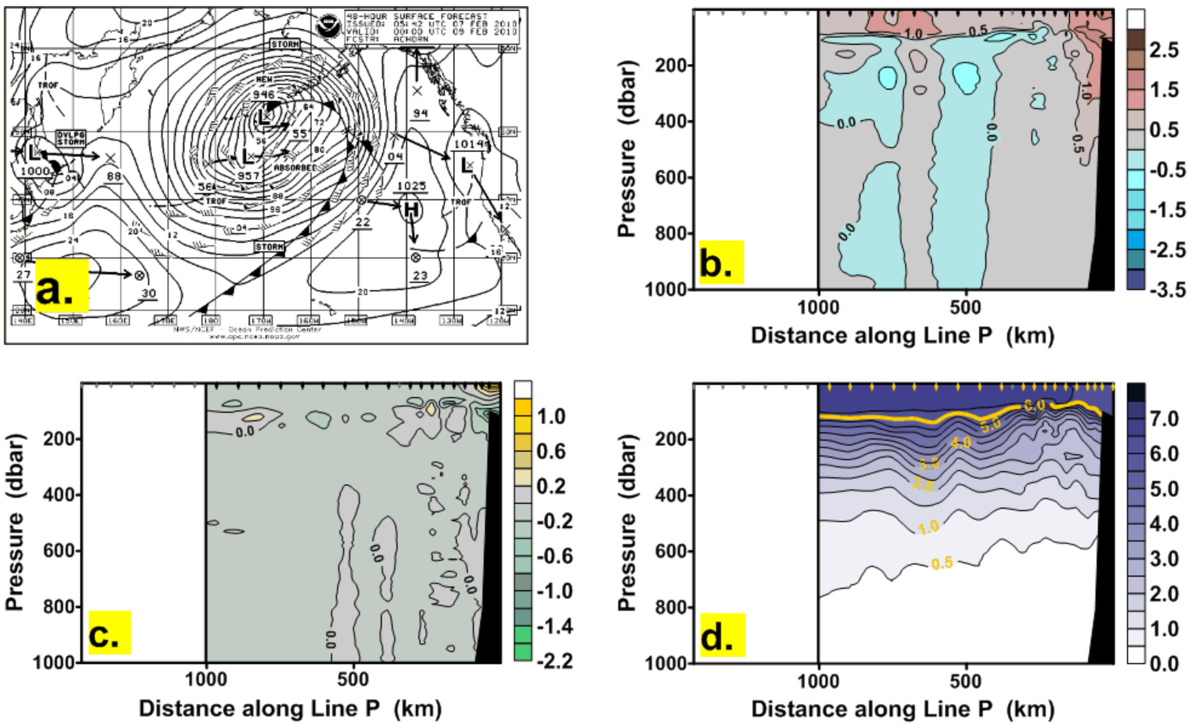

Figure 4: February 2010: a. Low pressure system over the North Pacific, 48hr surface forecast on 7 Feb 2010; b. Temperature anomaly (°C) with respect to the 1956-1991 average; c. Salinity anomaly with respect to the same period; d. Dissolved oxygen levels (ml/L) along Line P.

By June 2010, the North Pacific High extended over most of the Northeast Pacific Ocean (Fig. 5a). Surface waters along Line P were fairly cool with respect to the long-term average (1956-1991) but some residual warmer-than-average waters were still present just below the surface (Fig. 5b). There was a layer of salty waters between 90 and 150 metres, suggesting a shoaling of the mixed layer and of waters beneath the mixed layer during late winter (Fig. 5c). The 6.5 ml/L contour of dissolved oxygen now reached the coast at surface, but oxygen levels declined in deeper water of the continental shelf compared to winter concentrations, as was normal for late spring there. A thin layer of more oxygenated waters was present offshore centered on 60 metres of depth, possibly due to a local eddy. (Fig. 5d).

In August 2010 the North Pacific High was all across the Northeast Pacific, as revealed in Fig. 6a, driving coastal winds southward along the BC coast and inducing strong summer upwelling. This can be observed in the temperature anomaly (Fig. 6b) and salinity anomaly (Fig. 6c) graphs, where the coastal waters are cool and salty, brought up there from lower depths.

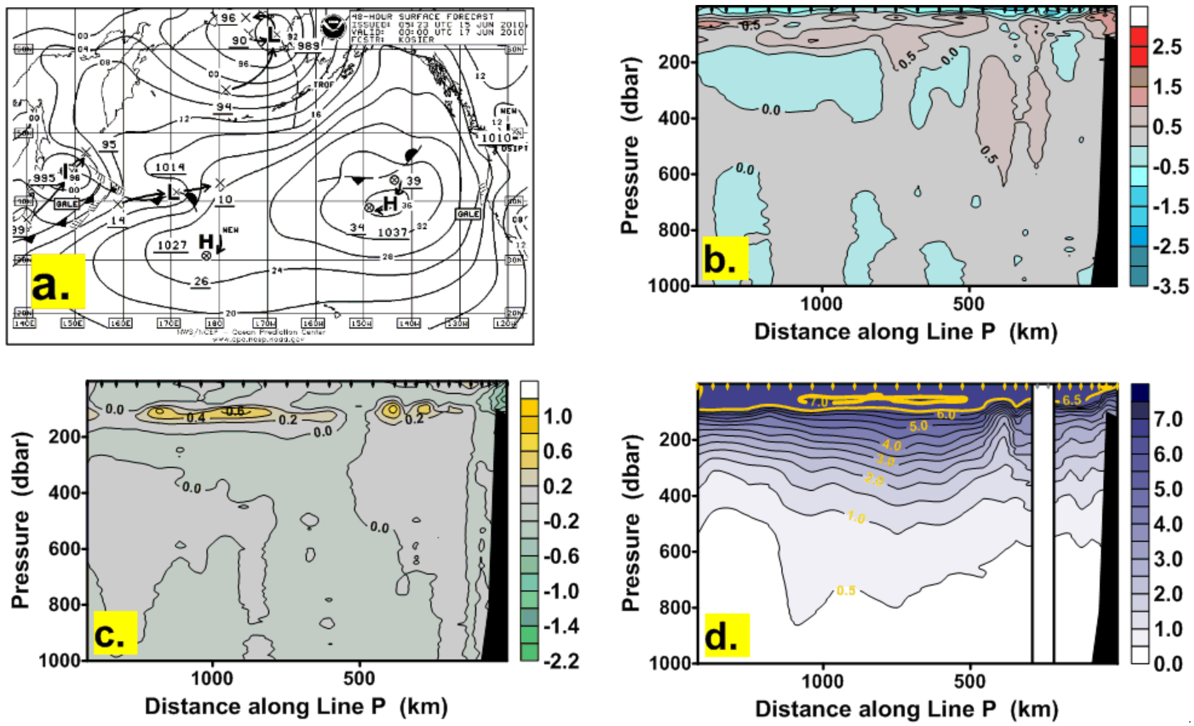

Figure 5: June 2010: a. Pressure systems over the North Pacific, 48hr surface forecast on 15-Jun-2010; b. Temperature anomaly (°C) with respect to the 1956-1991 average; c. Salinity anomaly with respect to the same period; d. Dissolved oxygen levels (ml/L) along Line P.

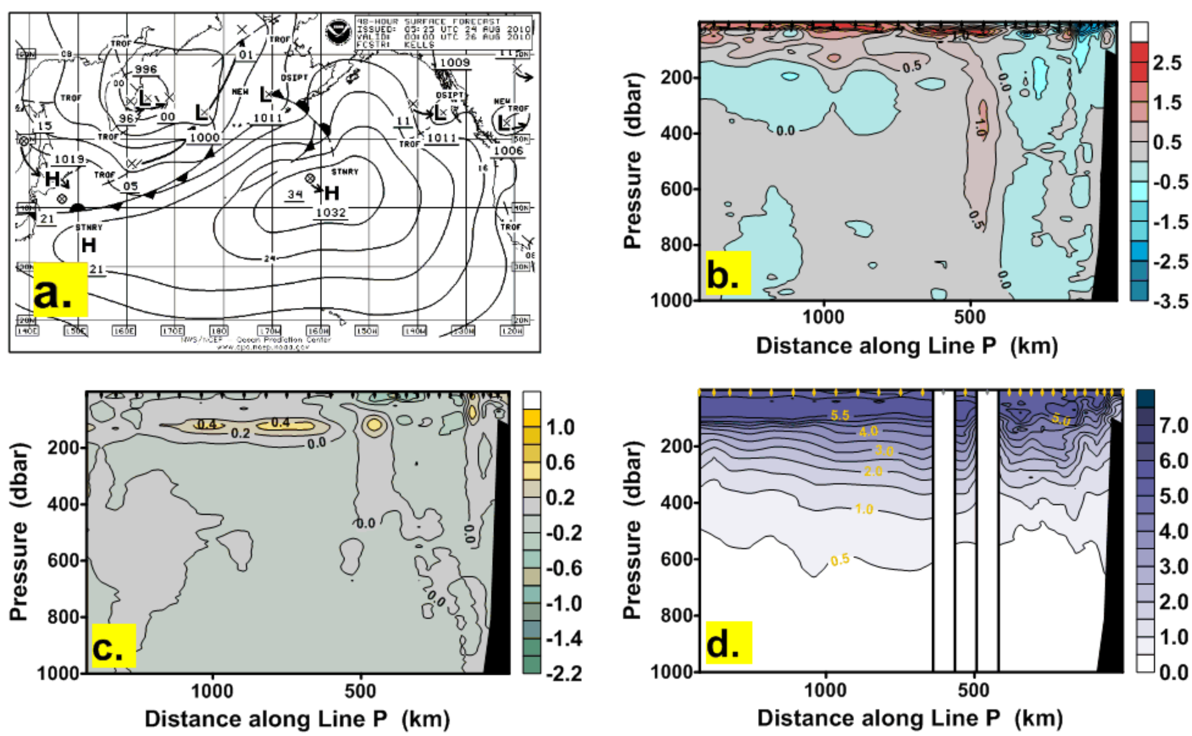

Figure 6: August 2010: a. Pressure systems over the North Pacific, 48hr surface forecast on 24 Aug 2010; b. Temperature anomaly (°C) with respect to the 1956-1991 average; c. Salinity anomaly with respect to the same period; d. Dissolved oxygen levels (ml/L) along Line P.

Oxygen concentration in August 2010 was the lowest of the year at the bottom of the continental shelf. Generally the lowest observed values there are in August to early October, when upwelling winds bring deep waters with low oxygen onto the bottom of the continental shelf from deeper offshore regions. These waters are further deprived of oxygen by decaying organic matter on the shelf bottom. A search of oxygen measurements by research vessels in this region revealed that the concentration in late August 2010 was about 1 ml/L near ocean bottom in 145 metres of water on mid-shelf off southwest Vancouver Island. Oxygen concentrations between 1.4 and 0.5 ml/L are labelled as hypoxic, and can disrupt bottom dwellers. A concentration of 1 ml/L is a rather typical value for this region, although observed values as low as 0.7 ml/L were found here in 2006 and 2009. (Crawford 2011, else where is this research document.)

The year 2011 started fairly stormy, although not quite as severely than 12 months prior (Fig. 7a). Offshore waters along Line P were again quite warm compared to the 1956-1991 average (Fig. 7b) and they were not as well mixed as they were in the very stormy conditions of the previous winter. The salty layer at the base of the mixed layer was still present (Fig. 7c). The dissolved oxygen data for February 2011 are not yet available.

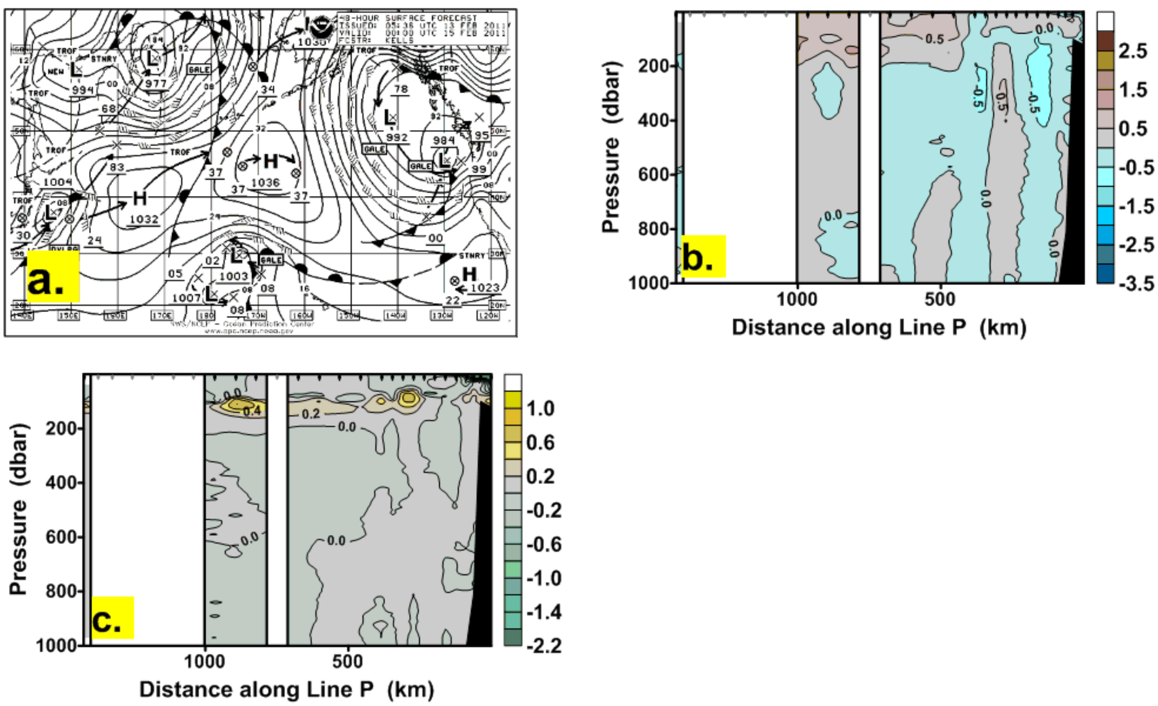

Figure 7: February 2011: a. Pressure systems over the north Pacific, 48hr surface forecast on 13-Feb-2011; b. Temperature anomaly (°C) with respect to the 1956-1991 average; c. Salinity anomaly with respect to the same period; Preliminary results.

The images above show changes in water properties over the past 15 months. With more than 50 years of regular observations along Line P we can show how present conditions compare to the ocean weather of the past decades. Graphs on the next two pages show these changes.

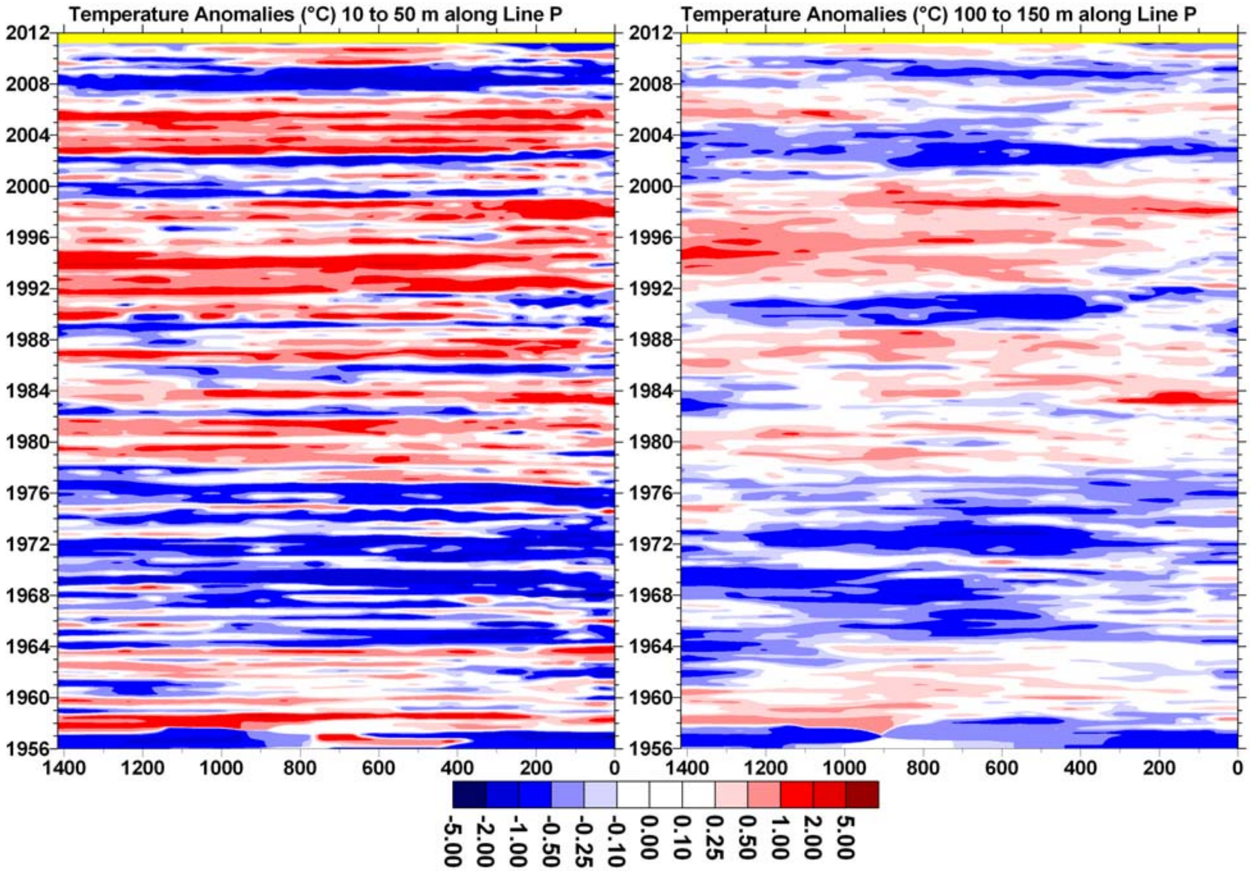

Figure 8. Time-distance plots of anomaly of temperature in °C along Line P at 10 to 50 metres depth (left panel) and 100 to 150 metres depth (right panel). Temperature anomaly scale is at bottom. The horizontal axis denotes distance west of Station P1 on the continental shelf of Vancouver Island near Juan de Fuca Strait. Ocean Station Papa is at far left in each panel. Vertical axes present the year. Details of how this plot was prepared are presented by Crawford, Galbraith and Bolingbroke, 2007.

The graphs in Fig. 8 show changes in ocean temperature along Line P over the past 54 years, based on the regular sampling during these years and supplemented with measurements at nearby stations by Argo profilers and other sampling programs. The anomalous temperature of each measurement was determined by comparing to the average of that week and depth and position along Line P, based on sampling up to 2005. Each panel presents contours of temperature anomaly over near surface waters (left panel) and deeper waters (right panel). Blue regions denote negative anomalies and relatively cool water whereas red regions show positive anomalies and relatively warm water.

Note the intense cooling along Line P from 2007 to 2008. Only in the 1960s and 1970s were such negative temperature anomalies found to persist for several years. Warmer water appeared in late 2009 and stayed until 2010; however cooling near shore began in mid-2010. The most recent observations in winter 2011 reveal cold water in both depth ranges near shore and more neutral temperature along deep-sea regions of Line P. The shifts in temperature from late 1990s to present have generally followed the El Niño – La Niña cycles, with warm ocean water associated with El Niño and cool water with La Niña. Prior to 1998 the El Niño cycles were less reliable predictors of ocean surface temperature along Line P.

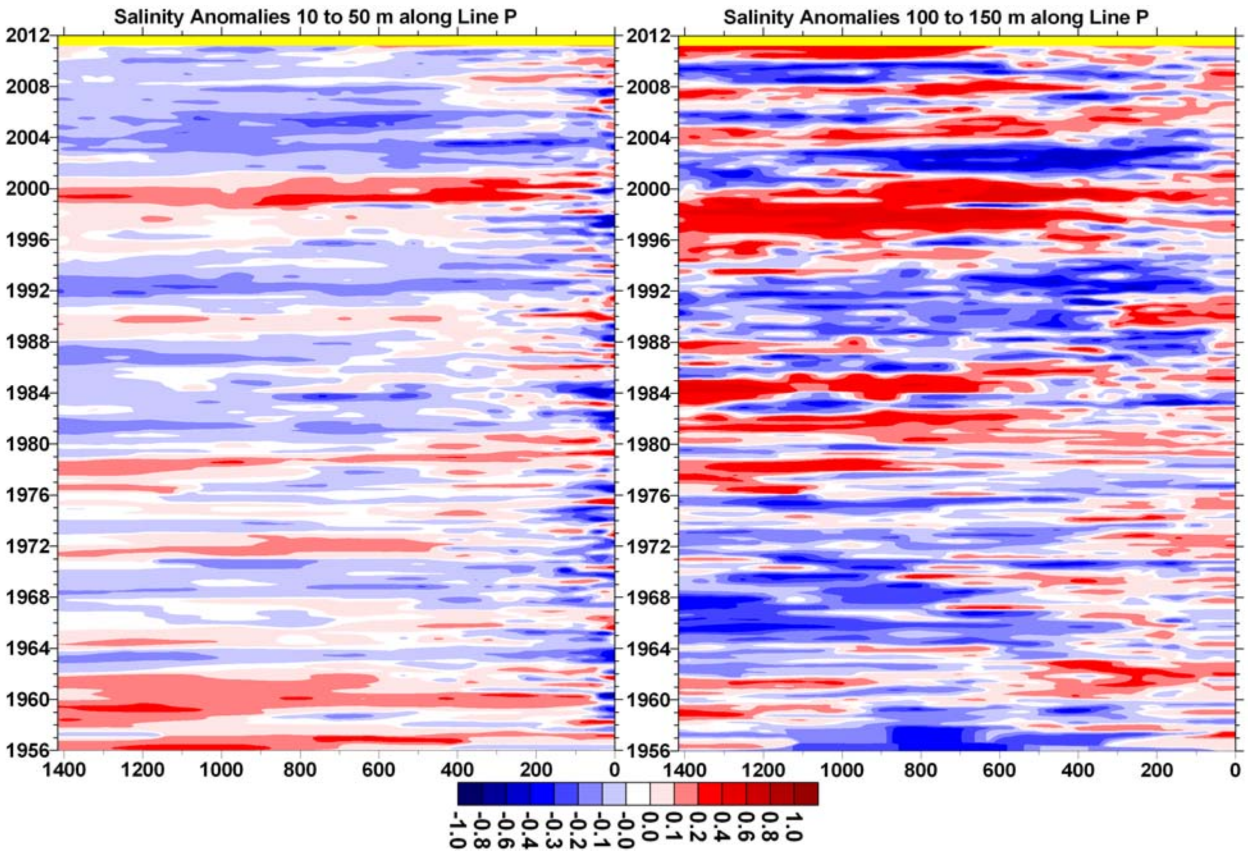

Figure 9. Time-distance plots of anomaly of salinity along Line P at 10 to 50 metres depth (left panel) and 100 to 150 metres depth (right panel). Salinity anomaly scale is at bottom. The horizontal axis denotes distance west of Station P1 on the continental shelf of Vancouver Island near Juan de Fuca Strait. Ocean Station Papa is at far left in each panel. Vertical axes present the year. Details of how this plot was prepared are presented by Crawford, Galbraith and Bolingbroke, 2007.

The ocean salinity varies little in the top 100 metres along the deep-sea region of Line P, but increases sharply from 110 metres to 150 metres. If these deep waters upwell the salinity at 100 to 150 metres increases sharply. For this reason the variability in salinity is greater at 100 to 150 metres depth (Fig. 9, right panel) than at 10 to 50 metres (Fig. 9, left panel). Since the mid-1990s the salinity anomalies from 100 to 150 metres depth have been greater than in previous decades, and most of Line P, as of early 2011, is saltier at these depths. Unlike changes in temperature, the salinity anomalies do not respond reliably to changes in the El Niño – La Niña cycle. Di Lorenzo *et al*. (2009) suggest that the North Pacific Gyre Oscillation and strength of the North Pacific Current are reasonable indicators of salinity changes at Ocean Station Papa, and of changes in nutrients all along Line P.

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Di Lorenzo, E., Fiechter, J., Schneider, N., Bracco, A., Miller, A.J., Franks, P.J.S., Bograd, S.J., Moore, A.M., Thomas, A.C., Crawford, W., Peña, A. and Hermann, A., 2009: Nutrient and salinity decadal variations in the central and eastern North Pacific. *Geophysical Research Letters*, 36, L14601, doi:10.1029/2009GL038261.

NORTHEAST PACIFIC SEA LEVEL INDEX

Patrick Cummins, Fisheries & Oceans Canada

The Northeast Pacific Sea Level (NPSL) index is calculated by regressing sea level anomalies observed by satellite altimetry at 10-day intervals onto the spatial pattern associated with the leading empirical orthogonal function of sea level over the northeast Pacific. This is taken as the oceanic region bounded to the south by the 30ºN latitude circle and to the west by 180W°.

On interannual time scales, sea level anomalies are thought to reflect changes in the height of the water column associated principally with integrated temperature anomalies through the top few hundred meters of the ocean. The index then indicates large-scale, low frequency variability of upper ocean heat content over the region. In this way the NPSL index is complementary to the Pacific Decadal Oscillation (PDO) which is based on sea surface temperatures over the entire extra-tropical North Pacific. The NPSL index has more 'inertia' than the PDO, and is less subject the relatively short-term variations. Fig. 2 presents the NPSL index for the 18-year period from January 1993 through December 2010, along with the PDO index.

The spatial pattern of the NPSL Index is shown in Fig. 1 for times when its amplitude is positive. Regions in red reveal highest sea level; dark blue denotes low sea level. Ocean currents follow these contours of constant sea level, flowing counter-clockwise around the low area and flowing from the south along the eastern Gulf of Alaska, carrying warmer water from the south. The eastern gulf is warmer when the NPSL Index is positive (1993-1998, 2003-2007). When the NPSL Index is negative (1999-2003, 2006-2011), the regions of high and low sea level anomaly reverse and these warm currents slow down in the eastern Gulf of Alaska, allowing these waters to cool. Fig. 2 reveals these changes in the NPSL Index.

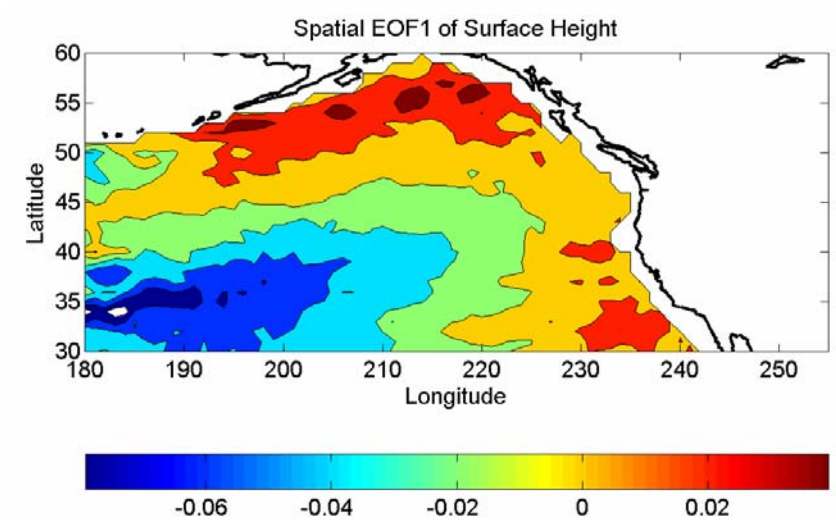

Figure 1. Region covered by the NPSL Index analysis and the spatial pattern of its variation. The scale bar at bottom shows relative magnitude of its amplitude on an arbitrary scale.

Since the beginning of the NPSL Index in 1993 its variations have generally followed those of the Pacific Decadal Oscillation. In 2010, variations in the NPSL index were similar to those of the PDO index (Fig. 2), but with smaller amplitude and lagged by several months. At the start of 2010, the PDO index was in its warm phase, reflecting the influence of El Niño conditions in the tropical Pacific. During late spring, as pronounced La Niña conditions began to develop, the PDO descended rapidly to strong negative values that are associated with below average sea surface temperatures over the Northeast Pacific. Such conditions persisted through the rest of 2010. The NPSL index followed suit but with a short lag. During the second half of the year, in response to the La Niña event, NPSL returned to the negative anomalies and lower sea level that had characterized the start of 2010.

The outlook for 2011 calls for gradual weakening of La Niña conditions in the tropical Pacific. La Niña is expected to last at least through spring, and (as of April 2011) a transition to ENSO-neutral conditions is expected by June 2011. Accordingly, it may be expected that relatively cool ocean conditions will prevail over the NE Pacific over the first half of 2011. With reduced upper-ocean heat content it seems likely that the NPSL index will remain negative over at least the first half of 2011.

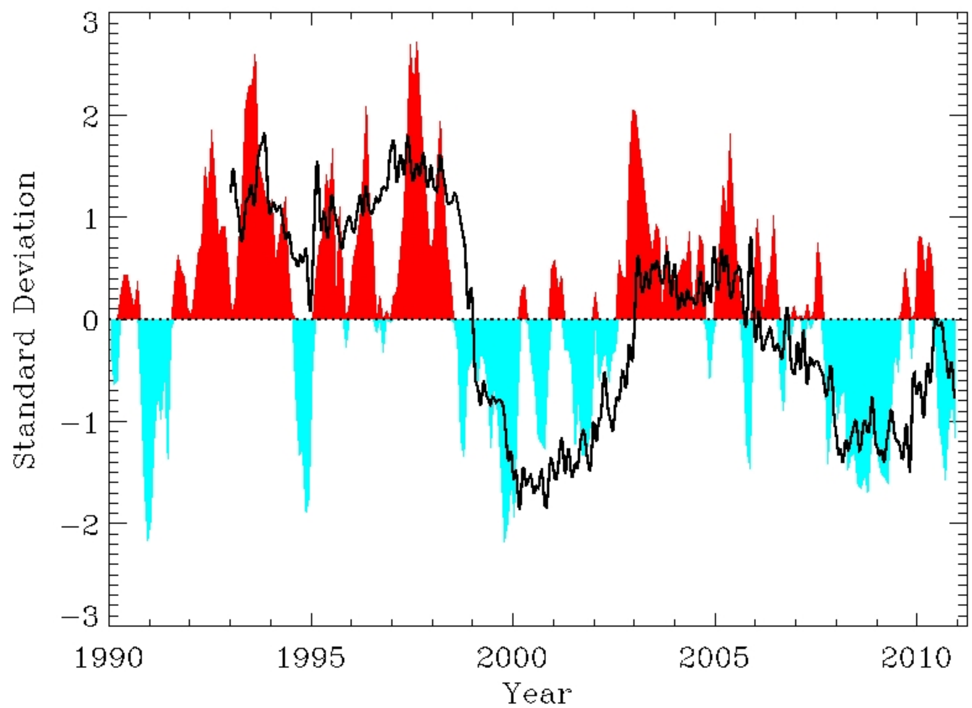

Figure 2. The NE Pacific Sea level Index (NPSL) is indicated by the solid black curve. Positive (negative) values are associated with anomalously elevated (depressed) sea level over the Gulf of Alaska and along the west coast. The PDO index since 1990 is shown with blue for the cold phase of the index and red for the warm phase. Both indices have been normalized by their standard deviations.

It is evident from inspection of Fig. 2 that the NPSL Index, and to a lesser extent the PDO, has frequently assumed negative values since 1999. With regard to the PDO, its record since 1999 stands in contrast to the previous period, 1977-1998, in which this index was most often in its positive, warm phase. Both the PDO and the NPSL index underwent a strong shift in 1999 from the positive to negative state as La Niña conditions developed in the tropics. Since this time, these indices (especially the NPSL index) have often tended to the cool phase. There are suggestions that the shift of 1999 is associated with a global-scale climate shift that heralds a break from the particularly strong warming trend that characterized the period 1976/77 -1998 (Swanson & Tsonis, 2009). If this is the case, then given that such shifts occur on decadal time scales, the cool phase of PDO and NPSL indices may be expected to occur frequently for some years to come.

<u>Reference</u>

Swanson, K.L. and A.A. Tsonis (2009) Has the climate recently shifted? *Geophys. Res. Lett.*, **36**, L06711, doi: 10.1029/2008GL037022

WIND-DRIVEN UPWELLING/DOWNWELLING ALONG THE WEST COAST

Roy Hourston and Richard Thomson, Fisheries & Oceans Canada

Highlights of the sea-level pressure and associated surface wind anomalies over the Northeast Pacific Ocean in 2010 include:

- A stronger than average and eastward-shifted Aleutian Low in January. This resulted in stronger than average downwelling-favourable (southeasterly) winds along the coast of British Columbia and upward (divergent) Ekman pumping in the central Gulf of Alaska centered near 160°W in January 2010 (Fig. 1);
- A stronger than average and northward-shifted North Pacific High in July. This was associated with stronger than average upwelling-favourable (northwesterly) winds along the coast of British Columbia and downward (convergent) Ekman pumping in the central Gulf of Alaska in July 2010(Fig. 2);
- A weaker Aleutian Low in January 2011 (Figs. 3 and 4), followed by a near-record weakening of the Aleutian Low in February. The cold winds of February 2011 along the west coast brought record cold air temperatures on several days to some cities, and ocean temperatures below normal for most of the Gulf of Alaska.

Due to their link to offshore surface Ekman transport and compensating onshore transport at depth, the duration and intensity of upwelling-favourable (northwesterly) winds are good indicators of coastal productivity. To gauge low-frequency variability in coastal productivity, we have summed upwelling-favourable-only wind stresses by month along the west coast of North America from 45°-60°N latitude (Fig. 5). Fig. 6 shows the monthly mean integrated upwelling anomalies smoothed using a five-year running mean for the period 1948-2010. The regime shift in the late 1970s appears as a sharp transition from stronger- to weaker-than-average upwelling-favourable winds. Upwelling-favourable winds have been stronger than average throughout the 2000s. In previous State of the Ocean Reports, we speculated that a repeat of the mid 1970s regime shift to weaker-than-average upwelling appeared imminent. However, stronger-than-average upwelling-favourable winds generally continued through 2010 as far north as 55°N (Fig. 7). The summer of 2010 was characterized by strong positive upwelling-favourable wind stress anomalies on par with those in 2006.

We have also examined the downwelling-favourable winds by considering only the poleward component of the alongshore wind stress. Anomalies of the monthly poleward sums are shown in Fig. 8. Here, the regime shift in the late 1970s is characterized by a latitude-dependent transition. Southward of 48ºN, the transition is from average to below-average downwelling, whereas northward of this latitude, the transition marks a change from below average to stronger than average downwelling. The major El Niños of 1982-83 and 1997-98 are characterized by stronger than average downwelling. The largest anomalies and greatest spatial extent are positive, beginning in 1998 and extending over the range of latitude from 45-60ºN through to the present. A more detailed (non-filtered) examination of the last five years (Fig. 9) shows mostly positive downwelling anomalies over this period, with strong (downwelling-favourable) poleward winds in the winter of 2006-2007 and stronger than average downwelling favourable poleward winds beginning mid-year in 2009 that continued to the end of 2010.

Strong mid-winter downwelling in January 2010 was due to intensification and/or an eastward shift of the Aleutian Low. We can interpret the shift from negative to positive downwelling index values in the winter of 2006-07 as an eastward shift plus intensification of the Aleutian Low. Positive downwelling index values throughout the winter 2009-10 also can be interpreted as an eastward-shifted and strong Aleutian Low throughout the winter. *Thus variations in the* *downwelling index are due to variability in the Aleutian Low, and consist of a combination of east-west shifts in the centre of the Low and variations in its strength.*

Both upwelling and downwelling indices are positive through much of the 2000s (Figs. 6 and 8), suggesting an overall increase in wind speed and wind stress, regardless of wind direction. While the effects on upwelling and alongshore advection are dependent on the wind direction, the effects on mixed-layer depth and Ekman pumping by the generally positive windstress curl in the Gulf of Alaska in winter should be mainly related to wind strength. The long-term effects in the northeast Pacific of changes in scalar wind properties is unclear, but could impact overall biological productivity.

Acknowledgements

NCEP/NCAR Reanalysis-1 sea-level pressure and wind stress and Reynolds Optimum Interpolation (OI) V2 SST data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/. Literature references for the data are given below.

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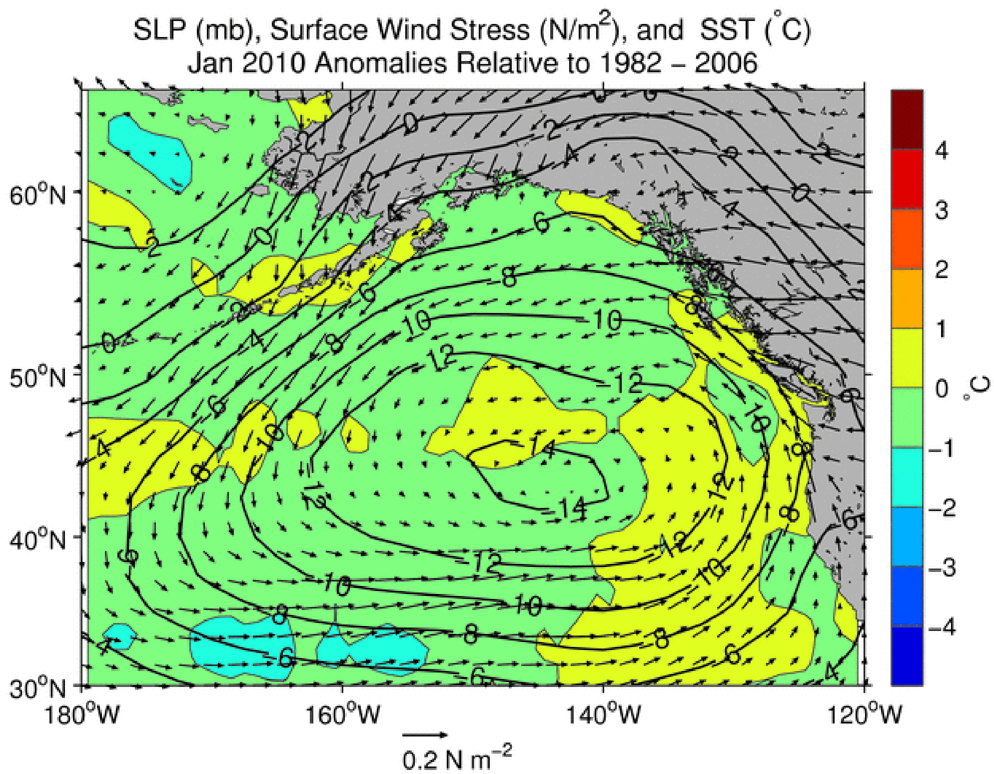


Figure 1. Anomalies (relative to 1982-2006) of sea-level pressure (contours), wind stress (vectors), and sea-surface temperature (colour contours) for the month of January 2010.

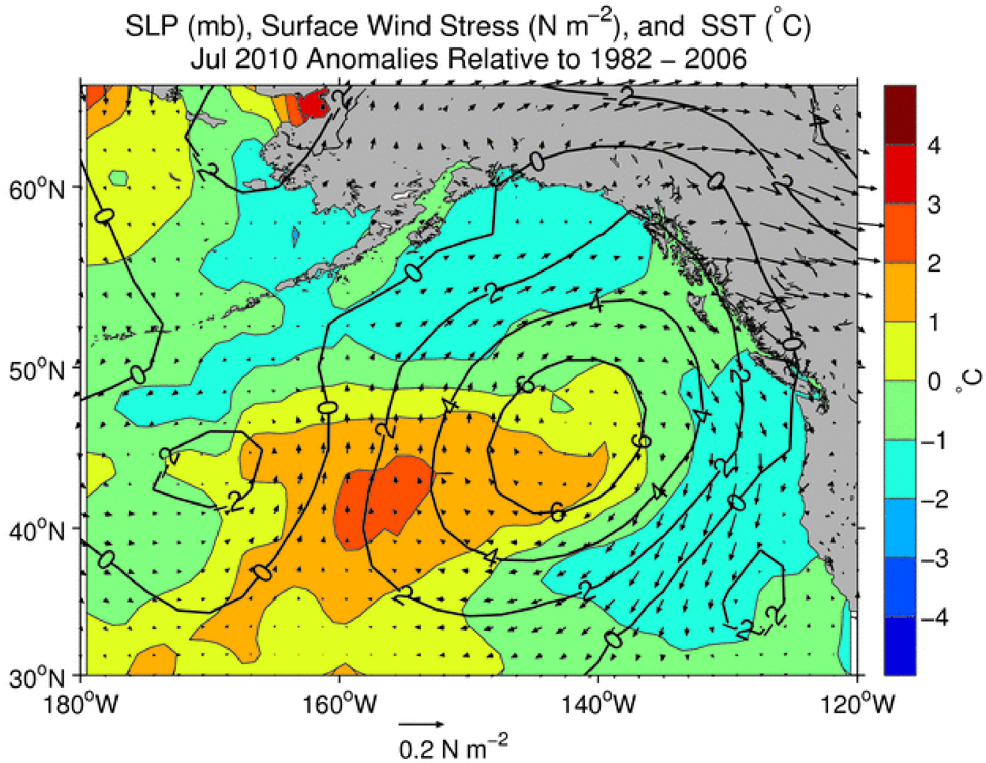


Figure 2. Anomalies (relative to 1982-2006) of sea-level pressure (contours), wind stress (vectors), and sea-surface temperature (colour contours) for the month of July 2010.

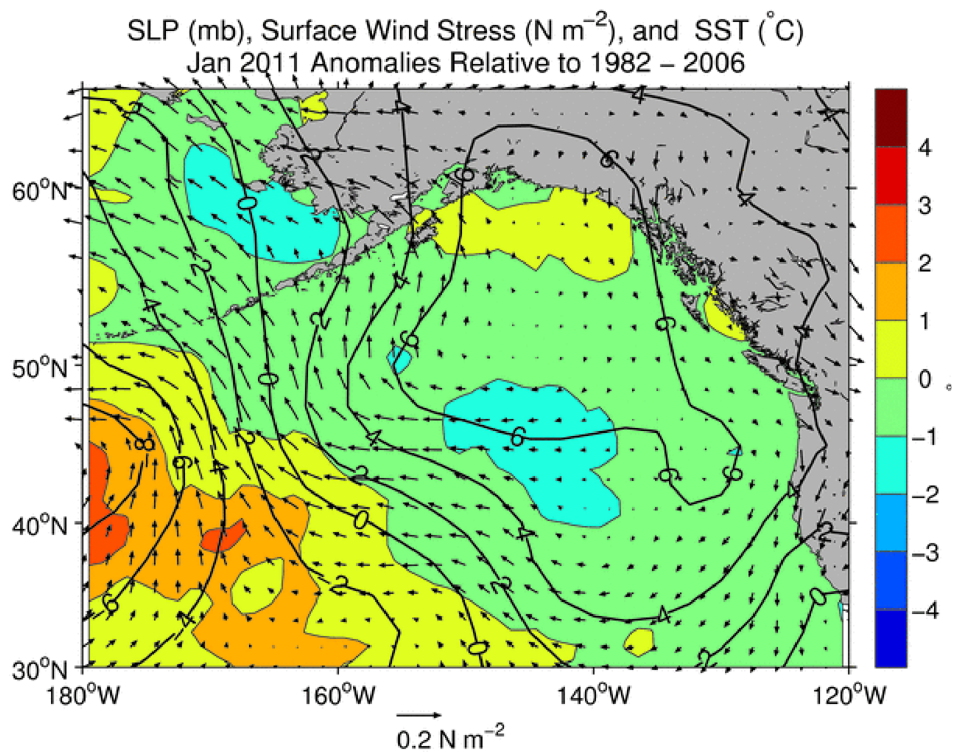


Figure 3. Anomalies (relative to 1982-2006) of sea-level pressure (contours), wind stress (vectors), and sea-surface temperature (colour contours) for the month of January 2011.

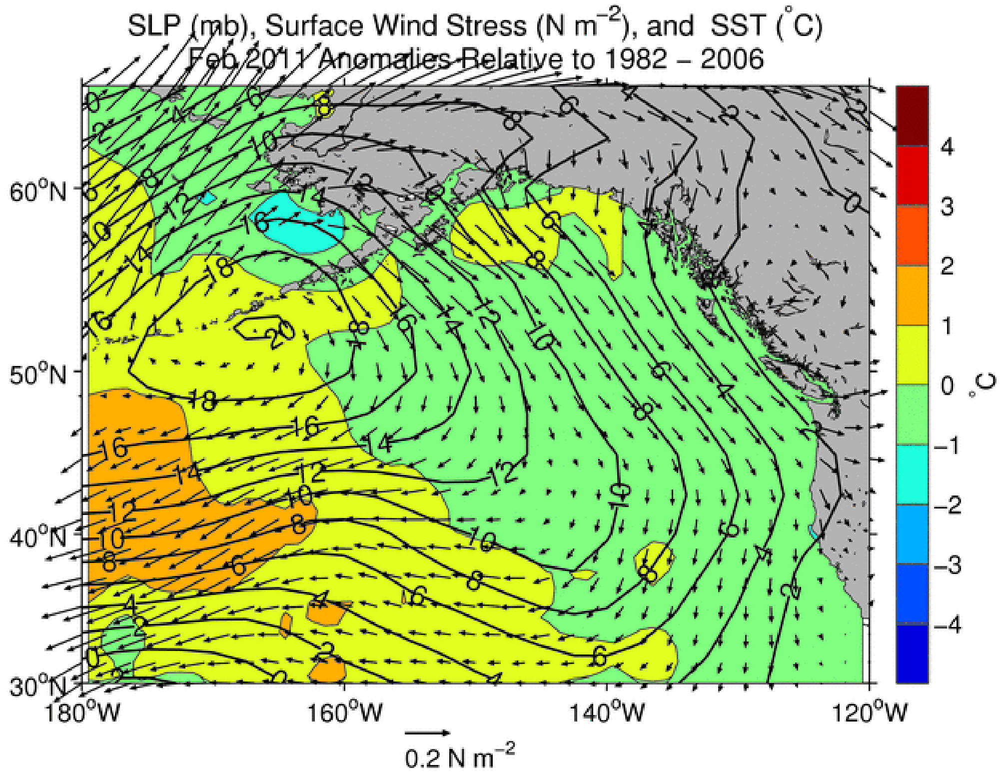


Figure 4. Anomalies (relative to 1982-2006) of sea-level pressure (contours), wind stress (vectors), and sea-surface temperature (colour contours) for the month of February 2011.

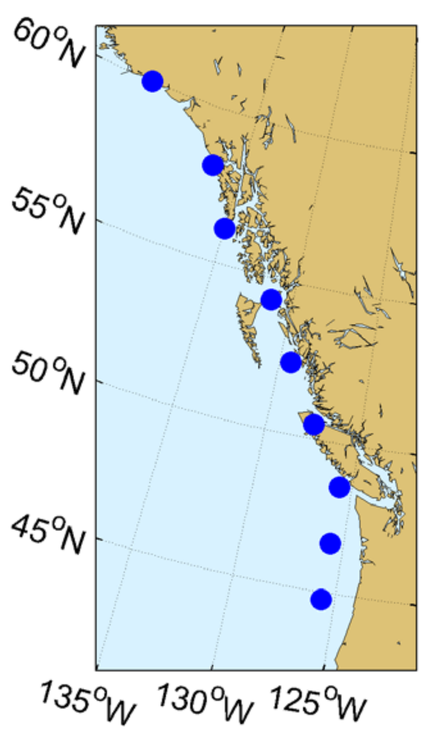


Figure 5. NCEP/NCAR Reanalysis-1 coastal surface wind stress grid locations.

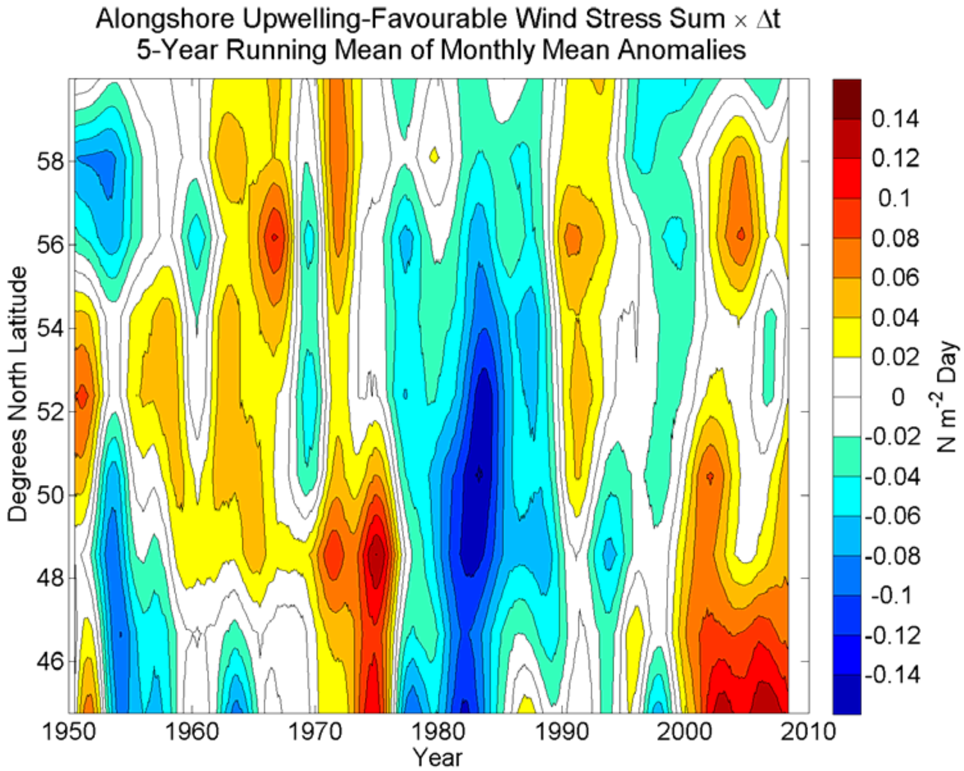


Figure 6. Five-year running means of monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress at coastal grid points from 45°-60° N.

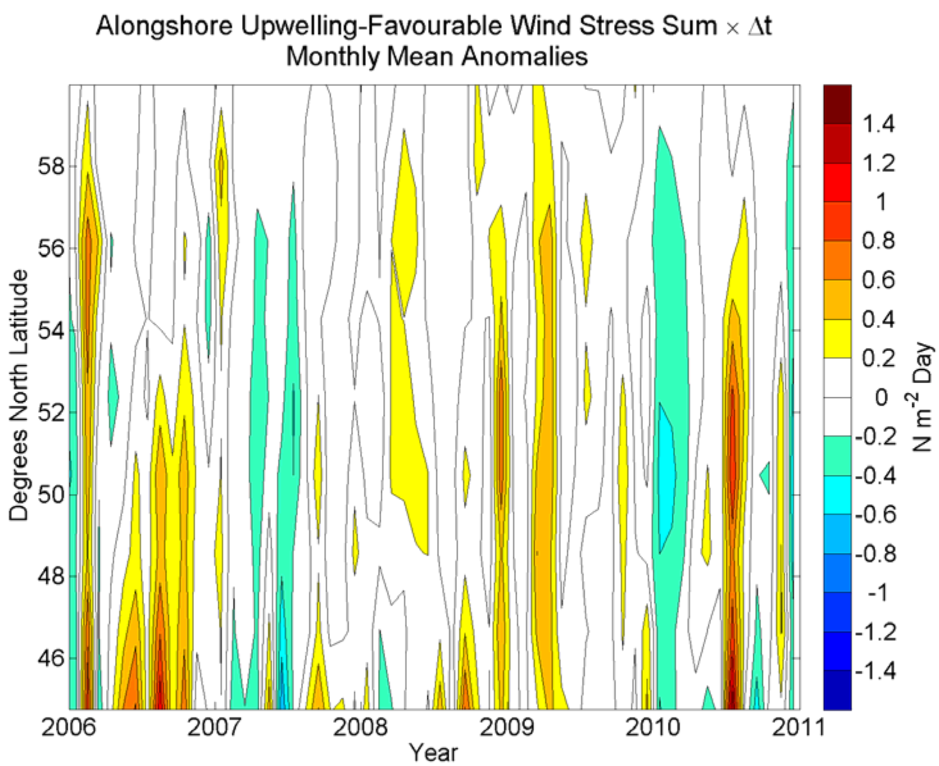


Figure 7. Recent (2006 to 2010) non-filtered monthly mean anomalies of monthly sums of alongshore upwelling-favourable (equatorward) wind stress at coastal grid points from 45°-60° N.

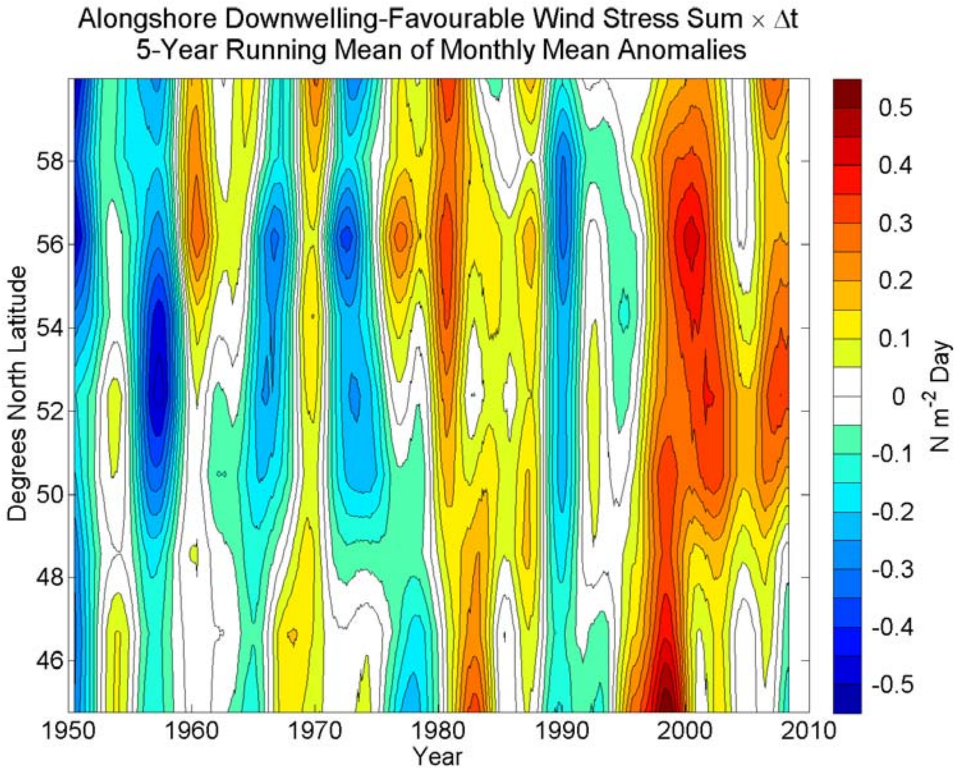


Figure 8. Five-year running means of monthly mean anomalies of monthly sums of alongshore downwelling-favourable (poleward) wind stress at coastal grid points from 45°-60° N.

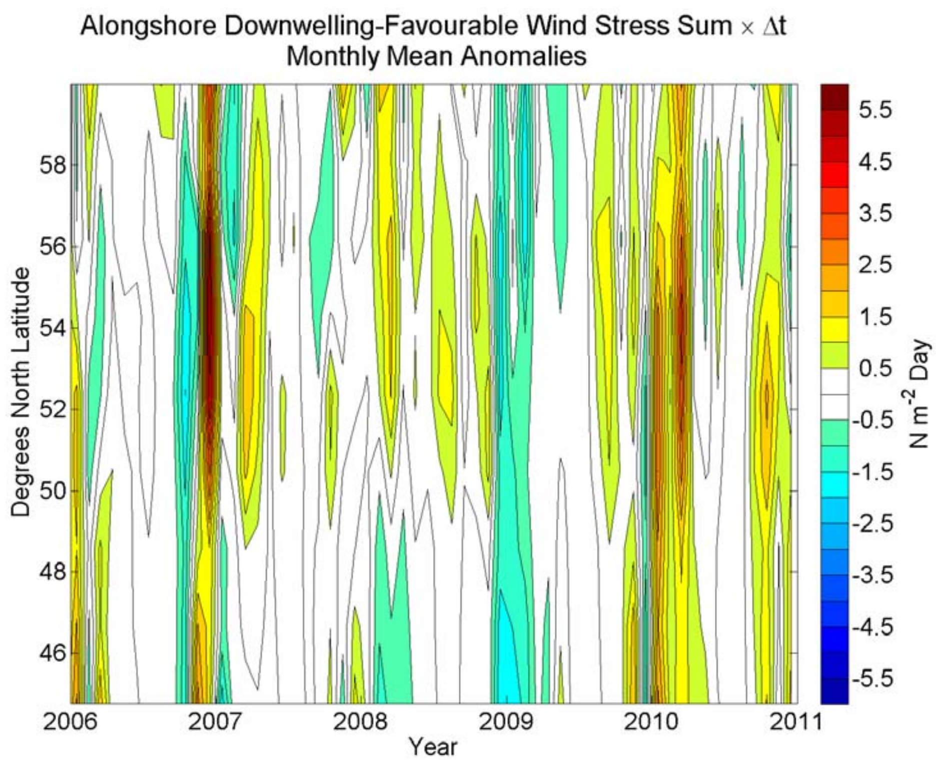
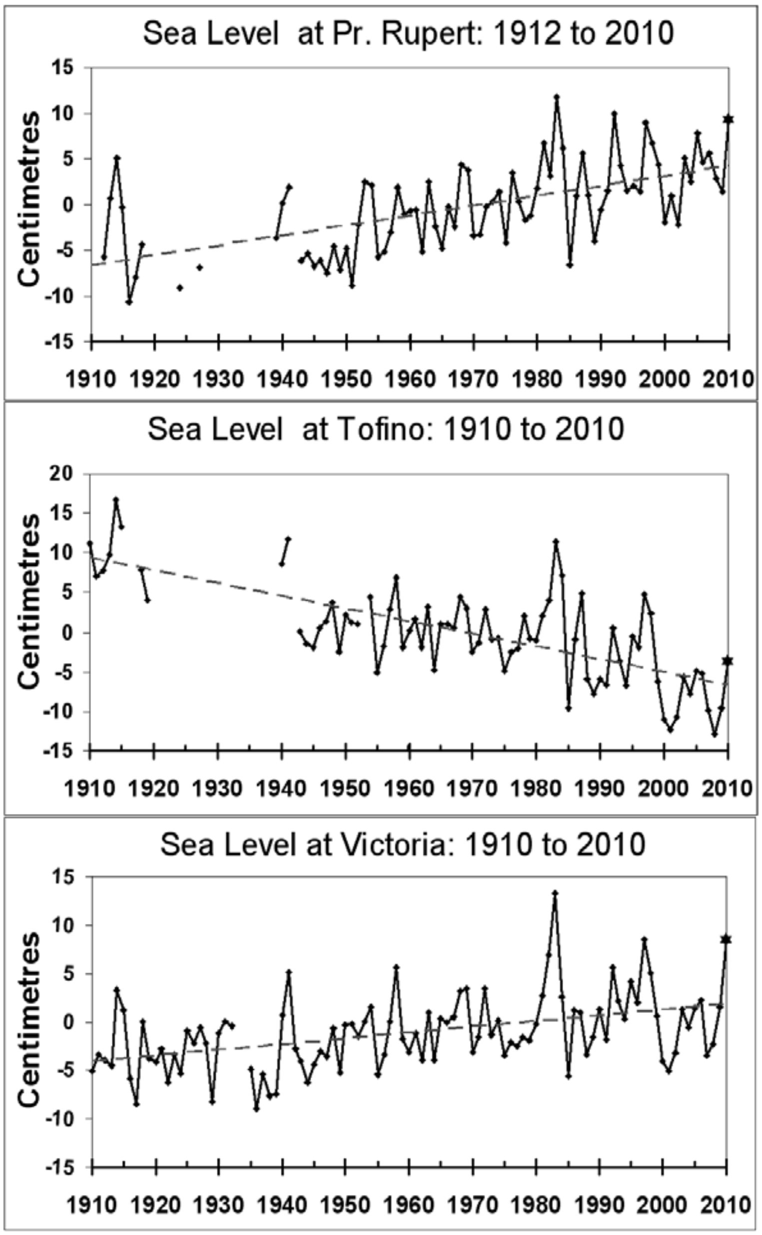


Figure 9. Recent (2006 to 2010) non-filtered monthly mean anomalies of monthly sums of alongshore downwelling-favourable (poleward) wind stress at coastal grid points from 45°-60° N.

SEA LEVEL IN BRITISH COLUMBIA, 1910 TO 2010

Bill Crawford, Fisheries and Oceans Canada

The Canadian Hydrographic Service monitors levels along the BC coast. The records below show annual deviations from the long-term average at three ports. Both Tofino and Victoria have records than begin in 1910, while record at Prince Rupert begins in 1912. Average sea level for 2010 is marked with a star.



Prevailing winter winds from the west reduced sea levels at Tofino and Victoria in 2007 to 2009. These westerly winds were associated with La Niña conditions, which ended in mid 2009. A shift to El Niño weather in late 2009 brought more southerly winds and higher sea levels to the British Columbia coast. As a result, average levels in 2010 were above the long term trend at these ports

Figure 1. Graphs of annual-average sea levels at three British Columbia ports. Long-term average linear trends are plotted as dashed lines. Levels for 2010 are indicated by a black star.

The linear trend at each port is listed below (in cm/century):

Prince Rupert +11

Victoria +6

Tofino -16

Tectonic motion is lifting the land at Tofino faster than sea level is rising, so local sea level is dropping at an average rate of 16 cm per 100 years.

The next big Cascadia Subduction Zone earthquake could drop the land at Tofino and along the west side of Vancouver Island by as much as a metre, and also send a major tsunami toward the BC coast.

Global sea levels rose by 17± 5 cm in the 20th century. Satellite observations since 1993 indicate sea levels are presently rising at a rate of 30 cm per century. The Intergovernmental Panel on Climate Change (IPCC 2007) predicts sea level to rise by 20 to 60 cm over the 21st century, but recent observations of ice melt in Greenland and Antarctica suggest these projections might be too low.

OXYGEN CONCENTRATIONS ON THE CONTINENTAL SHELF

Bill Crawford, Fisheries and Oceans Canada

Oxygen concentration on the continental shelf of British Columbia is generally lowest in late summer near the bottom. Oxygen concentration has been observed to drop below 1 millilitre per litre (ml/L) in some regions at or below 150 metres depth, and even lower in some fjord-type inlets where oxygen is naturally low. A concentration of 1 ml/L is about 50 micromolar (μM) at 6 °C.

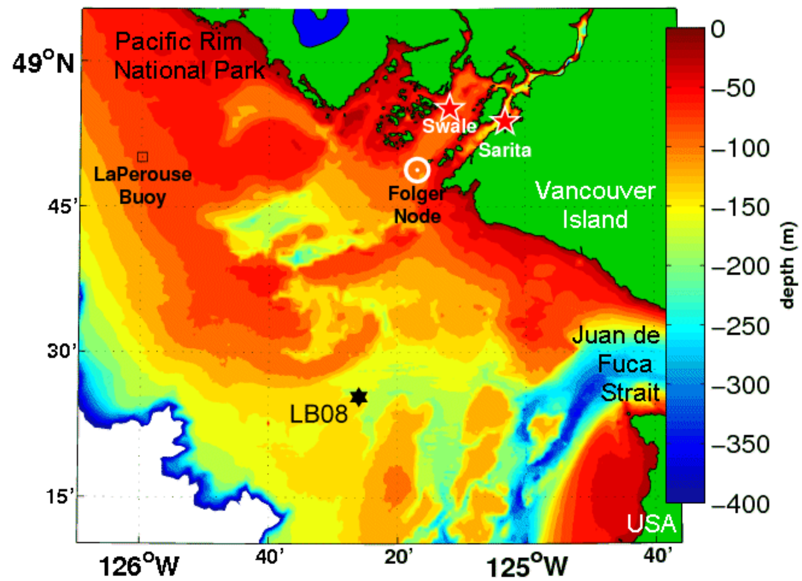


Figure 1. The continental shelf off southwest Vancouver Island, with colours denoting depth of bottom. Map is provided by Pawlowicz, this report.

The lowest concentration of oxygen on the west coast of Vancouver Island in the upper 150 metres is normally in August or September near the ocean bottom near station LB08, shown in Fig. 1. This conclusion is based on a study of archived measurements of oxygen concentration on the continental shelf in British Columbia. Each observation is derived from a research cruise, and is based on Winkler titration of a seawater sample, and in recent years on a SeaBird electronic sensor calibrated against Winkler titrations. Although there are only 2 to 4 cruises per year that test these waters for oxygen, this station is sampled on most cruises.

Figure 2. Graph of all individual samples of oxygen concentration collected within 10 km of station LB08 from 1979 to 2010. The X-axis is day of the year. Day 122 is May 2; day 244 is September 1. Colour and style of symbols denote the years of sampling.

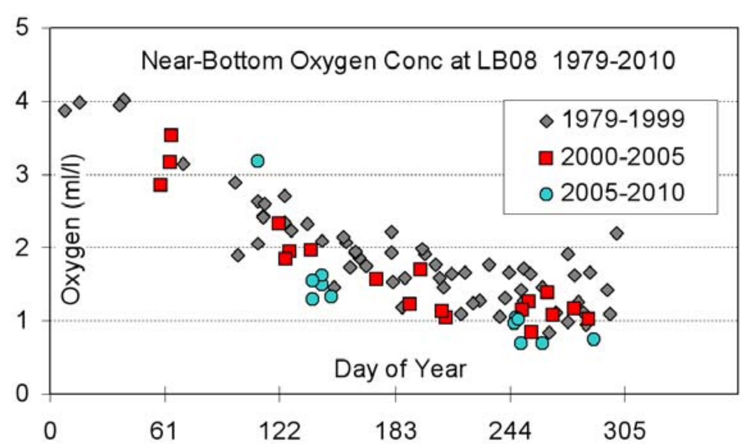


Fig. 2 shows all measured values sorted by day of the year. Lowest concentrations are in September to early October. Red and Blue symbols of Fig. 2 reveal that oxygen at this sampling station was generally lower in the years 2000-2010, and lowest from 2005 to 2010. The lowest concentration of the entire time series was 0.7 ml/L in 2006 and again in 2009.

Even lower concentrations of oxygen in bottom waters have been found off the coast of Washington State and Oregon, especially since 2000. Connolly *et al*. (2010) sampled the

Washington and southern BC shelf every September from 2003 to 2006 and discovered the greatest geographical range of hypoxic bottom waters (oxygen less than 1.4 ml/L) was in 2006. They attribute the general decline since 2000 and the specific decline in 2006 to more intense winds from the north and northwest in summer, as well as to declining oxygen concentration in waters of the continental slope below 200 metres depth. It is these waters that upwell onto the shelf in late spring and summer.

NEPTUNE Canada installed several continuously recording ocean sensors west of British Columbia in 2009. For oxygen studies the most relevant station is at the Folger Node shown in Fig. 1, which has recorded continuously since October 2009. Temperature and oxygen sensors are at about 100 metres depth, just above the bottom, so oxygen levels are higher than at LB08 where the ocean depth is about 50 metres deeper. Fig. 3 shows daily average oxygen and temperature at this station. Readers can update this time series using this link [http://www.neptunecanada.ca/], and requesting an account to view all observations.

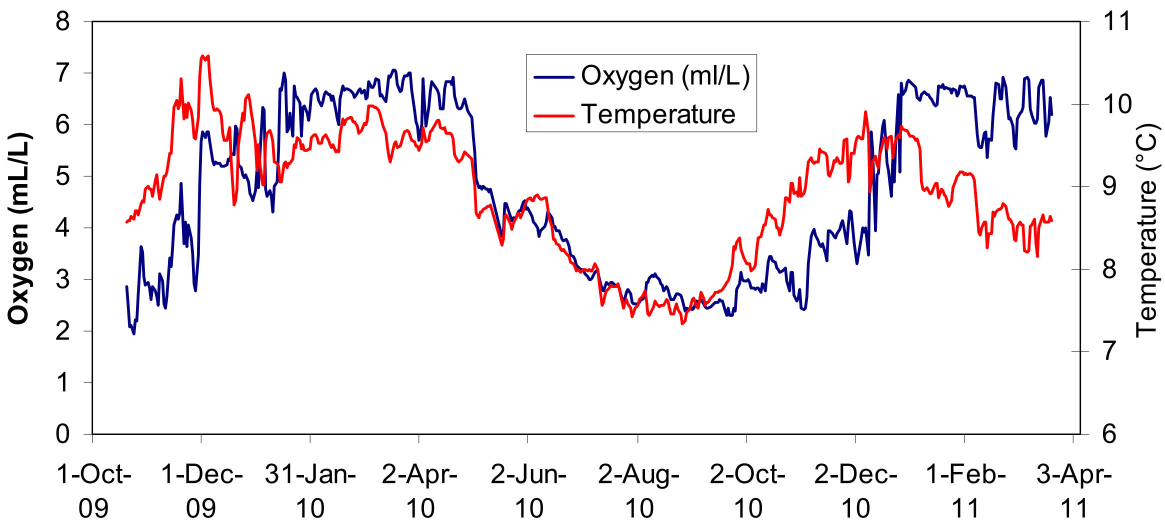


Figure 3. Daily averages of oxygen and temperature at Folger Pass in the entrance to Barkley Sound, from October 2009 to late March 2011. Station and real-time data access are provided by NEPTUNE Canada.

This time series reveals typical features of the British Columbia continental shelf. Coldest bottom water is summer, not in winter. Deeper cold waters upwell to shallower depths in summer, forced by the prevailing winds from the north and northwest. Oxidation of organic material on the ocean bottom causes an additional decay in local oxygen concentrations, and is believed to be the reason why lowest oxygen levels are in late summer, about a month or so after the strongest upwelling winds have ceased to blow. In winter, storm winds blow from the south and push warmer, oxygen-rich surface water onto the continental shelf and also mix and downwell it toward the bottom. Notice that the water in January to March 2010 was much warmer than in the following winter, due to stronger southerly winds in early 2010 compared to 2011. Oxygen concentrations were similar in these two winters, and close to saturation levels.

Reference

Connolly, T. P., B. M. Hickey, S. L. Geier, and W. P. Cochlan (2010). Processes influencing seasonal hypoxia in the northern California Current System. *Journal of Geophysical Research* 115: C03021, doi:10.1029/2009JC005283.

OCEANOGRAPHIC CONDITIONS IN BARKLEY SOUND, VANCOUVER ISLAND

Rich Pawlowicz, Dept. of Earth and Ocean Sciences, University of British Columbia

This report summarizes oceanographic conditions within Barkley Sound (Fig. 1), which are probably broadly representative of conditions in inlets along the west coast of Vancouver Island. Monthly conductivity-temperature-depth (CTD) and dissolved oxygen (O_2) profiles have been obtained at two stations in Barkley Sound beginning in 2004 (www.eos.ubc.ca/~rich/BSTS), with the assistance of R. Tanasichuk (DFO/PBS). Beginning in the summer of 2005, chlorophyll fluorescence profiles have also been obtained. The Sarita station (209m) is within Trevor Channel, which is the seaward extension of Alberni Inlet. Below 140m observations at Sarita station are representative of the relatively homogeneous Alberni Inlet bottom waters. In contrast, Swale station (90m) is on the broad plain of Imperial Eagle Channel, which can be thought of as the sill restricting the renewal of deep water into Alberni Inlet. Additional CTD+O_2 data from the mouth of Barkley Sound are available (late 2009 onwards) from bottom-mounted instruments located at the Folger Pass NEPTUNE node in 96 metres of water (www.neptune.uvic.ca). Finally, aspects of zooplankton and fish populations are described based on analysis of observations from a multi-frequency echo sounder deployed at the Folger Pass node.

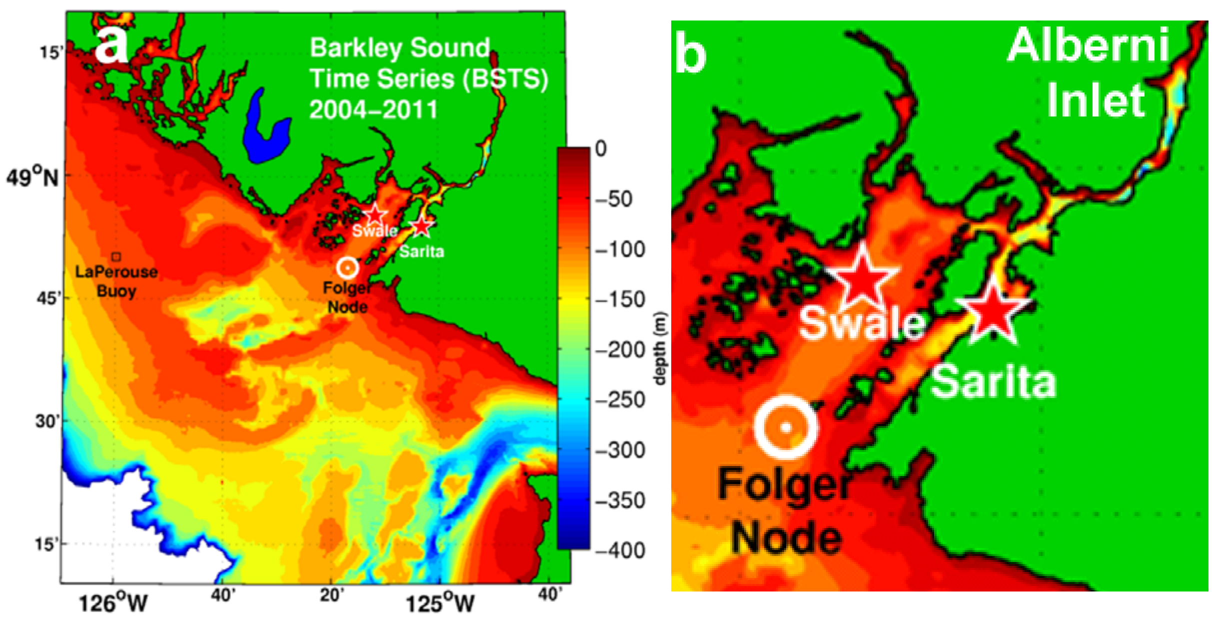


Figure 1. (a) Southwest Vancouver Island, and (b) Barkley Sound and Alberni Inlet, showing locations of the Barkley Sound Time Series stations, the NEPTUNE Folger Node, and LaPerouse Weather Buoy. Alberni Deep (not labelled) lies in the deepest portion of Alberni Inlet.

Physical Properties

Seawater densities in Alberni Inlet deep waters have a strong seasonal signal (Fig. 2a). Densities rise through the summer, and fall during the rest of the year. Renewal periods, defined as times during which deepwater densities increase, are shaded in Figures 2-4. Density increases occur in response to an inflow of heavier water. These periods correspond well with periods when the alongshore winds at the LaPerouse weather buoy C46206 (Fig. 2b) are upwelling favourable (blowing from the northwest), generally in summer. Upwelling will transport surface waters offshore, to be replaced by dense deep waters flowing inshore from the open ocean.

Offshore transport of surface waters also reduces sea level at Bamfield (gauge 8545) about 10 cm below the mean. The period of renewal or summer upwelling can be as long as 6 months (in 2006) or as short as 3 months (2010). In some years (2007, 2009) upwelling is not continuous through the summer but is interrupted by short periods of downwelling. Smaller discontinuities may also occur at shorter time scales not resolved in our measurements.

During renewal periods, Swale station densities at the bottom of Imperial Eagle channel are greater than those in Alberni Inlet at the same depth, and are often greater than Alberni Deep densities (Fig. 2a). This dense water, transported to the sill by offshore upwelling, plunges down to the bottom of Alberni Inlet. The close tracking of increases between Imperial Eagle Channel and Alberni Deep densities during renewal periods suggests that the residence time of the bottom water is very short. That is, deep renewals completely replace the bottom water, perhaps several times during the summer.

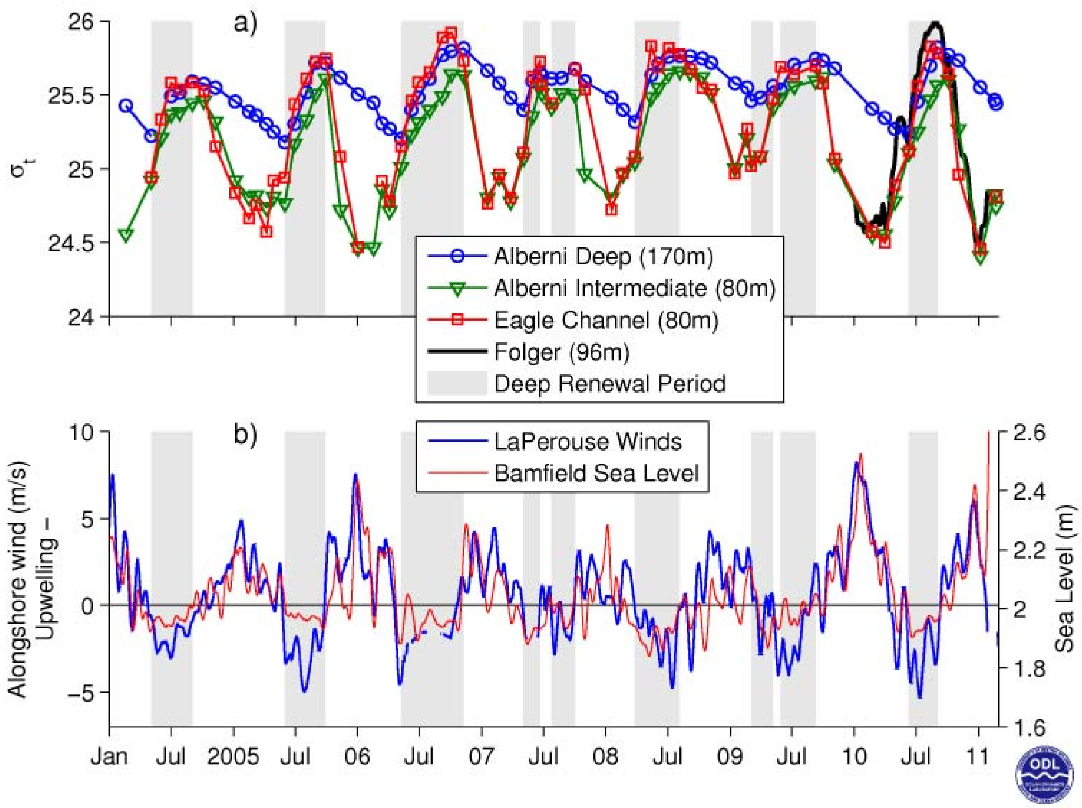


Figure 2. a) Seawater densities (indicated by σ_t) in Barkley Sound January 2004 to early 2011. Gray shading in this and subsequent panels indicates periods when the densities of Alberni Deep water are increasing. b) Along-shore winds at LaPerouse Weather Buoy (negative numbers are upwelling favourable), and Bamfield sea level. Both are low-pass filtered to periods greater than 2 weeks.

Outside renewal periods, densities at and above sill depth in intermediate depth waters are similar to those at the same depths in both Alberni Inlet and Imperial Eagle channel. They are also significantly lighter than the densities of Alberni bottom water. During these times (which also correspond with higher river inflows, not shown) the estuarine circulation drives an inflow at intermediate depths, and the characteristics of the intermediate depth water then follows that of waters on the open coast. Sea levels are elevated up to 20 cm above the mean by both upwelling-favourable winds, blowing from the southeast, and the effects of runoff. Alberni Deep waters are not affected by horizontal advection. However, their densities slowly and steadily decrease. At these times fresher water from above mixes downwards. The amount of density decrease relative to overlying densities suggests that much (but not all) of the deep water is replaced by vertical mixing before the next 'renewal' period.

In response to variations in upwelling, the densities of Alberni Deep water vary from year to year. However, measured densities at the end of the renewal periods are not simply related to the length of the upwelling period. Highest densities were seen in both 2006 (after the longest upwelling period), and in 2010 (after the shortest). Above sill depth, densities are greatest at the end of the upwelling period, and least in January and February when downwelling winds are strongest. Least dense waters were seen in early 2006, early 2010, and early 2011, after periods when downwelling-favourable winds were particularly strong (Fig. 2b).

Seawater densities are related to both temperature and salinity. Seasonal cycles are also seen in these variables, but there are also significant differences in their interannual behaviour. For example, the coldest bottom water temperatures of the year, appearing during the deep renewal period, dropped from 8.3°C to minimum of 7°C between July 2004 and July 2008, before rising again to 7.8°C (Fig. 3a).

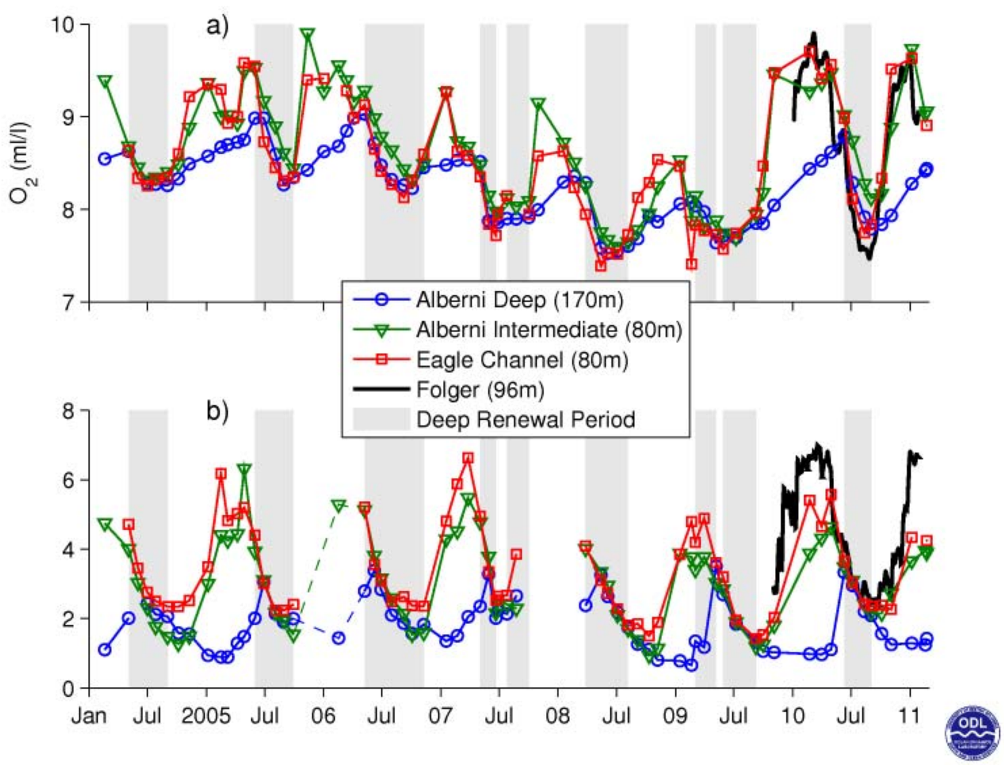


Figure 3. a) Dissolved oxygen levels associated with density time series in Fig. 2a; b) Temperatures at the same locations.

Dissolved oxygen levels in deep Alberni Inlet are lowest earliest in the year at about 1 ml/L (Fig. 3a). During the initial stages of renewal, deep oxygen levels are about 3 ml/L, but the more dense later inflows are somewhat lower in dissolved oxygen. Oxygen concentrations at the end of renewal periods are only about 2 ml/L. In autumn oxygen levels further decrease, but then have a tendency to increase slightly in the early months of the next year, before the deep renewal begins. During this time dissolved oxygen is simultaneously affected by respiration, which causes it to decrease, and by diffusion from above, which causes it to increase.

During renewal periods the bottom oxygen levels are similar all through Barkley Sound out to the Folger node. However, during the rest of the year there are significant spatial variations, with levels at the Folger node as much as 1 ml/L greater than those in Imperial Eagle Channel, and 2 ml/L greater than those in Alberni Inlet at 80m. This likely represents the combined effects of respiration and a long residence time in these two locations.

Near the surface, temperatures undergo a strong seasonal cycle (Fig. 4b), with warmest temperatures in August and coldest in January, typical for B.C. waters. Summer temperatures are a few degrees warmer in the more sheltered Alberni Inlet region relative to Eagle Channel, but during the rest of the year surface temperatures are similar everywhere. However, from 2005 to 2010 summer waters became steadily cooler by about 3 degrees. Temperatures in winter reveal no trend in these years, but during the early months of 2010 the waters were exceptionally warm, due to strong, warm, southerly winds of January and February 2010. (These same weather conditions melted snow just before the Vancouver Winter Olympics.)

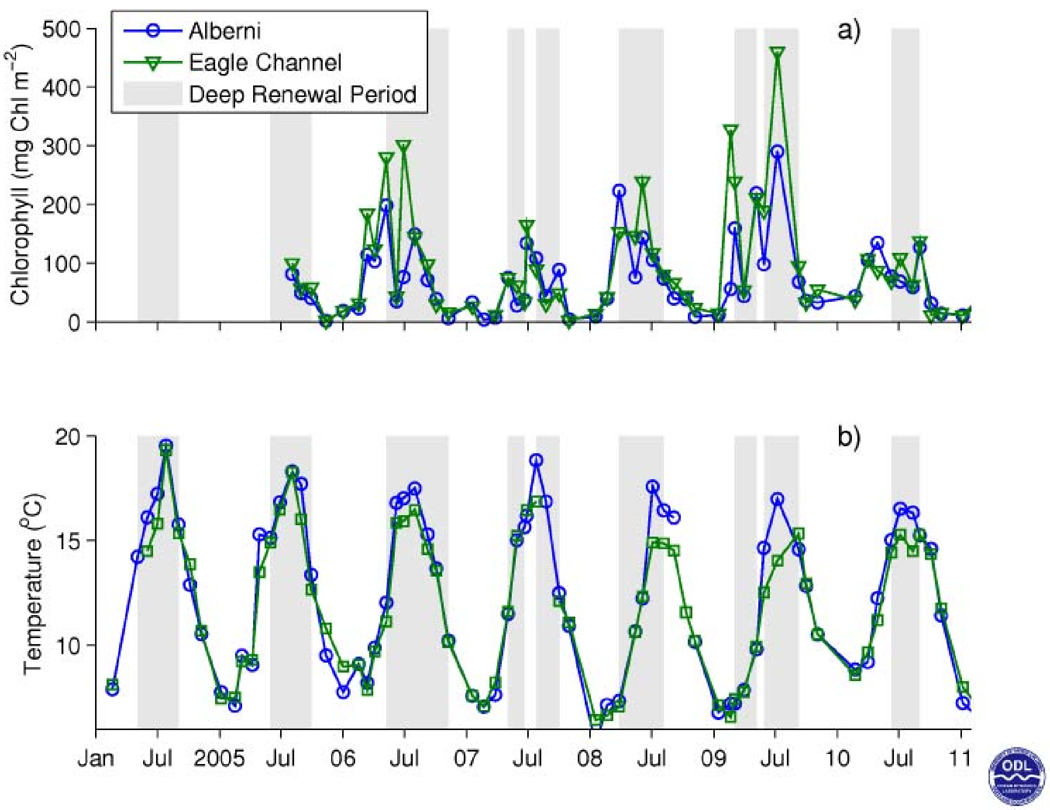


Figure 4. a) Depth-Integrated Chlorophyll biomass, and b) Temperature at 2m.

<u>Phytoplankton</u>

We use optical sensors to detect concentrations of chlorophyll in seawater, which is an excellent indicator of the biomass of phytoplankton. There is a seasonal pattern of depth-integrated phytoplankton biomass, high in summer and relatively low (although not zero) in winter (Fig. 4a). Although our electronic measurements of chlorophyll have not been calibrated against true values obtained from water samples they are consistently measured through the entire time series using the same instrument. They can be used as a relative index of chlorophyll biomass, with values that may differ from actual values by a factor of perhaps two.

Although the monthly sampling is too coarse to fully resolve phytoplankton blooms, in the past 5 years there has been no sign of a 'canonical large spring bloom' whose phytoplankton biomass dominates the annual mean. Instead biomass levels increase sometime during the February to April period, reaching a roughly constant level that characterizes the rest of the summer. Taking these time series at face value, the spring biomass peaked in March 2006, May 2007, March 2008, February 2009, and April 2010.

Although summer phytoplankton biomass levels are generally high, there is significant month-to-month variability. Biomass time series at the two stations are reasonably correlated suggesting that this variability has a wide spatial scale. In addition, there are large interannual differences in the summer levels. The mean summer (May-September) biomass was 170 mg Chl m^{-2} in 2009, but only 75 mg Chl m^{-2} in 2007. The mean biomass in 2010 was an intermediate 90 mg Chl m^{-2}.

Zooplankton and Fish

Hydroacoustic monitoring of the water column has been performed using a 3-frequency (38, 123, and 210 kHz) upward-looking echo sounder at the Folger Pass NEPTUNE node beginning in December 2009. The multiple frequencies allow discrimination between fish, which are typically seen more strongly at the lower frequencies, and zooplankton, which appear more strongly at the higher frequencies. Highly averaged summaries (Fig. 5) are displayed in terms of Volume Scattering Strength (S_V), which is roughly correlated with biomass. As yet these observations have not been matched to concentrations of zooplankton or fish determined by other sampling methods.

Strong diel variations are seen in most but not all months (Fig. 5a), and when present these are strongly linked to the timing of dawn and dusk (Fig. 5b). In January the night-time water column is almost completely filled with dispersed fish (possibly herring). Night-time biomass observed in January is by far larger than at any other time during the year (Fig. 5c). Numbers of these fish decrease in February, and they tend to appear only near the surface at night (Fig. 5a).

During late March and early April, diel variations in fish are less visible. Instead, a non-diel-migrating zooplankton biomass (probably copepods), appearing strongly at 123 kHz, shows a broad and sustained peak, whose timing coincides with the spring phytoplankton peak. Brief (1-2 week long) biomass peaks of fish appear in late May, and (appearing very strongly at 38 khz) in early June. These biomass peaks are again most visible near the surface at night.

From late June through September, the daytime water column down to about 20 m from the bottom is relatively empty. A strong diel migration of zooplankton (possibly euphausiids) is obvious, moving from the bottom to the surface (and vice versa) in less than an hour near dawn and dusk, and there are many fish near the surface at night. Finally, in the fall, when chlorophyll biomass decreases to winter levels, diel variations become less pronounced, although still present. Fish often appear in dense schools. These diel variations finally disappear in December when another biomass peak associated with non-diel-migrating zooplankton biomass appears.

Summary

Although the deep and intermediate water dynamics of Barkley Sound are directly affected by wind-driven upwelling and consequent deep renewal, and aspects of the seasonal cycle can be broadly explained by these factors, the actual characteristics of the Sound vary from year to year as a consequence of other, as yet unexplained, sources. The year 2010 was relatively cold and windy at the surface except for the early months of the year, but with somewhat warmer intermediate and deep waters compared with preceding years. Phytoplankton biomass was close to average, with spring growth occurring somewhat late in spring. However, this spring growth did coincide with a peak in the biomass of non-diel-migrating zooplankton.

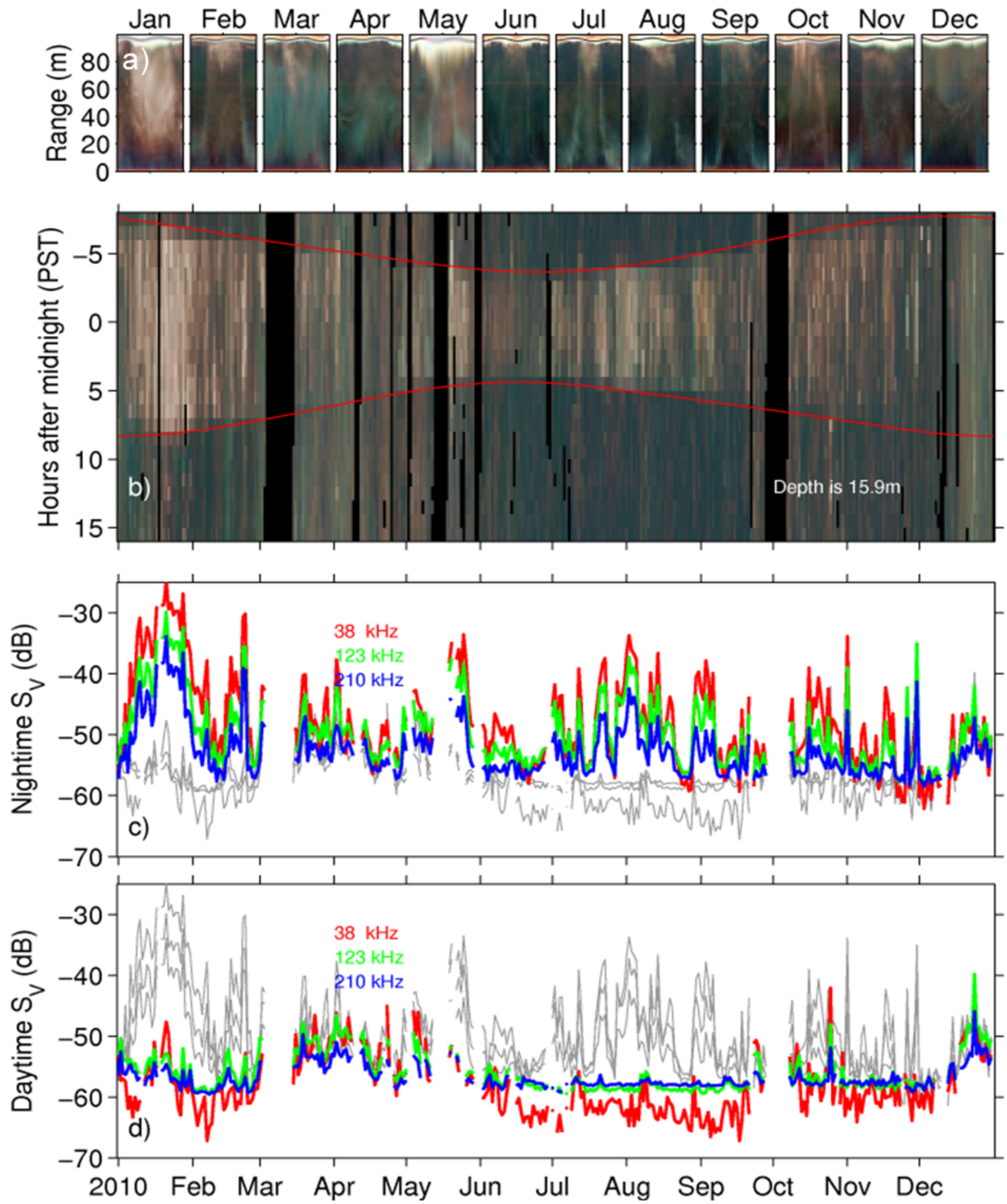


Figure 5. A summary of hydroacoustic conditions at the Folger node. a) Selected daily echograms (noon to noon PST) from each month of 2010. In these echograms, each frequency is colour coded, with 38kHz appearing in red, 123 kHz in green, and 210 kHz in blue. Bright white returns are strong in all frequencies, and zooplankton appear as greenish-blue patches. b) Volume scattering strengths at a depth of 15.9 m below mean sea level are arranged vertically by hour from midnight and horizontally by day. The red lines show sunset and sunrise, which are closest in June. Colour coding as in a). c) Mean Night-time Volume Scattering Strength at 15.9m. Curves for mean daytime values appear in gray to allow comparison. d) Mean Daytime Volume Scattering Strength at 15.9m. Curves for mean night-time values appear in gray to allow comparison.

MESOZOOPLANKTON IN THE GULF OF ALASKA IN 2010

Sonia Batten, Sir Alister Hardy Foundation for Ocean Science, UK

Mesozooplankton, organisms in the size range 200 µm to a few mm in length, are a key link between primary production and upper trophic levels such as fish, marine birds and mammals. Many of the mesozooplankton indices determined from Continuous Plankton Recorder sampling of the Northeast Pacific (Fig. 1) were within the range recorded since sampling began routinely in 2000, suggesting that 2010 was generally an unexceptional year.

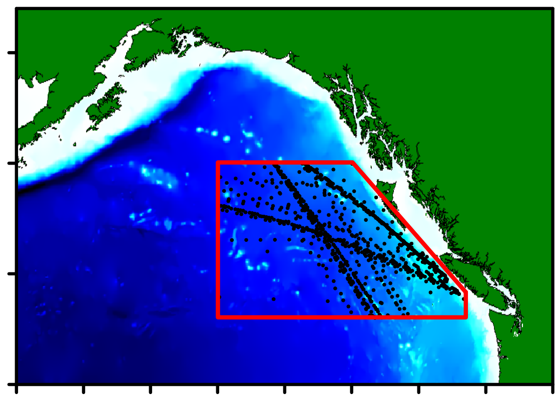


Figure 1. Region of sampling by Continuous Plankton Recorder (CPR). Red lines enclose waters sampled for this report. Black dots indicate sample positions.

Total mesozooplankton biomass showed a normal seasonal cycle (Fig. 2) with a peak in May, although at the time of writing, data for July to September are only partially completed and June was not sampled (sampling occurred on 2nd and 3rd July and mid July). Annual biomass anomalies suggest that 2010 was a year of low biomass, (2000 and 2005 were other low-biomass years).

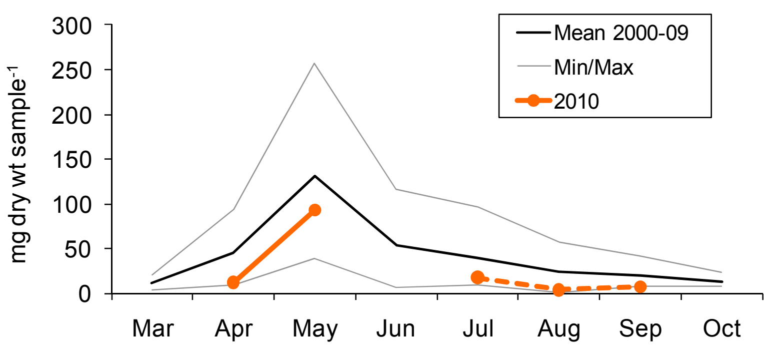


Figure 2. Mean monthly biomass for 2010, together with monthly mean, minimum and maximum mesozooplankton biomass (2000-09) in mg dry weight per sample (~3m^3) from CPR sampling (which occurs approx. monthly 6-9 times p.a. between March and October) in the off-shore Gulf of Alaska area. Data for July to September 2010 are preliminary.

Timing of the spring biomass peak of the dominant spring copepods, *Neocalanus plumchrus/flemingeri*, was normal in 2010 (Fig. 3). Its abundance was also slightly above average, so the reduced total biomass shown in Fig. 2 was not because of these species.

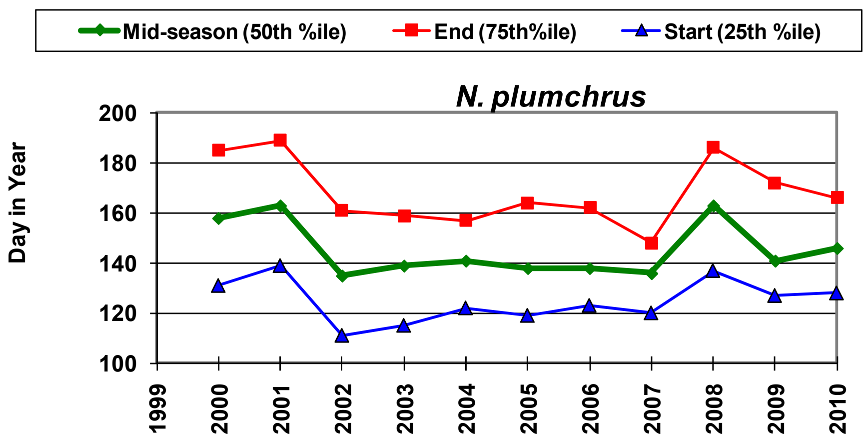


Figure 3. Day of year at which 25th, 50th and 75th percentile of cumulative biomass of Neocalanus plumchrus/flemingeri *was reached for the offshore Gulf of Alaska region.*

These copepods live at the ocean surface for only a month or two near the time of maximum size and abundance. Changes in timing of their growth will determine in which months they are near surface and available as food for predators that take advantage of this prey's peak abundance. The timing of the mid-point of their season in 2010 was in-line with the moderately cool conditions and somewhat negative Pacific Decadal Oscillation (PDO) (the day of 50th percentile correlates with the annual PDO index, r^2=0.55, p<0.01).

Pseudocalanus spp. (a small copepod) was unusually abundant in spring 2010. Data for April and May are finalised and show it to be 3 times as abundant as the previous monthly maximum and 20 times as abundant as the previous May mean. High abundances were widespread throughout the region and occurred offshore as well as the shelf of the NE Pacific. As yet we have no explanation, nor any likely impacts, and will see if 2011 shows similarly high numbers when sampling begins.

Detailed community composition analyses will be carried out when all of the data are finalised, but a breakdown of the composition of the mesozooplankton in summer 2010 into broad taxonomic groups showed the composition to be very similar to 2009 (Fig. 4). The proportion of small copepods is highly significantly correlated with the PDO, an index of climate variability. Years of positive PDO indicate warm waters of the Gulf of Alaska. Small copepods are more abundant in positive PDO and warm years. The proportion of chaetognaths, which prey on small copepods, is also significantly positively correlated with the PDO. The proportion of large copepods is highly significantly negatively correlated with the PDO (there are more large copepods in colder years as conditions favour these subarctic species and their season is lengthened). Average numbers of each were present in summer 2010, in-line with the moderately cool conditions.

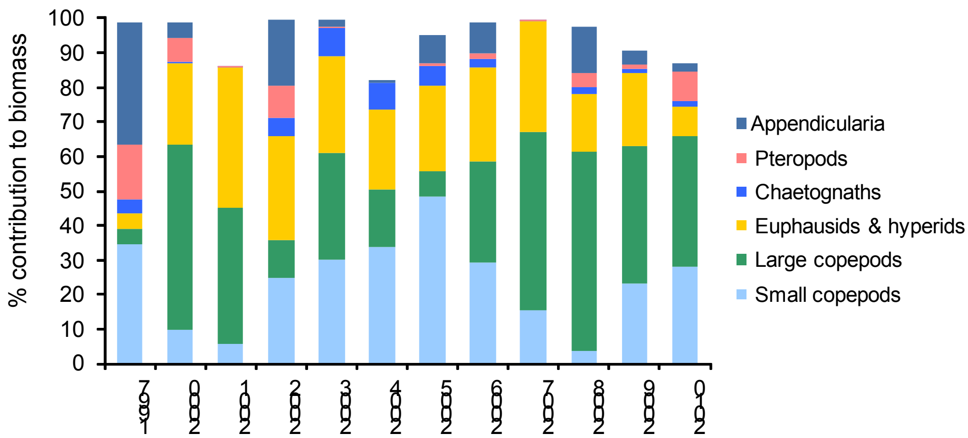


Figure 4. Mean summer (28 June to 31st August) community composition, 1997-2010.

http://pices.int/projects/tcprsotnp/default.aspx for data and more information

ZOOPLANKTON ALONG THE BC CONTINENTAL MARGIN: MODERATE DECLINE OF COOL WATER SPECIES, BIG INCREASE OF WARM WATER SPECIES, AND ABUNDANT SALPS AND JELLYFISH

Dave Mackas, Moira Galbraith, and Kelly Young, Fisheries & Oceans Canada

Zooplankton time-series coverage of the British Columbia continental margin extends from 1979 to present for southern Vancouver Island [SVI], from 1990 to present for northern Vancouver Island [NVI] (although with much lower sampling density and taxonomic resolution in 1991 to 1995), and from 1998 to present for southern Hecate Strait (with some scattered earlier sampling between 1983 and 1997). The present routine sampling locations in SVI, NVI and Hecate regions are shown in Fig. 1. Additional locations are included in averages when they are available. Samples are collected from DFO research vessels using vertical net hauls with black bongo nets (0.25 m^2 mouth area, 0.23 mm mesh aperture), from near-bottom to sea surface on the continental shelf and upper slope, and from 250 m to surface at deeper locations. We have also recently compiled historic data from various shorter term sampling programs in the Strait of Georgia (SoG]. Most of the SoG sampling did not follow a standard grid or sampling protocols. Because of time varying taxonomic resolution, the SoG data have been merged into broader categories (size classes within major taxa). Our analyses-to-date of the SoG time series are described later in this Research Document (see Mackas et al., 2011 elsewhere in this research document

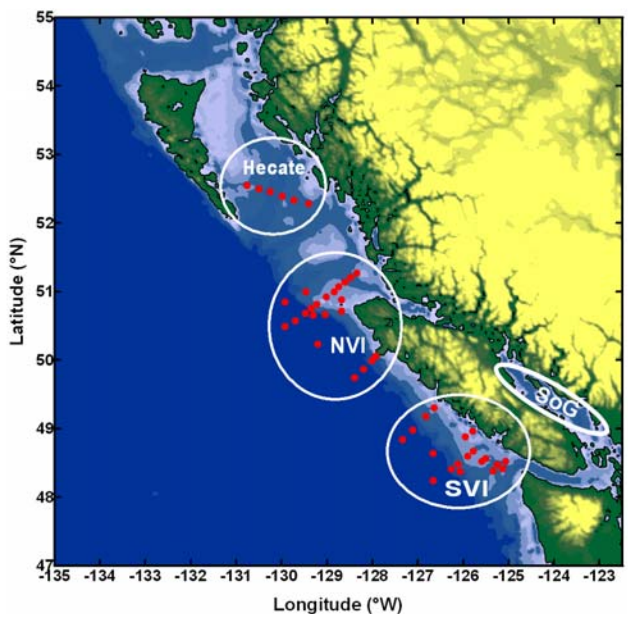


Figure 1. Zooplankton time series sampling locations (red dots) in BC marine waters. Data are averaged within major statistical areas indicated by ovals; the SVI and NVI regions are further classified into shelf and offshore sub-regions. The PNCIMA (Pacific North Coast Integrated Management Area) includes both NVI and Hecate stat areas.

We routinely estimate abundance and biomass for more than 50 zooplankton species in the SVI, NVI and Hecate regions. For all three regions, seasonal variability is intense and somewhat repeatable from year-to-year. However, because sampling dates vary from year to year, simple annual averages of observations risk confounding seasonal with interannual differences. We deal with this by first estimating a multi-year average seasonal cycle (= “climatology”) for each region, using the data from the start of each time series through 2005, and then using these climatologies as baselines against which we can then compare monthly conditions during any single year. To describe interannual variability, our approach has been to calculate within each year a regional, logarithmic scale biomass anomaly for each species and for each month that

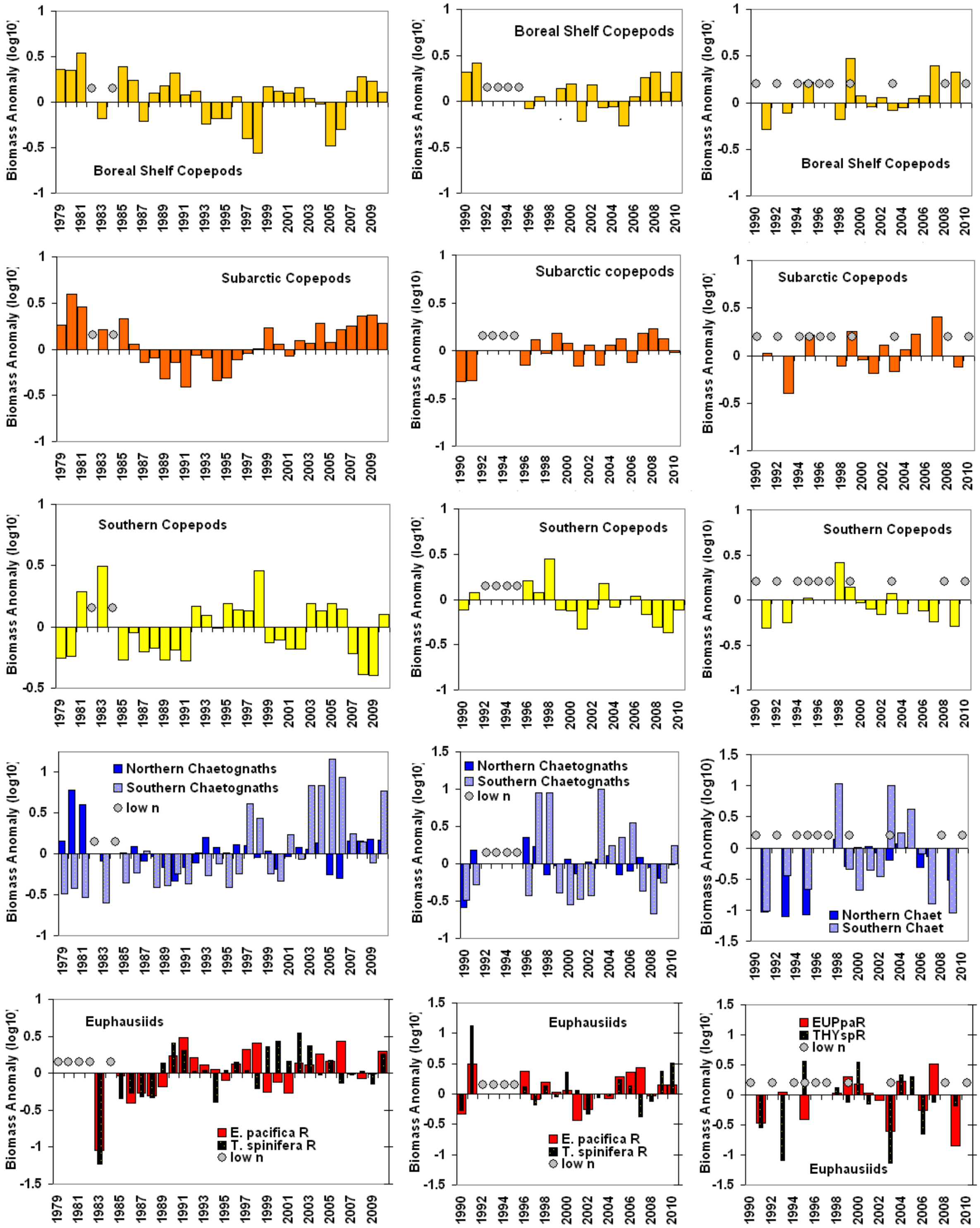


Figure 2. Zooplankton species-group anomaly time series (vs climatological baseline) for the SVI, NVI and Hecate regions shown in Figure 1. Bar graphs are annual log scale anomalies. Circles indicate years with no or very few samples from that region. Cool years favour endemic 'northern' taxa, warm years favour colonization by 'southern' taxa.

was sampled. We then average the monthly anomalies in each year to give an annual anomaly (see Mackas 1992 & Mackas *et al*. 2001 for mathematical details). It is important to note that the anomalies are log scale and therefore multiplicative on linear scale: an anomaly of +1 for a given taxon means that taxon had 10 times higher biomass than in the climatology; an anomaly of -1 means the biomass was 1/10th the climatology.

We have learned from our own and other west coast time series (Mackas *et al*. 2006) that zooplankton species with similar zoogeographic ranges and ecological niches usually have very similar anomaly time series. We therefore often summarize the interannual variability of multiple species by averaging within species groups. For example, the group 'boreal shelf copepods' is a composite of the copepods *Calanus marshallae*, *Pseudocalanus mimus*, and *Acartia longiremis,* all of which have distribution ranges that extend from southern Oregon to the Bering Sea. The group 'subarctic oceanic copepods' is a composite of *Neocalanus plumchrus*, *N. cristatus*, and *Eucalanus bungii*; all of which inhabit deeper areas of the subarctic Pacific and Bering Sea from North America to Asia. A third group, 'southern copepods' is a composite of five species with ranges centered about 1000 kilometers south of our study areas (either in the California Current and/or further offshore in the North Pacific Central Gyre).

Fig. 2 shows anomaly time series for these copepod species groups, as well as representative chaetognaths and euphausiids in each of the three BC statistical areas. The range of interannual biomass variability within a species or species group is about one log unit (i.e. factor of 10), and in our regions is about 2-3 times greater than the interannual variability of total biomass. Other features to note are that anomalies often persist for several years and that, in addition to the covariation within species groups mentioned above, there is strong covariation between some species groups. The clearest and most gradually varying signals have been in the three copepod groups and in the chaetognaths. Cool years such as the early 1980s, 1999-2002, and 2007-09 tended to have positive anomalies of boreal shelf and subarctic copepods, and northern chaetognaths. Warm intervals such as 1983, 1993-1998, and 2004-2005 tended to have negative anomalies of these taxa, but positive anomalies of southern copepods and chaetognaths. We now know that positive anomalies of the cool water zooplankton community off Vancouver Island are also associated with good local survival and growth of juvenile salmon, sablefish, and planktivorous seabirds (Mackas *et al*. 2007; Trudel, personal communication 2010).

Although mid-2009 to early 2010 was an El Niño event, the 2010 response of the zooplankton community along the BC continental margin was mixed. Annual average anomalies of the cool water copepod and chaetognath species groups remained positive in 2010, but continued to trend downward from their higher levels in the colder years 2007 and 2008. Conversely, the warm-water southern origin copepods and chaetognaths shifted to positive anomalies, continuing an upward trend that began midway through 2009 (described in greater detail in last year's State of the Ocean Research Document).

Another strong and ongoing signal in the zooplankton time series since about 2000 has been increasing incidence of strongly positive annual anomalies of one or more gelatinous zooplankton taxa (Fig. 3). Several high-order zooplankton taxa (with widely differing ecological niches) are classified as "gelatinous zooplankton". However, all have high to very high peak reproductive rates compared to the crustaceans and chaetognaths, and all tend to have "boom and bust" population time series. The most important groups in the SVI, NVI and Hecate regions are:

- Salps and doliolids. These are planktonic tunicates, and are primarily herbivorous (broad spectrum filter feeders)
- Hydromedusae and scyphomedusae ("jellyfish") and ctenphores ("comb jellies"). These are predatory on other zooplankton and sometimes on larval fishes.

- Thecosomatous pteropods. These are planktonic snails. Unlike the previous two groups, their bodies are not gelatinous, but they use a large external gelatinous feeding web to capture their food.

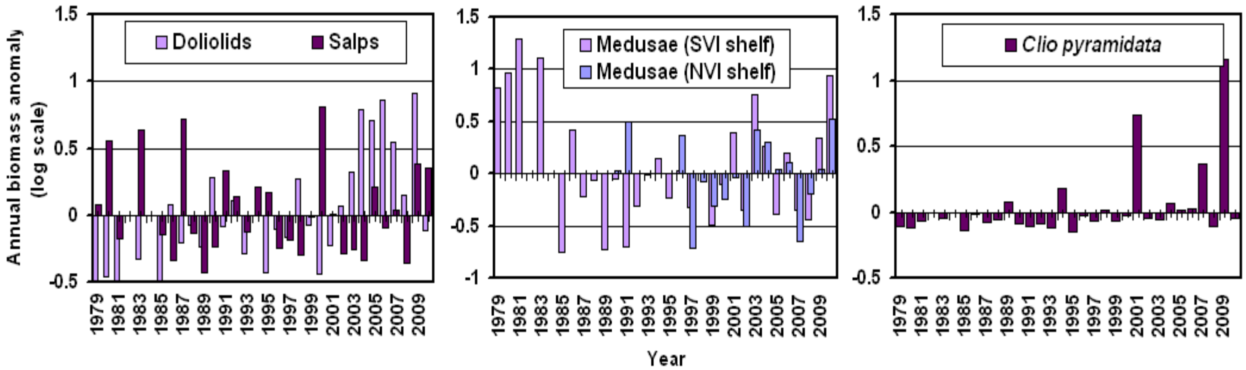


Figure 3 Anomaly time series for important gelatinous zooplankton off southern Vancouver Island. Left panel shows doliolids (genus Doliolett*a) and salps (genus* Salpa*) in the SVI region. Middle panel shows hydromedusae in the SVI and NVI regions. The large positive anomaly in 2010 consisted of* Mitrocoma*. Right panel shows the warm water thecosomatous pteropod* Clio pyramidata*. Their frequency and intensity of occurrence has increased dramatically since about 2000.*

Doliolids and the pteropod *Clio* were absent or rare in nearly all years before 2002, but since then have been abundant to very abundant in the SVI region in many years (and nearly as abundant in the NVI region). Years with positive salp anomalies have occurred throughout the time series, but both of the last two years (2009 and 2010) were well above average. A similar pattern is present in the jellyfish time series. As with the long term trend in the copepod species groups, the net effect has been to make the zooplankton community off BC more like the community found in nearshore parts of the California Current System to the south of BC, less like the historical SVI and NVI climatology, and less like the present-day zooplankton community off northern British Columbia and Alaska.

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OCEAN CONDITIONS IN COASTAL WATERS OFF OREGON

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National Oceanic and Atmospheric Administration, USA

The trend of cold ocean conditions, which started to become established in 2007, ended in mid 2009 due to the emergence of an El Niño event at the equator. This event continued into spring 2010 before dissipating. Because of the 2009-10 El Niño event, the ocean began to warm in autumn 2009 and remained warm through April 2010, after which a cooling trend resumed, in May 2010. Thus, 2010 began as a "warm year", began to cool in May, but by July, both SST and the deeper waters over the continental shelf were among the **coldest observed** in recent years. Thus we had very mixed signals in 2010 making it difficult to offer any reliable outlooks as to returns of coho salmon in 2011 and Chinook salmon in 2012. 2010 could be summarized in the words of Charles Dickens: "It was the best of times, it was the worst of times…"

Negative Signals for juvenile salmon in 2010

- The Pacific Decadal Oscillation (PDO) was positive and SSTs were warm during the winter of 2009-2010 indicating poor ocean conditions during the winter (Fig. 1).
- Although the winter storms ended in late March and the spring transition arrived on 5 April (day 95), strong upwelling was not initiated until two months later, on 9 June (day 160, Fig. 2). Within that two month period, several storms moved through the region with strong winds from the southwest. The occurrence of southwesterly winds in spring is generally an unfavorable sign for juvenile spring-run salmon that enter the ocean in April-May.
- Copepod species richness was very high during winter-spring-summer of 2010, ranking 12th of 15 years sampled since1996 (Fig. 4). We regard this as a negative sign because it indicates that the sub-tropical species that were brought to Oregon with the El Niño persisted for several months after the end of the El Niño event; species richness did not return to normal until autumn 2010.
- Catches of yearling coho in our juvenile salmonid surveys in September were among the lowest in 13 years, having a rank of 11.

Positive Signals for juvenile salmon in 2010

- The PDO was strongly negative beginning in May and continued so through the remainder of the year.
- SST anomalies were consistently colder than normal by several degrees during the summer and autumn of 2010 (Fig. 3).
- Deep water temperatures on the continental shelf in July-August were the coldest of our 14 year record (since 1997).
- The biomass of the lipid-rich "northern" copepod species during the summer of 2010 was the 4th highest since 1996 (Fig. 5).
- Catches of yearling spring Chinook during our June survey were above average, being the 5th highest in 13 years.

The fact that ocean conditions were poor early in the season but great later in summer makes it impossible to provide any reliable forecast of salmon returns (for coho in 2011 and spring Chinook in 2012): Our best "guess" is that "average" returns in 2011 (for coho) and 2012 (for Chinook) will be observed. We do not think that the El Niño had a devastating effect on salmon because the warm ocean conditions at the time of ocean entry (in April/May) were about "average". Perhaps the most positive sign is that the ocean became very cold in summer 2010, has remained cold through autumn and the PDO is still strongly negative, suggesting that ocean conditions in 2011 may shape up to be among the best in the past 15 years.

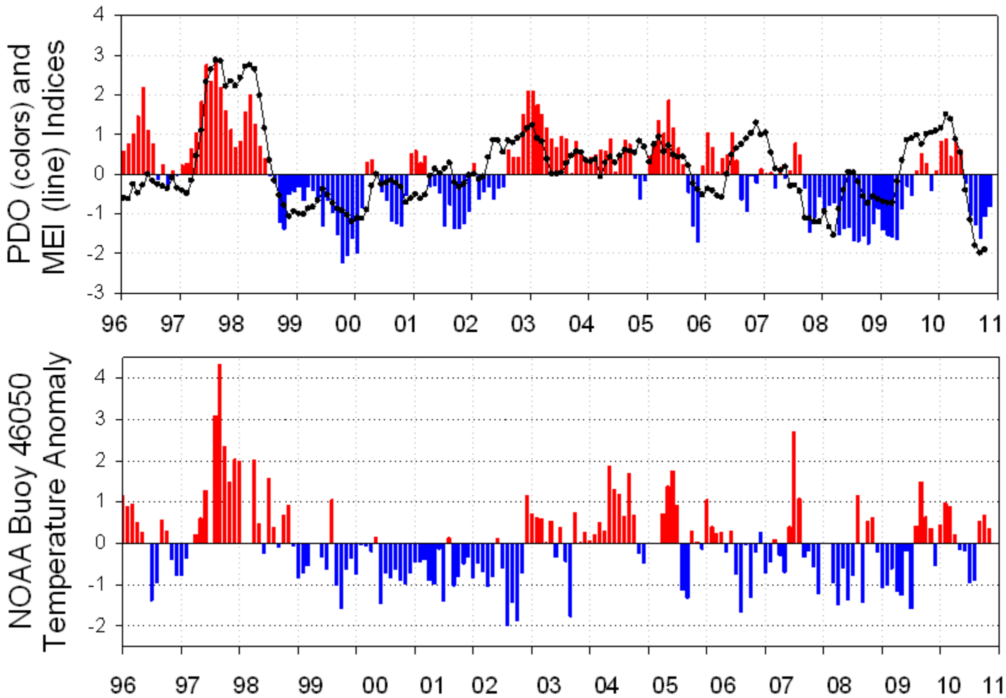


Figure 1. (Top). Time series from 1996 to 2011 of the PDO (colored bars), MEI (black line) and (Bottom) SST anomalies at NOAA Buoy 46050 located 20 miles off Newport.

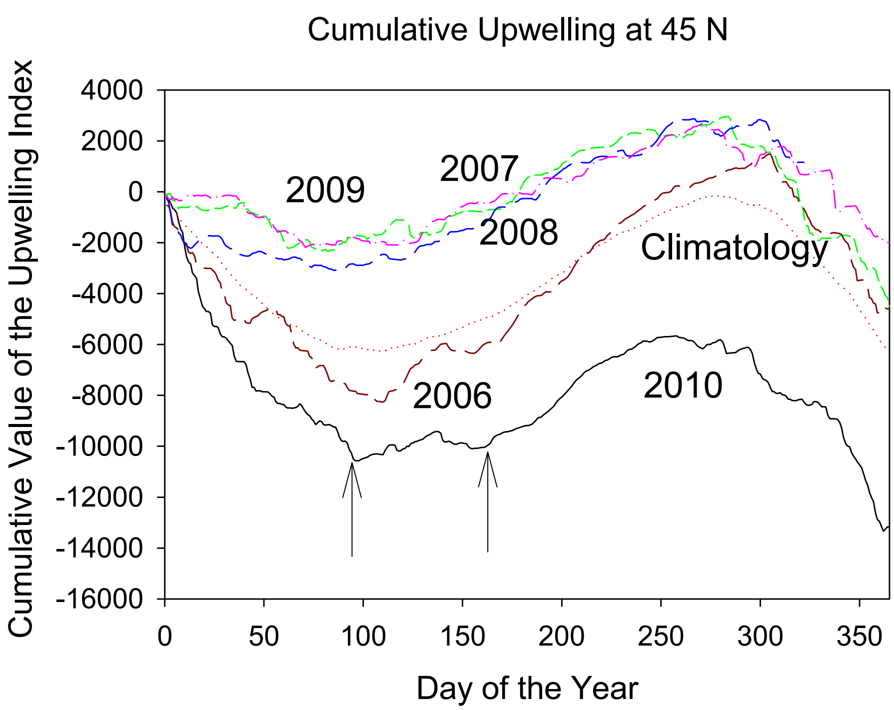


Figure 2. Cumulative PFEL daily upwelling index with the years 2006-2010 compared to climatology (red dotted line). 2010 had a greater number of storms in winter compared to 2007-2009. The vertical arrows associated with the 2010 data indicate that the spring transition came in early April but strong upwelling was not intitiated until early June.

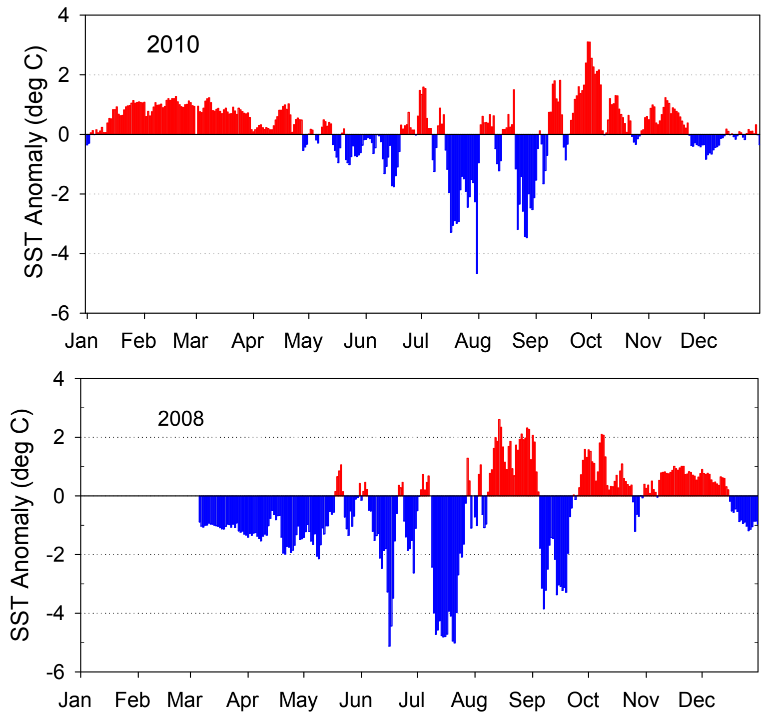


Figure 3. A comparison of SST anomalies at NOAA Buoy 46050 for the years 2008 and 2010. 2008 was a year of very good ocean conditions resulting in very high returns of coho in 2009 and spring Chinook in 2010). 2010 is likely to be a year with average returns. The observed high salmon returns for the 2008 ocean entry year suggest that a cold winter, spring and early summer present favorable conditions for high salmon survival. In contrast 2010 was warm in winter and spring with weak upwelling in May/June.

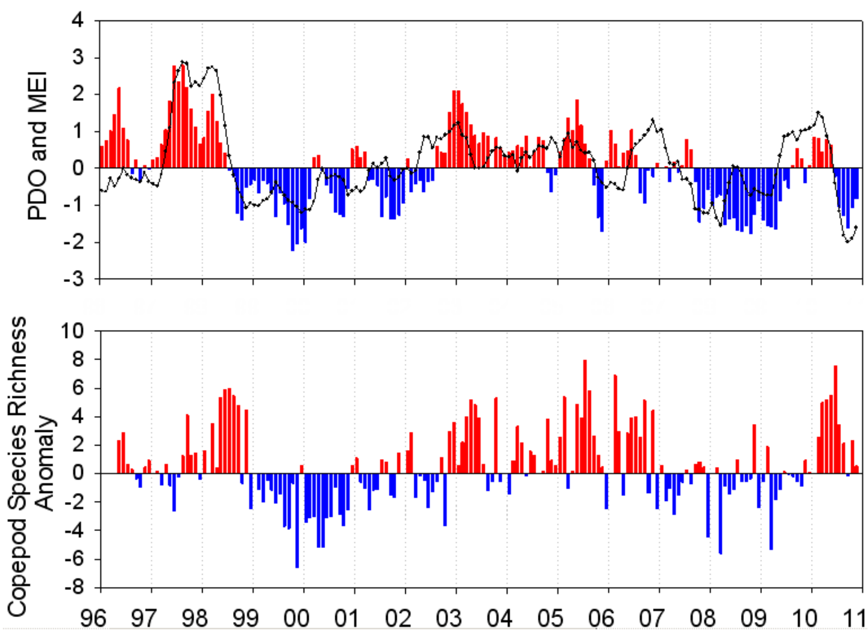


Figure 4. The PDO, MEI and copepod species richness anomalies from 1996-present, showing that species richness was very high through 2010, likely as a result of the moderately strong El Niño event that lasted from mid-2009 through mid-2010 (shown by the positive values of the MEI in the upper panel).

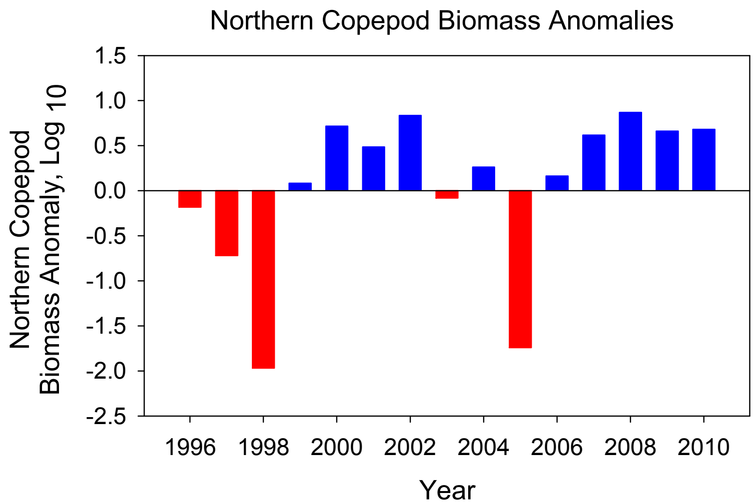


Figure 5. Oddly, despite a warm spring and high copepod species richness, the biomass of the "cold water, a.k.a. northern" species was high, ranking 4th out of 15 years (1996-2010). Much of the high biomass was due to the copepod Pseudocalanus mimus.

Table 1. Rank scores upon which color–coding of ocean ecosystem indicators is based. Lower numbers indicate better ocean ecosystem conditions, or "green lights" (ranks 1–4 green); average conditions are indicated by the ranks 5–9 (yellow), and poor conditions by ranks 10–13 (red). To arrive at these rank scores, each indicator was ranked from 1 (best for salmon) to 13 (worst for salmon). Note that the year 2010 was characterized by a mixed bag of the ocean conditions, being warm in winter and spring, but very cold in summer. Given the mixed signals we cannot provide a forecast with much confidence. Average returns would be our best guess.

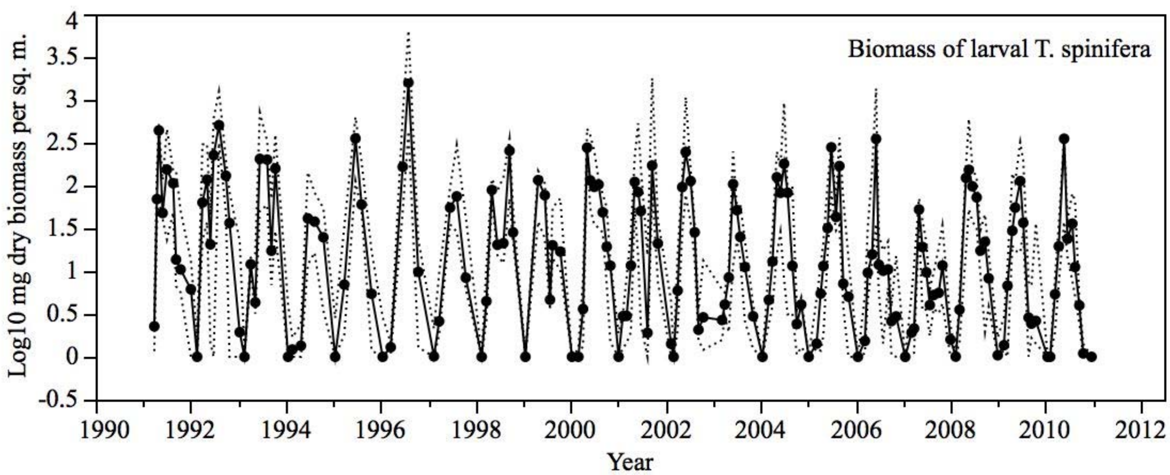
Environmental Variables	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
PDO (December-March)	12	4	2	8	5	13	7	11	9	6	3	1	10
PDO (May-September)	10	2	4	5	7	12	11	13	9	8	1	6	3
MEI Annual	13	1	3	6	12	11	9	10	7	5	2	8	4
MEI Jan-June	13	2	3	4	9	10	7	11	5	8	1	6	12
SST at 46050 (May-Sept)	11	8	3	4	1	7	13	10	5	12	2	9	6
SST at NH 05 (May-Sept)	8	4	1	6	2	5	13	10	7	12	3	11	9
SST winter before (Nov-Mar)	13	10	3	5	6	9	11	8	7	2	1	4	12
Physical Spring Trans (UI Based)	3	6	12	11	4	8	10	13	8	1	5	2	7
Upwelling Anomaly (Apr-May)	7	1	12	3	6	10	9	13	7	2	4	5	11
Length of upwelling season (UI Bas	6	2	12	9	1	10	8	13	5	3	7	3	11
Deep Temperature at NH 05	13	4	6	3	1	9	10	11	12	5	2	8	7
Deep Salinity at NH05	13	3	6	2	5	11	12	8	7	1	4	9	10
Copepod richness	13	2	1	5	3	9	8	12	10	6	4	7	11
N.Copepod Anomaly	13	10	3	7	2	11	8	12	9	6	1	5	4
Biological Transition	13	7	5	3	6	11	9	12	10	4	1	2	8
Copepod Community structure	13	3	4	6	1	9	10	12	11	7	2	5	8
Winter Ichthyoplankton	13	6	2	4	5	9	12	8	11	10	1	7	3
Catches of salmon in surveys													
June-Chinook Catches	12	2	3	10	7	9	11	13	8	6	1	4	5
Sept-Coho Catches	9	2	1	4	3	5	10	12	7	8	6	13	11
Mean of Ranks of Environmental Da	10.9	4.2	4.5	5.5	4.5	9.4	9.9	11.2	8.1	5.9	2.7	6.1	8.0
RANK of the mean rank	12	2	3	5	3	10	11	13	9	6	1	7	8

EUPHAUSIIDS AND WEST COAST VANCOUVER ISLAND FISH PRODUCTION

Ron Tanasichuk, Fisheries and Oceans Canada

Zooplankton and euphausiids (krill) have been monitored in Barkley Sound since 1991 to provide observations of prey availability for stocks of herring and salmon along the west coast of Vancouver Island. The information presented here focuses on the euphausiid *Thysanoessa spinifera* because it is an important prey item for Pacific herring (Tanasichuk *unpub.),* and juvenile coho (Tanasichuk 2002) and sockeye salmon (Tanasichuk and Routledge *In press*).

The time series of median biomass for larval *T. spinifera* (Fig. 1, top panel) illustrates the typical seasonal variations, with lowest biomass in December to February and largest biomass in March to June. The seasonal larval biomass fluctuations reflect Tanasichuk's (1998) observation that *T. spinifera* spawns several times between early spring and late summer.



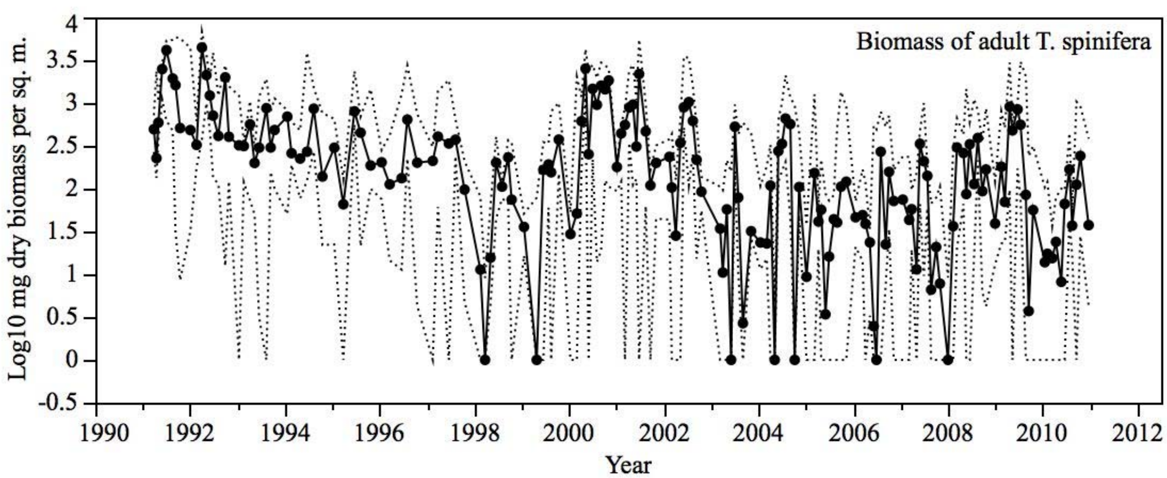


Figure. 1. The 1991-2010 time series of ***larval*** *(top panel, <10 mm long) and* ***adult*** *(bottom panel > 9 mm long) T. spinifera biomass. Median larval and adult biomasses in 2010 were near the average and the fourth lowest respectively in the time series. Larval biomass increased by about 160% and adult biomass decreased by about 90% from 2009. Closed circles – median biomass; dashed lines – minimum or maximum biomass.*

Adult biomass typically has a less well defined spring and summer maximum than the juveniles, attributed to over-wintering adults early in the year and the production of new adults later in the year; adult biomass was low in the spring of 2010 (Fig. 1, bottom panel). The adult biomass declined from the beginning of the record in 1991 to the year 1997, but in no month did the biomass decline below 60 mg dry mass•m^{-2} (In Fig 1, 60 mg•m^{-2} displays as 1.78 since $10^{1.78}$=60). Since then the interannual variability of the median biomass has been greater and many monthly cruises observed biomasses lower than 60 mg•m^{-2}.

Over the last 20 years our research has linked the variability of euphausiids to that of its predators, such as herring and salmon. Pacific hake are also relevant to herring and salmon as competitors for the same prey, and as predators. Studies have taken advantage of a time series of hydro-acoustic surveys (e.g. Fleischer *et al*. 2005; Forrest *et al*. 2011 elsewhere in this Research Document) of Pacific hake to test the effects of competition (see Tanasichuk 1999) and predation (Tanasichuk *et al*. 1991). Pacific hake dominates the pelagic biomass in summer and is potentially the most important predator of young herring and salmon. Forrest *et al*. (this report) present information on the status of hake. Their results suggest that hake biomass may be increasing to the average, but the estimate for 2010 is highly uncertain due to the presence of Humboldt squid in the most recent survey in summer 2009. The biomass estimate is for California to northern BC, and is not stratified by sub-region.

Pacific herring

Variation in the biomass of herring is a consequence of variations in the number of new (recruit, age-3 fish) spawners, size of recruit fish, adult growth and adult survival rates. These, in turn, are explained by the effects of piscivorous (fish-eating) hake and euphausiid prey variability. The effect of euphausiids is exerted by the biomass of the preferred herring prey (*T. spinifera* > 17 mm) in August, when herring growth (energy accumulation) is most rapid. Analyses do not extend beyond 2006 because the efficacy of subsequent reduced herring sampling effort has not been evaluated.

Two examples of the effect of predation and prey variability on herring production are the year-to-year changes in number of age-3 (recruit) herring (Fig. 2) and in their mass (Fig. 3). The regression equation describing the effect of hake and euphausiid biomass on West Coast Vancouver Island age-3 herring abundance is:

$$\ln R = 0.0026 \bullet Tds_1 + 0.0021 \bullet Tds_2 + 0.0031 \bullet Tds_3 - (6.62 \bullet 10^{-5}) \bullet Hd_1 - 10.73,$$

where p=0.00014, adjusted R^2=0.94, R is age-3 herring recruits per egg, Tds is the deviation of *T. spinifera* prey biomass from the 1991-2005 time series mean, Hd is the deviation of hake piscivorous biomass from the 1991-2005 time series mean and the subscripts are herring year of life.

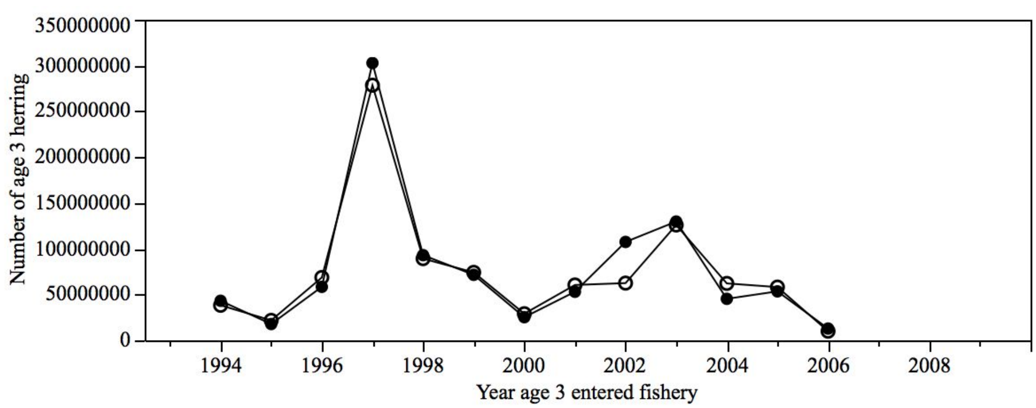


Figure 2. Observed (closed circles) and predicted (open circles) number of age 3 herring. Predicted values are estimated from the multiple regression analysis.

A second analyses showed that the variation in average mass of each herring recruit can be predicted by the biomass of *T. spinifera* in the first and third years of life. The regression equation describing the effect of krill biomass on size is:

$$M = 0.01 \bullet Ts_1 + 0.04 \bullet Ts_3 + 74.3,$$

where p=0.01, adjusted R^2=0.50, *M* is the average mass, in grams, of an age-3 herring recruit, *Ts* is *T. spinifera* biomass and the subscripts are herring year of life.

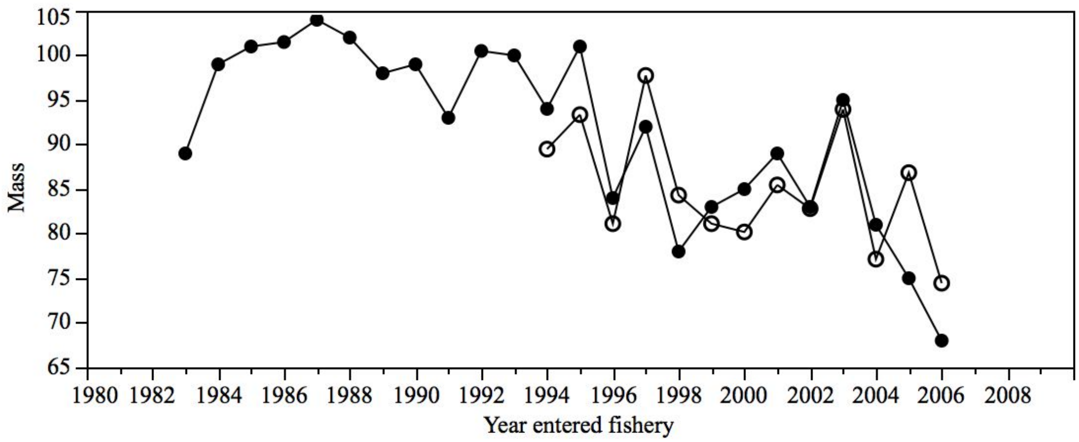


Figure 3. Observed (closed circles) and predicted (open circles) mass of age 3 herring. Predicted values are estimated from the multiple regression analysis.

Sockeye salmon

Tanasichuk and Routledge (*In press*) reported that the return of sockeye salmon to Great Central and Sproat lakes was explained by variations in the biomass of an important prey item (3-5 mm *T. spinifera*) in May, when the juveniles are migrating through Barkley Sound to the continental shelf. Regression equations are not presented because they are estimated for each of the six age groups in each of the two lakes.

Anticipated consequences

- Herring: implications are qualitative due to changes in herring sampling since 2007. Herring recruitment should remain low in 2011 because, although hake piscivorous biomass was low in 2008, *T. spinifera* prey biomass was low during the first three years of life; lower *T. spinifera* prey biomass in 2010 could continue to depress recruit and adult growth; adult survival rates in 2010 could decline because of lower *T. spinifera* biomass;
- Barkley Sound sockeye: low biomass of 3-5 mm *T. spinifera* in May 2010 should result in low returns of age 4 fish in 2012 and low returns of age 5 fish in 2013 relative to the time series.

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SMALL-MESH BOTTOM-TRAWL SURVEYS WEST OF VANCOUVER ISLAND: FURTHER INCREASES IN SMOOTH PINK SHRIMP BIOMASS IN 2010

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Bottom trawl surveys using a small-mesh net (targeting the smooth pink shrimp *Pandalus jordani*) have been conducted during May since 1973 in two regions off the west coast of Vancouver Island (Fig. 1).

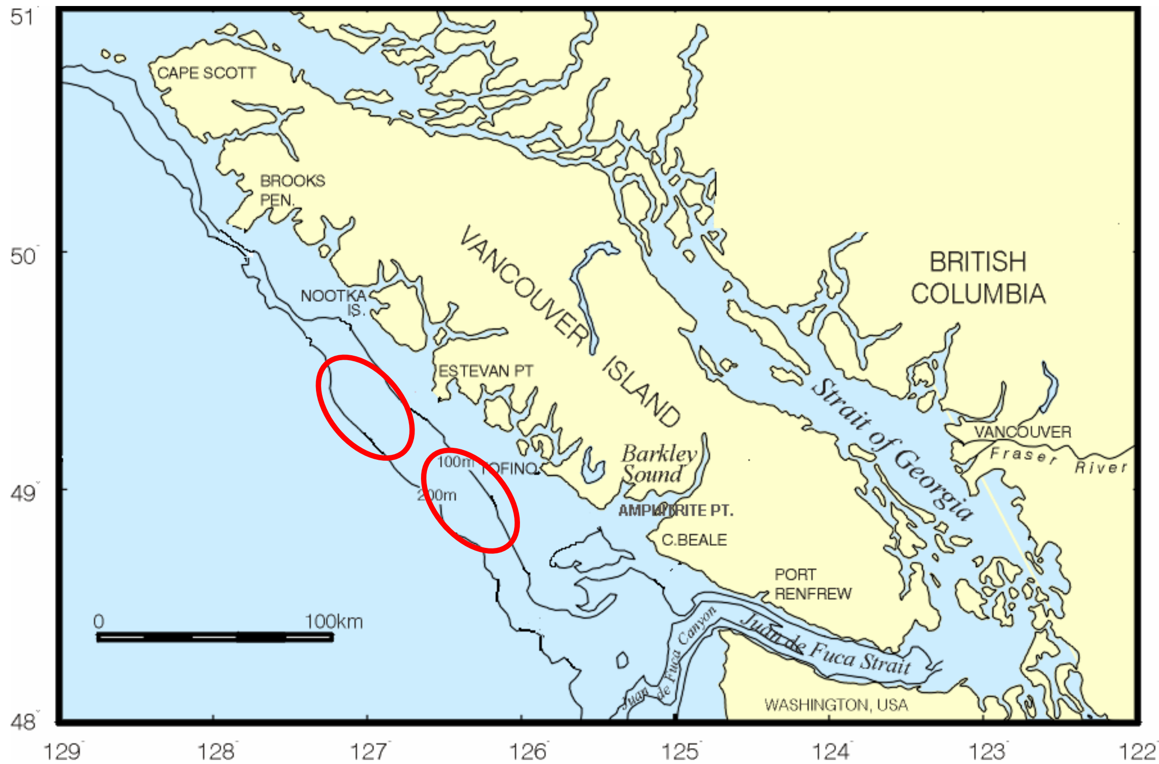

Figure 1. Map showing the two main shrimp (Pandalus jordani) fishing grounds off Vancouver Island (red ovals) considered in this report. The Nootka (Area 125) and Tofino (Area 124) Grounds are the northern and southern ovals, respectively.

Recent surveys found the biomass of *Pandalus jordani* shrimp off central Vancouver Island had increased in 2008, 2009, and 2010 from very low levels during 2004-2007 (Fig. 2). Such increases appear related to colder waters in 2006, 2007, and 2008 during the larval stages of the shrimp (this species has a 2-yr time lag from hatch to recruitment at age 2) and to low abundances of Pacific hake (a potential shrimp predator) in May surveys in 2008, 2009, and 2010. Comparisons of shrimp biomass and sea surface temperatures in this region during these surveys indicate a negative relationship: shrimp biomass has always been low when temperatures exceeded 11.5°C, whereas shrimp biomass could be high or low when temperatures were less than 11.0°C. Experimental studies suggest that the optimal temperature range for survival of larvae of this species of shrimp is 8.0°C to 11.0°C (P. Rothlisberg, 1979, *Marine Biology* 54: 125-134). Biomass trends of key flatfish indicator species all increased in 2010 (Fig. 2), as did the biomass of the “cold water indicator” species walleye pollock (Fig. 2).

This small-mesh bottom trawl survey was designed to target smooth pink shrimp on the shrimp fishing grounds in a relatively small area off the west coast of Vancouver Island (Fig. 1). Other taxa caught along with smooth pink shrimp may, or may not, be sampled quantitatively, depending on whether these other taxa are highly mobile in and out of the survey area or are highly patchy in their distribution. An autocorrelation analysis suggests that of the 36 taxa regularly sampled by this survey, 16 of them appear to be well-sampled by this survey (Table 1), and therefore inter-annual changes in their biomass as sampled by this survey can be interpreted to represent actual changes of their population biomass in this area. The time trend of the mean trophic level for these 'well-sampled' taxa illustrates a significant increasing trend over time (Fig. 3), which can be interpreted to mean that the ecosystem sampled by this survey has been changing from a predominance of low trophic level taxa such as shrimp in the 1970s to a predominance of higher trophic level taxa such as finfish in the 2000s.

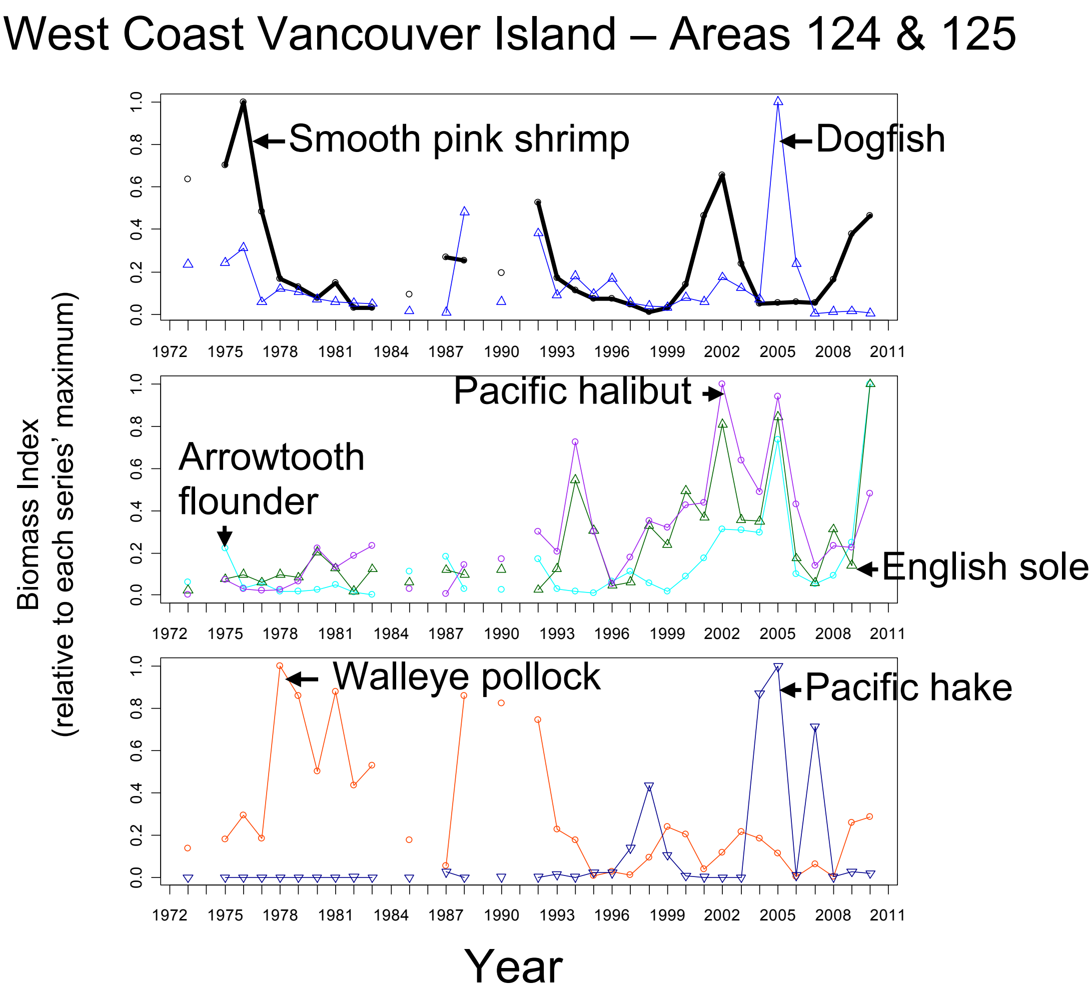

Figure 2. Time series of normalised (to maximum biomass) survey catches of smooth pink shrimp, dogfish, Pacific halibut, Arrowtooth flounder, English sole, Pacific hake and walleye pollock. Sampling was conducted in May of each year.

Pelagics	Demersals		Benthics
Eulachon	Darkblotch rockfish	Dover sole	Sea cucumber
Walleye pollock	Arrowtooth flounder	Pacific sanddab	
	Pacific halibut	Petrale sole	
	Pacific cod	Rex sole	
	Sablefish	Flathead sole	
	Lingcod	Slender sole	
	Smooth pink shrimp		

Table 1. The sixteen taxa that an autocorrelation analysis indicates may be 'well-sampled' by this multi-species bottom trawl survey (i.e. taxa which have significant autocorrelation of biomass at lags equal to or greater than one year).

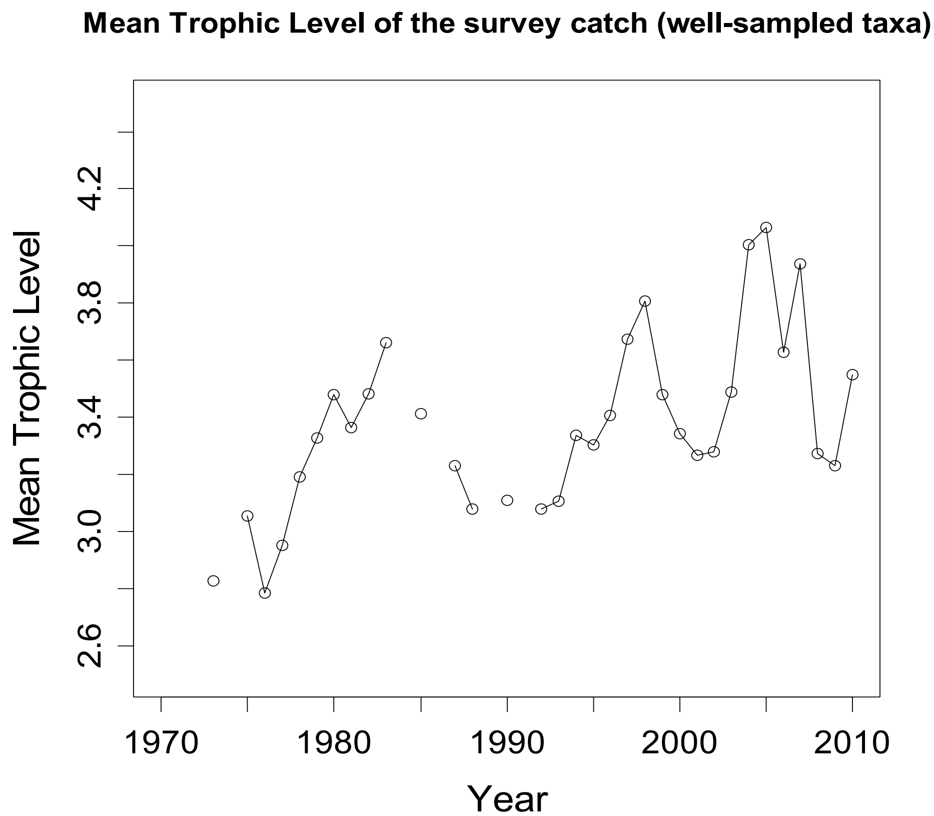

Figure 3. Mean trophic level over time for the 16 'well sampled' taxa from the small mesh bottom trawl surveys. Typical trophic levels are: herbivores (2), carnivores (3); apex predators (4 and 5).

REDUCED CATCHES OF JUVENILE SALMON OFF WCVI IN 2010 RELATIVE TO 2009, BUT IMPROVED GROWTH

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Ocean surveys for juvenile salmon have been used to assess the distribution, growth, condition, and survival of Pacific salmon in different parts of the British Columbia coastal ecosystem since 1998. These surveys are usually conducted in late spring-early summer (June-July) and in the fall (October-November). In addition, juvenile salmon have been collected during winter (February-March) since 2001. This work assumes that marine survival will be higher in years when salmon are rapidly growing and are in good condition compared to years of poor growth and condition. Hence, marine survival is expected to be positively correlated to indicators of juvenile salmon growth rate (Trudel *et al*. 2008).

June-July catch-per-unit-effort (CPUE) of juvenile Coho salmon salmon declined off the west coast of Vancouver Island (WCVI) in 2010 relative to the previous year, but remained stable for juvenile Chinook salmon (Fig. 1). CPUE declined for the second year in a row in both juvenile Sockeye and Chum salmon (Fig. 1). The low CPUE of juvenile Sockeye salmon off WCVI in 2010 may reflect the low return of adult Sockeye to Barkley Sound in 2008 (Hyatt *et al*. 2009). However, the juvenile Sockeye salmon caught off WCVI originate from Barkley Sound and the Columbia River (Tucker *et al*. 2009; S. Tucker, unpublished data). It is currently unknown if these CPUEs can provide an early indicator of adult returns in future years.

Growth rates of juvenile Coho salmon off WCVI increased above the 1998-2009 average while those in Southeast Alaska increased to near average values (Fig.2). As our analyses indicate that the marine survival of WCVI Coho salmon stocks is strongly correlated to their growth (Trudel *et al*. 2008), recent increases in growth suggest that marine survival will be average to above average for WCVI Coho salmon returning in 2011 relative to 1999-2010 (Figs. 3-4), as well as for WCVI Chinook salmon and Barkley Sound Sockeye salmon in 2012 relative to 2000-2010 (Trudel unpub.).

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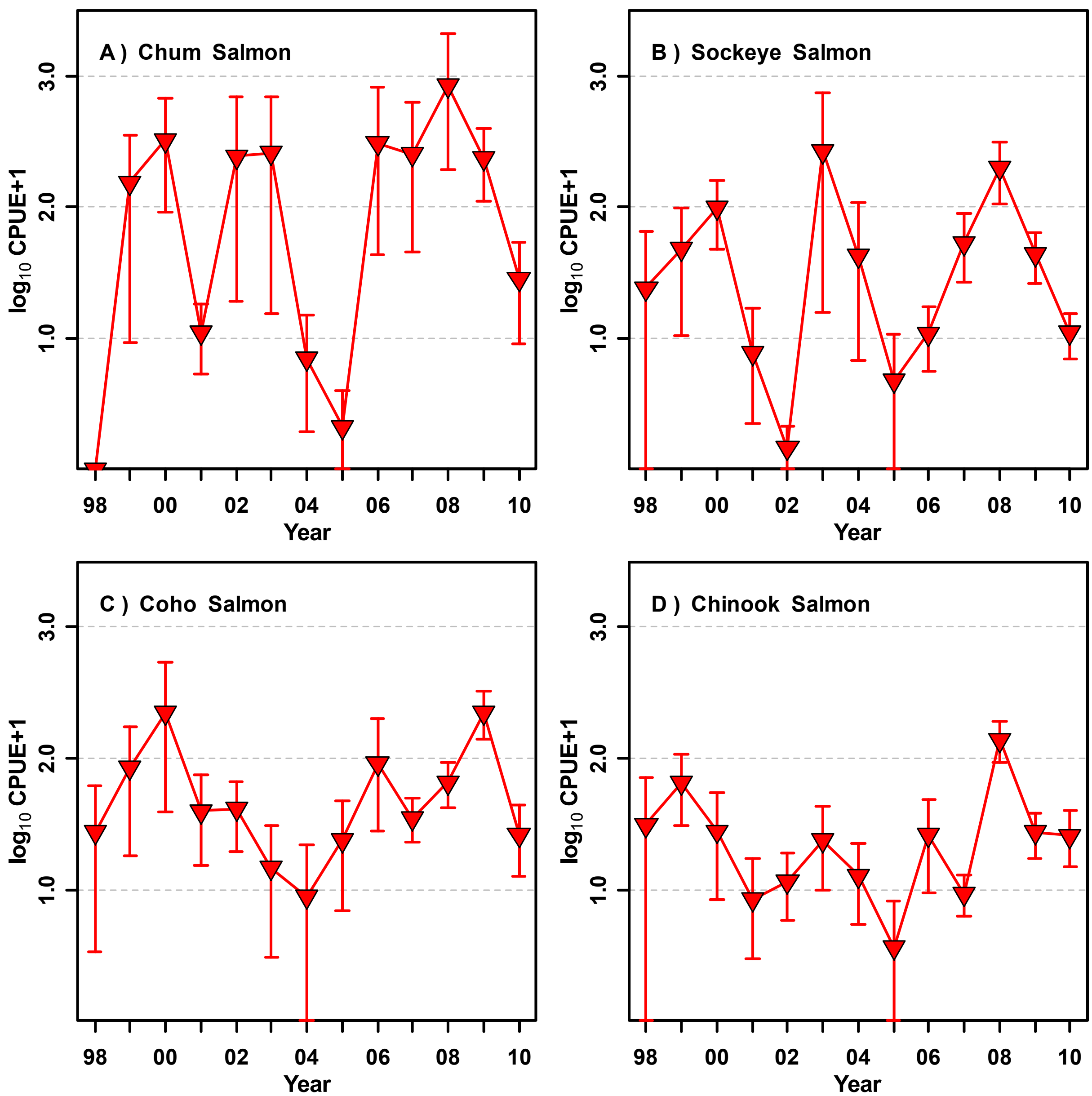

Figure 1. Catch-per-unit-effort (CPUE) of juvenile Chum salmon, Sockeye salmon, Coho salmon, and Chinook salmon on the continental shelf off the west coast of Vancouver Island in June-July 1998-2010. Average CPUE and 95% confidence intervals were obtained by bootstraping.

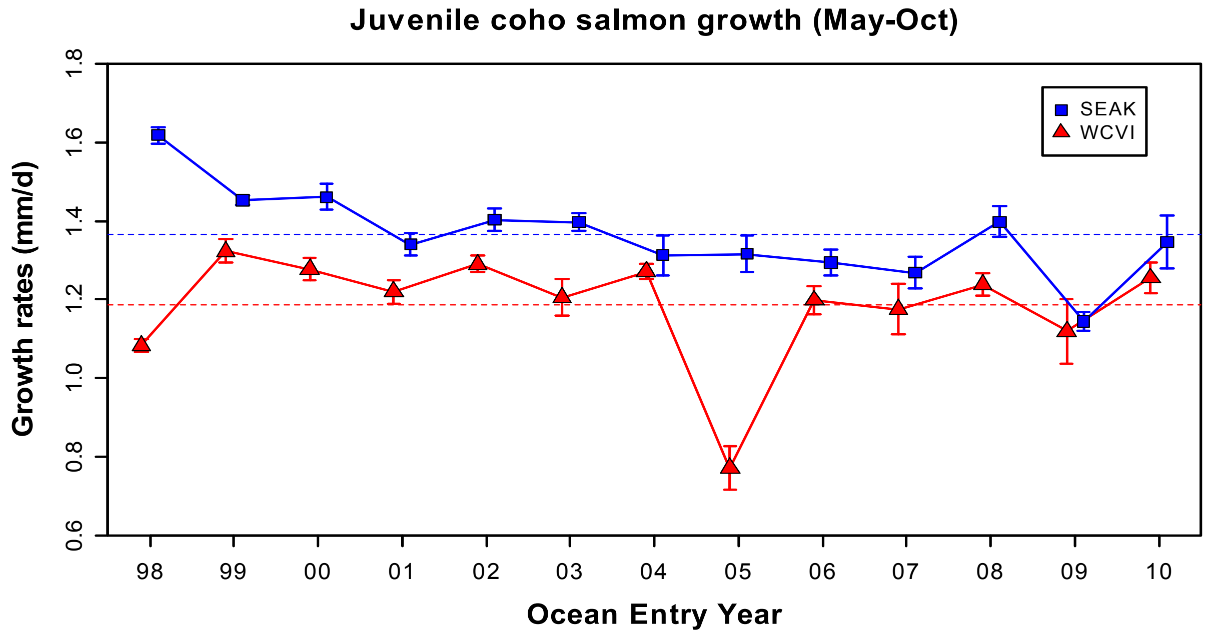

Figure 2. Growth rates (May-October) of juvenile Coho salmon off the west coast of Vancouver Island (red triangles) and Southeast Alaska (blue squares). The blue and red dotted lines represent the 1998-2009 average values for Southeast Alaska and the west coast of Vancouver Island, respectively. The error bars are 2 times the standard error. Details on the procedure used to estimate growth rate are provided in Trudel et al. (2007).

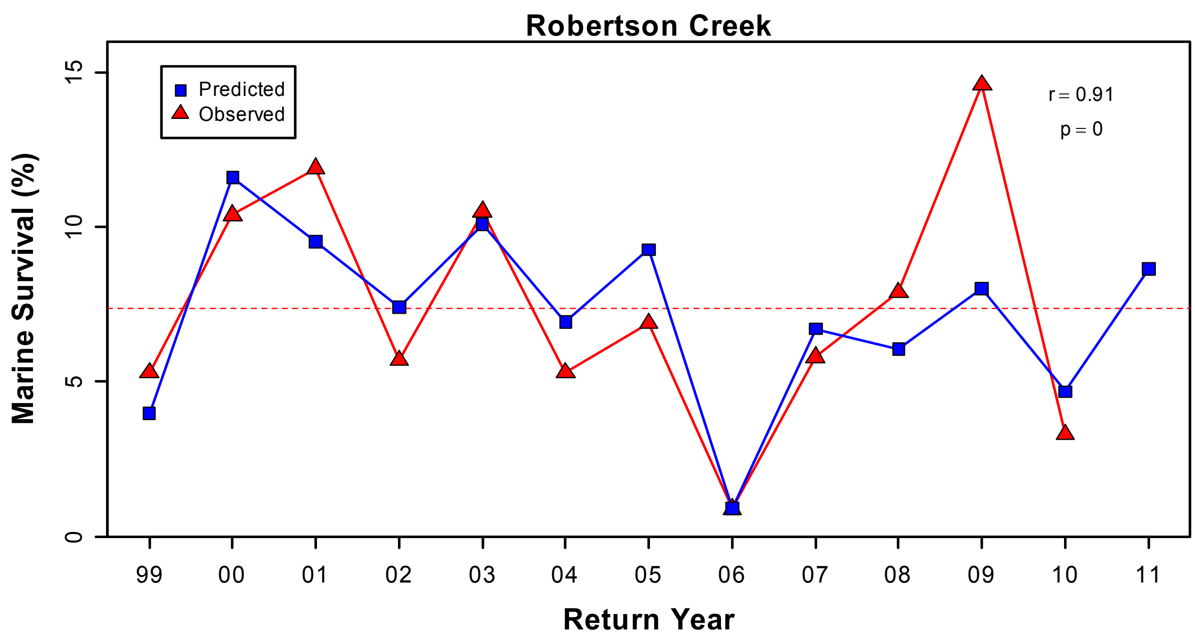

Figure 3. Marine survival and forecast of Robertson Creek Coho salmon. Predicted values were obtained by regressing the logit of marine survival with juvenile Coho salmon growth off the west coast of Vancouver Island. The dashed red line represents the average marine survival for 1999-2010 return years (here estimated as ocean entry year plus one).

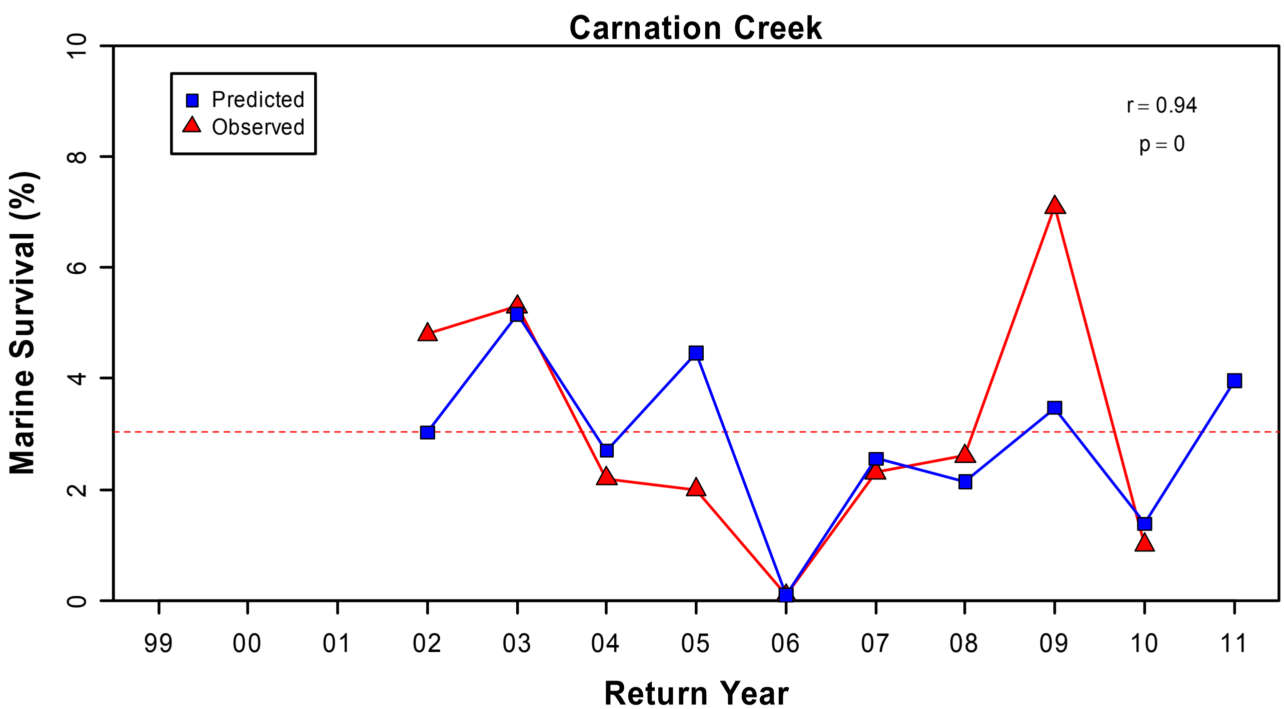

Figure 4. Marine survival and forecast of Carnation Creek Coho salmon. Predicted values were obtained by regressing the logit of marine survival with juvenile Coho salmon growth off the west coast of Vancouver Island. The dashed red line represents the average marine survival for 2002-2010 return years (here estimated as ocean entry year plus one).

ALBACORE TUNA ABUNDANCE IN BC WATERS: 2010 WAS AN ABOVE AVERAGE YEAR

John Holmes, Fisheries & Oceans Canada

Albacore tuna (*Thunnus alalunga*) is a highly migratory, large pelagic species widely distributed in tropical and temperate waters of all oceans. There are two distinct stocks of albacore in the Pacific Ocean, one in the South Pacific and one in the North Pacific. Juvenile albacore between two and five years of age in the North Pacific stock have been targeted by Canadian trollers along the west coast of North America and the adjacent high seas waters since 1939.

Juvenile albacore undergo annual migrations and are attracted to areas of sharp temperature and salinity gradients (fronts) in the transition zone between the subarctic and subtropical gyres in the North Pacific (Laurs and Lynn 1977), particularly the food-rich zone defined by the chlorophyll front along the northern boundary. The transition zone chlorophyll front is a zone of surface convergence where cool, high-chlorophyll surface waters from the north sink beneath warm, oligotrophic waters to the south and is located at about 30–35°N latitude in the winter and 40–45°N in the summer (Polovina *et al*. 2001). This frontal system provides migration pathways and rich foraging habitat for albacore and other species, which track the annual northward shift in frontal location (Polovina *et al*. 2001). In the northern California Current, decapods, euphuasiids, anchovy (*Engraulis mordax*), and hake (*Merluccius productus*) are dominant prey for albacore (Glaser 2009). Annual variations in the distribution and abundance of albacore within coastal waters are affected by water temperature (Alverson 1961), frontal structure along shoreward intrusions of warmer oceanic waters (Laurs *et al*. 1984), and food distribution in these frontal areas (Laurs *et al*. 1984; Polovina *et al*. 2001).

Available albacore data are fishery-related and include catch, catch-per-unit-effort (CPUE) or catch-rate, and length composition of the catch. Stock assessment scientists often use CPUE (total catch divided by the effort to achieve that catch) to index fish abundance. Nominal albacore CPUE's in BC coastal waters averaged 87 fish/vessel-day for the 2000-2009 decade and in 2010 was well above average at 113 fish/vessel-day. The 2010 CPUE is the second highest since 1990; the highest was in 2006 at 129 fish/vessel-day. 2010 catches in the majority of 1° x 1° spatial blocks north of the Canada-United States border and in offshore waters were above average while CPUE's in coastal waters of the US were mostly below average relative to 2000-2009 (Fig. 1). Total catch by the Canadian fishery in 2010 was 6,449 t, a 13% increase relative to 2009, and accompanied by a shift in the location of the catch. Historically, 80-90% of the Canadian albacore catch has occurred in coastal waters off of Washington and Oregon (through access provisions in the Canada-US Albacore Tuna Treaty), 15% in BC coastal waters and 5% in adjacent high seas waters.

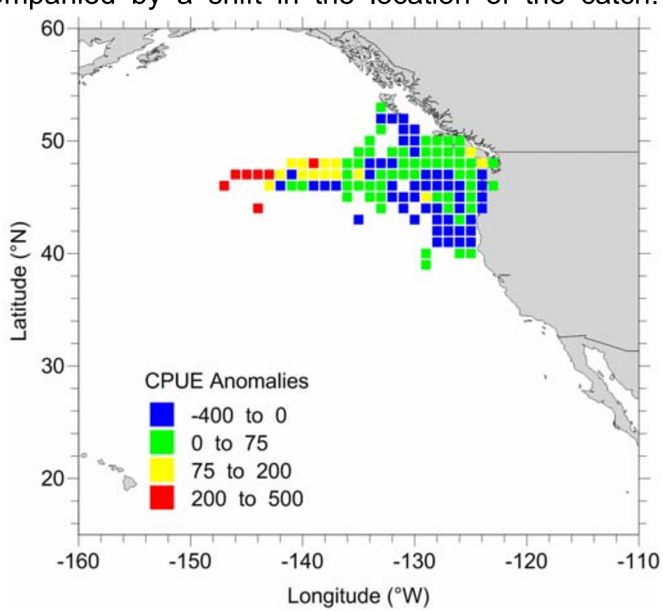

Figure 1. CPUE anomalies (fish/vessel-day) based on logbook data in areas fished by the Canadian fleet in 2010. Anomalies are calculated for 1° x 1° spatial blocks. Anomaly = $2010_{Observed\ catch\ rate} - Average_{2000\text{-}2009}$.

Blocks in blue are below average; all other colours are above-average catch rates

In 2010, catch in BC and the high seas waters increased to 36% and 14% of the total, respectively (2,321 and 884 t), while catch in US waters, particularly off Washington, declined to 50% of the total.

Two modes at 63-65 cm and 73-75 cm, corresponding to 2- and 3-year old fish, respectively, were observed in length composition data sampled from the 2010 Canadian catch (Fig. 2). The range of lengths in this sample (51-90 cm) is consistent with size composition data sampled from Canadian catches in previous years, but the dominance of the second mode at 73-75 cm is unusual in Canadian catches. Three-year old albacore (73-75 cm FL) are most common in troll catches south of 40 °N and in most years effort or catch by the Canadian fleet south of 42 °N is minimal.

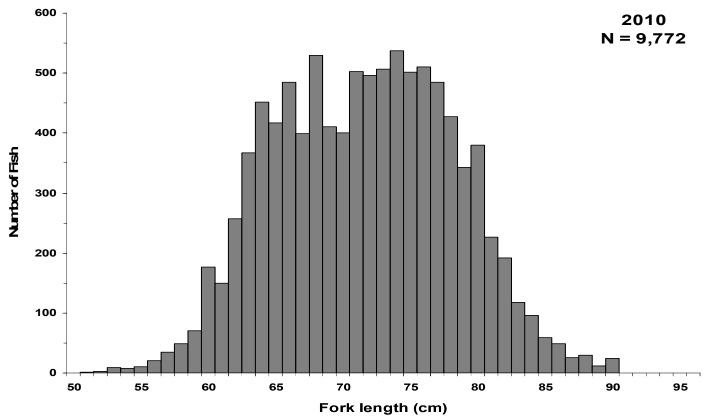

Figure 2. Fork length measurements (N = 9,772) from the Canadian albacore catch in 2010.

The above average CPUEs in northern waters (Fig. 1), changes in the contribution of different areas to total catch, and similar numbers of 2- and 3-year old fish in the catch (Fig. 2) point to a northward shift of the albacore population along the west coast of North America in 2010. Temperature does not appear to be the major driver of this shift. Coastal BC waters were 0.1-0.45 C° cooler than normal (based on Amphitrite Point data) during the fishing season (July-Oct) and more than 80% of the catch was made at temperatures of 14-16 °C in contrast to temperatures between 16 and 18 °C in previous years. Since albacore track the position of transition zone fronts and these fronts can exhibit considerable meandering and monthly latitudinal movement in position (Polovina *et al*. 2001), the increased abundance of albacore, especially 3-year old albacore, in northern California Current waters may be a response to a northerly shift or meander in the transition zone chlorophyll front near the North American coastline. More northern locations of the transition zone may be associated with higher productivity in British Columbia coastal waters and enhanced foraging opportunities for albacore. Assessments of interannual temporal and spatial variation in albacore distribution and abundance may benefit from considering indices of environmental processes at various spatial scales.

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HERRING

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Ron Tanasichuk, Matt Thompson, Fisheries and Ocean Canada

Description of indices

Model estimates of Pacific herring biomass, based on test fishery biological samples (age, length, weight, sex, etc.), herring spawn dive survey data, and commercial harvest data, provide an index of herring population trends for five major fishing stocks: Strait of Georgia (SOG), west coast of Vancouver Island (WCVI), Prince Rupert (PRD), Haida Gwaii (HG; previously referred to as the Queen Charlotte Islands stock), and the central coast (CC)), and two minor stocks (Area 2W and Area 27) (Cleary and Schweigert 2010; Fig. 1). In addition, an annual, offshore survey provides an index of recruitment to the WCVI and the SOG herring stocks, based on the catch-per-unit-effort (CPUE)-weighted proportion of age-3 pre-recruit herring in the common summer feeding area off the WCVI (both these stocks occupy the WCVI region in summer). A third index of herring recruitment trends is obtained with the juvenile herring survey conducted annually in the SOG and CC. These three indices provide information on population trends and inform Fisheries and Oceans Canada science advice regarding catch recommendations.

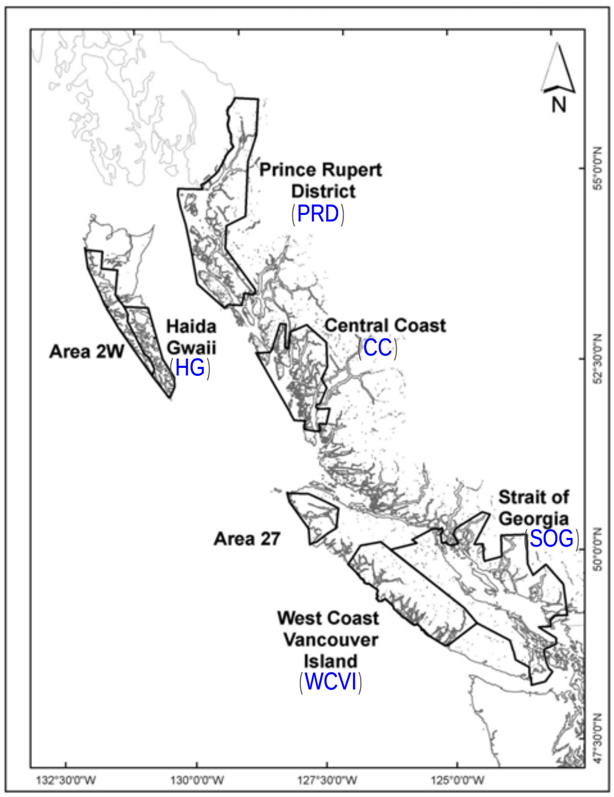

Figure 1. Location of the five major (Strait of Georgia, west coast of Vancouver Island, Prince Rupert, Haida Gwaii, and the Central Coast) and two minor (Area 2W and Area 27) Pacific herring fishing stocks in British Columbia.

Status and trends

West Coast Vancouver Island (WCVI): Herring biomass off the WCVI decreased from 1977 through to the present, to levels not seen since the late 1960s when the reduction fishery that operated during 1951-1968 caused a decline in herring stocks to low levels (Cleary and

Schweigert 2010; Fig. 2). The biomass in 2010 was similar to low levels observed since 2006 and remained well below the fishery threshold (Fig. 2). Since about 1977, the recruitment of herring off the WCVI has been generally poor, interspersed with a few good year-classes. As a result, the productivity of the WCVI herring stock has been declining since the early 1980s (Fig. 3). Recruitment in 2010 was poor; however, there is an indication that recruitment will improve in 2011. Results from the summer off-shore trawl survey indicate average recruitment for 2011. WCVI herring weight-at-age has declined since the mid-1970s or mid-1980s (Fig. 4).

Strait Of Georgia (SOG): The biomass of herring in the SOG reached near historic high levels from 2002-2004 at over 100,000 tonnes (Cleary and Schweigert 2010; Fig. 2). Recruitment to this stock has been very strong with 9 of the last 10 year-classes being average or better (Fig. 3). Recruitment to this stock has alternated between average and good over the last 10-years, with poor recruitment in 2008 and 2010. The summer off-shore trawl survey and the juvenile herring survey indicated good recruitment for 2011 and initial indications from the 2011 test fishery suggest recruitment was very high. SOG herring weight-at-age has declined since the mid-1970s (Fig. 4).

Prince Rupert (PRD), Haida Gwaii (HG), and Central Coast (CC): Exploitable herring biomass in the PNCIMA region represents a combination of migratory stocks from the HG, PRD and CC areas (Cleary and Schweigert 2010). Over the past decade, herring biomass in HG (Fig. 2) has been depressed whereas the biomass in both PRD and the CC has remained relatively stable, albeit with a slight decrease in the CC in the last five years (Fig. 2). Recruitment to the HG stock has been depressed with only 2 ‘good’ year-classes out of the past 10 while the PRD stock has experienced a ‘good’ recruitment at least every 4 years since 1980 (Fig. 3). Recruitment to the CC stock has been less regular but the ‘good’ year-classes that have occurred were very strong (Fig. 3). Indications are that the recent recruitments (2003-2006 year-classes) were ‘poor’ or ‘average’, resulting in declines of all three major northern stocks (Figs. 2 and 3). Recruitment in 2010 (i.e., 2006 year-class) increased slightly for PRD, but remained poor for the CC and HG. PRD, HG, and CC herring weight-at-age has declined since the mid-1970s (Fig. 4).

<u>Factors causing those trends</u>

Despite a precautionary harvest policy for herring that has been in place since 1986, the biomass of all five major fishing stocks has declined during the past decade (Schweigert *et al*. 2009). This suggests that factors other than fishing are influencing herring population trends. Changes in food supply and quality, predator abundance, and competition are factors that could affect trends in herring biomass and weight-at-age (Schweigert *et al*. 2010; also see Tanasichuk, this report).

Pacific herring are zooplanktivorous, consuming primarily euphausiids (krill) and some copepods (Wailes 1936). Changes in ocean conditions, such as temperature or currents, could affect the amount and types of prey available. For example, a northerly current direction could result in the presence off the WCVI of California current waters, including California Current zooplankton species that have a lower energetic value, thereby, bringing about poorer feeding conditions for herring (Schweigert *et al*. 2010, Mackas *et al*. 2004). In addition, Tanasichuk (this report) relates WCVI herring recruitment to the biomass of euphausiids.

There are a wide variety of herring predators, including Pacific hake, lingcod, spiny dogfish, Pacific cod, sablefish, arrowtooth flounder, Pacific halibut, Steller sea lions, northern fur seals, harbour seals, California sea lions, and humpback whales (Schweigert *et al*. 2010).

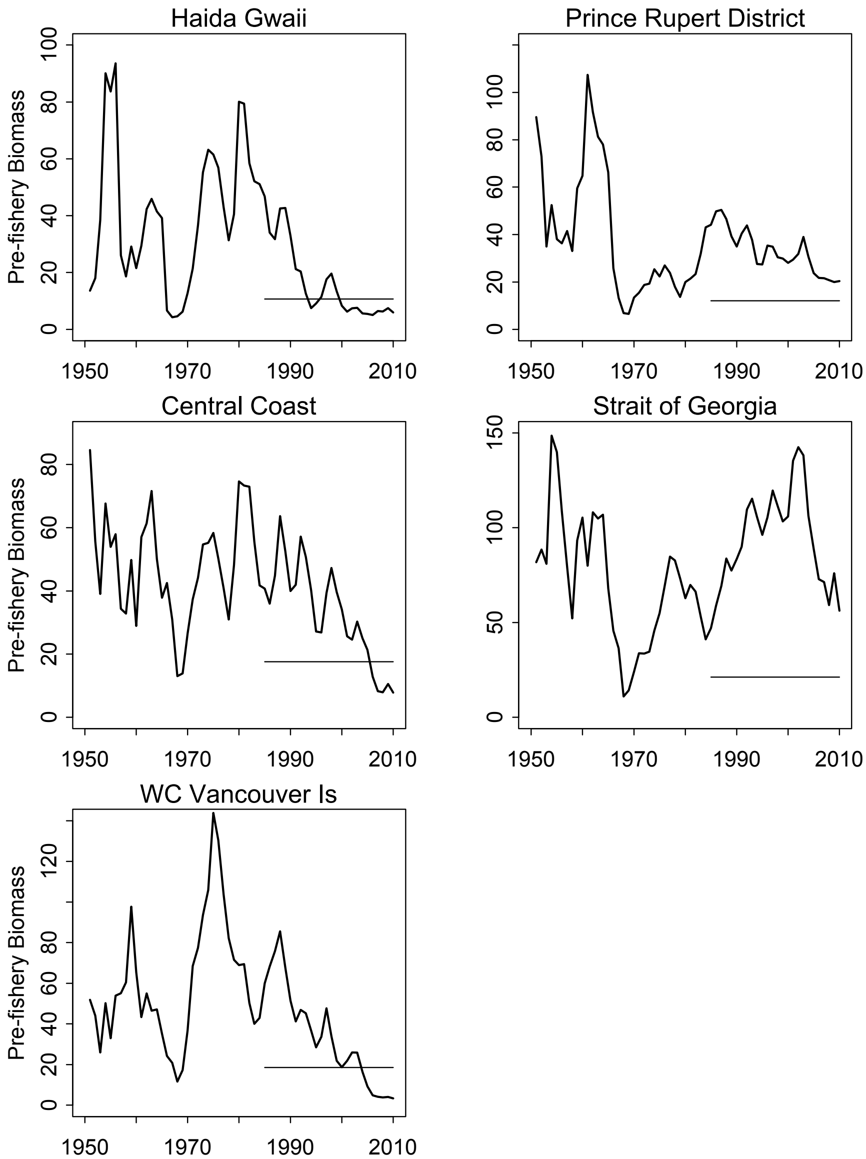

Figure 2. Pre-fishery biomass (solid line) of Pacific herring in the five major fishing stock areas in British Columbia. The horizontal line represents the fishing cut-off threshold. Commercial fishing is closed when the estimated pre-fishery biomass is below this threshold value.

Off the WCVI, fish predator abundance has decreased in recent years, while the abundance of most marine mammal predators has increased (Olesiuk 2008, Olesiuk *et al*. 1990). This has resulted in a relatively stable or slightly decreasing trend in the amount of WCVI herring consumed by predators since 1973 (Schweigert *et al*. 2010). Although a significant proportion of the herring population could be cropped annually by predation, natural mortality of WCVI herring was not found to be directly attributable to predation (Schweigert *et al*. 2010). Herring recruitment, however, has been correlated with piscivorous hake biomass (piscivorous hake are those hake that are large enough to consume herring), suggesting predation may be an important factor influencing WCVI herring recruitment (see Tanasichuk, this report).

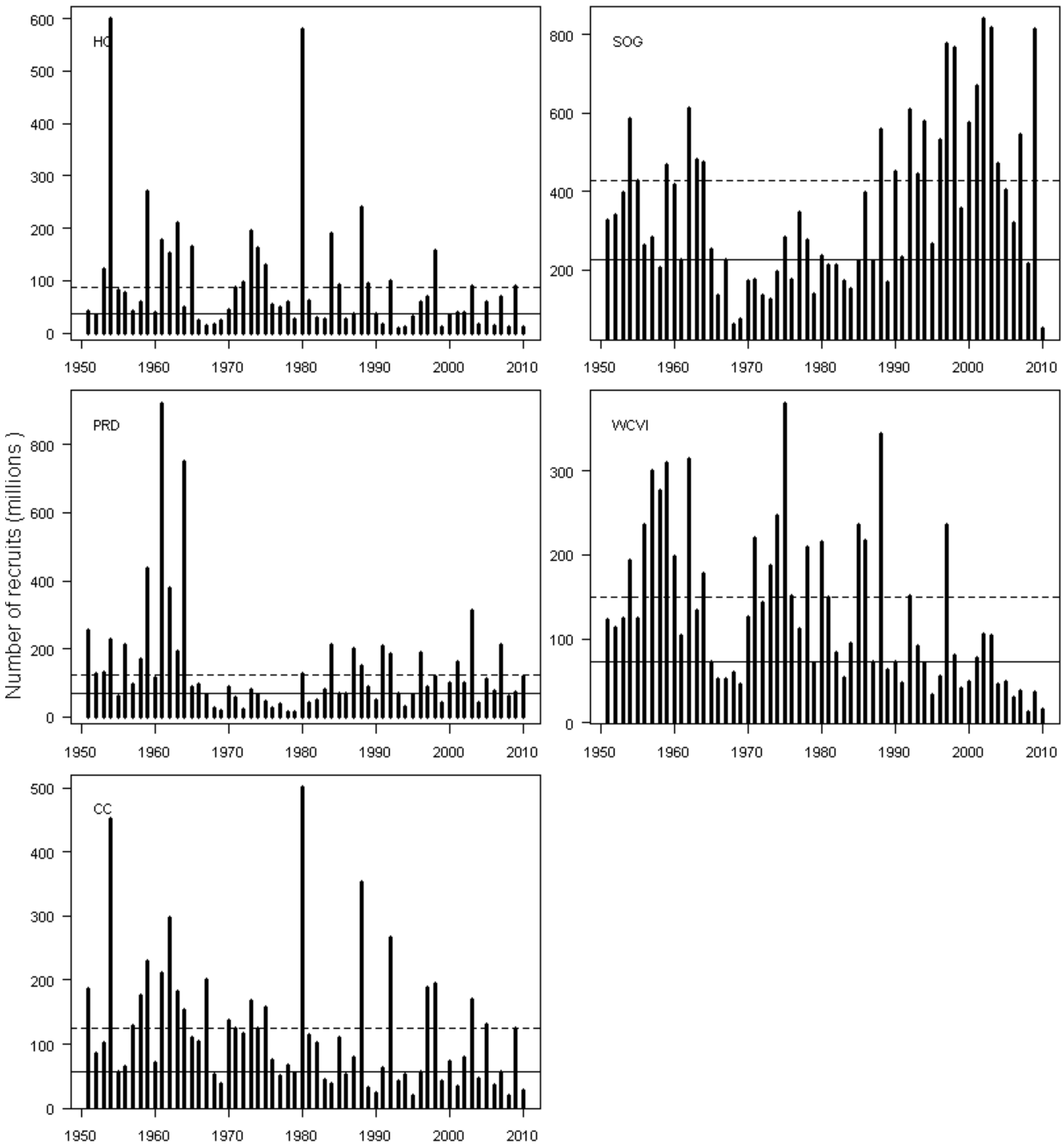

Figure 3. Estimated number of Pacific herring age-3 recruits (millions) for the five major fishing stocks in British Columbia. Horizontal lines delineate the lower, middle, and upper third of historical recruitment estimates.

Competition may also be a factor affecting herring population trends. Since the late 1990s, a substantial component of the Pacific sardine population off the west coast of North America has migrated into Canadian waters annually (Schweigert *et al*. 2009). Pacific sardine are primarily phytoplanktivores, but also consume some of the same prey as herring (McFarlane *et al*. 2005). Reduced survival of adult herring is most pronounced in areas exposed to offshore influences (WCVI, HG, and to a lesser extend CC; Schweigert *et al*. 2010), where sardine migrate. The large increases in Pacific sardine in the early 1990s to 2000s in Canadian waters may have increased competition for food with herring, and/or attracted predators (Schweigert *et al*. 2010).

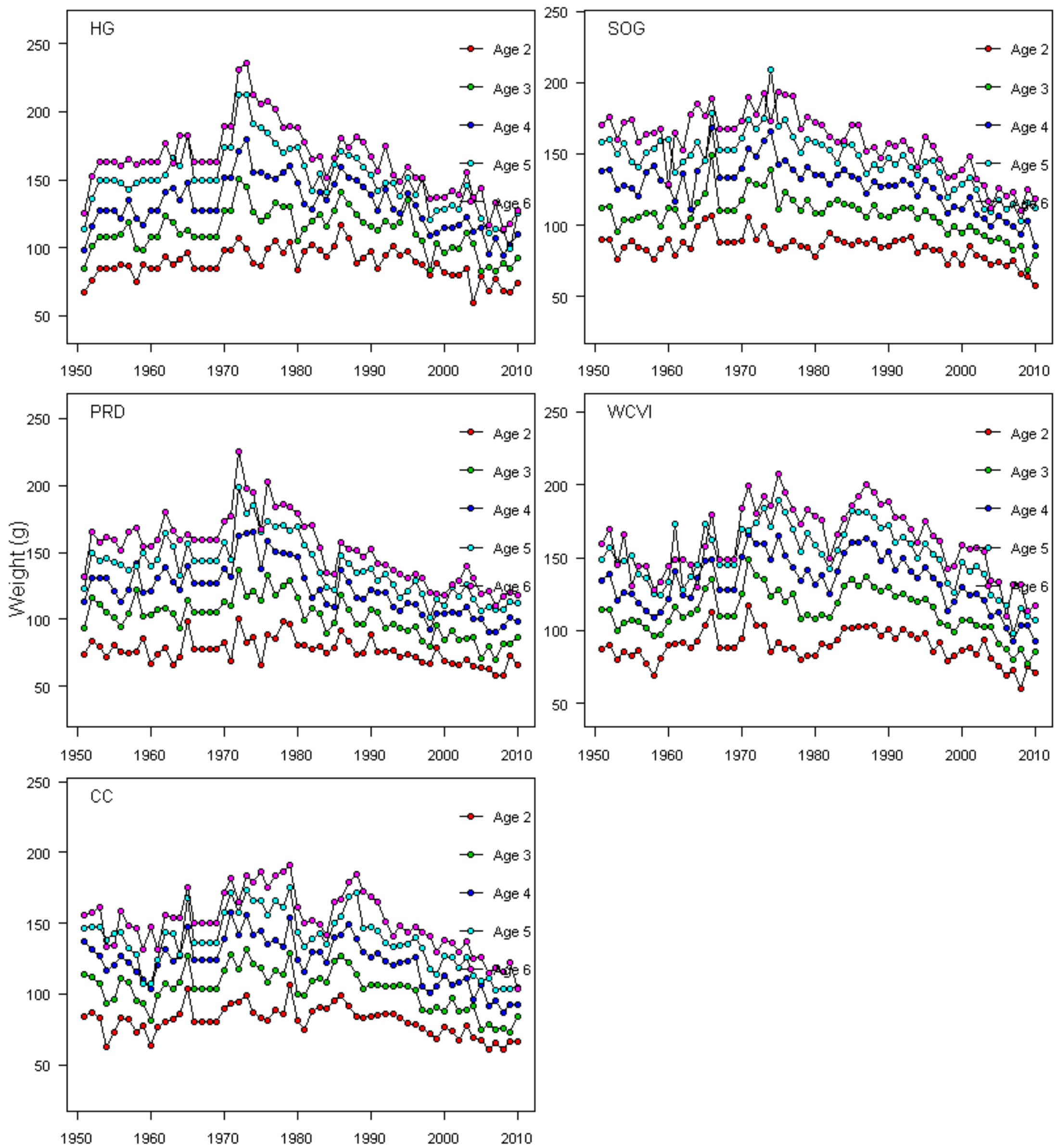

Figure 4. Weight-at-age (ages 2-6) of Pacific herring in the five major fishing stocks in British Columbia.

Implications of those trends

Pacific herring comprise an important component of commercial fisheries in British Columbia. Estimated biomass of herring relative to the fishery threshold has implications for the herring fisheries. The biomass estimates of SOG and PRD herring are above the fishery threshold or cutoff values and are, therefore open to commercial fishing (Cleary and Schweigert 2010). Following the herring harvest control rule, the maximum available harvest is based on a 20% harvest rate of the mature herring biomass (Cleary and Schweigert 2010). Biomass estimates for the HG, CC, and WCVI herring stocks are below fishery cutoff values, therefore those three areas are not open to commercial fishing (Cleary and Schweigert 2010).

Trends in herring biomass have implications for herring predators, such as fish, marine mammals and seabirds. The relative importance of herring in each predator's diet varies;

however, herring may represent up to 88% of lingcod diet (Pearsall and Fargo 2007), 40 % of Pacific cod and Pacific halibut diets (Ware and McFarlane 1986), and 35% - 45% of pinniped diets (Olesiuk *et al*. 1990, Womble and Sigler 2006, Trites *et al*. 2007, Olesiuk 2008). Depending on the level of diet specialization and ability to switch to alternate prey, herring abundance and condition may affect predators' growth and abundance. Diet data time series of animals in this ecosystem would improve our ability to examine temporal trends in predator-prey interactions and implications of those trends.

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SARDINE

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Fisheries and Oceans Canada

Description of indices

An annual surface trawl survey conducted off the west coast of Vancouver Island (WCVI), Canadian commercial catches of sardines, and the U.S. sardine stock assessment provide indices of sardine population trends. The annual survey Catch Per Unit Effort (CPUE) and commercial catches are utilized to estimate the minimum biomass of sardines in Canadian waters. The survey began in 1997, and switched to night time sampling in 2006 (Fig. 1). The survey and U.S. stock assessment information are used to predict sardine migration rates into Canadian waters. This information is then used to determine population trends and provide science advice on recommended catch levels.

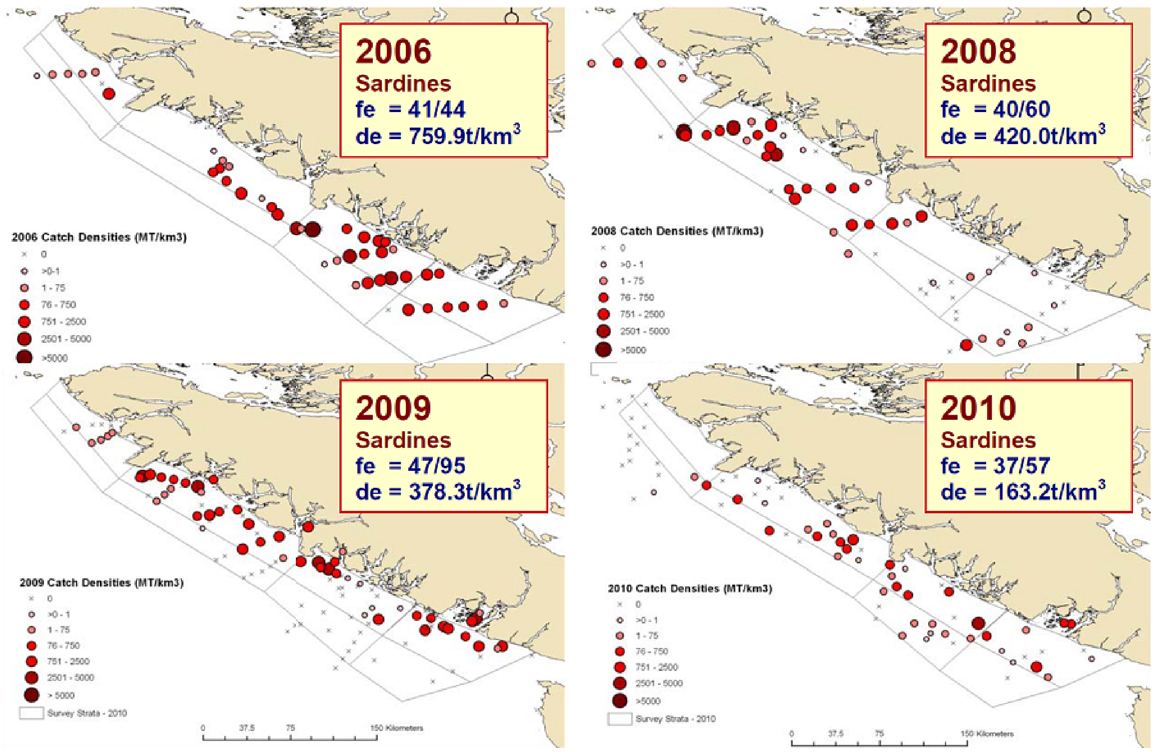

Figure 1. West coast of Vancouver Island (WCVI) summer trawl survey sampling locations and relative sardine catch densities for 2006, 2008-2010. The fraction (fe) of tows where sardine were caught and the mean density of sardines (de) within the core region are shown. Figure from Flostrand et al. (2011).

Status and trends

Pacific sardine is a migratory species, annually migrating between spawning grounds in southern California to the rich feeding areas off the west coast of Vancouver Island; the older and larger fish tend to move even further north (Clark and Janssen 1945). The sardine fishery in Canadian waters collapsed in 1947 and by the early 1950s off California (Fig. 2). Sardine returned to southern Vancouver Island waters in 1992 after a 45 year absence, and expanded their distribution northward throughout the west coast of Vancouver Island, Hecate Strait and Dixon Entrance by 1998 (Flostrand *et al*. 2011). In 2010, WCVI survey catches of sardine were much lower than the previous 3 survey years (Figs. 1 and 2). The exceptionally strong 2003 year-class continues to be the dominant component of large sardines throughout the area. The 2004 and 2005 year classes also had relatively high recruitment, whereas the 2006-2009 year classes had moderately low recruitment (Flostrand *et al*. 2011). The most recent U.S. sardine assessment suggests that coast-wide abundance off Canada and the U.S. peaked in 2000 and has declined since, decreasing to approximately 700,000 tonnes in 2010 (Fig. 2). The estimated migration rate into Canadian waters has also decreased since 2006 (Fig. 2).

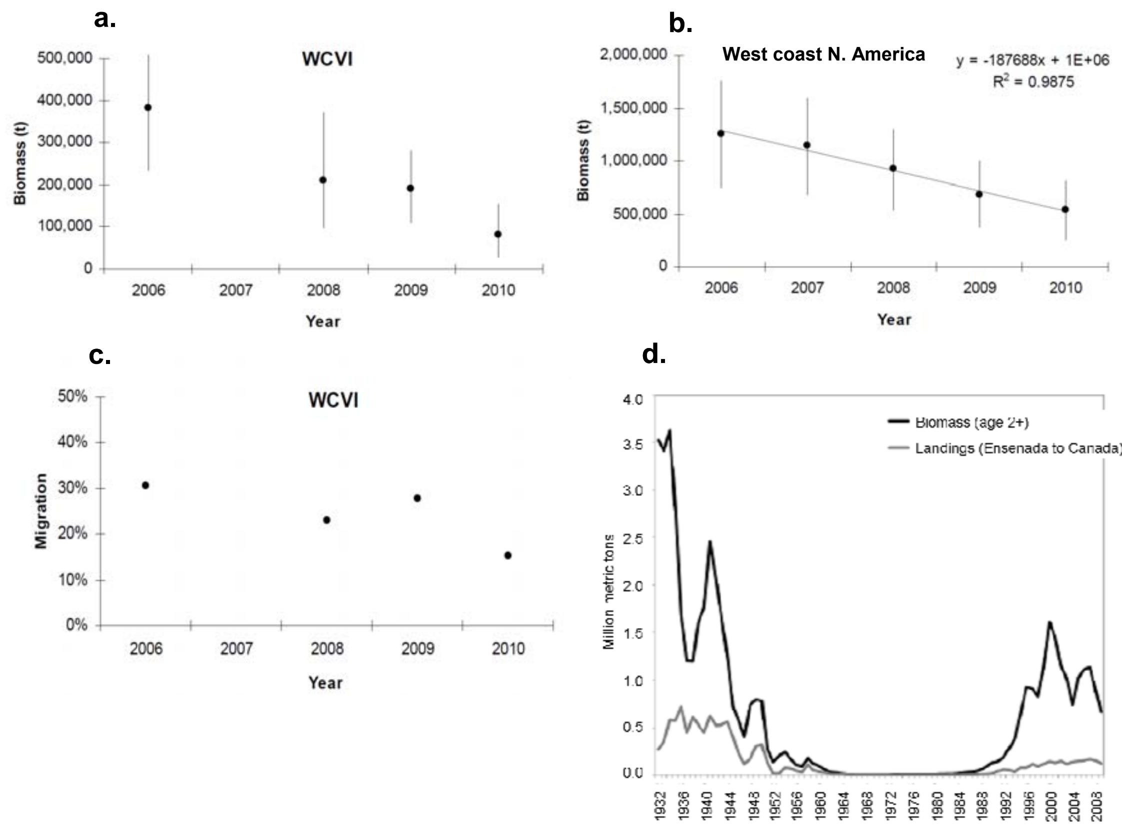

Figure 2. (a) Pacific sardine mean biomass estimates for the core west coast of Vancouver Island (WCVI) survey region, with 95% confidence intervals, during 2006-2010 (no survey in 2007); (b.) biomass estimates for the entire west coast of North America (based on Hill et al. 2010) with 95% confidence intervals, during 2006-2010; (c.) migration rates into Canadian waters, 2006-2010; (d.) sardine biomass and landings on the west coast of North America during 1932-2009. Figure adapted from Flostrand et al. (2011).

Factors causing those trends

Historical sardine abundance has been extremely variable along the US and Canadian west coast, varying over approximately 60-year periods (Cushing 1971, Hill *et al*. 2009). The number of sardines and the timing of their annual northward migration are determined, in part, by environmental factors that are not well understood (Flostrand *et al*. 2011, Hill *et al*. 2009). In addition, stock size may play a role in sardine recruitment (Hill *et al*. 2009). The decline in sardine biomass in the late 1940s was attributed to environmental conditions and overfishing (Clark and Marr 1955, Jacobson and MacCall 1995). During cold years, such as in the 1950s to 1970s, sardine productivity was low and their distribution was contracted in the southern part of their range (Hill *et al*. 2009, Jacobson and MacCall 1995). Recent warm years, associated with increased sardine productivity (Jacobson and MacCall 1995) and larger stock size resulted in a more northerly distribution of the stock (Hill *et al*. 2009). The cause of the current decreasing trend (since 2000) in sardine biomass is unknown, but may be due in part to environmental conditions and may represent the declining abundance phase of this naturally varying clupeoid species.

Implications of those trends

Commercial fisheries for Pacific sardine in British Columbia (BC) began in early 1995 and were primarily experimental with only a small proportion of the total allowable catch (TAC) being landed. More recently (2008-2010) commercial catch has increased in importance in BC (Flostrand *et al*. 2011) and declining sardine biomass has resulted in a reduced TAC available to commercial fishers in Canadian waters (Flostrand *et al*. 2011).

Pacific sardine are consumed by a variety of fish, such as Coho and Chinook Salmon (Chapman 1936), and marine mammals, such as California sea lions and other pinnipeds. Historically, sardine populations have undergone extreme variations in abundance and it is likely that predators have adapted to utilize this resource when it is abundant. For example, it was hypothesized that consumption of larval sardines by anchovies was an important source of mortality in US waters during 1951-1967 (Butler 1987). Diet data time series of all animals in the ecosystem would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

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EULACHON

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Description of indices

Three indices of eulachon population trends are: 1) eulachon catches occurring in annual offshore shrimp trawl surveys off the west coast of Vancouver Island (WCVI) and in Queen Charlotte Sound (QCS), 1973- 2010, 2) commercial eulachon catches in the Fraser and Columbia River systems, and 3) a spawning stock biomass estimate based on annual Fraser River eulachon egg and larval surveys. Information from these indices is utilized to provide information on population trends and science advice regarding eulachon catch recommendations.

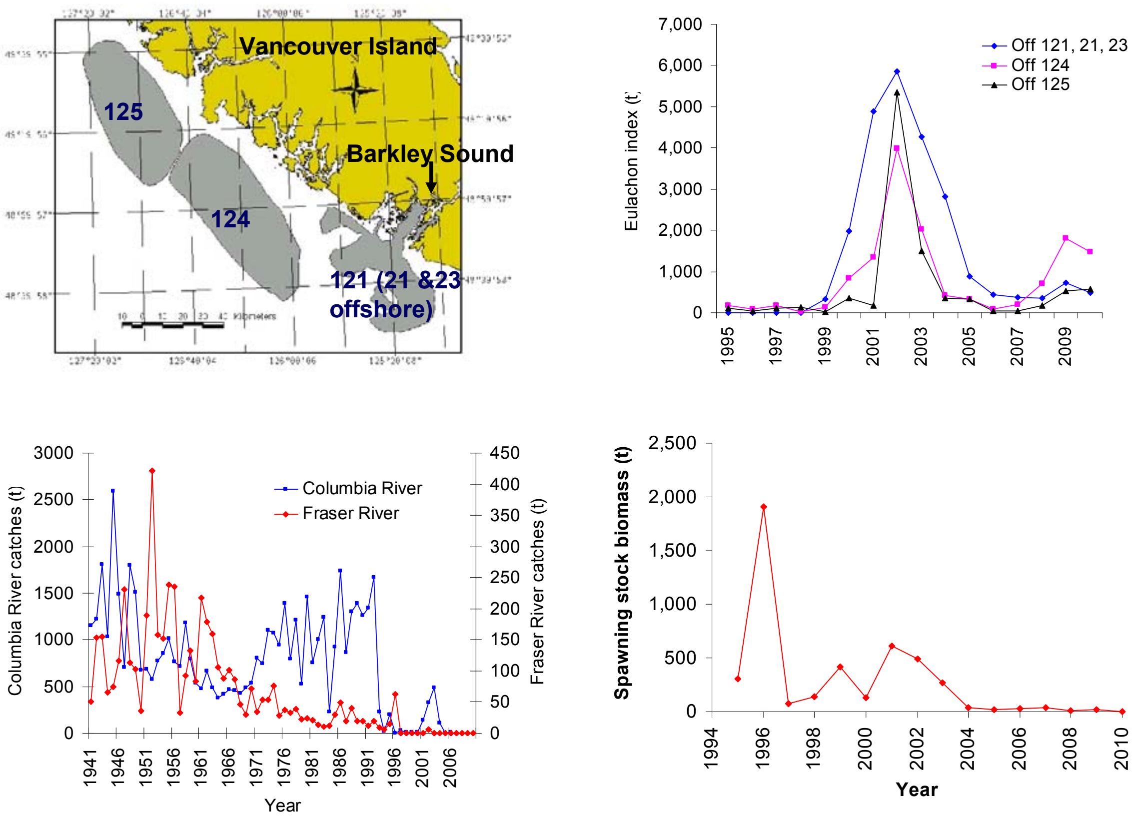

Figure 1. Three indices of eulachon abundance. The upper, right panel shows recent trends in the offshore shrimp survey trawl catches of eulachon in areas shown in the upper, left panel. The lower, left panel shows the commercial catches of eulachon in the Columbia and Fraser River systems. The lower, right panel shows the estimated spawning stock biomass of eulachon from egg and larval surveys in the Fraser River system.

Status and trends

Eulachon have experienced long-term declines in many rivers throughout their distribution from California to Alaska. Indices of eulachon abundance in central and southern British Columbia rivers remain at low levels, whereas offshore shrimp trawl survey catches indicate juvenile eulachon abundance has increased slightly since 2008 (Fig. 1). The estimated eulachon spawning stock biomass in the Fraser River decreased in 1994 and has consistently been below the 150 tonne reference point since 2004 (Fig. 1). Catches in the Columbia River system decreased dramatically in the early-1990s (Fig. 1). Columbia River eulachon were federally-listed as threatened under the Endangered Species Act (ESA) effective May 17, 2010 and all eulachon-directed fisheries were closed in 2011. COSEWIC has recently assessed eulachon in some BC rivers as "threatened" while others are listed as "endangered". Offshore indices of juvenile eulachon abundance do not necessarily reflect the abundance of adult eulachon that return to rivers. The biomass in the Fraser River will be estimated by an egg and larval survey in April-May 2011.

Factors causing those trends

It is unknown what is causing the trends in eulachon abundance. In-river factors may include habitat loss, pollution, directed fisheries, logging, and marine mammal predation. Marine factors that may affect eulachon abundance include: oceanographic conditions, bycatch in commercial fisheries, and trophodynamic changes, such as food availability and predator abundance.

Implications of those trends

Reduced biomass of eulachon has implications for First Nations and commercial fishers. Eulachon are socially and culturally significant to local First Nations and are fished by First Nations, recreational and commercial fishers.

Reduced eulachon abundance also likely has an impact on their predators. Important predators of eulachon include: marine mammals particularly sea lions in the estuaries, and porpoises, Chinook and Coho Salmon, spiny dogfish, Pacific hake, sturgeon, Pacific halibut, walleye pollock, sablefish, rockfish, arrowtooth flounder, and others (Levesque and Therriault 2011). Diet data time series of all animals in the ecosystem would improve our ability to examine temporal trends in predator-prey interactions and the implications of those trends.

Reference

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PACIFIC HAKE *(MERLUCCIUS PRODUCTUS)* OFFSHORE STOCK STATUS AND RESEARCH PROGRAM

Robyn Forrest, Chris Grandin, Greg Workman, Fisheries and Oceans Canada

Pacific hake is a semi-pelagic schooling species distributed along the west coast of North America, generally ranging from 25° N (southern California) to 55° N (northern British Columbia). Spawning is thought to occur in southern-central California during January to March (Saunders and MacFarlane 1997). Adults migrate north each spring to form extensive midwater summer aggregations that range from northern California to the west coast of Vancouver Island. Densest aggregations generally occur in depths of 200-300 m (Dorn 1991, 1992). This stock is separate from the hake population in the Strait of Georgia. Here we update last year's report (Grandin *et al* 2010) with specific reference to 2009 abundance estimate complications because of co-occurring Humboldt squid.

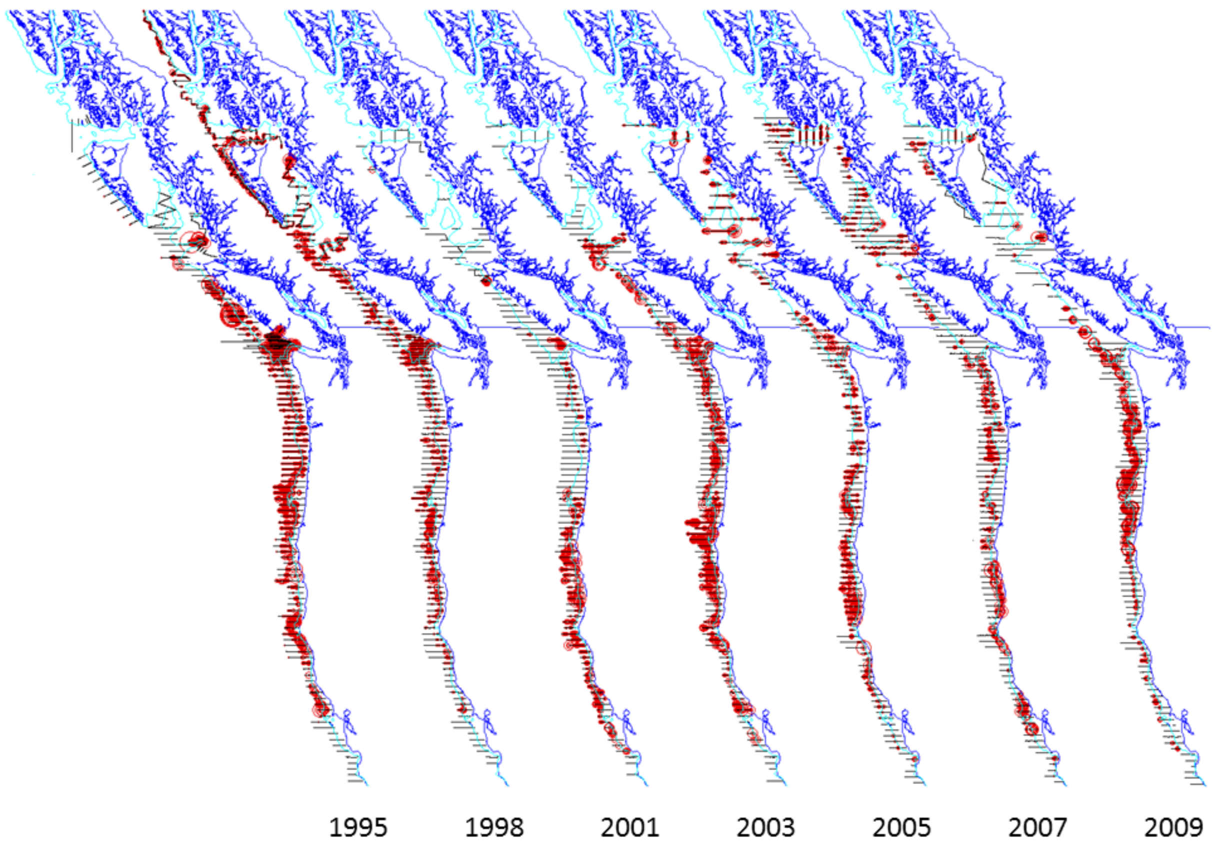

Figure 1. Acoustic backscatter time series for the offshore hake stock. Parallel grey lines represent transects spaced 10 nautical miles apart. The density of the red dots is proportional to 38 kiloHertz acoustic backscatter attributable to hake.

The maximum distribution of hake occurred in 1998 when hake were found well into southeast Alaska (to 58^{o} N). The minimum range was observed in 2001, when hake were found in only three locations north of the Washington-BC border (west side of Haida Gwaii, Brooks Peninsula, and the La Perouse area). Note that survey results were badly "contaminated" in 2009 by huge numbers of Humboldt squid (*Dosidicus gigas*) that occurred all along the Pacific coast, and it was not possible to distinguish squid from hake acoustically. Re-analysis of the acoustic survey data during 2010 enabled confidence intervals to be placed on the 2009 estimate of hake abundance, although the large uncertainty in current population size is unlikely to be reduced until some time after the 2011 acoustic survey. Source: Joint U.S. and Canadian Hake Technical Working Group 2011.

Triennial (until 2001), then biennial acoustic surveys, covering the known extent of the Pacific hake stock (Fig. 1) have been done since 1995. The stock is assessed annually by US and Canadian scientists (see Joint U.S. and Canadian Hake Technical Working Group (2011) for the latest assessment). 2010 was an intra-survey year during which the survey team responded to issues raised by the Stock Assessment Review (STAR) panel in 2010. The first issue was potential bias due to the protocol for sampling schools of hake to verify estimates of hake length from acoustic data. One reviewer felt that schools would likely be stratified by size and age and that the conventional approach of taking a “dip” with the fishing net from the top or side of a school would likely be biased. The survey team fished several hake aggregations where they were able to tow the net through the top, middle and bottom and across the length and width of a school and found no clear pattern of stratification. The intended second task was to estimate the target strength of Humboldt squid, which were pervasive during the 2009 survey, contaminating 39% of the acoustic transects with an unknown quantity of squid backscatter. This problem could not be resolved in the 2010 field season due to the absence of Humboldt Squid during the 2010 survey. The survey team was however able to reprocess the 2009 acoustic data to better separate hake from squid. As a result of this work, a revised 2009 acoustic estimate was generated and incorporated into the 2011 hake stock assessment. This estimate accounts for the uncertainty due to squid, The Pacific hake biomass estimate was lowered due to the revised accounting of Humboldt squid.

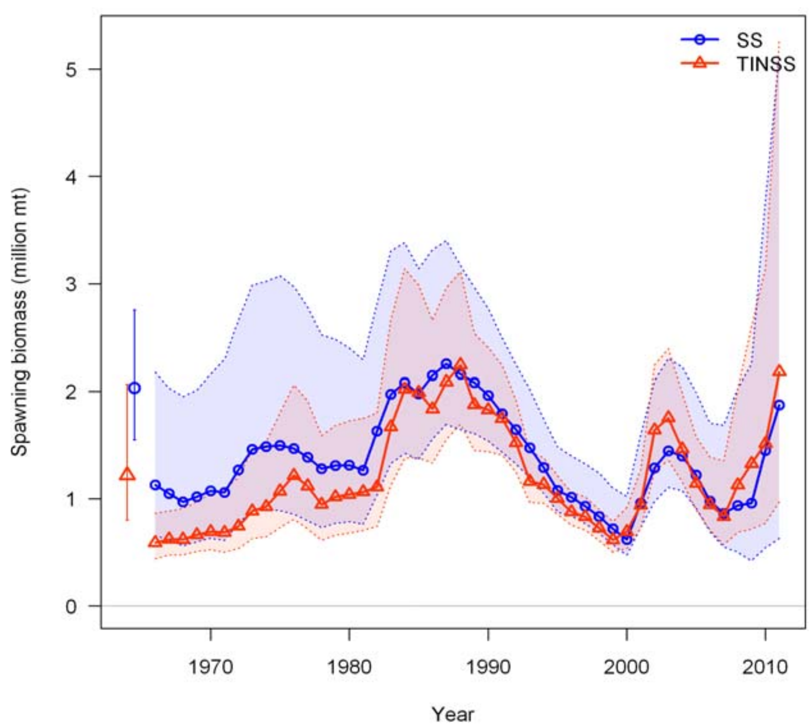

Figure 2. Estimated female spawning biomass (million mt) with 95% posterior credibility intervals from the 2011 Pacific hake stock assessment. Blue and red series represent estimates from two age-structured Bayesian models (SS and TINSS). Points (and confidence) intervals at the beginning of the series represent estimates of equilibrium unfished female spawning biomass. Source: Joint U.S. and Canadian Hake Technical Working Group 2011.

Hake are caught using midwater trawl gear by US, Canadian and US-Canadian joint venture fleets, with catches averaging 221,000 mt from 1966 to 2010, peaking at 363,000 mt in 2005. Since 2002, the fishery has been largely sustained by a very strong 1999 year class, with above-average 2005 and 2006 year classes also contributing to the current exploitable biomass. Age-composition data from the 2010 commercial fishery suggest that the 2008 year class was also above-average, although 2011 survey age-composition data are needed to determine whether the high proportion of age-2 fish in the 2010 commercial catch was due to a large recruitment event or a change in fishing activity. Uncertainty in the magnitude of the 2008 year class led to extreme uncertainty in biomass estimates (Fig. 2), and catch advice in the 2011 stock assessment (Joint U.S. and Canadian Hake Technical Working Group 2011).

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TRENDS OF CHINOOK SALMON ABUNDANCE IN FISHERIES MANAGED UNDER THE PACIFIC SALMON TREATY

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Fisheries & Oceans Canada

Under the jurisdiction of the Pacific Salmon Treaty (PST), 30 Chinook Salmon stock aggregates and 25 fisheries distributed between southeast Alaska and northern Oregon are managed annually to either projected landed catch targets or are limited by maximum allowed exploitation rates. Estimates of escapements or terminal runs of mature fish for each of the stock aggregates and estimates of numbers of Chinook landed or released in the PST fisheries are assembled annually and provide some of the crucial data inputs to the calibration of the Coast-wide Chinook Model (CM). The Chinook stocks (consisting of both wild- and hatchery-origin fish) and fisheries represent nearly all Chinook and fishing-related impacts known to occur within the PST jurisdiction.

A result of the CM calibration procedure is a time series of aggregate Chinook abundance estimates for each fishery starting with 1979 and ending with the most recently completed fishing year. For each stock and fishery, abundances are estimated for up to four age classes, including immature fish that would not spawn for one or more years. An abundance forecast is also generated for the upcoming fishing year and is the basis for establishing the annual catch targets in three highly mixed-stock ocean fishery areas (southeast Alaska, Northern BC including areas around Haida Gwaii, and west coast Vancouver Island).

Time series of abundance indices (AIs) are annually derived and reported to the Pacific Salmon Commission in technical reports prepared by the bilateral Chinook Technical Committee (e.g., TCCHINOOK 11(2), 2010 Annual Report of Catches and Escapements, TCCHINOOK 11(3), 2010 Annual Report of Exploitation Rate Analysis and Model Calibration available at http://www.psc.org/publications_tech_techcommitteereport.htm#TCCHINOOK).

The AIs are derived by dividing the annual estimated Chinook abundance in any one fishery by the average from the 1979-1982 'base period'. These provide a means to assess temporal and spatial trends in the relative abundance of Chinook stocks contributing to regional fisheries.

The time series of AIs for some of the major northern ocean fisheries (Fig. 1) show generally that abundance has been consistently higher than in southern fisheries (Fig. 2). More interestingly, Chinook abundance has reached a high of more than twice the base period average (BPA) in the most northerly fishery (southeast AK troll) and a low of less than half the BPA in the most southerly fishery (combined WA and OR ocean troll).

There have been two obvious peaks in abundance (1988 and 2003) in the two most northerly fisheries, SEAK troll and Northern BC troll, with lows just dipping below the BPA (Fig. 1). In southerly fisheries (e.g., WCVI troll and WA/OR troll), there have been corresponding smaller peaks, with abundances mostly below the BPA, and a third peak is developing (Fig. 2). Abundances in the 'inside' area fishery, covering all of Georgia Strait and Juan de Fuca sport in BC, declined below its BPA early in the time series, with abundances of about half the BPA during the last two decades.

The annual calibration of the CM in 2010, supported by agency forecasts for some of the major Chinook stocks, indicated a notable increase in overall Chinook abundance. The increases were expected to be modest in the most northerly fisheries under jurisdiction of the Pacific Salmon Commission (e.g., the AI for SEAK troll increased from 1.20 for 2009 to 1.35 for 2010; see Fig. 1 in Brown *et al*. (2010, Trends of Chinook salmon abundance in fisheries managed under the Pacific Salmon Treaty, p. 103-104 *in* W. R. Crawford and J. R. Irvine, State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in

2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/053). They were expected to be greatest, however, in more southerly outside fisheries (e.g., the AI for WA/OR troll increased from 0.36 for 2009 to 1.20 for 2010; see Fig. 2 in Brown *et al*. (2010). The expected increases were mainly from increased forecasts of certain large stocks from the lower Fraser River and the Columbia River, which are greater contributors to southern fisheries compared to northern fisheries. These increases were generally observed although the 2010 returns were even larger than expected in some cases (e.g., the lower Fraser River Chinook). The increase for one large Lower Columbia River stock (Spring Creek Tule Fall Chinook), the primary contributor to the catch in WA/OR coastal troll, was not quite as large as forecast. Thus, the post-season assessment of the AI for this fishery was not as large as the pre-season forecast (0.99 vs 1.20) but even so, it represented a large increase relative to the AI estimated for recent years.

The 2011 CM calibration again projects increases in Chinook abundance for most fisheries but a modest decrease for the WA/OR troll fishery. The modest increases are due to expectations for large abundances of Lower Fraser River and most Columbia River stocks that entered the sea in 2008 and produced record high, or nearly so, returns of jack Chinook (the youngest age class maturing which has spent time in the ocean) to spawning grounds in 2009 and age-3 Chinook to spawning grounds in 2010.

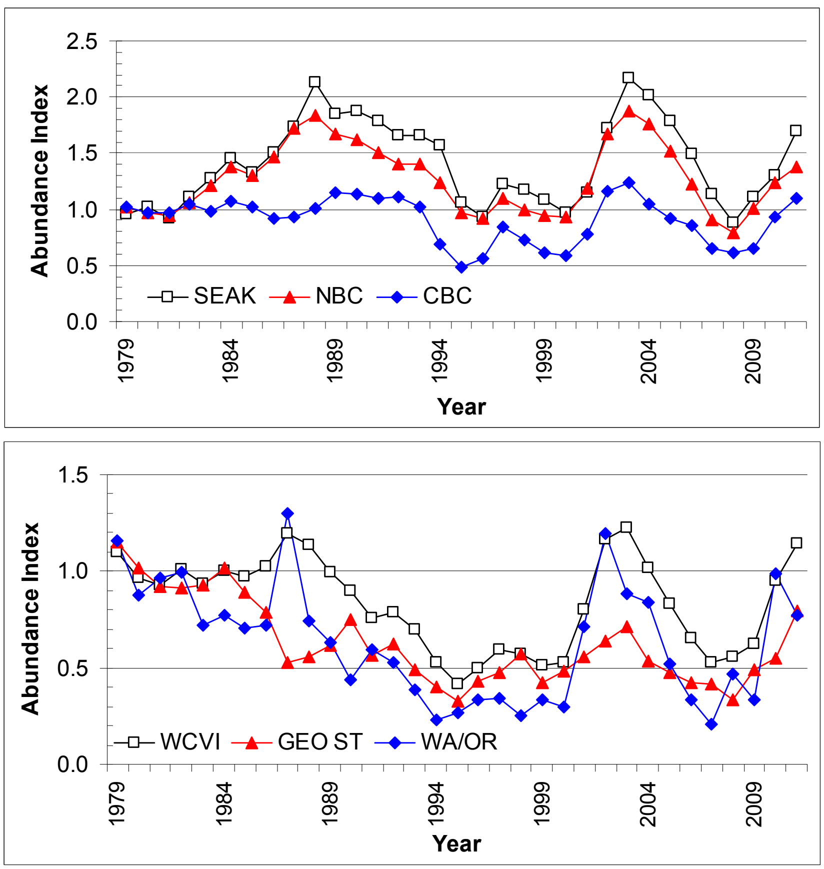

Figure 1. Time series of Chinook Salmon abundance indices for three major northerly PST fisheries, 1979-2011 (top panel) and for three southerly PST fisheries, 1979-2011 (bottom panel). The fisheries are (top) southeast Alaska troll (SEAK), northern BC troll in statistical areas 1-5 (NBC) and central BC troll in statistical areas 6-12 (CBC) and (bottom) Vancouver Island troll (WCVI), Georgia Strait and Juan de Fuca Sport (GEO ST), and Washington and northern Oregon ocean troll (WA/OR). Note that 2011 values are forecasts resulting from the March 2011 calibration of the Coast-wide Chinook Model.

Reference

Crawford, W.R., and Irvine, J.R. 2010, Trends of Chinook salmon abundance in fisheries managed under the Pacific Salmon Treaty, p. 103-104 *in* State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/053.

POPULATION TRENDS IN SEABIRDS AND INTERTIDAL BIVALVES IN PACIFIC RIM NATIONAL PARK RESERVE

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We review the annually averaged May-to-August marine abundance trends of the more common and regularly encountered species of seabirds in Barkley Sound and an adjacent coastal stretch between 1994 and 2010. At-sea bird surveys were conducted by staff of Pacific Rim National Park Reserve in 1994 - 1996 and 1999 – 2010 along three transects – two in the Broken Group Islands and one further south along the West Coast Trail (BGI-Inner, BGI-Outer, and WCT, Fig. 1). We also present trends for intertidal bivalves monitored since 1997 at five locations in the Broken Group Islands. The data (annual abundance estimates) were analysed for overall slope (trend) as well as any break points across the entire time series using generalised estimating equations implemented in TRIM (http://www.ebcc.info/trim.html). Bird abundance was expressed as linear density in individuals 10 km^{-1} of transect, bivalve abundance as number of animals m^{-2}.

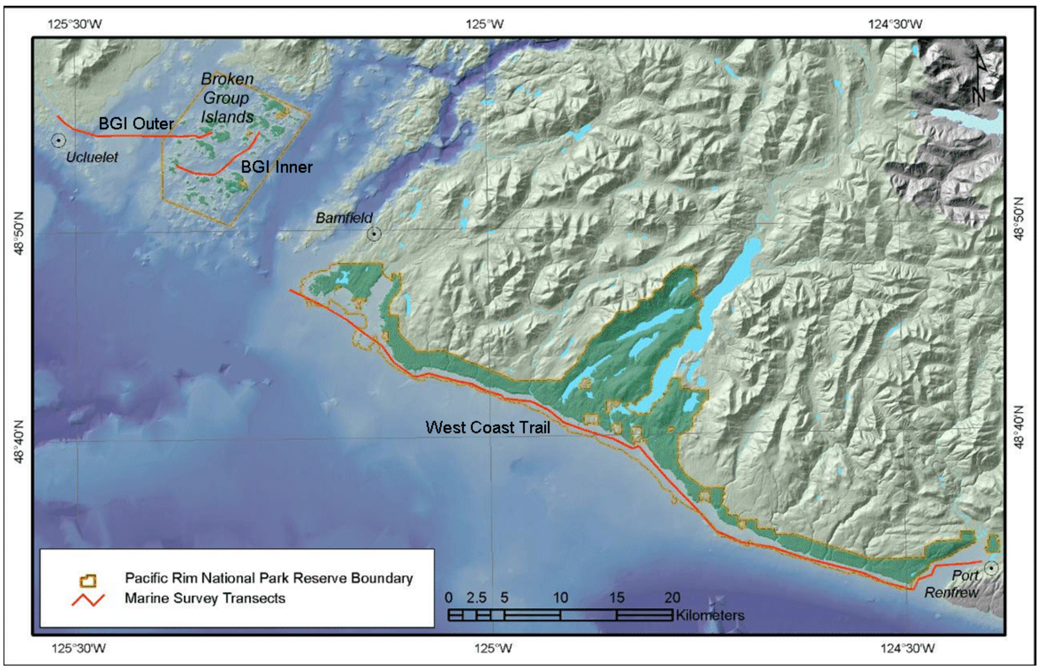

Figure 1. At-sea seabird transects in the waters of Pacific Rim National Park Reserve of Canada. The Broken Group Islands unit of the Park is in the top left corner.

Seabirds

The results are presented for nine taxa that comprise >95% of all individuals counted: common murre (*Uria aalge*), marbled murrelet (*Brachyramphus marmoratus*), Pacific loon (*Gavia pacifica*), pelagic cormorant (*Phalacrocorax pelagicus*), pigeon guillemot (*Cepphus columba*), red-necked phalarope (*Phalaropus lobatus*), rhinoceros auklet (*Cerorhinca monocerata*), sooty shearwater (*Puffinus griseus*) *and* three species of scoters (black *Melanitta nigra*, surf *M. perspicillata* and white-winged *M. fusca*) combined. Several common patterns are apparent (Table 1). Of the nine taxa, five had uncertain trends, (The standard error around the slope was too large to assign a trend.) but experienced no apparent declines. Three species (common murre, rhinoceros auklet and marbled murrelet) experienced pronounced significant declines and one species (pigeon guillemot) has significantly increased over the time series (Fig. 2).

Year 2010 had among the highest abundances of most seabirds; abundance increases were significant or nearly so (apparently positive) for most species over the past 5 years.

SPECIES	Overall trend 1994-2010, slope (se)	Recent Trend (slope, years)	2010 Abundance (Density, Rank)	Comments
Common murre	-10.8(±1.8)%	-62.4(±10.5), 2004-08	3.3*10 km^{-1}, 3rd lowest	
Marbled murrelet	-4.7(±1.1)%	+24.3(±7.6)%, 2006-10	129.5*10 km^{-1}, 4th highest	WCT only
Pacific loon	Uncertain (no app. decline)	App. increase, 2006-10	2.0*10 km^{-1}, average	
Pelagic cormorant	Uncertain (no app. decline)	+30.1(±14.2), 2006-10	0.7*10 km^{-1}, highest on record	
Pigeon guillemot	+3.1(±1.1)	App. increase, 2006-10	3.7*10 km^{-1}, highest on record	
Red-necked-phalarope	Uncertain (no app. decline)	App. increase, 2006-10	1.8*10 km^{-1}, average	
Rhinoceros auklet	-8.2(±0.0)	App. increase, 2006-10	19.1*10 km^{-1}, 2nd highest	WCT only
Sooty shearwater	Uncertain (no app. decline)	App. increase, 2006-10	0.5*10 km^{-1}, 2nd highest	WCT only
Scoters	Uncertain (no app. decline)	App. increase, 2006-09	3.0*10 km^{-1}, average	

Table 1. Summary of overall seabird population trends and recent population trends as determined by the most recent break point in the slope. Abundance densities are the average number of seabirds per 10 kilometres. Only significant (P<0.05) slopes are reported.

Most species have responded positively to the cooler local oceanic conditions observed in 2007 - 2009. Cooler coastal waters in BC are generally thought to result in increased energy flows through phyto- and zooplankton to juvenile fish to seabirds (Mackas *et al*. 2007 and elsewhere in this Research Document). The steep increases in abundance in the past few years and 2010 in particular suggest that we are mostly observing aggregative responses – birds congregate in areas with abundant food sources. High at-sea abundance as for example in the case of the rhinoceros auklet (Fig 2. It jumped 3 fold relative to 2009) may in fact indicate a breeding failure and thus presence of birds in coastal waters that otherwise would be incubating or attending chicks at colonies elsewhere.

Only longer-term increase in at-sea abundance (as with pigeon guillemot, Fig. 2, Table 1) may indicate a demographically expanding population. Common murre is the only species that has both declined steeply over the past 15 years and continues to display low abundance levels in Pacific Rim water and elsewhere in the Northwest Pacific region in 2010. The seabird trends reported here generally correspond with 10-year trends presented in the recent British Columbia Coastal Waterbird Survey newsletter by Birds Canada:

(http://www.bsc-eoc.org/library/bccwsnews.pdf).

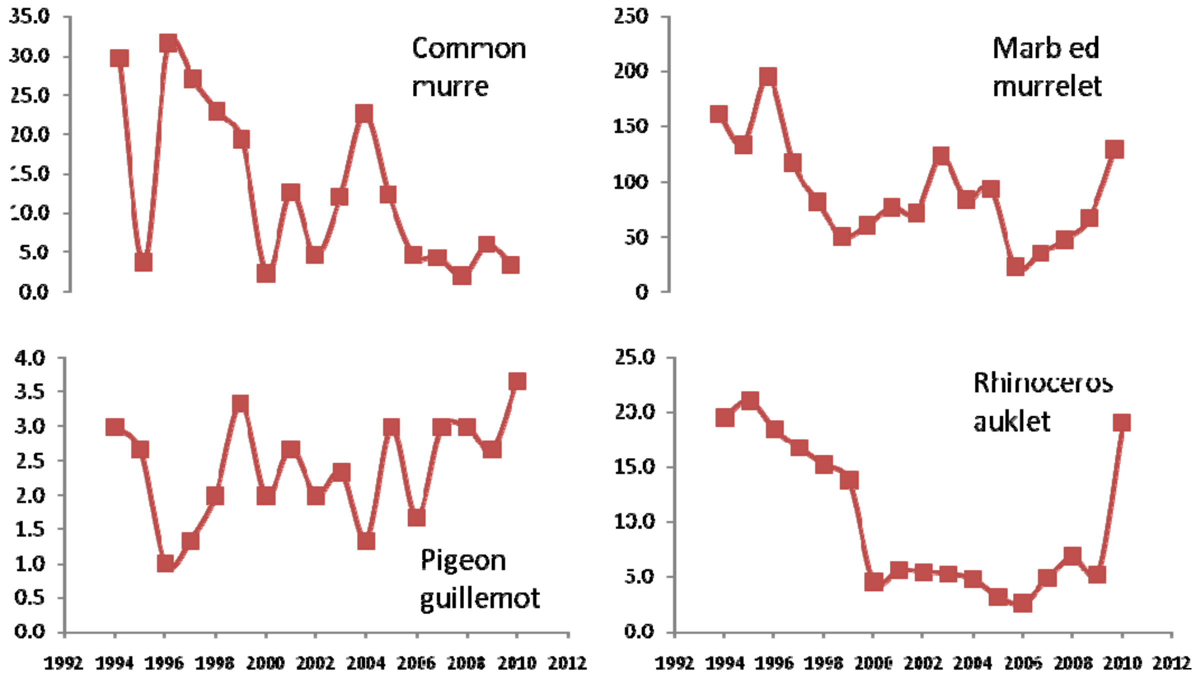

*Figure 2. Seabird abundances (individuals * 10 km^{-1}) in Pacific Rim National Park Reserve.*

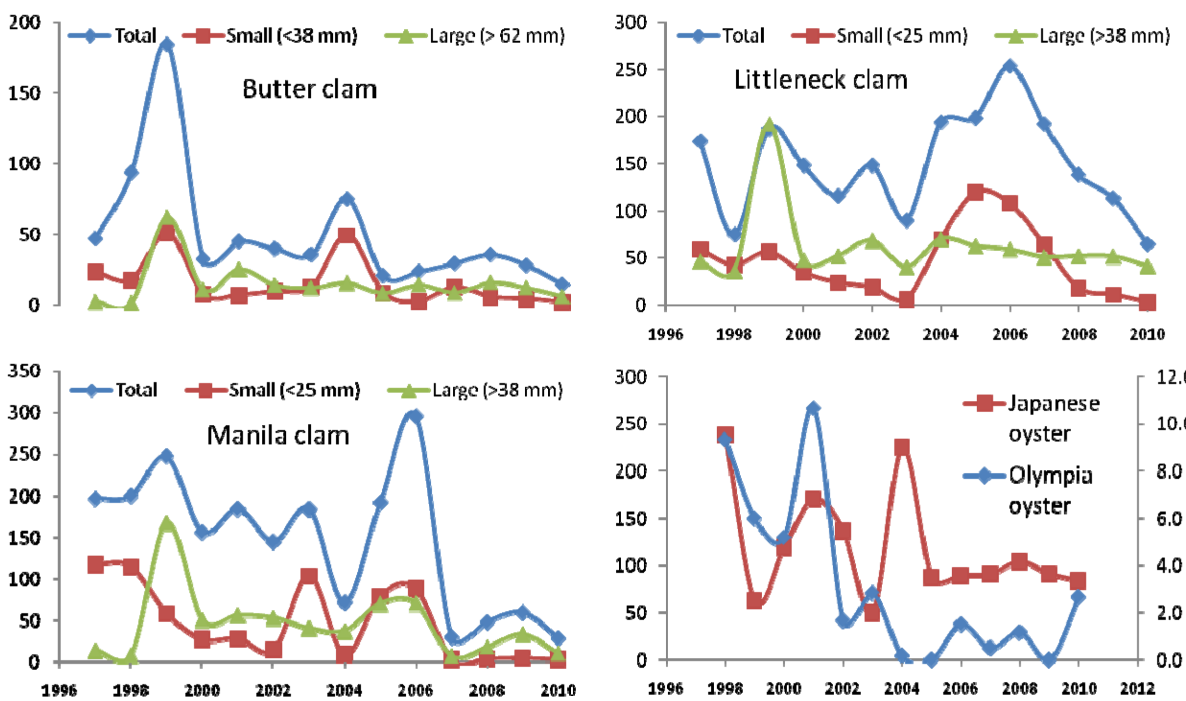

*Figure 3. Bivalve abundances (individuals * m^{-2}) in the Broken Group Islands unit of Pacific Rim National Park Reserve. No size cohorts were distinguished for the oysters. Abundance for the Olympia oyster are on the right Y-axis.*

Bivalves

Rresults are presented for three species of clams: butter (*Saxidomus gigantea*), manila (*Venerupis philippinarum*) and littleneck (*Protothaca staminea*) and two species of oysters – Japanese (*Crassostrea gigas*) and Olympia (*Ostrea conchaphila*) (Fig 3, Table 2). For the clams, data are presented as the total abundance (clams * m^{-2}), and abundance (clams * m^{-2}) for two size cohorts – small (immature, assumed <1 year individuals) and large (mature and commercially harvestable individuals). As above, trends are given only when statistically significant.

SPECIES	Overall trend 1994-2010, slope (se)	Recent Trend (slope, years)	2010 Abundance (Density, Rank)
Butter clam			
Total	-10.7(±3.8)%	Uncertain, 2005-10	Lowest on record
Small	-14.6(±6.2)%	Uncertain, 2006-10	Lowest on record
Large	Uncertain	-9.1(±5.2)%, 2001-10	3rd lowest
Littleneck clam			
Total	Uncertain, app. stable	-32.1(±7.7)%, 2006-10	Lowest on record
Small	-9.9(±5.3)%	-85.8(±14.7)%, 2006-10	Lowest on record
Large	Uncertain	-7.6(±4.7)%, 2004-10	3rd lowest
Manila clam			
Total	-13.7(±3.7)%	Uncertain, 2007-10	Lowest on record
Small	-26.4(±9.3)%	Stable, 2007-10	Lowest on record
Large	Uncertain	Uncertain	3rd lowest
Japanese oyster	Uncertain, app. stable	Stable, 2004-10	Average
Olympia oyster	-23.4(±7.2)%	Uncertain, 2006-10	Average

Table 2. Summary of overall bivalve population trend and recent population trends as determined by the most recent break point in the slope. Only significant (P<0.05) slopes are reported.

All clam species displayed globally and/or recently declining trends for at least some size cohorts. Year 2010 in particular and the last 4 to 5 years in general have had very low stock abundances for all three species. It is noteworthy that the recent trends in bivalves run opposite to what we have seen in most seabirds.

The situation was different with the two oyster species. The introduced Japanese oyster remained stable through the past 6 years and 2010 has seen average numbers. The native Olympia oyster has declined precipitously but during the past 5 years numbers fluctuated at a low level and in 2010 an average abundance was observed. Bivalves are known to have sporadic recruitment patterns (http://www.pac.dfo-mpo.gc.ca/science/species-especes/shellfish-coquillages/clam-palourde/index-eng.htm) that depend on different biotic factors such as standing stocks, larval supply or epibenthic predation as well as changes in environmental conditions, such as water temperature (Phillipart *et al*. 2003), and air temperature in the winter (Gillespie 1999) and therefore are difficult to predict (Straaser *et al.* 2003). In the future we intend to analyze the data with respect to oceanographic and environmental data in search for possible explanations of the observed patterns.

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RECOVERY OF LARGE BALEEN WHALE POPULATIONS IN CANADIAN PACIFIC WATERS: ECOSYSTEM IMPLICATIONS

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Seven species of baleen whales (blue, fin, sei, humpback, North Pacific right, minke and grey) inhabit Canadian Pacific waters and the Northeast Pacific. With the exception of the minke whale, all were targets of commercial whaling in the 19th and 20th centuries. The eastern Pacific grey whale population was driven to the brink of extinction by the late 1800s (Rice *et al.* 1984). As a result of protection from hunting, eastern grey whales have recovered substantially to near historic levels. North Pacific right whales were targeted during the mid-1800s and severely depleted by the end of that century

Shore-based whaling in British Columbia (BC) (1905 to 1967) focussed on the blue, fin, sei and humpback whale, (as well as sperm whales), killing at least 18,316 baleen whales during this period (Gregr *et al.* 2000). During this same period, shore-based commercial whaling was also underway in Alaska, Washington and California (Reeves *et al.* 1985; Rice 1974). Pelagic whaling in the North Pacific, using factory ships, commenced in the 1930s. Japanese and Soviet factory ships operated until at least 1975 (Mizroch *et al.* 2009). As a result of this whaling pressure, all of these species' populations were severely reduced.

Blue, sei and North Pacific right whales are listed as Endangered under Canada's Species at Risk Act (SARA); fin and humpback whales are listed as Threatened. Since 2002, the Cetacean Research Program at the Pacific Biological Station has undertaken studies in support of conservation and recovery of these species using various techniques to determine their current distribution, relative abundance, stock structure, habitat association, diet and seasonal occurrence in Canadian Pacific waters. Techniques include ship-based line transect surveys, photo-identification of individual animals, genetic analysis of biopsy samples, prey sampling, remote acoustic monitoring and hydroacoustic backscatter analysis to document potential prey patches in association with whales.

Several SARA-listed species are slowly recovering while trends are less clear for the North Pacific right whale and sei whale. Presently, the humpback whale is the most frequently encountered baleen whale in BC (Fig. 1), with a BC population of ~2,100 whales estimated in 2006 (by photo-identification and mark recapture analysis) and a growth rate of 4% per year (Ford *et al.* 2009). The most recent population estimate for the entire North Pacific is ~18,000 animals in 2005 based upon an intensive photo-identification study and mark recapture analysis (Calambokidis *et al.* 2008). By the end of the 1960s when hunting humpback whales was banned in the North Pacific, a population of 1,200 - 1,600 animals remained. There are no BC specific estimates of post or pre whaling abundance, but whaling records suggest a large population. In BC, 5,618 humpback whales were killed from 1908 to 1965, but 77% of this catch was taken prior to 1920 suggesting the species, because of its nearshore distribution, was depleted early by coastal whalers (Gregr *et al.* 2000; Nichol *et al.* 2002).

BC whaling records suggest the fin whale was abundant, representing the largest portion of the total catch with 7,520 taken from 1908 - 1967 (mean = 153 killed per year) (Nichol *et al.* 2002). Currently fin whales remain relatively uncommon in BC waters, at least when compared to sighting rates obtained for humpback whales during Fisheries and Oceans Canada (DFO) ship surveys (Fig. 2). Sightings of fin whales during DFO surveys averaged 1.61 whales per 100km from 2002- 2008 and totalled sightings of 482 animals. This compares with the humpback whale sighting rate of 10.58 individuals/100km during the same period (Ford *et al.* 2010a). However there are signs that fin whales in the Northeast Pacific are recovering (Mizroch *et al.* 2009). Fin whales appear to have a more diffuse migration than other baleen species with at least some animals remaining in northern latitudes year-round potentially protracting the seasonal period in BC (Mizroch *et al.* 2009; Ford *et al.* 2010a; Ford *et al.* 2010b). Trends in timing of peak catch and size of animals in the BC whaling data suggest there was a summer resident population particularly of immature animals that occupied BC waters (Gregr *et al.* 2000; Pike and MacAskie 1969).

Blue whales remain relatively rare in BC even with the cessation of whaling (Fig. 3), but there is evidence of recovery of this Northeast Pacific population with movements of individuals between California/Mexico and historic feeding grounds in the waters of BC/Alaska in late summer (Burtenshaw *et al.* 2004; Calambokidis *et al.* 2009). Blue whale population estimates off California during the 1990s ranged from 2,000 to 3,000 animals depending on the method (Calambokidis and Barlow 2004) Blue whales appear not to have been as abundant historically in BC as other species (1,378 killed in BC, 1908 - 1965, mean = 28 killed per year) (Nichol *et al.* 2002). Since 2001, there have been six sightings of single animals (Ford *et al.* 2010a). Changes in euphausiid distribution driven by oceanographic conditions including the "cool" regimes of the Pacific Decadal Oscillation (PDO) appear to coincide with recent sightings of blue whales in BC and Alaska since the late 1990s and with the early and late years of the BC whaling era. Conversely, during "warm" regimes blue whales were more common off California. The largest numbers of blue whales killed by BC whalers were taken prior to 1924 and coincided with a "cool" regime (Calambokidis *et al.* 2009).

There have been only two recent sightings of sei whales in BC, all since 2004, yet during the BC whaling era 3,779 sei whales were taken offshore of west coast Vancouver Island, mostly during the 1960's (Gregr *et al.* 2000). Similarly, there have been only five sightings of sei whales made during extensive line transect surveys off California, Oregon and Washington between 1991 and 2005. The best estimate of abundance from these is a population of 46 animals but there is considerable uncertainty in this estimate given the very small sample size (Carretta *et al.* 2008). During the 1950s and 1960s, however, sei whales were the fourth most common species in the whaling catch off California (Rice 1974). Sei whales are often observed on the same foraging ground for many years and then disappear for prolonged periods of time. Whalers referred to "sei whale years" in the Antarctic (Gambell 1985). Episodic influxes of sei whales into areas are not uncommon and likely in response to prey availability (Jonsgård and Darling 1977; Schilling *et al.* 1992). BC sei whale catch records suggest that such a phenomenon may account for the high numbers of sei whales caught in the 1960s in BC (Gregr *et al.* 2000).

The North Pacific right whale is the most critically endangered species. Although they were protected from whaling by the 1937 *International Agreement for the Regulation of Whaling* (which also protected grey whales), seven were reported in the catch of BC whaling stations and the last reported kill was in 1951 (Nichol *et al* 2001).There have been no sightings in Canadian Pacific waters since 1951, although there have been a few sightings in waters adjacent to Canadian waters. A recent estimate from photo-identification of animals in the Bering Sea is of a sub population of 31 animals. Illegal Soviet whaling during the 1960s in the North Pacific is considered a major cause of an extremely reduced population (Wade *et al.* 2010).

Blue whales feed almost exclusively on euphausiids while North Pacific right whales feed on copepods. Fin and sei whales feed on euphausiids, copepods and schooling fish, and humpback whales on euphausiids and schooling fish such as herring and sardine. The distribution of these whales in higher latitudes including Canadian Pacific waters appears to be coupled with dense patches of prey which are relatively tightly linked to the timing of primary production (Benson *et al.* 2002, Burtenshaw *et al.* 2004). Numerous small scale studies of baleen whale presence and habitat variables have shown a close association between these animals and eddies, fronts and SST gradients and densities of prey (Woodley and Gaskin 1996;

Gregr and Trites 2001; Doniol-Valcroze *et al.* 2007; Laidre *et al.* 2010). Pacific Canadian waters represent feeding habitat for these whale species which generally move to warmer waters nearer the equator during winter to breed.

Large whale species are significant consumers of pelagic prey (euphausiids, copepods, and schooling fish). For example, estimates of consumption are as follows, blue whales consume ~1,120 kg of prey/individual/day, fin whales ~901 kg, humpback whales ~532 kg, sei whales ~371 kg and North Pacific right whales ~501 kg of prey/individual/day (Croll *et al.* 2006). It is likely that the severe depletion of populations of baleen whales as a result of commercial whaling in the North Pacific has changed energy flow and species composition at other trophic levels (Bowen 1997). Croll *et al.* (2006) estimate that large whale populations in the North Pacific presently consume 5.1% of the average daily primary production. Prior to whaling, the much larger pre-exploitation whale populations of the North Pacific would have consumed the equivalent of 10.3% of the average daily primary production. They acknowledge that these estimates are likely conservative (low). In the Bering Sea and Gulf of Alaska, the reduction in plankton consumers as a result of whaling and fishing is hypothesized to have contributed to the shift in dominant fisheries seen in the Bering Sea during the 1970s and 1980s (Bowen 1997; Benson and Trites 2002). In the Antarctic, where intensive commercial whaling resulted in an enormous reduction in the biomass of large baleen whales, Law (1985) estimated the effect was to release 150 million tonnes of krill annually to remaining predators, resulting in an increase in smaller whales, seals, seabirds, and fish. These potential interactions suggest a top-down effect of marine mammals on plankton production (Bowen 1997).

In summary, because large baleen whales are major consumers of oceanic productivity, they play a significant role in structuring ocean ecosystems (Croll *et al.* 2006). The continued recovery of baleen whale populations in the Northeast Pacific will contribute to changes in oceanic ecosystems that may become more apparent in Canadian Pacific waters as recovery continues.

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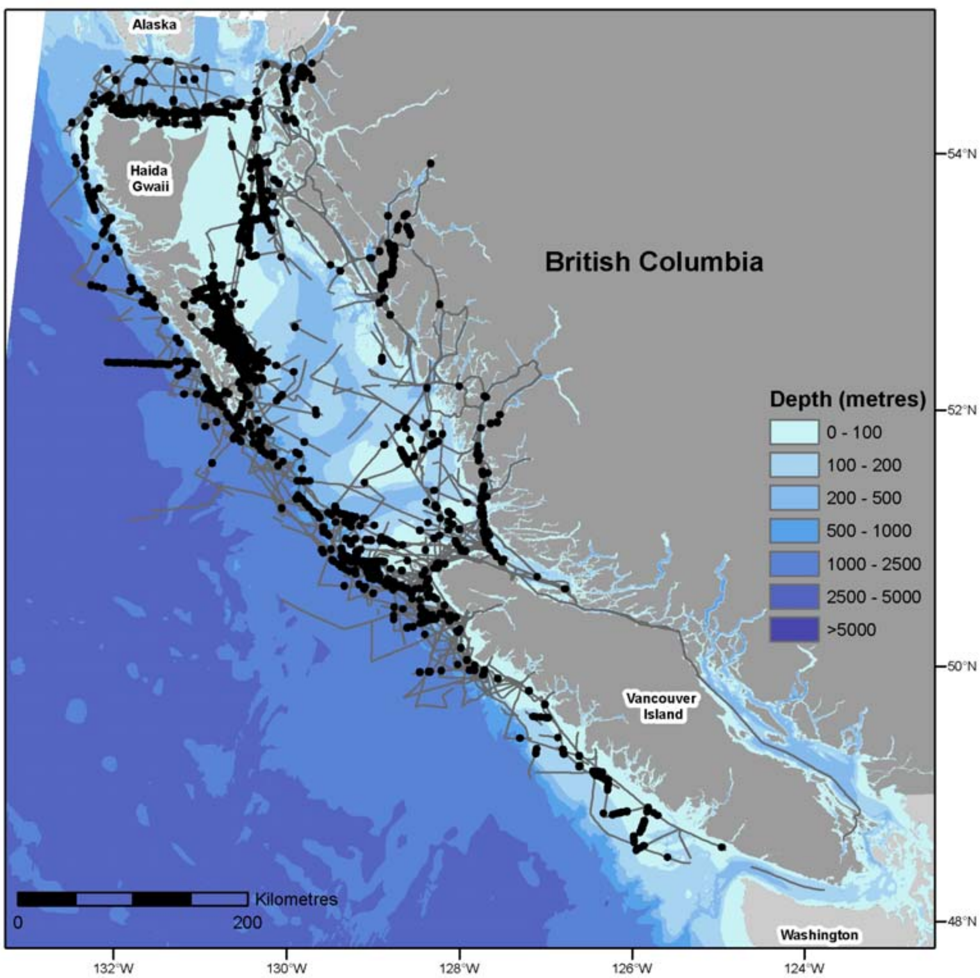

Figure 1. Sightings of humpback whales from DFO ship surveys (n = 1,700 sightings) 2002 to 2008 (Ford et al. 2010a).

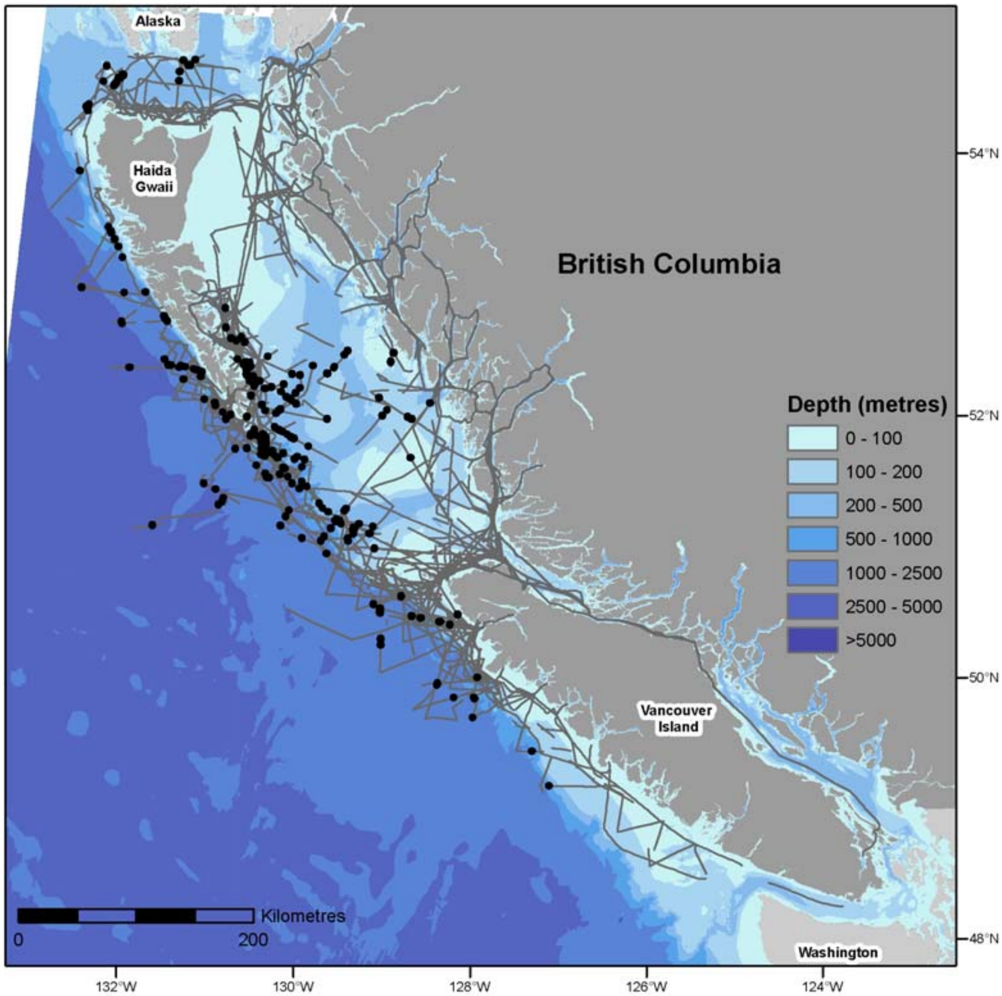

Figure 2. Sightings of fin whales from DFO ship surveys (n = 257 sightings) 2002 to 2008 (Ford et al. 2010a).

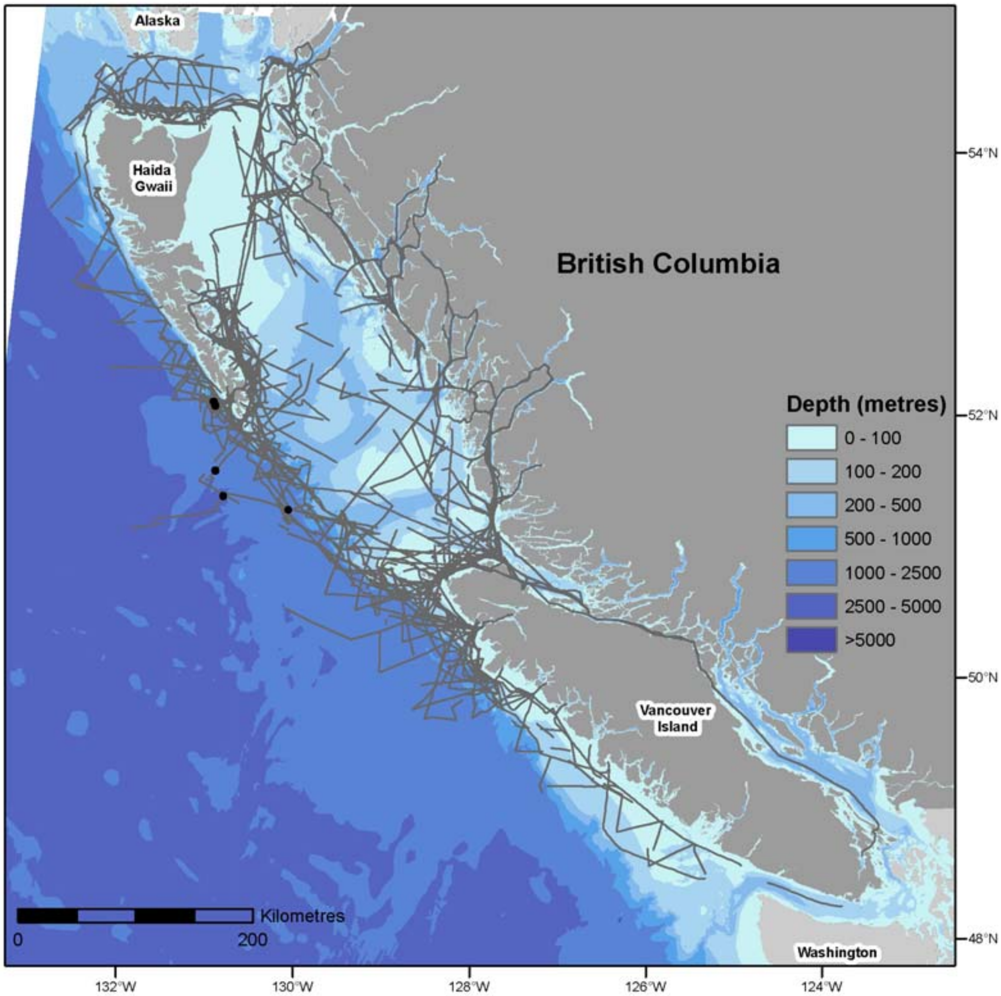

Figure 3. Sightings of blue whales from DFO ship surveys (n = 6 sightings) 2002 to 2008 (Ford et al. 2010a).

SALISH SEA

VENUS OBSERVES MILD AND FRESH WATERS IN THE SALISH SEA

Richard Dewey, Victoria Experimental Network Under the Sea (VENUS), University of Victoria

The Victoria Experimental Network Under the Sea (VENUS) is a coastal observatory network with arrays in both Saanich Inlet and the southern Strait of Georgia. VENUS provides continuous records of ocean properties below the ocean surface in southern British Columbia. The Saanich Inlet (SI) array includes a shore station at the Institute of Ocean Sciences and a 3-km cable to a Node at 100-metres depth in Patricia Bay ("SI" at 48° 39.0540'N 123° 29.2027'W). The Strait of Georgia (SoG) array consists of a shore station at the Iona Waste Water Treatment Plant, a 40 km cable and two Nodes, one in the "central" southern strait at 300 metres depth ("SoG Central" at 49° 2.41'N 123° 25.53'W), and a second on the "eastern" flank at 170 metres depth ("SoG East" at 49° 2.52'N 123° 19.06'W). At each VENUS Node there is a standard VENUS instrument platform (VIP) hosting a variety of oceanographic instruments including a CTD to measure temperature and salinity, an ADCP to measure currents, and an inverted echo-sounder to detect zooplankton.

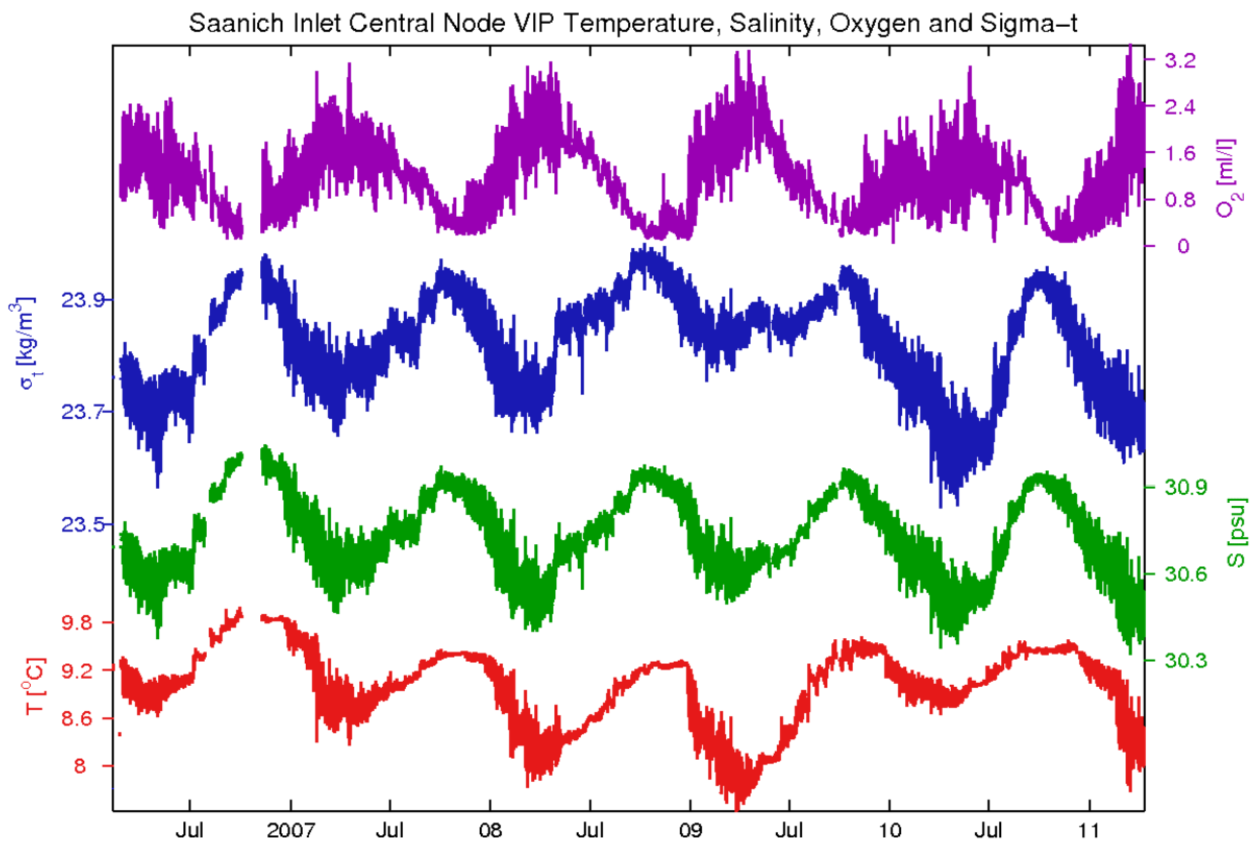

Figure 1. Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station in Saanich Inlet., located at the mouth of Patricia Bay at a depth of 97 m. Shown are the full VENUS records, from 2006 through to early 2011.

The data records from Saanich Inlet sensors reveal that the winter of 2009/10 was the mildest since VENUS was installed in 2006 (Fig. 1). The coldest seawater temperatures recorded near 100 metres depth in the winter of 2009 reached 7.4 °C, while in 2010 the minimum temperature recorded was 8.6 °C, more than a degree warmer. The winter of 2010 was fresher than in the previous few years, a result of higher than usual local rainfall in the late fall of 2009 and the first few months of 2010. by May 2010, when conditions at 100 metres depth should have been their coldest and freshest, the waters were both abnormally warm (8.6°C) and fresh (30.4 psu). This combination resulted in the low seawater density of 1023.5 kg/m^3, recorded at 100 metres depth at the VENUS Saanich Inlet site.

In addition to the anomalous temperatures and salinities recorded during the winter of 2010, the dissolved oxygen concentration at 100 metres depth remained suppressed (Fig. 2) during the winter cooling period, with concentrations rarely exceeding 2.4 ml/l (3.35 mg/kg). This is normally the season of renewal of oxygen in these deep waters. Peak oxygen levels in the previous 4 winters were in excess of 3.0 ml/l at this time of year.

The spring and summer seawater warming in 2010 was minimal, a trend mirrored by mild atmospheric temperatures during June, July, and August 2010. Forced by strong upwelling along the west coast of Vancouver Island in summer 2010, late summer salinities increased, with pulses of salty, dense water penetrating into deep waters of Saanich Inlet during the weeks following the monthly weak neap tides. by the end of 2010, as a result of both minimal cooling the previous winter and minimal spring/summer warming, seawater conditions (temperature, salinity, density, and dissolved Oxygen) in Saanich had returned to climatic norms (Fig. 2).

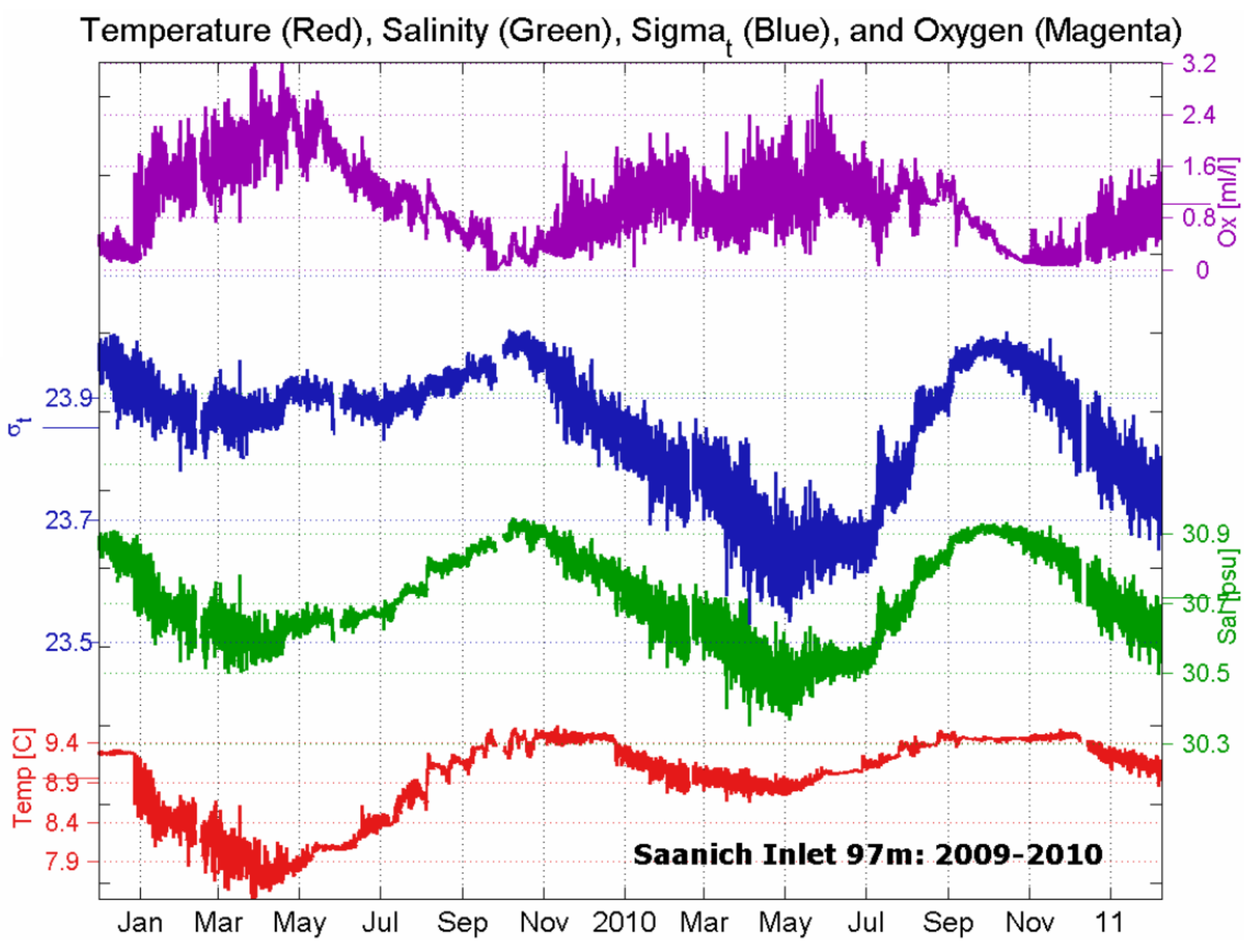

Figure 2. Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station in Saanich Inlet. Shown are the VENUS records, from January 2009 through to early 2011, high-lighting differences between 2009 and 2010. The 2010 winter was rather mild (<1 °C cooling) followed by a cool summer that resulted in minimal heating (<1 °C warming)

Seawater variations in the Strait of Georgia were similar to those seen in Saanich Inlet in many respects. At the VENUS SoG East site (170 m depth, Fig. 3) winter cooling ceased by the end of January, with a minimum temperature of 8.4 °C. In comparison, the coldest temperatures in 2009 occurred in late March and reached 7.2 °C. The minimum salinity at this site was reached in February 2010 at 29.8 psu, also coinciding with the minimum density of 1023.1 kg/m^3. From January through to the end of June, both salinity and density (which is dominated by the salinity variations) revealed very large, daily variability, suggesting that very different water masses were advecting back and forth past the sensors every tidal cycle.

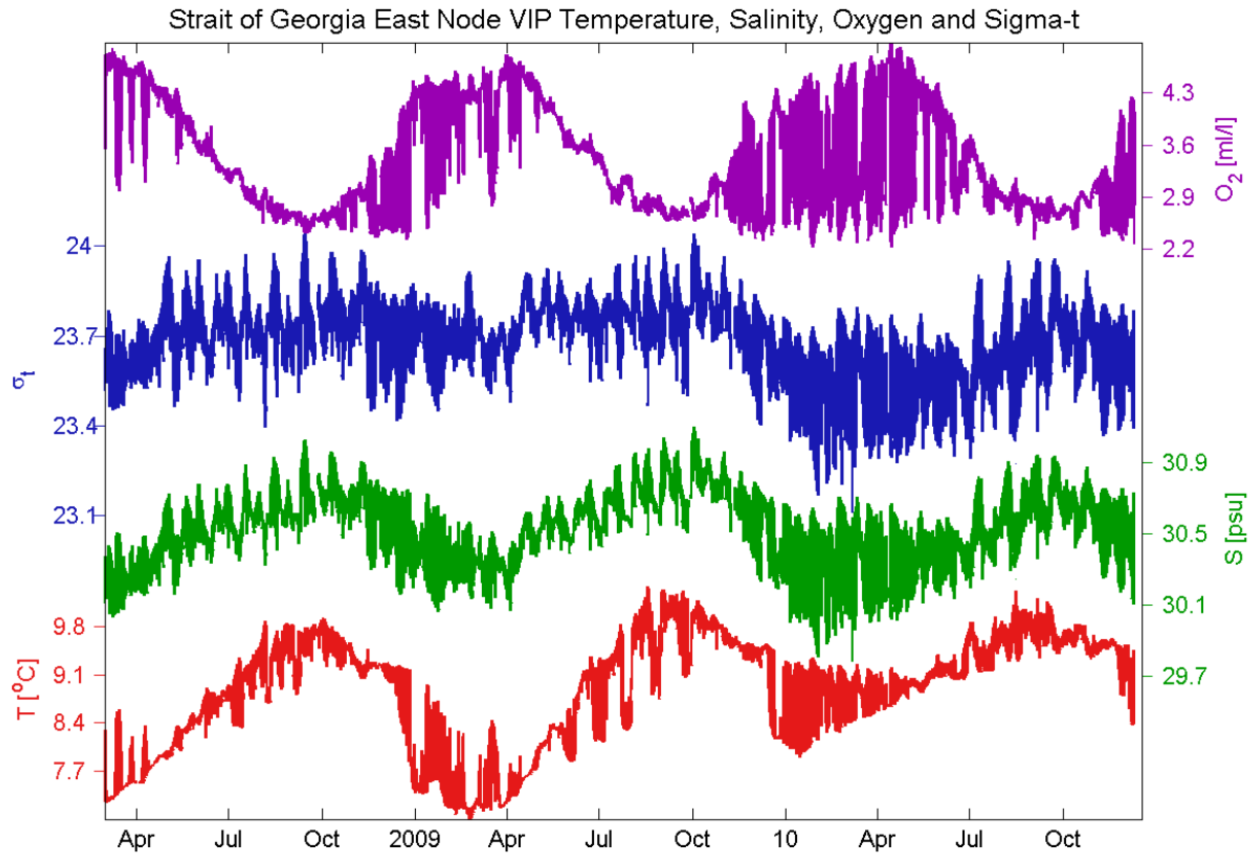

Figure 3. Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station (SoG East) in south eastern Strait of Georgia at a depth of 170 m. Shown are the full VENUS records, from September 2008 through to early 2011.

Higher salinity water at 170 metres depth (advecting along the bottom from west of Vancouver Island) arrived in the Strait in several significant pulses, starting in early July (Fig. 4). At least four pulses of high salinity (and therefore dense) water were detected during each of the weak neap tides during July, August, and September (vertical lines, Fig. 4). This is consistent with the hypothesis that during neap tides, although the volume exchange associated with the large scale estuarine circulation decreases, the reduced vertical mixing results in less-diluted bottom water entering the Strait. These dense, salty pulses also bring essential nutrients, which feed the ecosystem for the next year. An alternate perspective is the freshening and lightening of the water during each spring tide (Fig. 4), when surface waters infused with Fraser River freshet from June to August are mixed down to the bottom by the turbulent tidal currents.

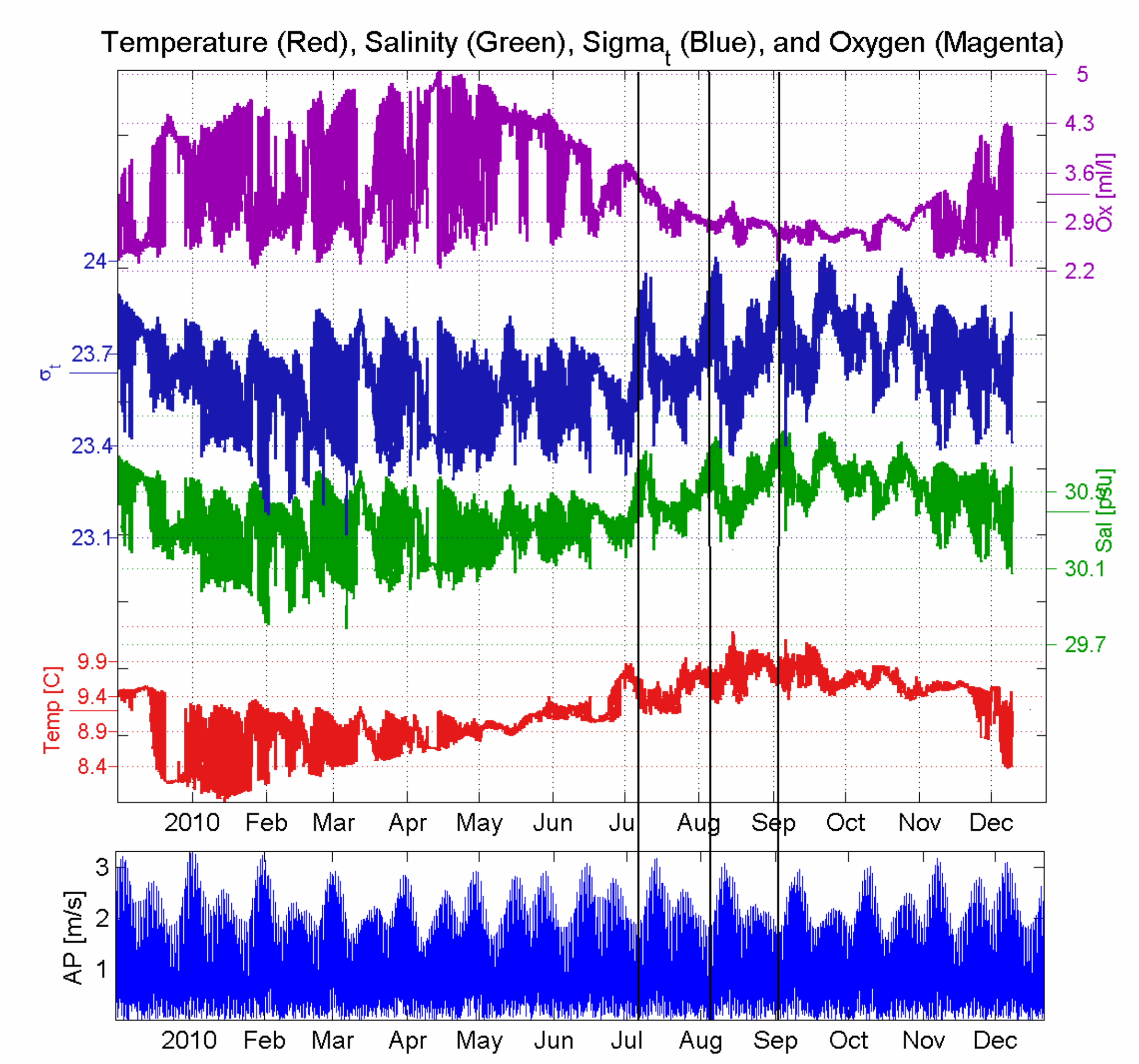

Figure 4. Temperature (red), salinity (green), density as σ_t (blue) and dissolved oxygen (magenta) from the VENUS Station (SoG East) in south eastern Strait of Georgia at a depth of 170m (upper panel) in 2010. The bottom panel shows the speed of tidal currents in Active Pass (tidal prediction), where we have identified (vertical black lines) the weak neap tidal periods in July, August, and September. Each neap tide coincides with an influx of salty/dense water (green/blue traces, upper panel).

In conclusion, several important annual cycles continue to be recorded by the sensors on the VENUS network. Seasonal changes in temperature through atmospheric cooling and solar heating dominate the temperature variations, where the mild winter and summer of 2010 is reflected in the seawater temperatures. Salinity variations are tied to both the regional rain and river discharge in the fall and winter, when rain/run-off causes salinity to decrease, while salinity increases associated with tidal modulations of the inflow of deep, salty Pacific water entering via Juan de Fuca are evident during the late summer upwelling season. Deep-water inflows show up as pulses correlated tightly with the spring-neap tidal cycle, and are likely forced by vertical mixing and water mass formation within the Gulf Islands. At the depths of the VENUS sensors (100-300 m) the role of the Fraser River appears to be secondary, through its ability to drive regional estuarine circulation is essential in the infusion of deep, salty, nutrient rich ocean water during the later summer months.

BACK TO NEAR NORMAL TEMPERATURES IN THE STRAIT OF GEORGIA

Diane Masson and Patrick Cummins, Fisheries and Oceans Canada

The relatively cold conditions that prevailed in the Strait of Georgia since mid 2007 were replaced by near normal temperatures in 2010. Fig. 2 shows contours of temperature since 2000 measured at the Nanoose station, which is located in the central deep basin of the strait (Fig. 1). In the spring and early summer of 2010, sub-surface intrusions of near-normal temperature raised water temperatures throughout the water column of the strait.

Figure 1: The red dot indicates the position of the Nanoose sampling station (49º 18.7’ N, 124º 2.7’ W).

Fig. 3 gives the temperature anomalies over the last 11 years at the Nanoose station relative to the 30-year average over the period 1971-2000. It shows that the cooler period that started in 2007 has ended, and temperatures in 2010 have risen to near normal conditions in response to an oceanic warming associated with pronounced El Nino conditions in the tropical Pacific in 2009 and early 2010.

Surface temperatures in the Nino 3.4 region (5ºN-5ºS, 120º-170ºW) showed that El Niño peaked during November 2009 to January 2010, bringing stronger southerly winds and warmer ocean waters to the west coast in early 2010. This warming was felt subsequently during 2010 in the sub-surface waters of the strait.

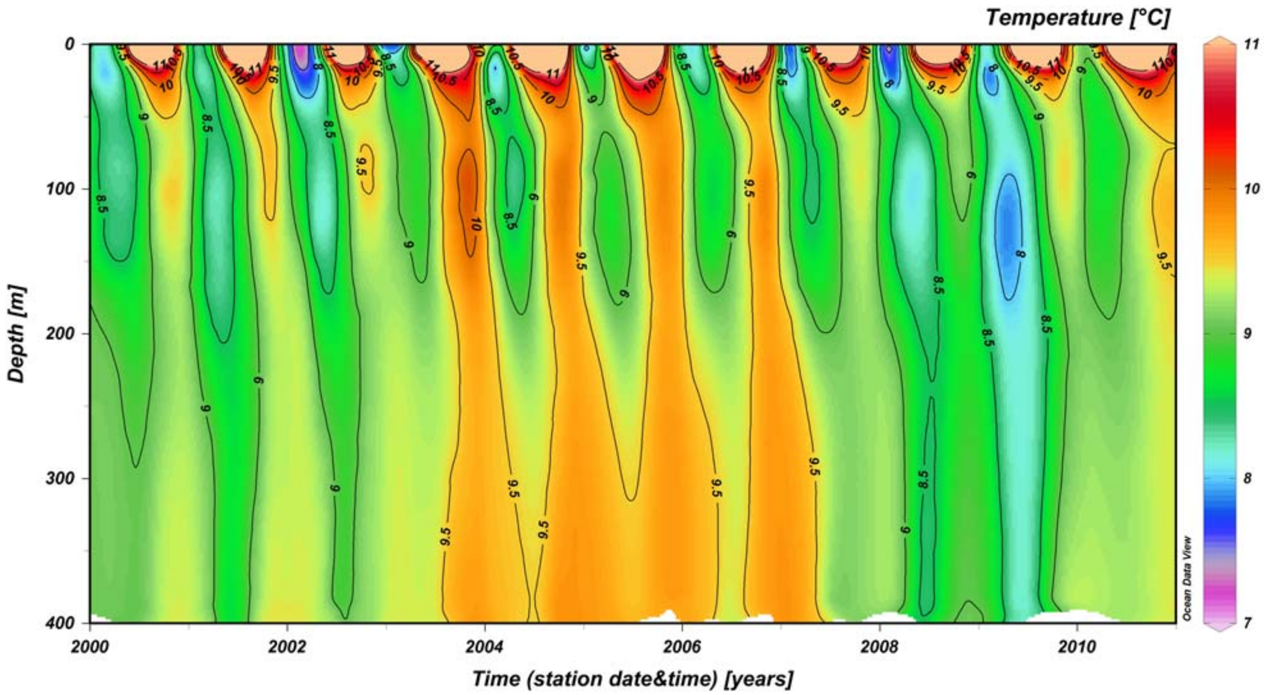

Figure 2: Contours of temperature (°C) measured at the Nanoose station (central Strait of Georgia) since 2000. Labels along the bottom of the graph indicate the start of each year.

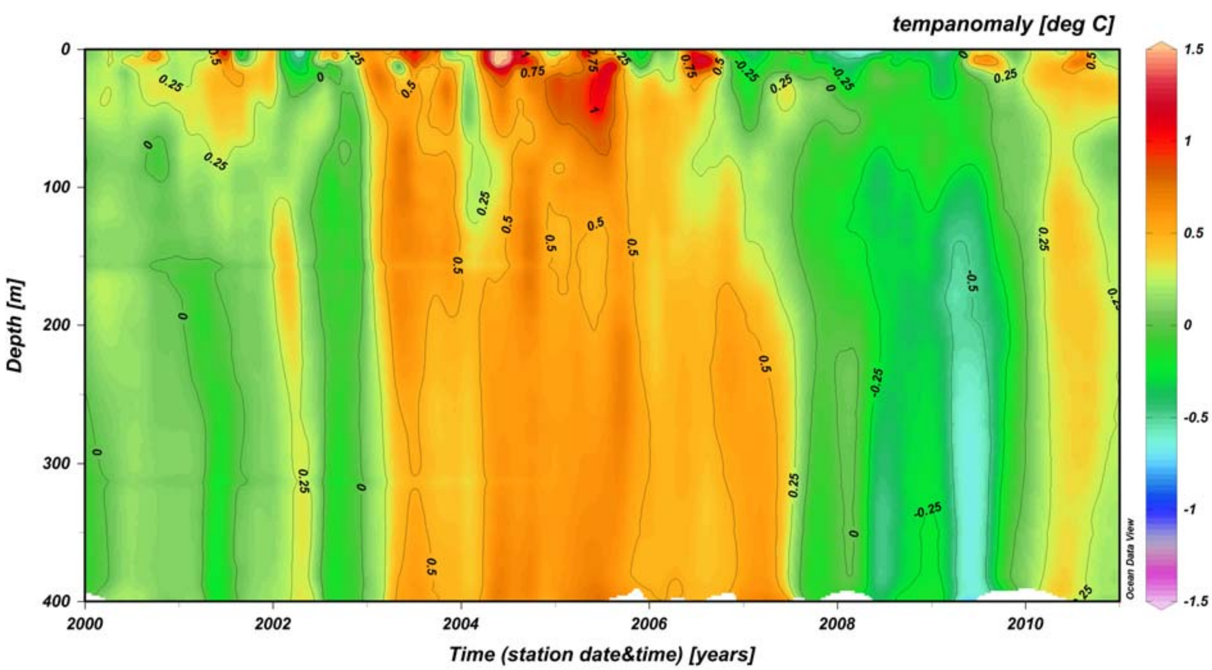

Figure 3: Temperature anomalies (°C) measured at the Nanoose station, for the period 2000-2010. Anomalies are computed relative to the climatological mean for 30-year period 1971-2000. Labels along the bottom of the graph indicate the start of each year.

PHYTOPLANKTON IN THE STRAIT OF GEORGIA

Angelica Peña, Fisheries and Oceans Canada

Nitrate and chlorophyll-*a* (an indicator of phytoplankton biomass) concentrations are measured on seasonal surveys (4 times a year) along a 20-station transect in the Salish Sea (Fig. 1). In general, upper layer (0-10 m) chlorophyll concentrations in the Strait of Georgia are high and variable in spring, being >15 mg m^{-3} during the spring bloom (March-April), low (1-4 mg m^{-3} on average) during the summer and fall, and lowest (<0.5 mg m^{-3}) during winter. In comparison, chlorophyll concentrations in Juan de Fuca Strait are significantly lower (<3 mg m^{-3}) than in the Strait of Georgia in spring, perhaps due to strong vertical mixing, but similar at other times of the year.

Figure 1. Location of sampling stations in the Juan de Fuca Strait/ Strait of Georgia region. The thick, shaded line shows the main transect of stations used in Figures 2 and 3, with the numbers giving the distance in km from the mouth of Juan de Fuca Strait.

Conditions in 2010 based on these seasonal surveys (Fig. 2), show that spring chlorophyll-a concentrations along the main transect were close to the average from 2004-2009. In summer, relatively low (more than one standard deviation below average) chlorophyll concentrations were often measured in the southern Strait of Georgia and Juan de Fuca Strait. In comparison, fall chlorophyll concentrations were higher in Juan de Fuca Strait and slightly lower in the Strait of Georgia compared with those observed in previous years (2004 to 2009). Upper layer nitrate concentrations in 2010 were within the range of values observed in surveys of previous years (2002-2009), except for lower concentrations in the Juan de Fuca Strait during the fall survey at the stations where phytoplankton biomass was higher than usual.

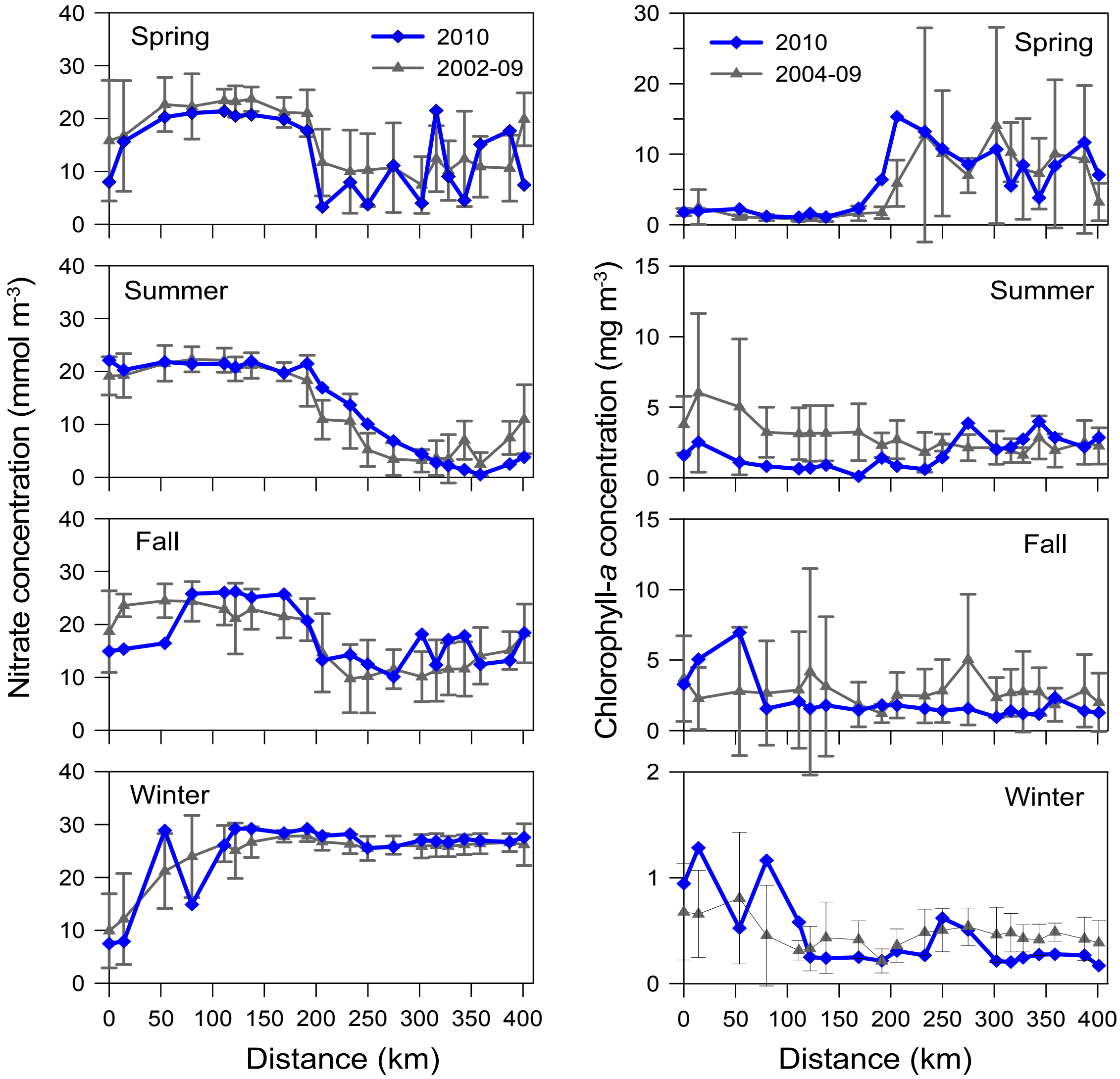

Figure 2. Upper layer (0-10 m) concentrations of nitrate (left panel) and chlorophyll-a (right panel) along the main transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring, summer, fall, and winter. Blue diamonds are observations in 2010. Grey triangles and bars denote averages and standard deviations from 2002 to 2009 for nitrate and 2004 to 2009 for chlorophyll-a. Numbers along lower axes are cumulative distance from the mouth of the Juan de Fuca Strait (see Fig. 1).

The spring 2010 survey shows that diatom abundance, as derived from High-Performance Liquid Chromatography (HPLC) phytoplankton pigment measurements, was similar to the values observed in previous years (Fig. 3). Fucoxanthin, the biomarker for diatoms, was the most abundant accessory pigment in the Strait of Georgia at this time of the year, as expected during the spring bloom of diatoms. Fucoxanthin concentrations during summer and fall surveys indicate that at most stations diatoms were less abundant in 2010 than during previous years' summer and fall surveys (2004-2009).

In comparison, the contribution of dinoflagellates to total phytoplankton biomass (as indicates by the biomarker peridinin) is often low and very variable at most stations making it difficult to determine unusual observations. However, in the 2010 fall survey a bloom of dinoflagellates was observed in Juan de Fuca Strait, being the highest concentration of peridinin so far observed in this region (Fig. 3, right panels).

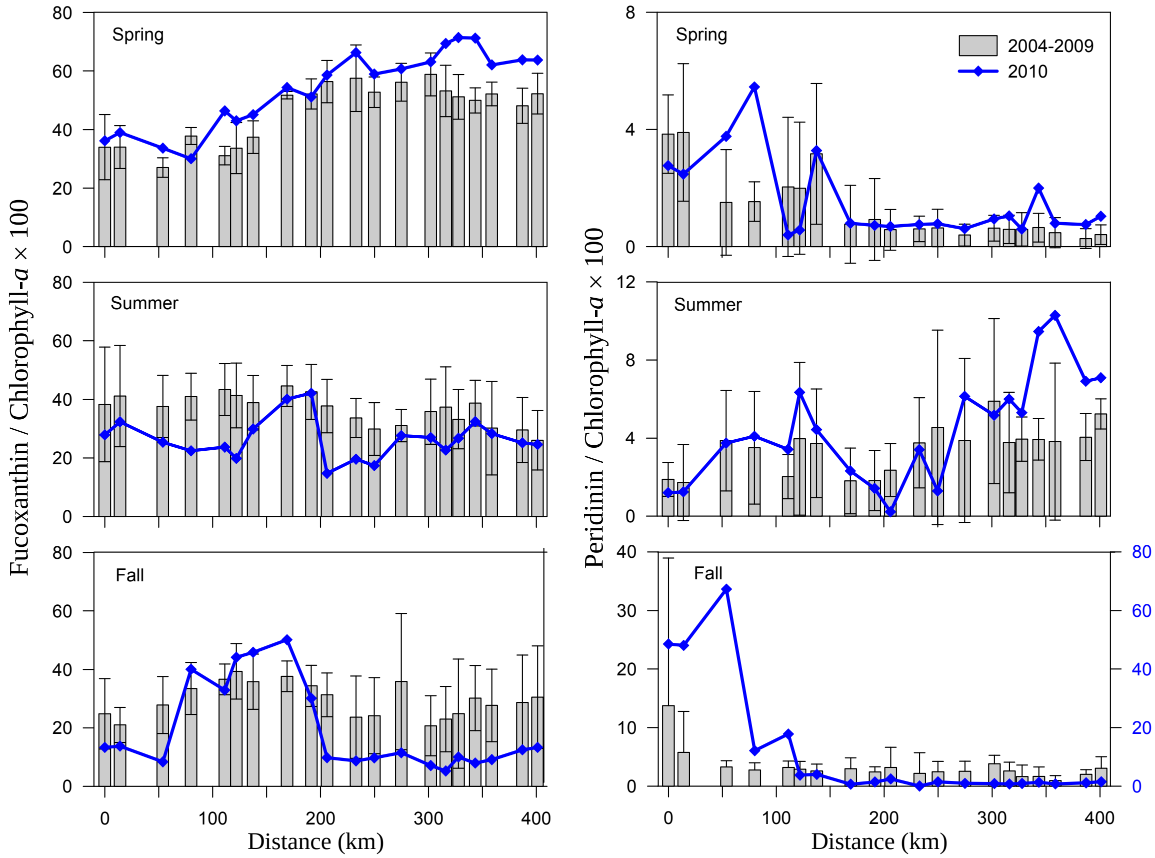

Figure 3. Upper layer (0-10 m) distribution of fucoxanthin (left panel) and peridinin (right panel) normalized to chlorophyll-a along the main transect from the mouth of the Juan de Fuca Strait to the north end of the Strait of Georgia during spring, summer and fall. Grey bars denote averages and standard deviations from 2004 to 2009. Blue diamonds are observations in 2010. Note the different scale (right-axis) for 2010 fall peridinin in the bottom right panel. Numbers along lower axes are cumulative distance from the mouth of the Juan de Fuca Strait (see Fig. 1).

PREDICTION OF THE SPRING PHYTOPLANKTON BLOOM IN THE STRAIT OF GEORGIA

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A phytoplankton bloom develops in late winter or early spring in the Strait of Georgia when rapid growth is triggered by sufficient light in a shallow surface layer. This bloom continues until the nutrients near surface are consumed by the phytoplankton. A zooplankton bloom usually follows phytoplankton closely in time. Because zooplankton provide feed for the entire food chain, timing and intensity of these blooms are believed to be critical for growth and survival of juveniles of many species, including Fraser River salmon.

Dates of the spring phytoplankton blooms in the Strait of Georgia have been observed to vary interannually from the beginning of March until mid-April. We have developed a one-dimensional, coupled, biophysical model of the Strait of Georgia and used it to predict spring blooms. We define the time of the spring bloom to be on the day of maximum biomass of the bloom, which occurs within days of the nitrate at the ocean surface dropping to zero. This means our timing can be significantly later than the timing determined from satellite observations of ocean colour by Gower (elsewhere in this Research Document), which is defined as the beginning of significant chlorophyll-a in the Strait. (Chlorophyll-a, is the component of phytoplankton that colours the ocean and is identified by satellite.)

The figure below shows the model results for winter to spring of 2010. The bloom started in mid-February and by the end of February (day 59) looked like it might peak in mid to early March. However, strong winds with maximum gust of 98 km/hr on March 11 (day 70) deepened the mixing layer and delayed the bloom. In late March, the phytoplankton biomass increased and nitrate was drawn down to about 15 uMol. However again storms moved in with maximum gust of 89 km/hr of March 29 (day 88) mixing the upper ocean layers and delaying the bloom.

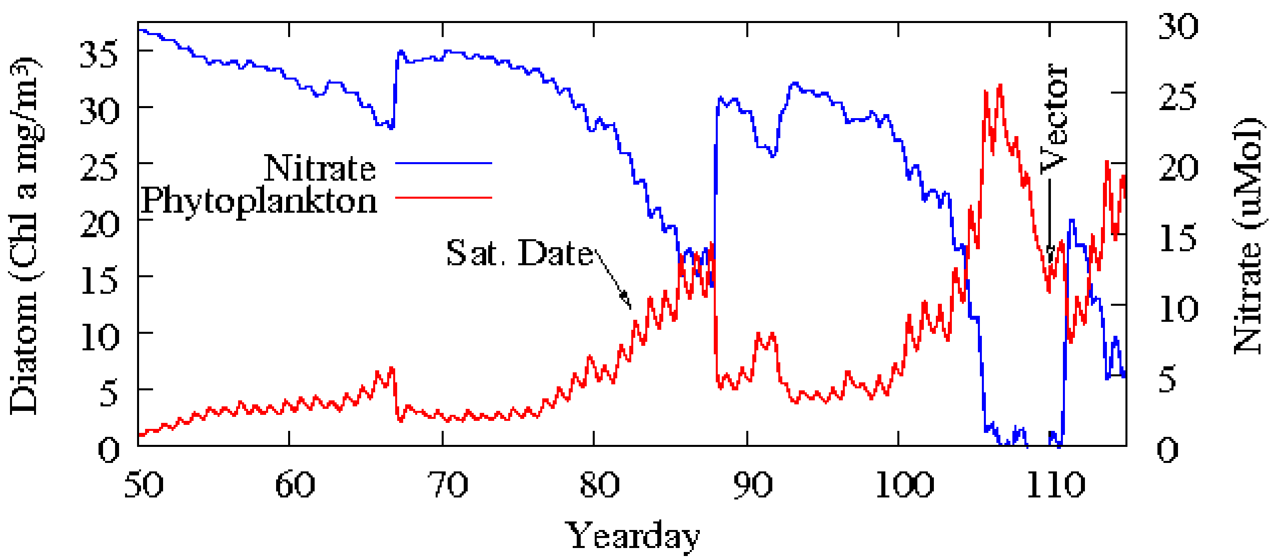

Figure 1: Time series from the coupled bio-physical model for spring 2010 showing phytoplankton chl a (in red) and nitrate(in blue) averaged over the top 3 m of the model. The peak of the spring bloom is day 106, April 16. Marked are day 82, March 23, the date the satellite data showed the start of the spring bloom (Gower 2011, elsewhere in this Research Document) and day 110, April 20, when data from the Coast Guard Ship Vector showed that the spring bloom was over (Pena 2011, elsewhere in this Research Document).

Prediction for the bloom in 2011

Using the biophysical model and observations over previous years, we have investigated the sensitivity of the time of spring bloom to physical forcings, such as December-to-February averaged wind speed cubed, cloud fraction and river outflow (Collins *et al*, 2009). However, we do not attempt to predict the March weather, instead we assume it will be "typical". Thus, if like in 2010, there are significant storms, the bloom will come later than the prediction.

In Dec 2010- Feb 2011 our weather has been very typical. Like the last two years river flow has been low. We are predicting a 2011 spring bloom with timing only a couple of days later than the average bloom; specifically our prediction is for March 16 – April 5.

Details of the model

Our numerical model is based on the KPP mixing-layer model (Large *et al*., 1994) with baroclinic pressure gradients and estuarine circulation added (Collins *et al*., 2009). The physical model is coupled to a simple, standard, nitrogen-phytoplankton model. The phytoplankton modelled is *Thalassiosira* spp., which is observed to be the first phytoplankton to bloom in the Strait. Physiological parameters are taken from the literature and the model is tuned using the zooplankton biomass. The model hindcasts accurately (within 3 days) the spring blooms of 2002-2006 for which detailed observations were made as part of the STRATOGEM project (Collins *et al*., 2009).

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ZOOPLANKTON IN THE STRAIT OF GEORGIA: A PARTIAL RECOVERY FROM LOW COPEPOD AND EUPHAUSIID BIOMASS LEVELS IN THE 2000S

Dave Mackas, Moira Galbraith, and Kelly Young (Fisheries & Oceans Canada) and
The Dower Lab (University of Victoria) and Lingbo Li (University of British Columbia)

As part of the Pacific Region Ecosystem Research Initiative, we compiled historic data from various shorter term sampling programs in the Strait of Georgia [SoG] and have begun a retrospective analysis of long term changes in the SoG zooplankton community. Temporal coverage extends (with many gaps) back into the 1960s. Because of the diversity of sources and original project objectives, SoG zooplankton sampling did not follow a standard grid or sampling protocols, and in addition the data have highly variable resolution of taxonomic composition. For this reason, our analyses to date of the total SoG zooplankton community have merged the source data into broader categories (size classes within major taxa) than the species level resolution used in our outer coast time series (described elsewhere in this Research Document).

Data from individual samples are also grouped into roll-up categories based on month of sampling, depth, and horizontal location. Fig 1 shows the spatial classification regions we use. Of these regions, by far the largest number of samples, and the best temporal complete coverage is within the Northern and Central Strait regions, and their adjoining “nearshore” margins. Density of temporal coverage, and consistency of field sampling and taxonomic identification methodologies improved considerably after 1990. This report will therefore focus on changes that have occurred since 1990 in the Central and Northern SoG regions.

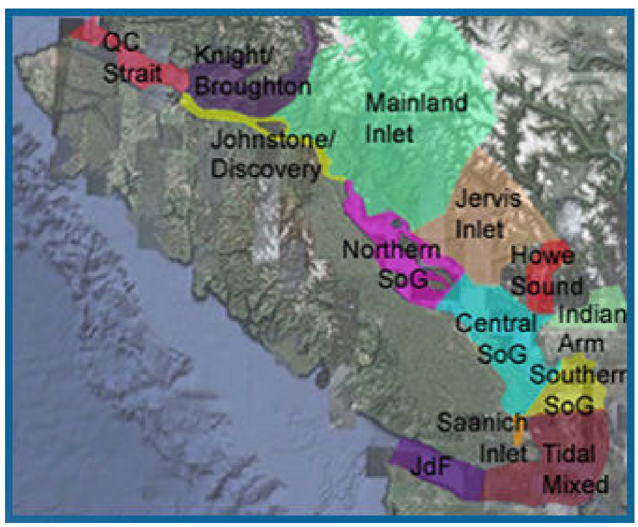

Figure 1. Subregions into which samples have been classified, to produce regional climatologies and time series. An additional “Nearshore” region (not shown) includes all locations inshore of the local 50 m isobath.

Our retrospective analysis of Strait of Georgia zooplankton data has revealed large decadal changes in the zooplankton community. The SoG zooplankton variability has been quite different in time scale and phasing from the outer coast time series described elsewhere in this Research Document: within the SoG we see little or no evidence of advectively-driven oscillation between ‘northern’ and ‘southern’ communities, and somewhat more evidence of sustained trends and/or very low frequency fluctuations. Within the SoG, biomass of large and medium-sized copepods was much lower after 2000 than in the early 1990s (Fig. 2) although there has been some recovery in 2009 and 2010. Historically, the large copepod size category (and total spring zooplankton biomass) in the SoG was strongly dominated by the large copepod *Neocalanus plumchrus*. This species has an annual life cycle in the SoG (Fulton 1973) and completes its entire growing season between about January and May, after which it migrates downward (to depths greater than 200m) and enters a prolonged seasonal dormancy. Several recent grad student studies (e.g. Bornhold 1999; Campbell *et al*. 2004; El Sabaawi *et al*. 2009) have documented large changes in its seasonal timing (early in years with warm spring temperature anomalies), abundance, and chemical composition.

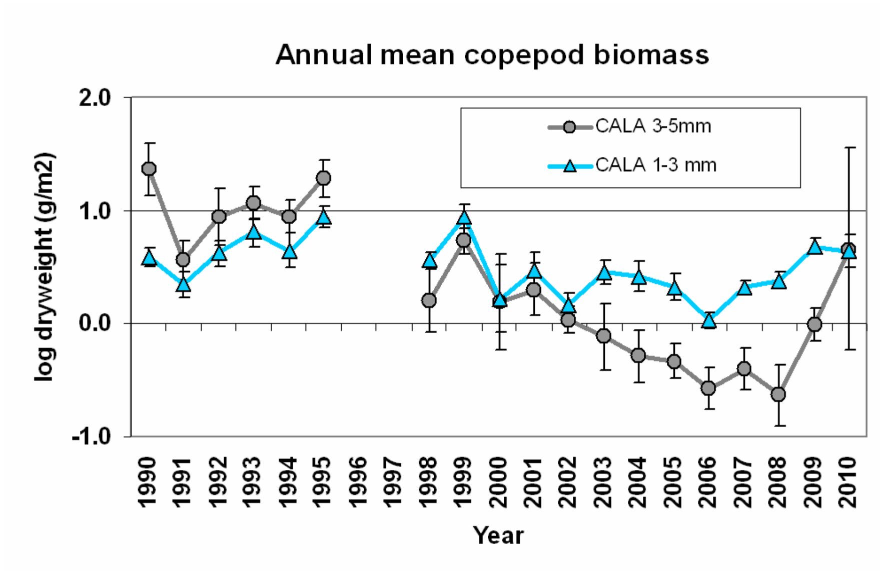

Figure 2. Annual geometric mean biomass of large- (3-5 mm prosome length) and medium-sized (1-3 mm) calanoid copepods in mid-strait full-water-column samples from the Central and Northern Strait of Georgia. The very large decline of the large copepods (note that Y-axis scale is log_{10}) is mostly due to decreased abundance of Neocalanus plumchrus.

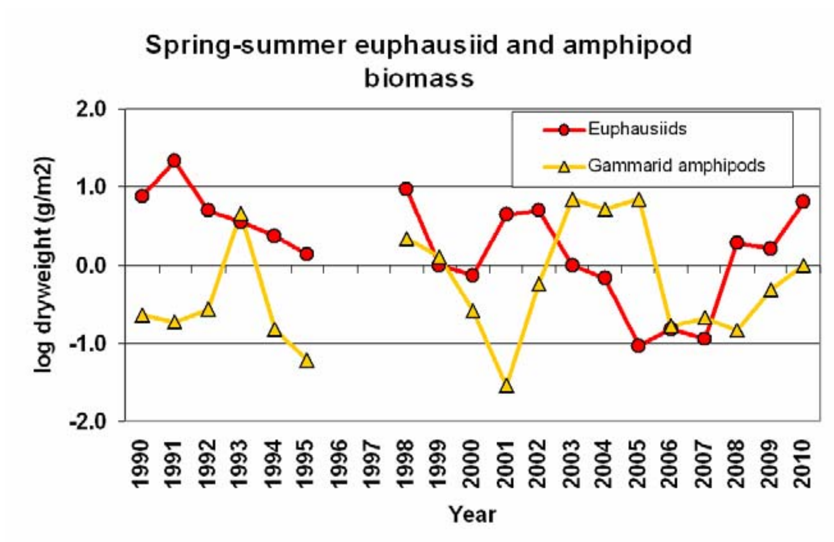

Figure 3. Spring-early summer (March-July) geometric mean biomass of euphausiids and gammarid amphipods in mid-Strait samples from the Central and Northern Strait of Georgia. Euphausiid data are adjusted for day-night differences in catchability before being averaged.

Euphausiid biomass was also low in the 2000s. For spring-season samples, the time series is a downward trend (with superimposed year-to-year variability) from 1990-2004, a minimum 2005-2007, followed by a partial recovery after 2008. For late summer-fall samples (not shown, and less relevant for juvenile fish), the decline is more step-like and centered ~1999-2000. Large copepods, euphausiids, and large amphipods all provide an energy-rich food resource for higher trophic levels (either direct or indirect through intermediate predators). High availability of these zooplankton taxa appears to enhance the growth and survival of juvenile salmon, herring and sablefish (Mackas *et al*. 2007; Trudel, pers. comm., Schweigert, pers. comm..). Low SoG zooplankton biomass and changes in zooplankton community composition may have contributed to recent poor survivals and recruitments of certain salmon populations that forage in the Strait. However, the period of low biomass lasted at least 5 years, extending both before and somewhat after the 2007 ocean entry year for the Fraser River sockeye stocks that had poor returns in 2009.

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AQUATIC INVASIVE SPECIES

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Monitoring Efforts

Monitoring for aquatic invasive species (AIS) in Pacific Region is relatively new. In the marine environment, two large scale surveys provide information on the distribution and/or relative abundance of AIS in intertidal and subtidal habitats. The intertidal survey has used checklists during the past five years to document known or suspected invaders at beaches throughout BC. In addition, this survey deploys baited traps to characterize the distribution and relative abundance of invasive European green crab (*Carcinus maenas*). The subtidal survey uses collector plates to characterize AIS in fouling communities, notably four tunicates invasive in BC: clubbed tunicate (*Styela clava*), violet tunicate (*Botrylloides violaceus*), golden star tunicate (*Botryllus schlosseri*) and the colonial tunicate (*Didemnum vexillum*) that were considered high risk (Therriault and Herborg 2007). Recent subtidal monitoring has been directed at locations receiving the greatest propagule load, the Ports of Vancouver and Victoria.

Intertidal AIS

Early intertidal bivalve surveys tracked distribution and dispersal of non-indigenous Manila clams (*Venerupis philippinarum*) beyond their established range in the south coast of BC (e.g., Bourne and Cawdell 1992, Bourne *et al*. 1994), and later surveys also tracked non-indigenous varnish clams (*Nuttallia obscurata*) (e.g., Gillespie and Bourne 2005a, b). Baseline surveys were initiated in 2005 in the Strait of Georgia. Their results helped inform the species checklist that was used to characterize the subsequent distribution of these AIS (or new ones) on BC beaches. The rotational basis for these surveys has precluded the identification of trends and can only provide information on status (AIS presence). The species identified thus far during surveys are summarized in Table 1. Most AIS in BC are found in southern areas, which have experienced more aquaculture imports and international shipping activity (Gillespie 2007). Fewer species have dispersed to (or originated in) northern BC, widespread species include *Sargassum muticum*, *Mya arenaria* and *Venerupis philippinarum*.

Table 1: Intertidal AIS detected by DFO surveys in BC (note that other species have been reported in the literature, but not confirmed by these DFO surveys).

Scientific Name	Common Name	Scientific Name	Common Name
Plants			
Sargassum muticum	Japanese Wireweed	*Zostera japonica*	Dwarf Eelgrass
Cnidaria			
Diadumene lineata	Orange-striped Green Anemone		
Molluscs			
Batillaria attramentaria	Japanese Mudflat Snail	*Nassarius fraterculus*	Eastern Black Nassa
Crassostrea gigas	Pacific Oyster	*Neotrapezium lirata*	Quadrate Trapezium
Crassostrea virginica	Eastern Oyster	*Nuttallia obscurata*	Varnish Clam

Crepidula fornicata	Atlantic Slippersnail	*Ocinebrellus inornata*	Japanese Oyster Drill
Musculista senhousia	Asian Date Mussel	*Ostrea edulis*	European Flat Oyster
Mya arenaria	Softshell Clam	*Potamopyrgus antipodarum*	New Zealand Mudsnail
Myosotella myosotis	Mouse-ear Snail	*Venerupis philippinarum*	Manila Clam
Mytilus edulis complex*	Bay (Blue) Mussel		
		Crustaceans	
Carcinus maenas	European Green Crab		

** Two non-indigenous species of bay mussel, Mytilus edulis and Mytilus galloprovincialis, cannot be definitively distinguished by morphology and readily hybridize; tissue samples have been collected for molecular analyses, but results are not available at this time.*

European Green Crab

This high profile invader was detected in DFO's first systematic survey on the west coast of Vancouver Island in 2006 (Gillespie *et al*. 2007); a biological risk assessment was completed two years later (Therriault *et al*. 2008). Extensive sampling has documented that green crab populations remain restricted to the west coast of Vancouver Island – they have not been found further north of or in Johnstone Strait or Strait of Georgia (Gillespie, unpublished data). Catch rates from Pipestem Inlet in Barkley Sound can serve as a proxy for abundance trends. Based on these data, green crab appeared to increase between 2006 and 2008 but since then have shown some evidence of decline, possibly the result of recent poor recruitment (Fig. 1).

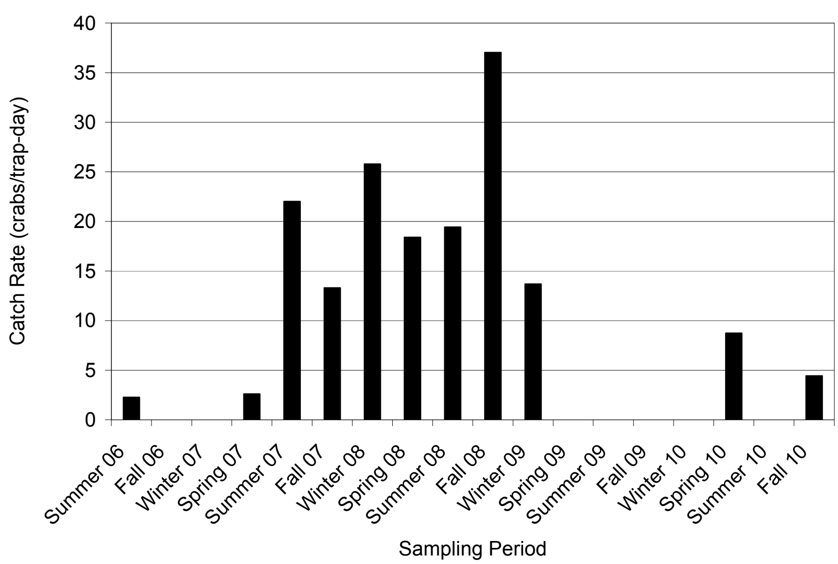

Figure 1: Catch rates (crabs/trap) of European green crab, Carcinus maenas*, from Pipestem Inlet, Barkley Sound, 2006-2010 (Gillespie and Therriault, unpublished data).*

Subtidal AIS

Monitoring for subtidal AIS began in the Strait of Georgia in 2008 at two locations (Burrard Inlet and Port of Vancouver). In this first year, four invasive amphipods were detected (*Caprella mutica*, *Incisocalliope derzhavini*, *Melita nitida*, and *Monocorophium acherusicum*) in addition to the cryptogenic polychaete *Polydora limicola*. In 2009, monitoring efforts were conducted again at the Port of Vancouver as well as in Victoria (Canoe Club, Fisherman's Wharf, Inner Harbour, and Ogden Point). At the Port of Vancouver, *Incisocalliope derzhavini* and *Monocorophium acherusicum* were again found, and the bryozoan *Schizoporella japonica* was detected for the first time. Four AIS were detected in Victoria including the tunicates *Botrylloides violaceus* and *Botryllus schlosseri*, and the amphipods *Caprella mutica* and *Monocorophium acherusicum*. In 2010, four Vancouver sites (Burrard Inlet, Reed Point, West Vancouver Labs, and Port of Vancouver) were surveyed and two Victoria sites (Fisherman's Wharf and Inner Harbour). In Vancouver, the cryptogenic bryozoan *Bowerbankia gracilis* was detected in addition to eight AIS including: five amphipods (*Amphithoe valida*, *Caprella drepanochir*, *Caprella mutica*, *Monocorophium acherusicum*, *Monocorophium insidiosum*), a barnacle (*Balanus amphitrite*), a bryozoan (*Schizoporella japonica*), and a tunicate (*Botryllus schlosseri*). Two cryptogenic bryozoan species were detected in Victoria, *Bowerbankia gracilis* and *Cryptosula pallasiana* as well as the tunicates *Botrylloides violaceus*, *Botryllus schlosseri* and *Molgula manhattensis*, the bryozoan *Schizoporella japonica*, and the amphipods *Caprella mutica* and *Incisocalliope derzhavini*.

Abundance Trends

Due to short time series, it is not yet possible to infer abundance trends in AIS, with the possible exception of European green crab.

Intertidal monitoring has provided valuable data on the dispersal and distribution patterns of non-indigenous species. This information helps us understand potential vectors responsible for introduction and/or spread and also assists in identifying habitats that may be susceptible to future invasion. Monitoring data also are useful for identifying organisms that might be limited by current environmental conditions such as *Venerupis philippinarum* or *Crassostrea gigas* that require relatively warm conditions for spawning. While these conditions currently occur only episodically in our waters, with climate change these conditions might occur more frequently and/or extend further north, thereby increasing the potential for spread. In addition, climate change is likely to result in conditions that are more favourable for invasive species currently restricted to locations further south such as San Francisco Bay (see Cohen 2005).

Subtidal monitoring has detected several persistent invasive species. The invasive amphipod *Caprella mutica* only recently has been confirmed in BC (Frey *et al*. 2009) and the barnacle *Balanus amphitrite* is reported for the first time in BC, highlighting the need for larger scale AIS monitoring efforts. The exact native range for this species is unknown but is suspected to include the Indian Ocean and/or southwest Pacific Ocean but this species has been introduced to various warm and temperate waters, including California (Cohen 2005). The occurrence of a warm water invader in the Strait of Georgia could represent a single introduction (establishment uncertain) but also a warning that additional species might be expected if the Strait continues to warm.

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RECENT FRASER SOCKEYE SALMON RETURNS AND FORECASTS FOR 2011

Sue Grant, Fisheries and Oceans Canada

Most Fraser River Sockeye spend their first two winters in freshwater (the first as eggs/alevins, the second as fry), followed by two or three winters in the ocean, returning to spawn as four or five year old fish. Harrison Sockeye Salmon are the major exception to this life-history and age structure, spending only one winter in freshwater followed by two or three winters in the ocean, returning to spawn as three or four year old fish. Fraser Sockeye mortality occurs throughout their life-history (from the egg stage through their freshwater and marine residency periods to when the adults return to the Fraser watershed to spawn). To decrease the high uncertainty associated with Fraser Sockeye forecasts, environmental variables have been used, both quantitatively in stock-recruitment forecast models (Grant *et al*. 2010), and qualitatively into the forecast advice (DFO 2009). However, to date, environmental variables have not decreased forecast uncertainty significantly and the influence of environmental conditions on survival remains an area of active research.

Fraser Sockeye Salmon forecasts have been particularly uncertain in recent years; many stocks have exhibited systematic declines in productivity, some beginning as early as the 1960’s (Grant *et al*. 2010). Exceptions to this trend include the Late Shuswap, Raft, and Weaver stocks, which have not exhibited any systematic productivity trends, and Harrison Sockeye Salmon, which have generally increased in productivity. Fraser Sockeye Salmon survival has been extremely variable in the last two brood years. The 2005 brood year (2009 return year for most Fraser Sockeye) productivity was amongst the lowest on record for all stocks, including Harrison Sockeye Salmon (Grant *et al*. 2010). In contrast, preliminary return data for 2010 indicate that productivity was generally much higher for the 2006 brood year.

To account for uncertainty due to stochastic (random) variability in annual Sockeye Salmon survival rates, Fraser Sockeye forecasts are presented as standardized cumulative probabilities (10%, 25%, 50%, 75%, 90%). For example, at the 25% probability level there is a one in four chance that the actual number of returning Sockeye Salmon will be at, or below, the forecasted value, given the assumptions regarding Fraser Sockeye Salmon survival. At the mid-point of this distribution (50% probability level), there is a one in two chance that the return will come in above or below this value. To account for uncertainty in survival from the egg stage through to adult returns, alternative forecasts have been presented for the 2010 and 2011 return years, representing different assumptions regarding productivity that include long-term average productivity and recent (brood years: 1997-2004) productivity. ‘Recent Productivity’ forecasts are generally smaller than ‘Long-Term Average Productivity’ forecasts, given the lower productivity exhibited by most stocks in recent years with some exceptions that include, amongst others, Raft, Weaver, Late Shuswap and Harrison Sockeye Salmon.

For the 2010 pre-season planning process, DFO recommended the ‘Recent Productivity’ forecast scenario (Table 1, left hand side) since recent productivities had generally been below average. The ‘Long-Term Average Productivity’ forecast (Table 2) was given a lower probability of occurring. However, 2010 returns were above recent productivities (‘Recent Productivity’ forecast) for most stocks (Table 1), and generally fell within the average range (between the 25% and 75% probability level) under the ‘Long-Term Average Productivity’ forecast scenario (Table 1, right hand side), with the exception of Seymour and Late Shuswap, which were well above long-term average productivity. The 2010 Fraser Sockeye return (~30 million) was amongst the largest observed in the past 100 years and Late Shuswap, in particular, was the key driver of this return. The recommended forecast for Fraser Sockeye Salmon returns in 2011 again assumes that ‘Recent Productivity’ conditions will persist. Under this scenario there is a one in ten chance (10% probability) that returns will be at or below 1.0 million, and a nine in ten chance (90% probability) they will be at or below 12.1 million. The mid-point of this distribution

(50% probability level) is 3.2 million (one in two chance returns will be above or below this value). Under the alternate, and presumably less likely, assumption that “Long-Term Average Productivity” conditions will persist, there is a 10% probability returns will be at or below 1.7 million, a 90% probability they will be at or below 15.1 million and a 50% probability they will be at or below 4.6 million (Fig. 1).

Table 1. 2010 Fraser Sockeye Salmon forecasts assuming recent productivity (left hand table) and long-term average productivity (right table) conditions prevailed (Grant et al. 2010). Preliminary 2010 returns are color coded: yellow for returns within the 25% to 75% probability distribution and green for returns >75%

Probability of Return at/or Below Specified Run Size

Run Timing Group Stocks	10%	25%	50%	75%	90%	
Early Stuart	17,000	26,000	41,000	66,000	101,000	104K
Early Summer	**174,000**	**374,000**	**783,000**	**1,601,000**	**3,047,000**	
Bowron	400	700	1,300	2,500	4,600	13K
Fennell	9,000	16,000	31,000	56,000	90,000	58K
Gates	2,000	4,000	9,000	17,000	33,000	17K
Nadina	9,000	16,000	30,000	60,000	107,000	35K
Pitt	7,000	12,000	26,000	53,000	96,000	40K
Raft	7,000	13,000	24,000	42,000	71,000	25K
Scotch	40,000	106,000	265,000	640,000	1,450,000	1.4M
Seymour	55,000	101,000	195,000	380,000	691,000	1.4M
Summer	**1,045,000**	**1,605,000**	**2,612,000**	**4,343,000**	**6,984,000**	
Chilko [j]	864,000	1,273,000	1,958,000	3,011,000	[illegible]	4M
Late Stuart	8,000	21,000	60,000	169,000	429,000	300K
Quesnel	111,000	215,000	438,000	909,000	727,000	700K
Stellako	62,000	96,000	156,000	254,000	393,000	
Late	**3,331,000**	**5,023,000**	**8,003,000**	**12,305,000**	**19,695,000**	
Cultus [j]	5,000	6,000	9,000	14,000	19,000	17K
Harrison [k]	53,000	97,000	195,000	429,000	1,167,000	1.4M
Late Shuswap	3,101,000	4,652,000	7,252,000	10,791,000	16,702,000	17M
Portage	8,000	18,000	42,000	99,000	221,000	153K
Weaver	71,000	126,000	264,000	472,000	799,000	300K
Birkenhead	26,000	52,000	109,000	230,000	444,000	300K
TOTAL	**4,567,000**	**7,028,000**	**11,439,000**	**18,315,000**	**29,827,000**	

Probability of Return at/or Below Specified Run Size

Run Timing Group Stocks	10%	25%	50%	75%	90%	
Early Stuart	**55,000**	**85,000**	**135,000**	**213,000**	**315,000**	104K
Early Summer	**387,000**	**723,000**	**1,518,000**	**[illegible]**	**7,993,000**	
Bowron	3,000	6,000	9,000	15,000	24,000	13K
Fennell	12,000	20,000	33,000	55,000	86,000	58K
Gates	5,000	10,000	21,000	44,000	98,000	17K
Nadina	12,000	20,000	35,000	60,000	99,000	35K
Pitt	29,000	44,000	66,000	113,000	178,000	40K
Raft	20,000	29,000	47,000	74,000	113,000	25K
Scotch	124,000	315,000	884,000	[illegible]	6,275,000	1.4M
Seymour	182,000	279,000	423,000	704,000	1,120,000	1.4M
Summer	**1,434,000**	**2,304,000**	**3,972,000**	**6,981,000**	**11,875,000**	
Chilko	881,000	1,376,000	2,221,000	[illegible]	5,626,000	4M
Late Stuart	35,000	82,000	211,000	547,000	1,286,000	300K
Quesnel	263,000	475,000	1,019,000	1,968,000	3,867,000	700K
Stellako	255,000	371,000	521,000	774,000	1,096,000	
Late	**3,484,000**	**5,239,000**	**8,364,000**	**12,803,000**	**20,741,000**	
Cultus	6,000	10,000	19,000	36,000	59,000	17K
Harrison	50,000	93,000	262,000	729,000	[illegible]	1.4M
Late Shuswap	3,184,000	4,746,000	7,414,000	10,848,000	16,752,000	17M
Portage	14,000	27,000	62,000	130,000	296,000	153K
Weaver	90,000	136,000	219,000	376,000	621,000	400K
Birkenhead	140,000	227,000	388,000	684,000	1,090,000	300K
TOTAL	**5,360,000**	**8,351,000**	**13,989,000**	**23,541,000**	**40,924,000**	

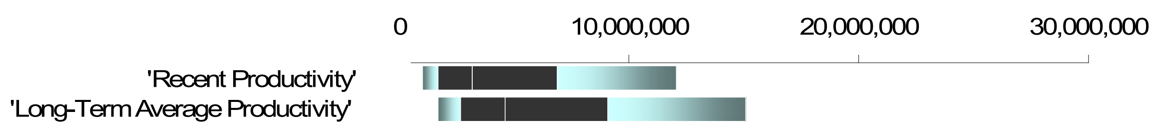

Figure 1. 2011 forecast probability distributions for all Fraser Sockeye Salmon stocks. Black horizontal bars represent the 25% to 75% probability distribution range, the 50% probability level is indicated by the white vertical line and the blue (lighter) horizontal bars represent the 10% to 90% probability distribution range. Separate distributions are provided for the two forecast scenarios: ‘Recent Productivity’ and ‘Long-Term Average Productivity’ (DFO 2001).

References

DFO. 2009. Pre-season run size forecasts for Fraser River sockeye and pink salmon in 2009. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2009/022.

Grant, S. C. H., Michielsens, C. G. J., Porszt, E. J., and Cass, A. J. 2010. Pre-season run size forecasts for Fraser Sockeye (*Oncorhynchus nerka*) in 2010. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/042, -vi + 127

DFO. 2011. Pre-season run size forecasts for Fraser Sockeye and Pink Salmon in 2011. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. (in press).

PNCIMA AND NEIGHBOURING WATERS

LONG-TERM TEMPERATURE AND SALINITY AT BC LIGHTHOUSES

Peter Chandler, Fisheries & Oceans Canada

Temperature and salinity are measured daily at the first daylight high tide at 13 lighthouse stations as part of the DFO Shore Station Oceanographic Program.

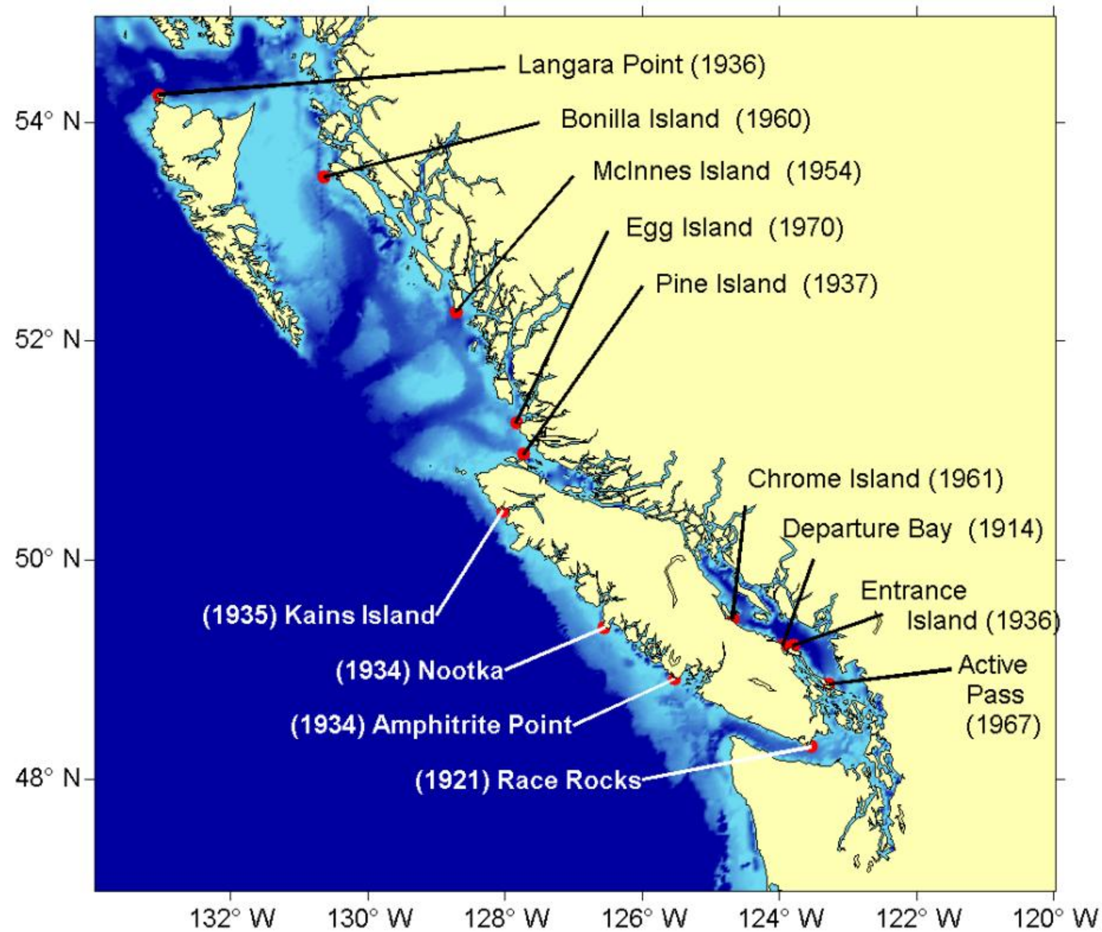

Figure 1. The 13 stations presently in the network and the year the data record began.

The lighthouse data at all 13 stations show that the ocean was warmer in 2010 than in 2009, as shown in Fig. 2 on the next page. Stations of central and northern BC (PNCIMA, left panel, Fig. 2) i9ndicate that 2010 temperatures increased on average by about 0.7°C from 2009 and were closer to the 30-year average temperature than were the 2009 conditions.

Temperature

The 30-year average temperatures from 1981-2010 were about 0.1 °C warmer than the average temperatures in the 30 years from 1971-2000.

The increases of average sea surface temperatures between 2009 and 2010 were more variable at the Strait of Georgia stations than those in the PNCIMA. Three of the seven stations in the right panel of Fig. 2 show both 2009 and 2010 to have been warmer than the 1981-2010 average, indicating a steady warming trend.

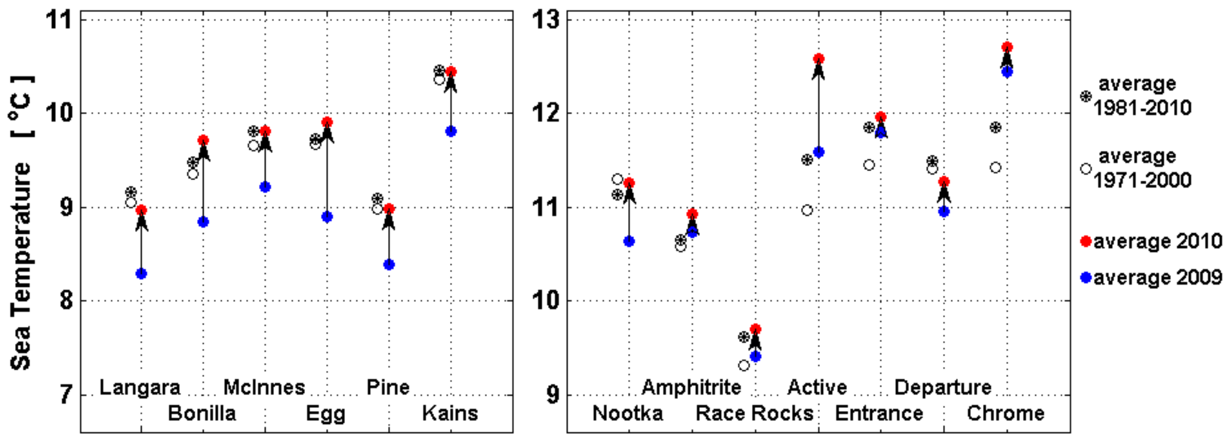

Figure 2. The average daily sea surface temperature in 2009 and 2010 at BC lighthouse stations, and the annual average calculated from 30 years of data (1971-2000 and 1981-2010). The six stations in the left panel are in the Pacific North Coast Integrated Management Area (PNCIMA) in central and northern BC.

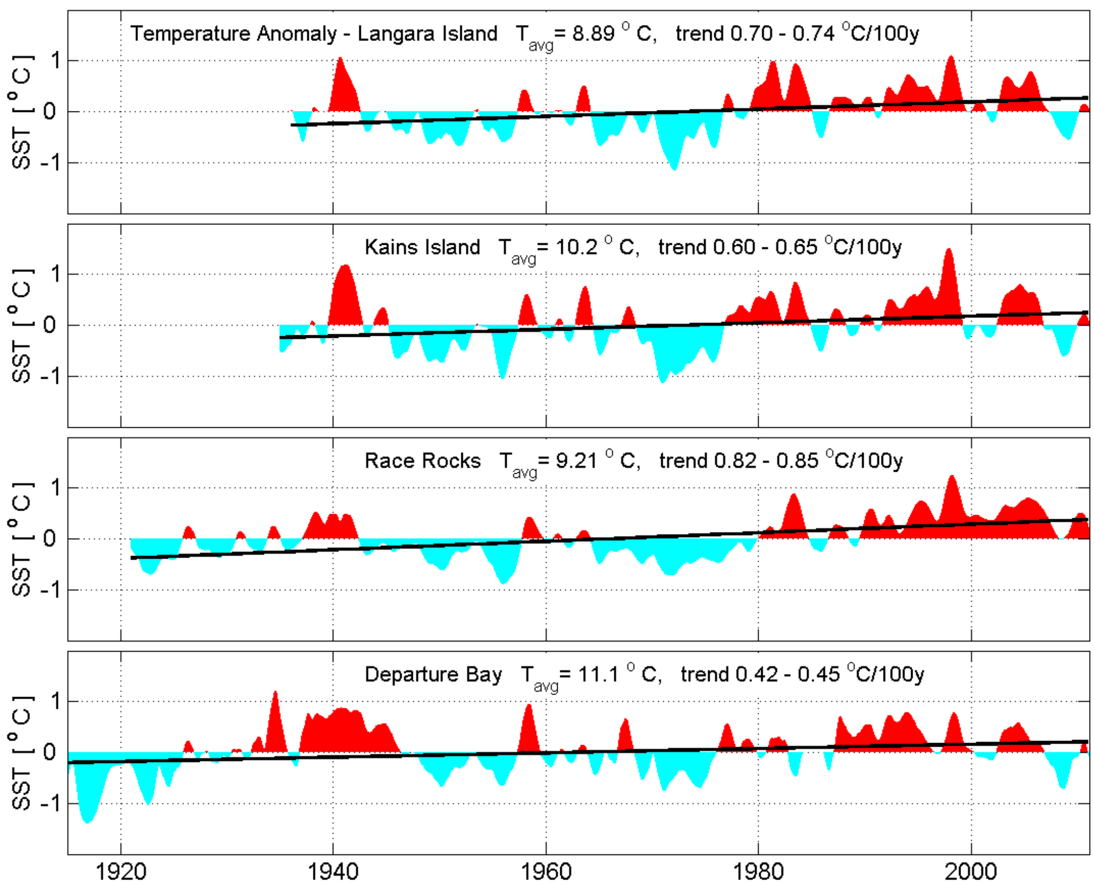

Figure 3. Long-term time series of annually averaged temperature at stations representing the north coast, west coast and Strait of Georgia. Positive (negative) anomalies from the average temperature at each station are shown in red (blue). The slope of the trend lines assumes a linear change over time, and the 95% confidence intervals of the slopes are given as the range in the trend over 100 years.

There is a general pattern that sea surface temperatures are warmer in the Strait of Georgia than along the west coast and in the PNCIMA. Over the time period that temperature observations have been made a consistent warming trend is evident that depends both on location as well as the length of the record.

Salinity

In general there is a slight, but not statistically significant, decrease in salinity over the duration of the observations; the exception is Langara Island where a consistent decrease in salinity is observed. The variations in salinity are greater, and the long-term average salinity is lower, in the Strait of Georgia than in the waters of the west and north coasts of British Columbia.

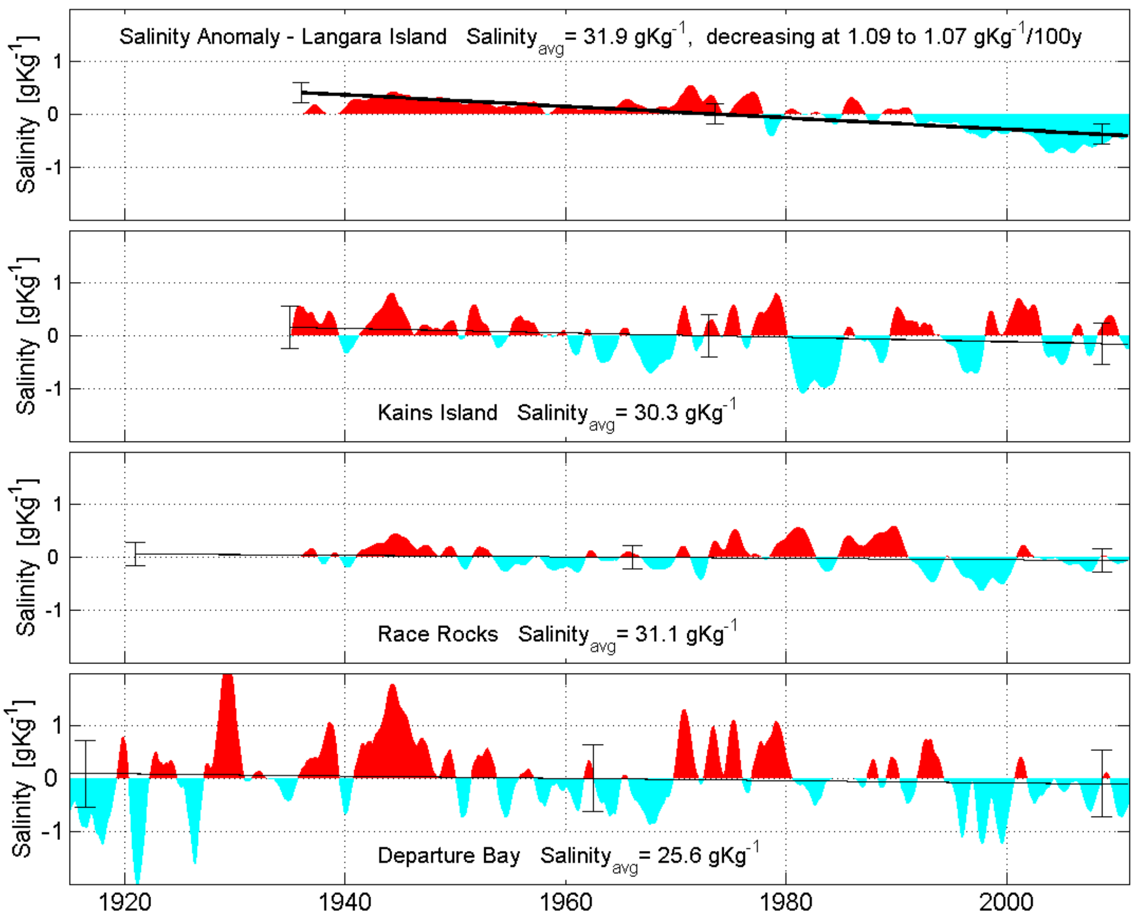

Figure 4. Long-term time series of annually averaged salinity at stations representing north coast, west coast and Strait of Georgia. Positive (negative) anomalies from the average temperature at each station are shown in red (blue). The black lines represent the linear relationship between time and salinity; the 95% confidence limits of the slope show a statistically significant decreasing trend at Langara Island, and a negative, but not statistically significant trend, at the other stations.

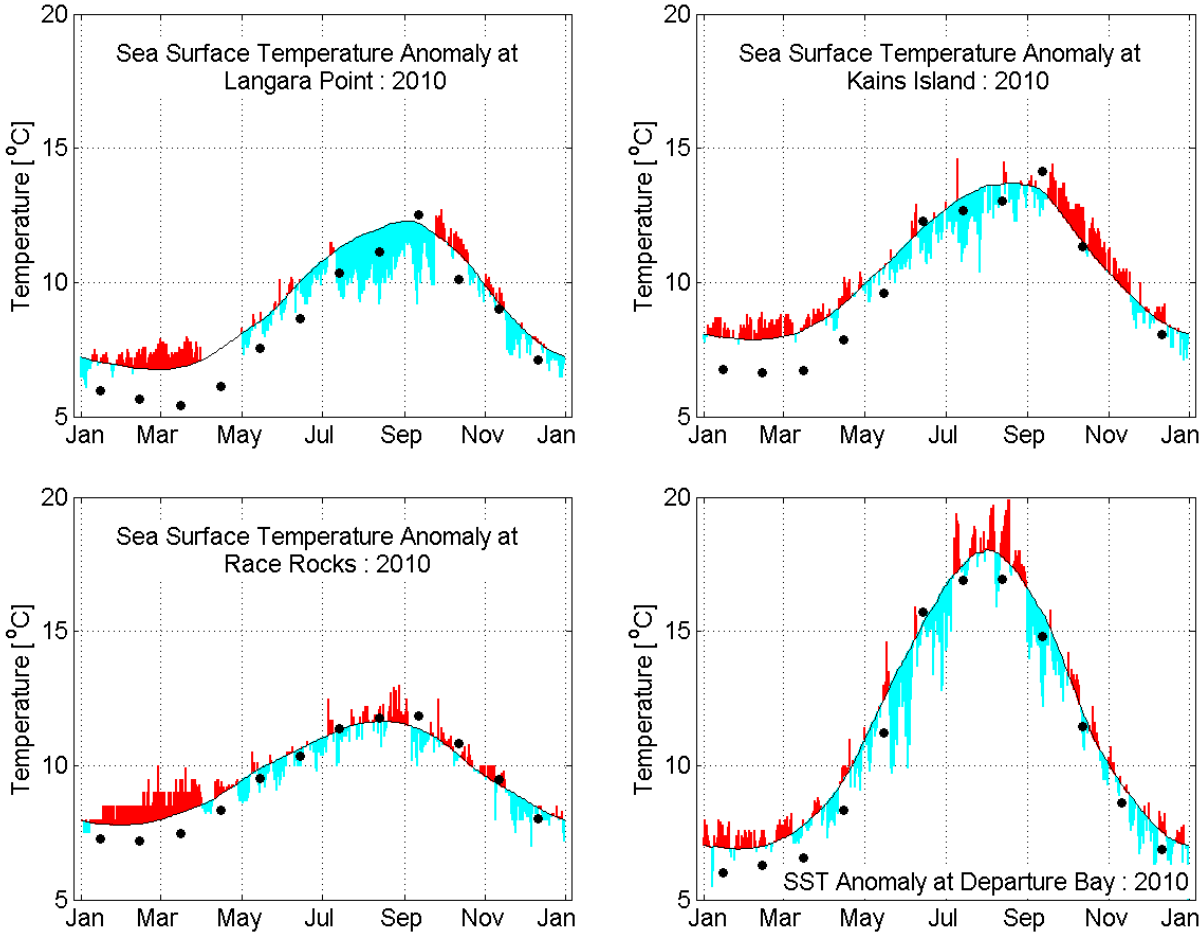

Figure 5. Daily temperatures observed in 2010, and the average annual cycle (calculated from 1981-2010 data), at stations representing the north coast, west coast and Strait of Georgia. Positive (negative) anomalies from the average 30-year temperature for each day are shown in red (blue). The black dots represent the monthly temperature anomalies observed in 2009.

The annual temperature cycles show greater summer-to-winter change in sea surface temperature in the Strait of Georgia than elsewhere on the British Columbia coast. From January to March of 2010 the sea temperatures at all stations were above normal, and considerably warmer than in 2009. The PNCIMA stations (Langara and Kains) show cooler-than-normal temperatures in the summer of 2010 (as in 2009), with slightly warmer than normal temperatures in the fall. Warmer-than-normal summer conditions were observed at Race Rocks and at Departure Bay in the Strait of Georgia, with short-term variations around the normal temperatures observed for the remainder of the year.

Links: BC Seawater sampling at Lighthouses

http://www.pac.dfo-mpo.gc.ca/science/oceans/data-donnees/lighthouses-phares/index-eng.htm

FRESHWATER FLUX ON THE B.C. COAST

John Morrison

Background

The drainage basins supplying water to the British Columbia coast cover an area of approximately 1,315,000 km^2. Rivers along the B. C. coast originate in variety of climatic zones resulting in a variety of flow patterns. Rivers in coastal plains have hydrograph profiles that match the precipitation profiles with minimal flow in the summer and peak flows in late fall or early winter. Rivers originating the coastal mountains follow the same pattern in the warm months but store precipitation as snow cover over the winter months. Coastal mountain rivers have peaks in both the early fall and early spring. However the majority of the area in the drainage basins is located inland. This means that the fresh water inflows are dominated by climate zones that are remote from the coast. Here the flow pattern is dominated by winter storage with minimal impact from fall precipi-tation. Peak flow occurs from late May to late June.

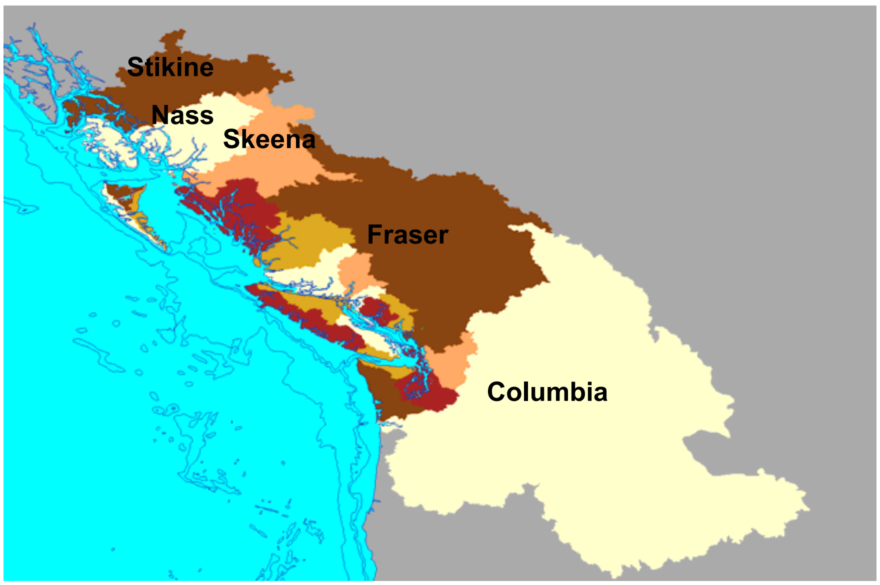

Figure. 1 Map of drainage basins affecting BC coastal waters. The named basins are those with large inland drainage areas.

Runoff estimation

River flow is estimated at gauging stations by measuring the river height and calculating the flow based on corresponding cross sectional areas and water velocities. Unfortunately there are large areas of drainage basins that are ungauged. In order to calculate the total runoff for a basin it is necessary to provide estimates for the ungauged areas.

The classic water balance equation is *Runoff = Precipitation – Evaporation* which can be rewritten as $1 = \frac{R}{P} + \frac{E}{P}$. With observations of runoff and precipitation we calculate the *R/P* ratio at the gauges. If we assume that in a local area that *E* and *R/P* are constant then we can use the *R/P* ratio to estimate runoff for the ungauged portion of the area.

$$R_u = Area_u \bullet P_u \bullet {}^{R}\!/_{P}$$

We define the local areas to be in the same Water Survey of Canada drainage basin. We further divide the drainage basins into “coastal” i.e. elevation less than 1000 m and less than 100 km from the coast. Areas above 1000 m or more than 100 km from the coast are considered to be “inland”. Here snowfall that accumulates over the winter months (Oct.-Mar.) has to be redistributed over the spring freshet (Apr-Aug).

Total inland flow is calculated as the sum of three components:

$$R_m = B + P_m \square R/P_m + f(snow)_m$$

B	Base flow – the background flow rate.
$P_m \square R/P_m$	Response flow – the flow directly tied to rainfall.
$f(snow)_m$	Redistributed flow – the flow attributed to snow accumulation.

Annual freshwater outflow along the BC coast was near normal for 2010 at 963 km^3/yr. Including Neal *et al*'s (2010) estimate for average Alaskan outflow the freshwater outflow into the Gulf of Alaska was approximately 1740 km^3 in 2010. Along the coast winter and spring flows were near normal in 2010 (with the exception of the low flow in February). Summer flows were below normal but early fall flow was above normal. In the PNCIMA region winter flows were normal followed by low flow in both spring and summer. Early fall rains pushed the flow rate above the normal fall peak. The Salish Sea region had near normal flows throughout 2010.

Table 1 Annual freshwater outflow (km^3)

	Normal	2010
Stikine	95.2	94. 4
BC Coastal	657.9	620.9
Washington Coast	33.3	35.3
Columbia	211.4	212.3
Total	997.8	962.9

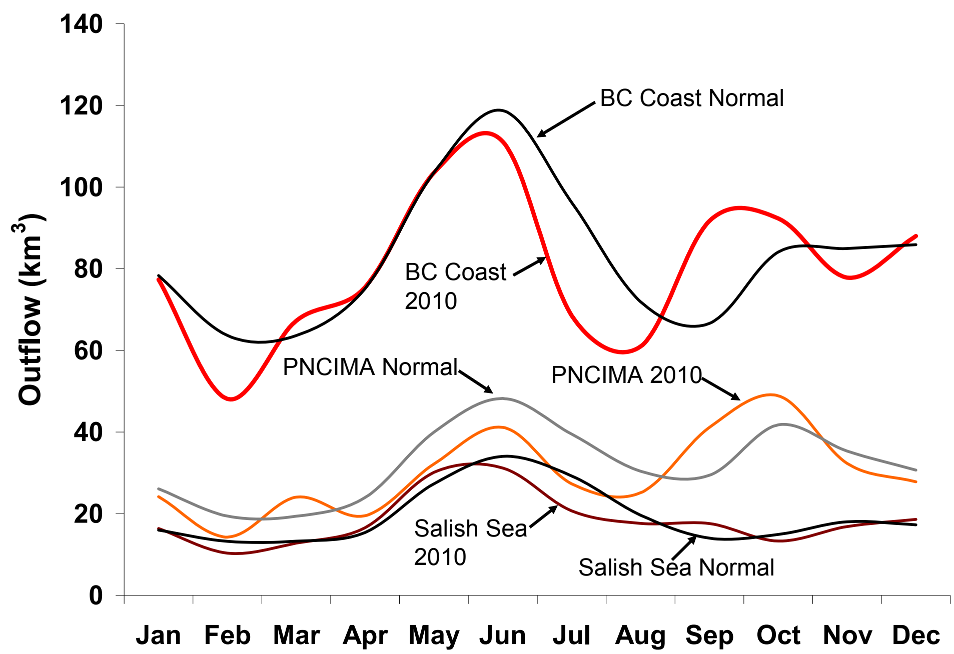

Figure. 2 Monthly river outflow 2010.   1 km^3/yr = 31.7 m^3/s

<u>Fraser River 2010 Discharge</u>

The longest continuous record for flow in British Columbia is for the Fraser River at Hope and so, although there are gauging stations below Hope, it has become the de facto standard location for evaluating changes in flow conditions for the Fraser River. In 2010 the flow tracked the long term average until May. From May until October flow was low but finished the year once again at near normal levels. Peak flow occurred on June 28 at 5950 m^3/s. This peak was later than the normal peak of 7200 m^3/s, which, on average, occurs on June 18.

Fraser River Summer Temperatures

River temperatures Observed at Qualark were above the long term average from July 8 through August 27. Throughout this time period the temperature stayed within one standard deviation of the long term average. The peak temperature was 19.2 °C on August 8 which was 2.3 °C above the 1942-2009 average for that date.

Outlook for 2011

River flows were very close to the long term average for the first 3 months of 2011. Snow accumulation, as measured by the British Columbia Ministry of Environment River Forecast Centre (http://bcrfc.env.gov.bc.ca/index.htm) is close to average throughout most of the province with some above average accumulations on Vancouver Island and the South Western corner of the Province. Close to normal outflows can be expected with the timing and intensity of the peak flow governed by spring time weather conditions.

Reference

Neal, E. G., E. Hood, and K. Smikrud, (2010) Contribution of glacier runoff to freshwater discharge into the Gulf of Alaska, *Geophys. Res. Lett*., 37 L06404

THE BC MARINE CONSERVATION ANALYSIS: COMPILING & ANALYZING COASTWIDE SPATIAL DATA FOR MARINE PLANNING

Karin Bodtker, Co-chair BCMCA, on be-half of the BCMCA Project Team (www.bcmca.ca)

The B.C. Marine Conservation Analysis (BCMCA) is a collaborative, coast-wide project whose purpose is to generate map-based data that can support marine planning initiatives in B.C., without advocating any particular outcome. The BCMCA project does not seek to replace marine planning initiatives underway or in preparatory stages in B.C. Rather, the BCMCA has developed products that illustrate the spatial distribution of biological and human use values in B.C.'s marine environment in order to inform these planning initiatives.

Products

The overall goal of the BCMCA is to identify marine areas of high conservation value and marine areas important to human use. To achieve this goal, the BCMCA assembled and analysed best-available spatial information about Canada's Pacific Ocean. Our products include:

1. An online marine atlas and data library (www.bcmca.ca/data) containing more than 260 atlas pages (Fig 1). The library is an open access resource where users can browse, view, or download ecological and human use maps, data and metadata for the Canadian Pacific. The human uses that are mapped include commercial fisheries, recreational fisheries, shipping and marine transportation, energy, recreation and tourism, and marine or foreshore tenures such as aquaculture or log booms. The ecological features include physical representation, plants, birds, fish, invertebrates and mammals.
2. A printed atlas containing a limited number of the atlas pages was released in May 2011.
3. Results from spatial analyses using the Marxan (Ball *et al* 2009) decision support tool (See Marxan analysis)
4. Workshop reports generated during data collation and review (www.bcmca.ca/document-_library/).

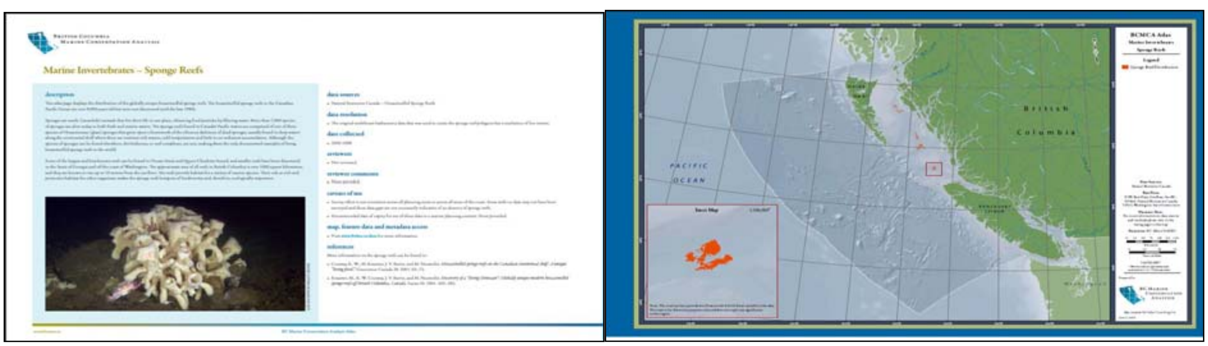

Figure 1. Example of BCMCA atlas page format. Facing page and map page are each 17 x 11 inches. No map is provided without an accompanying facing page.

Project Organisation and Collaboration

The BCMCA consists of a project team that provides overarching direction and decision-making, a Human Use Data Working Group (HUWG) that provides guidance on human use data, atlas pages, analyses using human use data, and project staff whose job it is to undertake the work of the project, as directed by the project team. The project team is made up of representatives from federal and provincial governments, academia, marine users, environmental non-governmental organizations, and observers (who are self-identified as such) from First Nations groups, the WCVI Aquatic Management Board, and the provincial government. The HUWG consists of two representatives from each of six marine use sectors. Project staff include a project manager, data manager, project assistant, and external consultants from time to time.

Since the project started in 2006, individuals involved in the BCMCA representing those organizations, agencies, and marine user groups may have changed, but the organizations, agencies and groups collaborating on the project have remained fairly consistent. All these groups are collaborating in order to prepare for marine planning and because they saw value in commonly held data sets that were collaboratively assembled and reviewed. The discussion about best-available data was initiated several years ago so that planning tables today could focus on planning.

Methods – collating biophysical and human use data

Beginning in the fall of 2006, the BCMCA held five expert workshops on seabirds, invertebrates, plants, mammals, and fishes. At each workshop we asked experts in their field to recommend an inventory of biophysical features, identify the best-available data to represent those features, and to recommend targets to be used in Marxan analyses for each feature. Features to best represent the physical marine environment were proposed by the BCMCA after reviewing best-practices and other similar projects. Expert review was sought and the feature and data lists were revised accordingly. In all, about 250 datasets were recommended, and 185 features were assembled and mapped. It took more than two years to obtain, assemble, and prepare data sets, which were then reviewed again by experts.

In 2008, the BCMCA began assembling known human use data held by BCMCA project team organisations and identified six sectors of human use (i.e., commercial fisheries, recreational fisheries, ocean energy - wind, wave, tidal, oil, gas - , shipping and transportation, tenures, and recreation and tourism). Seeking advice and feedback from human use groups about the overall project, the BCMCA met with representative organisations and advisory boards and, based on feedback from these meetings, a Human Use Data Working Group was created. Through this group, and with the cooperation and assistance of many individuals, approximately 100 human use data sets were reviewed for accuracy and completeness. In a few cases data were improved by the BCMCA, but in all cases comments from reviewers are included as part of the atlas facing page information.

Results – marine atlas and data library content

The online library content includes:

- 182 ecological and 78 human use atlas pages (pdf)
- Metadata for all features
- Spatial data for download as permitted
- Information on data sources, custodians

Over the next two years BCMCA plans to focus on increasing awareness, and delivering and facilitating the use of their products. This next phase of the project is flexible enough to provide improvements and updates that are broadly requested. The BCMCA is working to ensure the long-term life of the data library either through a sustainable financing mechanism or integration with another appropriate data sharing group or site.

Marxan analysis

The BCMCA used Marxan to explore a range of “What if…?” scenarios designed to identify areas of high conservation value and areas important to each sector of human use based on data collated for the atlas. Marxan uses an optimization algorithm to select areas that meet a range of targets at the least cost. In the examples presented here, the BCMCA asked, “What if… *xx* percent of each of the ecological features we mapped were to be captured in the solution in the least amount of overall area?” The BCMCA experimented with different targets (Fig. 2) and a parameter that controls the size of the ‘solution areas’ (Fig. 3).

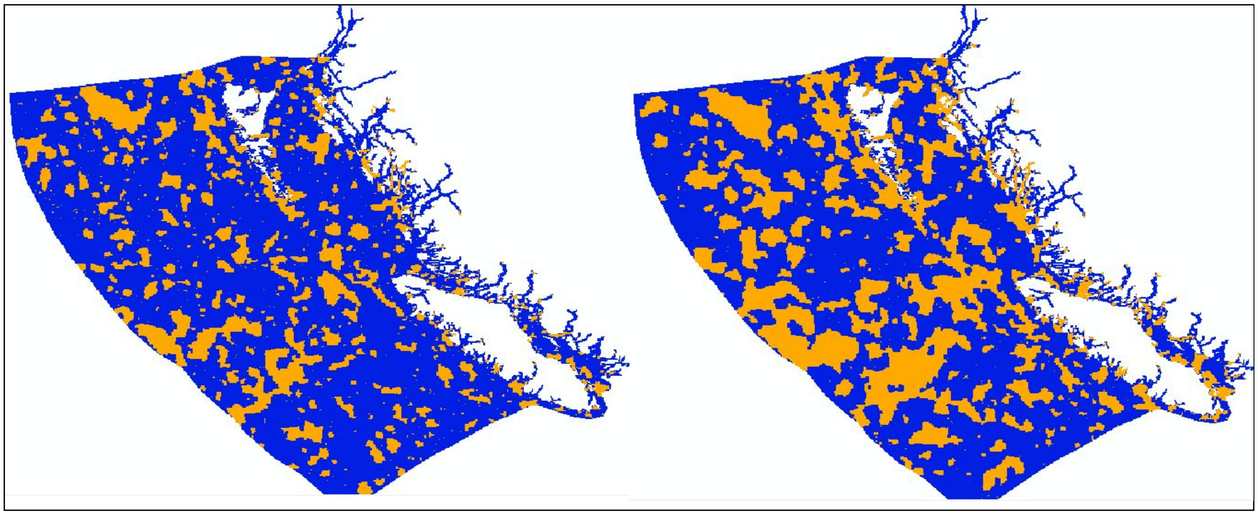

Figure 2. Example results from Marxan analyses for marine waters of B.C. extending to the limits of the Canadian Pacific Economic Exclusive Zone. Yellow clumps comprise one possible solution to the question, "What if… you want to capture 20% (left) versus 30% (right) of all ecological features?"

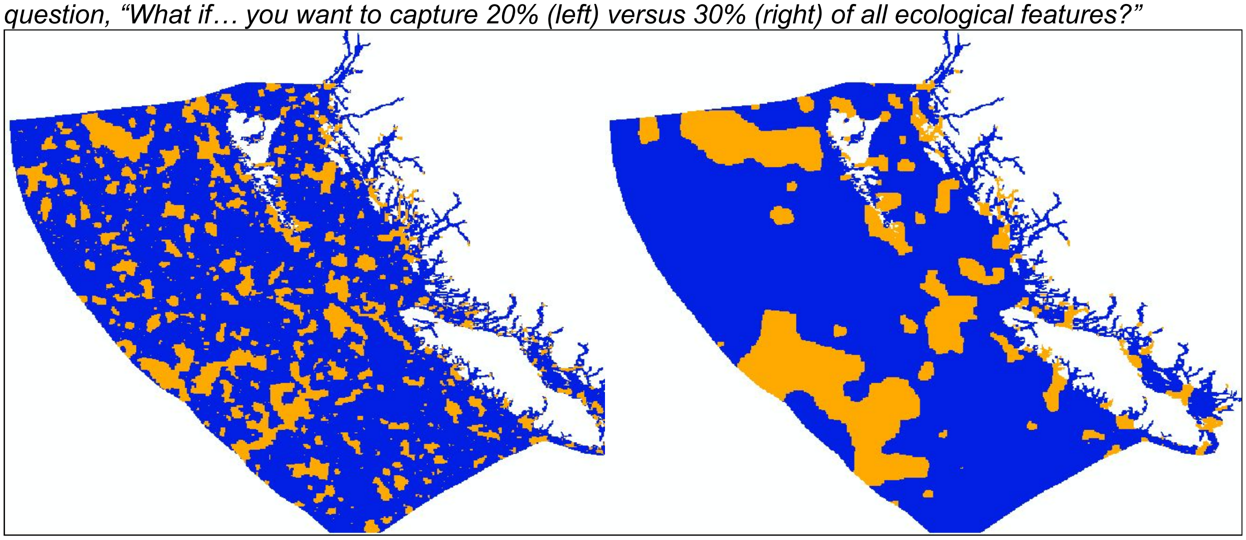

Figure 3. Example results from Marxan analyses for marine waters of B.C. extending to the limits of the Canadian Pacific Economic Exclusive Zone. Yellow clumps comprise one possible solution to the question, "What if… you want to capture 20% of all ecological features in small (left) versus large (right) areas?"

In each of these examples the orange areas taken together represent one possible solution to the question posed, meaning all the targets were met in the least total area with the requested size of 'clumps.' Higher targets result in a larger 'footprint' overall (Fig. 2). The solutions illustrated in Fig. 3 both capture 20% of all the ecological features, but they do it in significantly different spatial patterns. Marxan results provide fodder for discussion. Please visit www.bcmca.ca/data for comprehensive reporting on methods and results.

Reference

Ball, I.R., H.P. Possingham, and M. Watts. 2009. Marxan and relatives: Software for spatial conservation prioritisation. Chapter 14: Pages 185-195 *in* Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen, A., K.A. Wilson, and H.P. Possingham. Oxford University Press, Oxford, UK.

RIVERS INLET ECOSYSTEM

Rich Pawlowicz, Susan Allen, Brian Hunt, Dept. Of Earth and Ocean Sciences, University of British Columbia, (on behalf of the Rivers Inlet Ecosystem Study team)

Introduction

Rivers Inlet is a fjord-type inlet opening directly into southeast Queen Charlotte Sound. Historically the third most important sockeye salmon fishery in BC, after the Fraser and Skeena rivers, Rivers Inlet supported almost a dozen canneries in the 1930s. However, the stock crashed in the 1990s to below 0.1% of historic levels. Although the stock has since recovered slightly, it remains closed to commercial fishing but has a small First Nations fishery of ≤ 4000 fish / year.

Recently, it was proposed that the demise of the stock might be due to increased mortality in the early marine phase of the smolts' life history (Mckinnell *et al*., 2001). The Rivers Inlet Ecosystem Study (RIES, www.ries.ubc.ca, a collaboration between UBC, SFU, and DFO) was then developed in order to quantify the seasonal and interannual variation in marine conditions in the inlet, and its relationship to smolt growth. The program conducted intensive bio-oceanographic sampling, generally fortnightly, between late February and September from 2008 to 2010, and seine netting for smolts during their ocean entry period (May and June) over the same years. This report will provide a brief overview of the physical oceanographic conditions, the timing of the spring bloom and estimates of phytoplankton biomass, zooplankton biomass and sockeye smolt size.

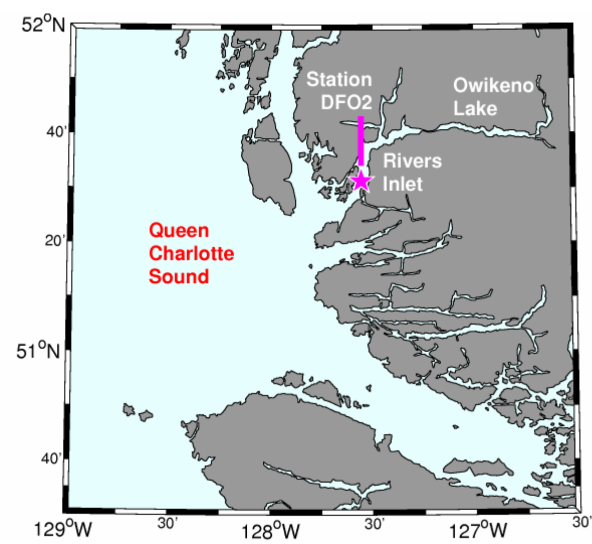

Figure 1. Rivers Inlet in the British Columbia central coast.

Oceanographic Background

Rivers Inlet has a relatively simple bathymetry, consisting of a single main channel about 40km long, 3km wide, and 200-300m deep. It does not have a sill per se, but rather opens out onto the SE part of Queen Charlotte Sound where bottom depths are around 120m. The main source of freshwater is the 6.5km-long Wannock River, which joins Rivers Inlet to the 60km long Owikeno Lake. The Wannock River has a pronounced freshet pattern, with low flow through the winter, increasing through May and June to an average peak in early July, and then falling through the remainder of the year. However, the flow can rapidly increase to several times the mean in response to storms, and this typically happens up to 4 times over the summer and fall.

Surface waters in Rivers Inlet are highly stratified, especially during the freshet. At these times salinities rapidly decrease in the upper 4m and nearly fresh water can be found at the surface some distance from the river. However, the river is not particularly turbid in the early parts of the freshet. Turbidity increases rapidly and peaks only in late July/early August.

Deep Water Renewal

Densities (and salinities) below 200m have an opposite cycle to that in surface waters, showing a summer increase (Fig. 2a). The summer increases are not continuous, but are divided into periods when density is increasing and periods when a small decrease occurs. Periods of density increase correspond well with upwelling-favourable winds from the north and northwest at the Sea Otter weather buoy (c46204) in Queen Charlotte Sound. Thus wind-driven upwelling governs deep water renewal of Rivers Inlet as it does on the Washington, Oregon and west coast Vancouver Island coasts. However, although weak upwelling can occur over long periods of time (as in 2008), or briefly but strongly (as in 2010), the precise characteristics of the deep water are not easily related to these features. During the period from October to May densities decrease, although at present there has been little sampling during these times so the rate of decrease can only be inferred.

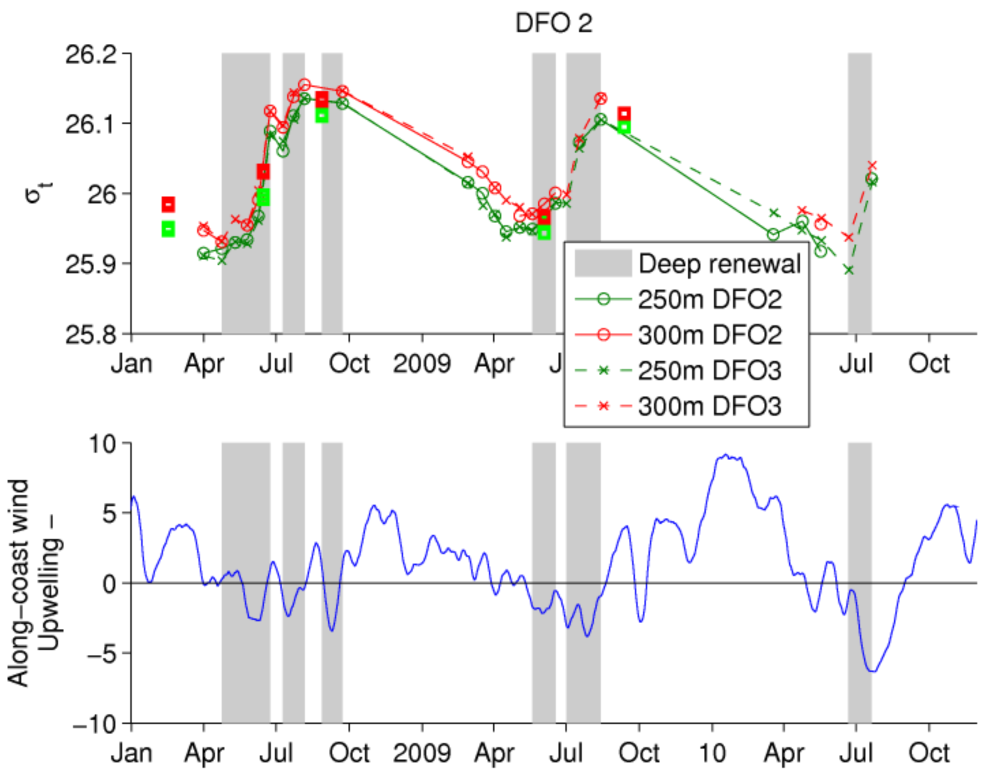

Figure 2. a) Densities at 250m and 300m from two stations in Rivers Inlet. b) Alongshore winds at Sea Otter weather buoy (metres/s). Gray shading indicates periods when deep water densities are increasing.

Phytoplankton biomass

Nutrient levels in waters deeper than 30 m are in the range of 20-30 uM (Fig. 3a), but do vary slightly from year to year (Hodal, 2011). In winter nutrient levels at the surface are high, and may be similar to deep levels. However, from approximately April onwards near-surface nitrate levels are low (Fig 3a), even close to zero at some depths (not shown). Chlorophyll biomass peaks sometime in April or May (Fig. 3c) as a classic spring bloom (somewhat later than blooms on WCVI and in the Strait of Georgia). Following this peak, biomass levels drop abruptly and remain at a lower level throughout the rest of the summer. These lower levels cannot entirely result from nutrient limitation, because rates of new production of phytoplankton inferred from nutrient budgets are relatively constant through the spring and summer (Fig. 3b). Instead, the onset of the freshet dramatically reduces the residence time of surface waters in Rivers Inlet. Advective losses increase and ultimately limit the available phytoplankton biomass in summer.

Spring bloom timing

The timing of the spring phytoplankton bloom has been investigated using a one-dimensional coupled biophysical model constructed for deep estuarine systems (Collins *et al*, 2009). It was found that the timing of the spring bloom was not governed by variations in available light, as skies are always relatively overcast. Instead, blooms are inhibited by wind-driven mixing and especially from large, short-term advective losses that result from short-lived but intense outflow winds (Wolfe, 2010). In 2009 the spring bloom was two weeks later than in 2008 even though cloud cover, wind strength, and river flow were almost identical to 2008; (Fig. 3). The difference between the two years was the direction of the winds; with the strong late winter/early spring winds being outflow winds in 2009 and inflow winds in 2008. High winds in these strongly stratified fjords lead to rapid near-surface flows (Baker and Pond, 1995). If the winds and thus the surface currents flow out of the fjord, phytoplankton biomass is lost from the fjord through advection. The annual shift in wind direction from inflow to outflow in late March to early May is labelled the spring transition (Wolfe, 2010). This transition can be abrupt, but is normally spread out over several weeks to a month. The general trend towards a later spring transition since the 1990's may therefore have delayed the onset of the spring bloom in the last two decades (Logerwell *et al*. 2003).

Interestingly, advection of plankton-rich water from Rivers Inlet might provide needed prey for seabirds on Triangle Island in southwest Queen Charlotte Sound. Seabirds on this island require plankton-rich waters early in April for a successful breeding year (Borstad *et al*. 2011)

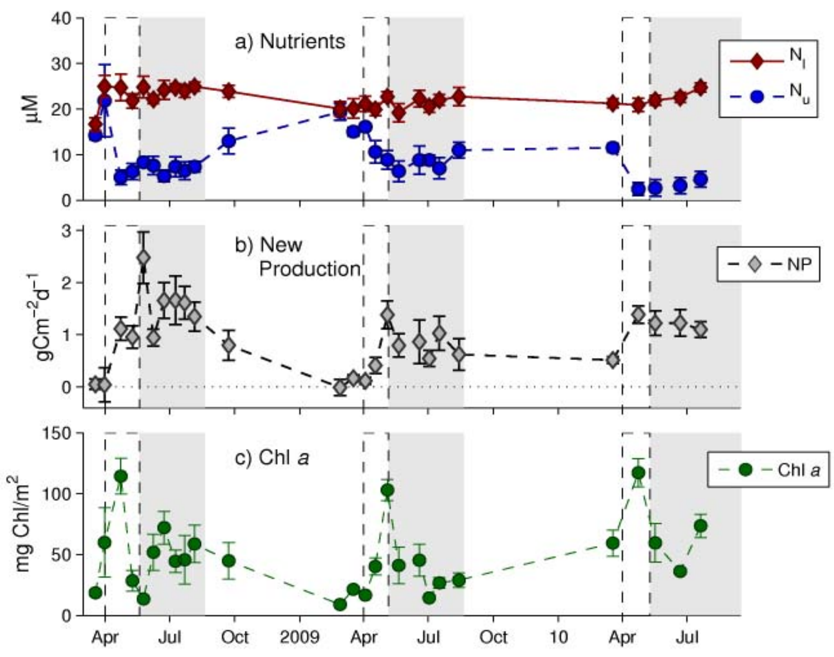

Figure 3. (a): Average nutrients in upper (Nu) and lower (Nl) layers of Rivers Inlet. (b): New Nitrate production inferred from nitrate budgets. (c): Chlorophyll biomass. Shaded areas show the freshet. Figure from Hodal (2011).

Zooplankton biomass

It was hypothesized that the timing of the spring bloom would control interannual variation in zooplankton biomass in the inlet. Average June biomass between 2006 and 2010 was 17.57 g dry weight m^{-2} (Fig. 4a). Lowest biomass levels were recorded in 2008 (9.87 gDW m^{-2}) when bloom timing was typical, and highest in 2010 when the spring bloom was earliest (23.95 gDW m^{-2}). Overall, however, no clear relationship was seen between bloom timing and summer zooplankton biomass.

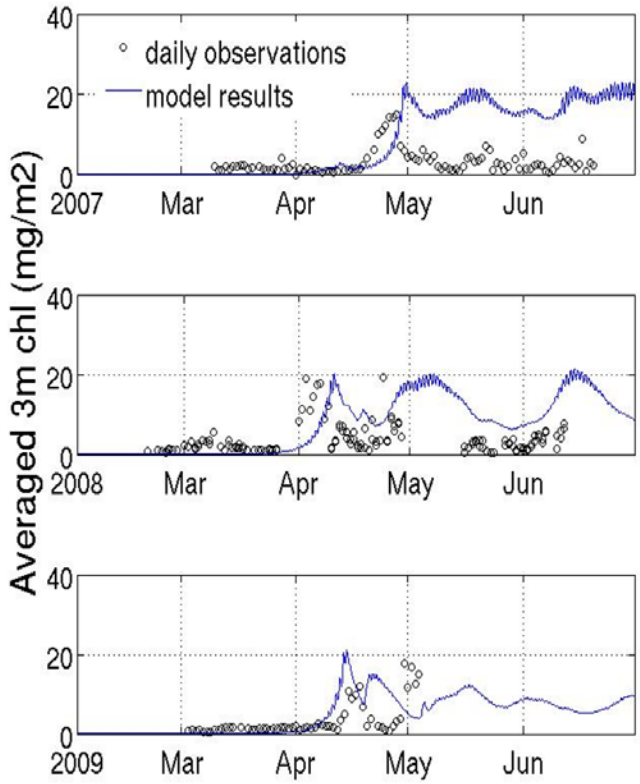

Figure 4. Comparison of model results to daily observations in Rivers Inlet for 2007, 2008 and 2009, respectively. Note that the model is designed only to represent the spring bloom and details after the bloom are not expected to match the observations. From Wolfe (2010)

Smolts

Sockeye smolt average weight-at-length (A. Ajmani, unpublished data) showed no clear relationship with integrated zooplankton biomass (Fig. 5b). The length-weight relationships of smolt were almost identical in 2008 and 2009 despite 47% greater zooplankton biomass in the latter year. In 2010 however, smolt consistently had a higher biomass per unit length after entering the inlet, and at 110 mm were ~13% heavier than fish of the same length in 2008 and 2009. Differences in smolt growth between years may be determined by prey type and and/or quality. Preliminary results show that interannual variation in smolt gut contents have no relationship with water column integrated zooplankton communities (A. Ajmani and D. Tomassi, unpublished data), suggesting that it is surface processes (upper 30m) that are critical to sockeye growth. Future work is focussing on the fine scale distribution of zooplankton in relation to the halocline. The physiological rate processes of smolt, and the effect of salinity and temperature on these, can also not be discounted as factors affecting their early marine growth.

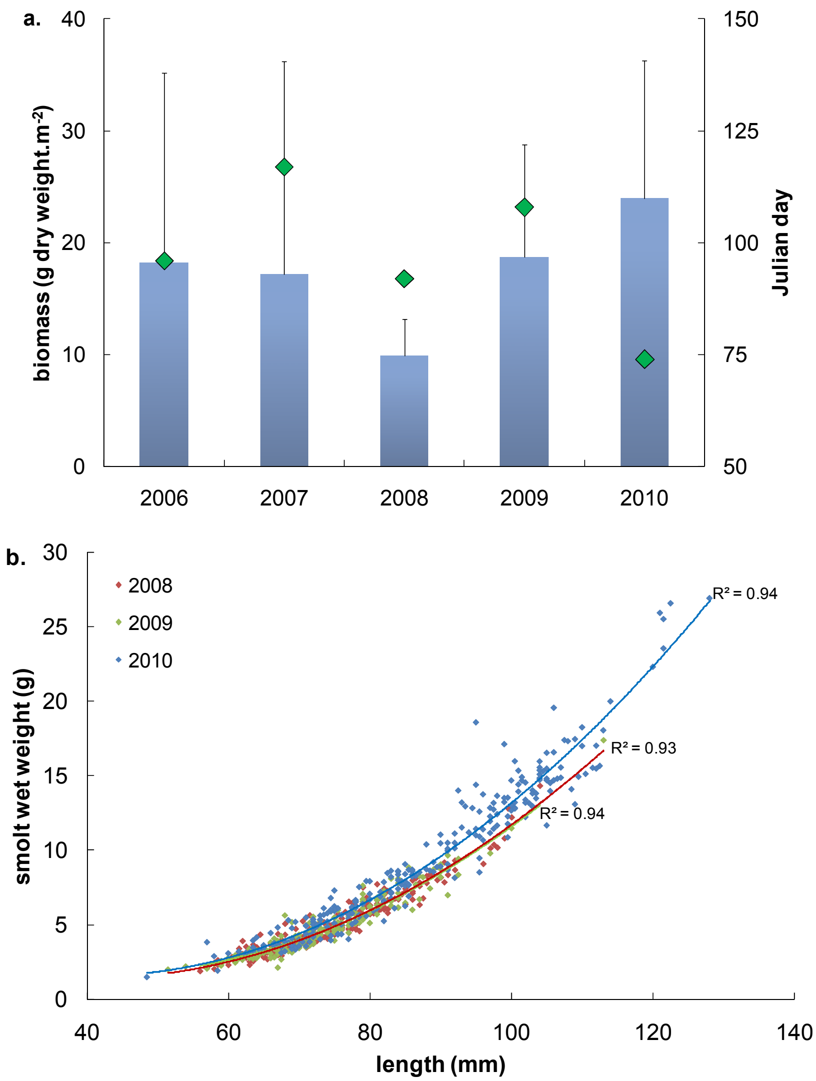

Figure 5: a) Average June zooplankton biomass (g dry weight .m^{-2}) integrated over the entire water column from six Rivers Inlet stations for 2006 to 2010 (bars, scale at left). Also indicated is the timing of the spring bloom (green diamonds, Julian day scale at right); b) Length-wet weight (g) relationships for sockeye salmon smolt collected by seine net at sites spanning the entire inlet, for 2008 (red), 2009 (green), and 2010 (blue). Trendlines are second order polynomials.

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SEABIRD BREEDING ON TRIANGLE ISLAND IN 2010: AN EXTREMELY POOR SEASON

Mark Hipfner, Environment Canada

Triangle Island Background and Species Natural History

Marine birds can be effective indicators of the state of marine ecosystems because they gather in large and highly visible aggregations to breed and because, as a group, they feed on a variety of trophic levels (zooplankton to fish). Seabird breeding success is closely tied to the availability of key prey species, and as a result, can vary widely among years, depending on ocean conditions.

Triangle Island (50°52' N, 129°05' W) in the Scott Island chain off northern Vancouver Island, supports the largest and most diverse seabird colony along the coast of British Columbia. Since 1994, researchers from the Centre for Wildlife Ecology (a collaboration between Environment Canada and Simon Fraser University), have visited Triangle Island to collect annual time-series information on seabird demography and ecology. This report presents key indicators of seabird breeding at Triangle Island in 2010, and places 2010 results within the context of the 1994-2010 time series.

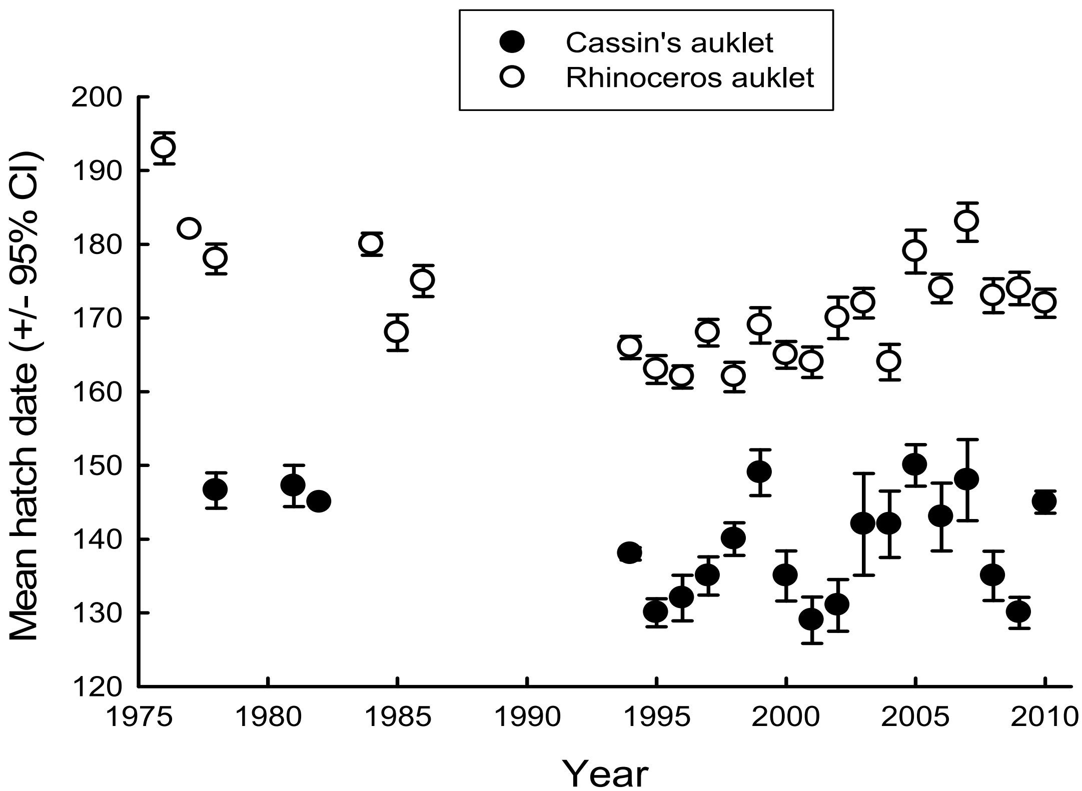

Figure 1. Timing of breeding for two focal seabirds – zooplanktivorous Cassin's auklet and more piscivorous Rhinoceros auklet - on Triangle Island, British Columbia, 1976-2010. Timing of breeding was late in Cassin's auklets, and near long-term averages in Rhinoceros auklets

Timing of breeding

Variation in the timing of avian breeding is determined primarily by female condition prior to and during the period of egg formation, which is itself related to food availability early in the season. Over the last 16 years, Cassin's auklets in general have tended to lay eggs earlier in cold-water years and to breed more successfully as a result. Note that hatching occurred relatively late in 2010 (Fig. 1). For Rhinoceros Auklets, timing of breeding in general remained consistent in recent years and close to long-term averages (Fig. 1).

Breeding success

The mean growth rate of Cassin's Auklet nestlings that hatched prior to 25 May was extremely low in 2010 – in fact, the lowest in the time series by quite a wide margin (Fig. 2). In general, the auklets' offspring grow more quickly and fledge at heavier masses in cold-water years, because timing of their hatching is strongly temporally matched with the phenology of an important prey species, the copepod *Neocalanus cristatus*. Thus, the low growth rates in 2010 were expected, based on the warm spring sea-surface temperatures in 2010. Unfortunately, diet data for 2010 are unavailable at time of writing.

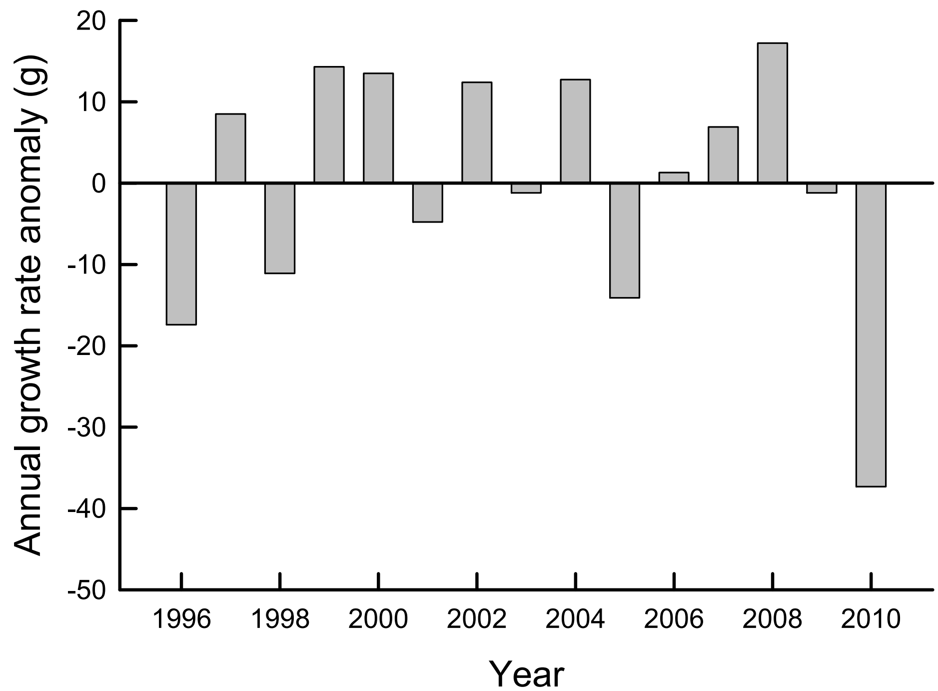

Figure 2. Anomaly of annual growth rate of Cassin's auklets nestlings from 1996 to 2010.

Links:

Scott Islands Marine Wildlife Area http://www.cpawsbc.org/pdfs/scott_islands_mwa.pdf

Canadian Wildlife Service bird monitoring in BC
http://www.ecoinfo.ec.gc.ca/env_ind/region/seabird/seabird_data_e.cfm#Map

Environment Canada Contact: Mark Hipfner (mark.hipfner@ec.gc.ca)

AN OVERVIEW OF PNCIMA GROUNDFISH RESOURCES AND FISHERIES

Greg Workman and Kate Rutherford, Fisheries and Oceans Canada

The following synopsis endeavours to capture the overall scale, status, diversity of species and diversity of commercial fisheries within this region of the BC coast. Table 1 presents the average annual catches from 2007 to 2010 by trawl gear (bottom and mid-water combined) in PNCIMA. Catches are summarized as landed, released, and total, in metric tonnes, and for the purposes of comparison we present the coast-wide catch, the catch from PNCIMA and the proportion of the catch from the PNCIMA region. Pacific Hake is the single largest species catch both coast-wide and within PNCIMA with almost all catch being taken by mid-water trawl gear. An average of almost 44,000 metric tonnes of mixed groundfish was harvested annually within PNCIMA by trawl gear, of which approximately 22,500 metric tonnes (51%) was Pacific Hake.

Table 1. Comparison of average annual trawl catches (metric tonnes), 2007-2010, between the PNCIMA area and the entire BC coast.

	Total (mt, landed + released)			Landed (mt)			Released (mt)		
SPECIES	Entire coast	PNCIMA area	Proportion from PNCIMA	Entire coast	PNCIMA area	Proportion from PNCIMA	Entire coast	PNCIMA area	Proportion from PNCIMA
Pacific Hake	61499.06	22497.00	0.37	60033.39	22077.77	0.37	1465.67	419.23	0.29
Pacific Ocean Perch	4617.28	4116.11	0.89	4477.00	4007.83	0.90	140.28	108.28	0.77
Walleye Pollock	2813.13	2629.49	0.93	2540.60	2393.40	0.94	272.53	236.09	0.87
Arrowtooth Flounder	3771.05	2174.24	0.58	1781.28	690.01	0.39	1989.77	1484.23	0.75
Yellowtail Rockfish	4302.30	1624.15	0.38	4210.93	1565.15	0.37	91.37	59.00	0.65
Yellowmouth Rockfish	1292.38	1255.51	0.97	1264.93	1229.11	0.97	27.45	26.40	0.96
Dover Sole	1747.27	1045.46	0.60	1584.20	937.08	0.59	163.07	108.38	0.66
Rock Sole	958.45	937.63	0.98	854.05	836.57	0.98	104.40	101.06	0.97
Widow Rockfish	1542.41	749.68	0.49	1529.66	742.82	0.49	12.75	6.86	0.54
Silvergray Rockfish	893.78	745.99	0.83	623.57	540.07	0.87	270.21	205.91	0.76
Pacific Cod	962.55	703.22	0.73	909.16	674.69	0.74	53.39	28.53	0.53
Rougheye Rockfish	724.02	653.35	0.90	705.39	642.04	0.91	18.63	11.30	0.61
Lingcod	1276.70	615.22	0.48	1195.92	571.17	0.48	80.78	44.05	0.55
English Sole	690.63	535.30	0.78	553.77	442.61	0.80	136.86	92.69	0.68
Big Skate	529.78	504.16	0.95	467.54	445.52	0.95	62.25	58.64	0.94
Redstripe Rockfish	694.19	499.92	0.72	462.99	351.07	0.76	231.21	148.84	0.64
Spiny Dogfish	1517.33	360.31	0.24	524.82	8.92	0.02	992.51	351.39	0.35
Shortspine Thornyhead	457.46	317.48	0.69	439.30	305.53	0.70	18.15	11.95	0.66
Rex Sole	424.19	313.87	0.74	268.92	218.38	0.81	155.27	95.49	0.61
Canary Rockfish	668.97	297.17	0.44	667.27	296.62	0.44	1.69	0.55	0.33
Pacific Halibut	363.51	296.38	0.82	3.28	0.13	0.04	360.24	296.25	0.82
Petrale Sole	610.89	265.06	0.43	570.85	250.39	0.44	40.04	14.67	0.37
Sharpchin Rockfish	264.65	186.67	0.71	140.19	93.71	0.67	124.47	92.96	0.75
Redbanded Rockfish	163.06	146.35	0.90	160.56	144.88	0.90	2.50	1.47	0.59
Sablefish	360.31	145.05	0.40	259.19	96.35	0.37	101.12	48.70	0.48
Splitnose Rockfish	184.45	119.85	0.65	87.21	52.20	0.60	97.25	67.65	0.70
Longnose Skate	193.07	65.78	0.34	148.02	46.82	0.32	45.05	18.96	0.42
Bocaccio	106.08	63.53	0.60	62.23	34.86	0.56	43.85	28.67	0.65
Longspine Thornyhead	101.14	44.84	0.44	83.84	37.63	0.45	17.30	7.22	0.42
Other	3.21	1.88	0.59	2.87	3.26	1.14	2.24	1.41	0.63

The start locations of trawl sets during 2007-2010 (Fig. 1) illustrate the major fishing grounds in Queen Charlotte Sound (e.g. Goose Island Gully, Mitchells Gully and Cape St. James) and in Dixon Entrance (e.g. near Dundas Island) and off the northwest coast of Haida Gwaii.

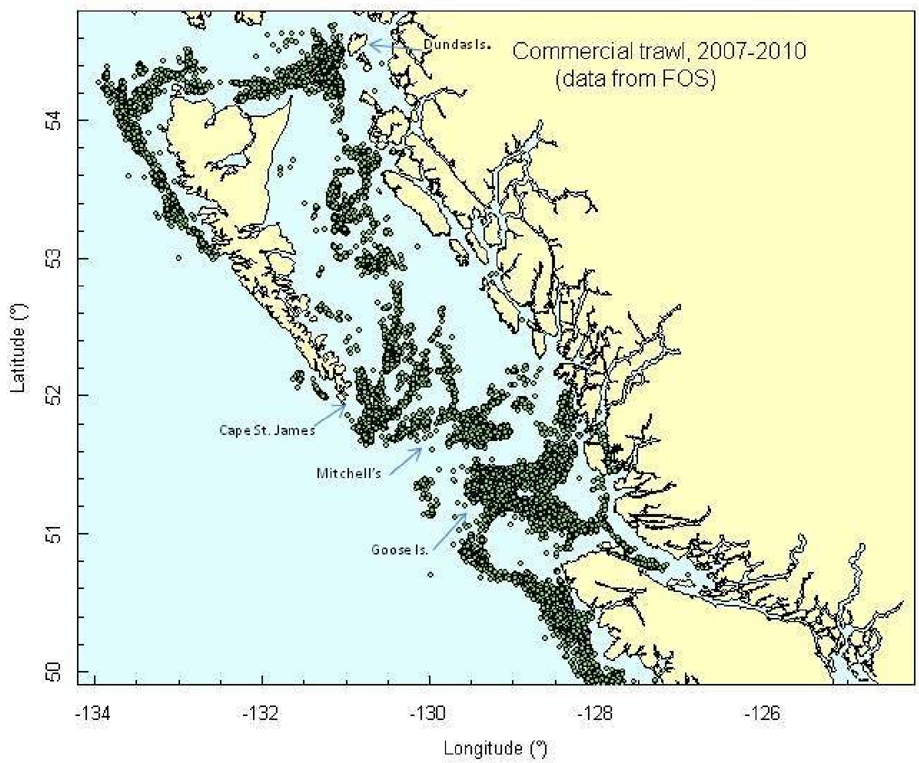

Figure 1. Plot of the start location of all trawl sets (bottom and mid-water) within PNCIMA. FOS = Fishery Operations System.

Groundfish are also taken by a variety of non-trawl gear (Fig. 2) including longline hook and line, longline trap, jig and troll across several license categories, see the DFO Integrated Fisheries Management Plan (DFO 2011) for species and gear specific TACs (Total Allowable Catches) and management measures. The largest catches by non-trawl gear within PNCIMA are Pacific Halibut, Sablefish and Lingcod. Coastwide the story is a little different with Pacific Halibut, Sablefish and Spiny Dogfish comprising the three largest non-trawl groundfish catches.

Table 2. Comparison of average annual trap & longline catches, 2007-2010, between PNCIMA and the entire BC coast.

	Total (mt, landed + released)			Landed (mt)			Released (mt)		
SPECIES	Entire coast	PNCIMA area	Proportion from PNCIMA	Entire coast	PNCIMA area	Proportion from PNCIMA	Entire coast	PNCIMA area	Proportion from PNCIMA
Pacific halibut	4203.80	3823.88	0.91	4082.21	3713.58	0.91	121.59	110.30	0.91
Sablefish	3145.21	2338.59	0.74	3055.26	2278.18	0.75	89.95	60.41	0.67
Lingcod	861.69	706.28	0.82	857.35	702.80	0.82	4.34	3.48	0.80
Rougheye rockfish	352.27	303.15	0.86	352.26	303.15	0.86	0.01	0.01	1.00
Spiny dogfish	2696.18	239.22	0.09	2607.19	199.55	0.08	88.99	39.68	0.45
Yelloweye rockfish	289.92	237.65	0.82	289.91	237.63	0.82	0.02	0.02	0.94
Redbanded rockfish	238.15	210.61	0.88	238.13	210.60	0.88	0.02	0.02	1.00
Longnose skate	290.13	189.77	0.65	284.37	184.01	0.65	7.67	7.67	1.00
Quillback rockfish	131.46	108.87	0.83	131.46	108.87	0.83	0.01	0.01	1.00
Shortraker rockfish	91.16	74.16	0.81	91.14	74.15	0.81	0.07	0.07	1.00
Shortspine thornyhead	81.05	70.08	0.86	81.05	70.07	0.86	0.01	0.01	1.00
Silvergray rockfish	67.16	61.68	0.92	67.14	61.66	0.92	0.02	0.02	1.00
Big skate	112.88	50.23	0.45	111.09	48.44	0.44	2.39	2.39	1.00
Copper rockfish	39.91	33.03	0.83	39.91	33.02	0.83	0.00	0.00	1.00
Canary rockfish	25.45	18.25	0.72	25.44	18.25	0.72	0.02	0.02	1.00
Bocaccio	17.03	14.01	0.82	17.03	14.01	0.82			
China rockfish	12.71	10.53	0.83	12.71	10.53	0.83	0.00	0.00	1.00
Yellowmouth rockfish	11.04	9.85	0.89	11.04	9.85	0.89	0.00	0.00	1.00
Black rockfish	10.87	9.43	0.87	10.87	9.43	0.87			
Kelp greenling	8.67	7.79	0.90	8.67	7.79	0.90			
Other	1.03	0.79	0.77	1.24	1.02	0.83	0.23	0.24	1.04

As was the case with trawl gear the following three maps plot the start location of fishing events between 2007 and 2010.

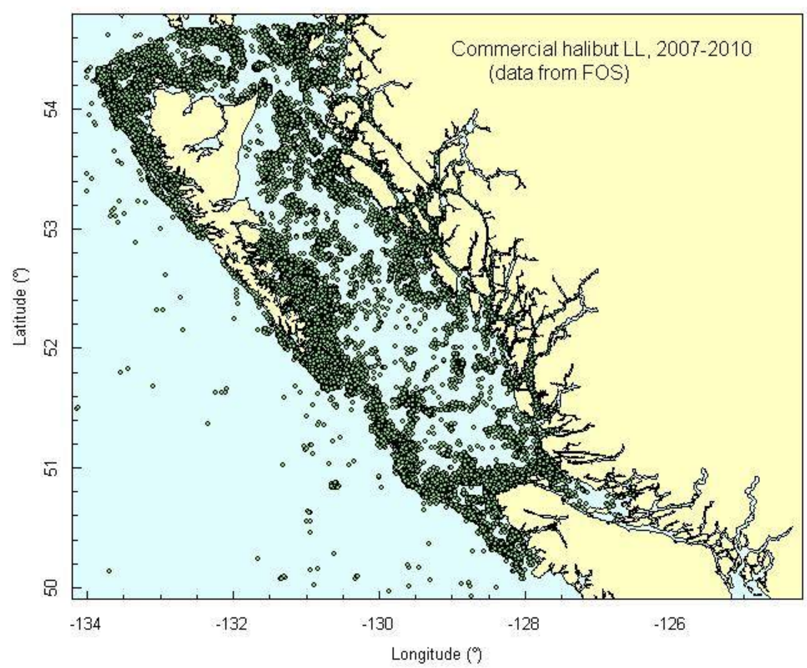

Figure 2: Set locations for all directed sets for Halibut by longline hook and line gear in PNCIMA. FOS = Fishery Operations System.

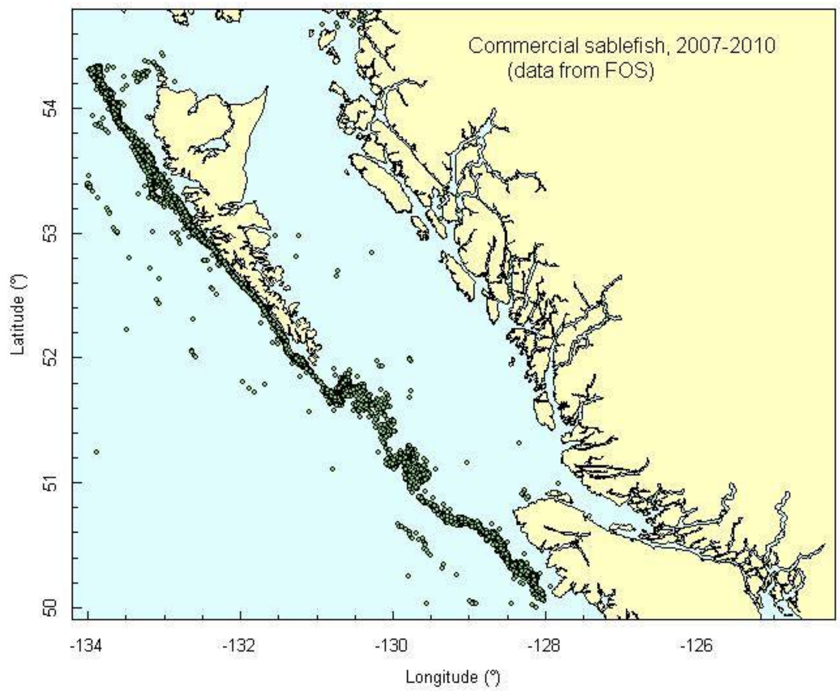

Figure 3: Set locations for all directed sets for Sablefish by longline trap and hook and line gear in PNCIMA. FOS = Fishery Operations System.

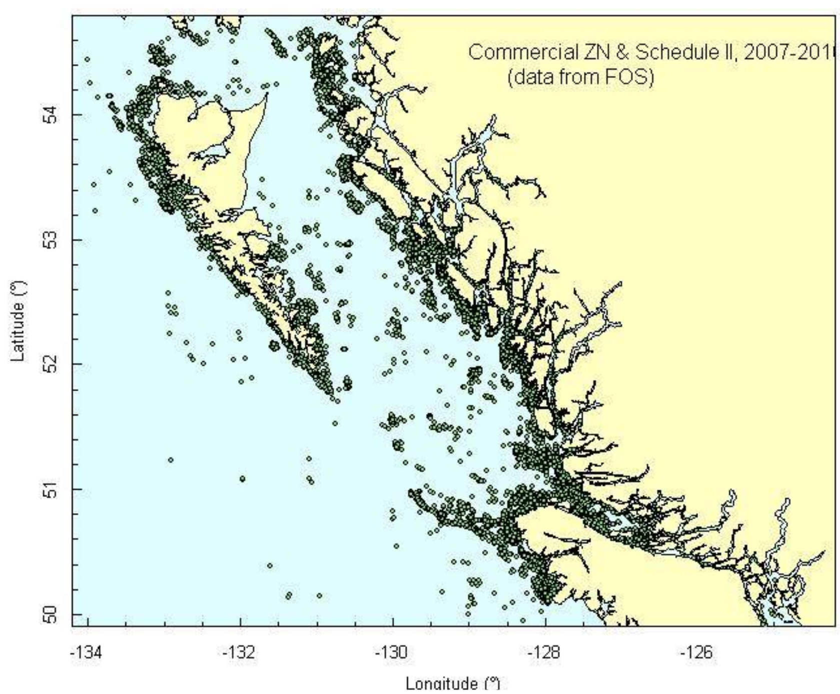

Figure 4: Set locations for all directed sets for rockfish, lingcod and dogfish by hook and line gear in PNCIMA. FOS = Fishery Operations System.

Species specific spatial patterns are evident from Fig. 3-4. For instance the sablefish fishery operates primarily in a narrow depth band off the continental slope (Fig. 3), while inshore rockfish (ZN), Lingcod and Spiny Dogfish (Schedule II) fisheries occur primarily near shore (Fig. 4). The Pacific Halibut fishery appears to be more dispersed (Fig. 2) but this does not necessarily illustrate Pacific Halibut distribution because many of these trips may have been targeting other species as well as Halibut under the integrated fisheries management plan (DFO, 2011).

In this section of the document we will summarize the status of each of the major species or species groups within PNCIMA with respect to the status of harvest advice, the proportion of the catch taken within PNCIMA, the status of individual species with respect to assessment by the Committee On the Status of Endangered Wildlife In Canada (COSEWIC) and status under the Species At Risk Act legislation (SARA).

<u>Rockfish</u>

Slope rockfish are a large species aggregate comprising seven species managed by DFO using total allowable catch (TAC) limits plus half a dozen minor species, generally distributed on the continental slope between 200 and 1500 m depth. The seven species managed by TAC are: Pacific Ocean Perch, Yellowmouth, Redstripe, Rougheye, Shortraker, Shortspine Thornyhead, and Longspine Thornyhead Rockfishes. Non-quota species include Darkblotched, Sharpchin, Redbanded, and Splitnose Rockfishes which are landed incidentally with the more abundant quota species. All species are long-lived, which usually means that stocks decline when fished until an oceanic regime fosters better-than-average recruitment success. Four slope rockfish species have been assessed by COSEWIC including one non-quota species, Darkblotched Rockfish. Rougheye Rockfish, and Longspine Thornyhead were designated 'Special Concern' by COSEWIC in 2007 and by the Species at Risk Act (SARA) in 2009; a draft management plan for these species has been submitted for first review by DFO National Headquarters. Yellowmouth Rockfish were designated 'Threatened' by COSEWIC in 2010, triggering a stock assessment and recovery plan due 2011. Darkblotched Rockfish were designated 'Special Concern' by COSEWIC in 2009 and a management plan is under development. Yellowmouth and Darkblotched Rockfishes have not yet been designated by SARA.

Queen Charlotte Sound Pacific Ocean Perch were assessed in 2010 using a Bayesian catch-at-age model (Edwards *et al*. 2011). Results showed that the stock has declined to 12-43% or 8-24% of its unexploited equilibrium value (two ranges refer to the two accepted model runs). However, the population probably lies above its limit reference point of 0.4 of the biomass at maximum sustainable yield (B_{msy}), with probabilities of 0.96 or 0.82. If below the limit reference point, the stock would be considered to be in the 'critical zone' with respect to DFO's Precautionary Approach framework.

As Yellowmouth, Redstripe, Rougheye, Shortraker, and Shortspine Thornyhead stocks were last assessed in 1999 (Schnute *et al*. 1999), their current stock status is unknown. Longspine Thornyhead rockfish were last assessed in 2001 when localized declines in catch per unit effort were noted at several locations on the BC coast (Starr 2001). Rougheye Rockfish have recently been determined to be a complex of two sympatric species, Rougheye and Blackspotted Rockfish; this has hampered development of a stock assessment for this species due to the impossibility of assigning catch to one species or the other.

On average over the last four years 86% of trawl and 86% of non-trawl slope rockfish catches coastwide were taken in the PNCIMA.

Shelf Rockfish comprise five species managed by TAC and, like slope rockfish, include a half dozen or more less common species generally distributed between 50 and 300 m depth over the continental shelf. The quota managed species include Boccaccio, Canary, Silvergrey, Widow and Yellowtail Rockfishes; non-quota species include Chillipepper, Shortbelly, and Black Rockfishes. Two shelf rockfish species have been assessed by COSEWIC, Bocaccio in 2002 and Canary Rockfish in 2007; both species were designated 'Threatened' triggering preparation of updated stock assessments in 2008 and 2009, respectively (Stanley *et al*. 2009, Stanley *et al*. 2009). Stock status for both species is deemed to be depleted but stable and the stocks are currently rebuilding under reduced Total Allowable Catches (TACs). Neither Bocaccio nor Canary Rockfish have been designated by SARA.

Silvergray Rockfish were last assessed in 2002 (Stanley and Olsen 2002) and concluded to be stable or increasing. Widow Rockfish were assessed in 1999 at which time it was determined that the species was data limited and that quotas should not be raised. Yellowtail Rockfish were last assessed in 1997, and were considered in decline at that time, the current status for all three species is unknown.

On average over the last four years 46% and 86% of trawl and non-trawl shelf rockfish catch coastwide were taken in PNCIMA.

Inshore Rockfish comprises two species (groups) managed by TAC: Yelloweye Rockfish and an aggregate including Quillback, Copper, China, Tiger and other rockfishes, which tend to be nearshore in depths of 5 – 200 m. Yelloweye Rockfish were assessed as two distinct populations by COSEWIC, an inside population found within the Strait of Georgia and an outside population occupying the rest of the BC coast; both stocks were designated 'Special Concern' in 2008. Quillback Rockfish were assessed by COSEWIC in 2010 and designated 'Threatened' coastwide. Neither Quillback nor Yelloweyey have been assigned a status under SARA. These species were heavily fished during the 1980's and 1990's; presently fisheries tend to be small and non-directed. The inside stock of Yelloweye Rockfish was assessed in 2011 (Yamanaka *et al*. 2011) and while confidence bounds are wide, the stock is estimated to be at 12.3 % of unfished biomass (5.7 – 43%). Outside Yelloweye and Quillback rockfish were last assessed in 2001 (Yamanaka and Lacko, 2001); they were found to have been over-fished, leading to the implementation of the rockfish conservation strategy in 2003 that resulted in ~20% of the available inshore rockfish habitat coastwide being closed to all groundfish bottom fishing. On average over the last four years 82% of inshore rockfish catch coastwide was taken in PNCIMA.

Codfish

Codfishes comprise three species managed by TAC in BC: Pacific Cod, Walleye Pollock, and Pacific Hake, as well as one non-quota, non-commercial species, Pacific Tomcod.

Pacific Cod are distributed over muddy, sand or gravel bottoms between roughly 10 and 150 m. Pacific Cod have not been assessed by COSEWIC. They are managed and assessed as four distinct stocks in BC: the Strait of Georgia (4B, SOG), the west coast of Vancouver Island, (3CD, WCVI), Queen Charlotte Sound (5AB, QCS), and Hecate Strait (5CD, HS). Historically this was a (the) major fishery on the Pacific coast with landings peaking in the early 1990s at nearly 10,000 metric tonnes, with most of the catch being taken in Hecate Strait. The WCVI stock was last assessed in 2002 (Starr *et al*. 2002) and found to be at low abundance with sustainable quotas but current status is unknown. QCS and HS stocks were assessed in 2005 (Sinclair and Starr 2005); HS was found to be recovering from a historic low in 2001 and the QCS stock was deemed not assessable and hence the status of this stock is not known. There are, however, anecdotal reports from industry of increasing abundance in QCS and HS. On average over the last four years 73% of the coastwide catch of Pacific Cod was taken in PNCIMA

Pacific Hake are the single most abundant non-forage marine fish species in BC. Pacific Hake are a pelagic or mid-water species and are managed as two distinct populations: a large coastwide offshore stock ranging from Baja California to SE Alaska, and a smaller distinct inshore stock within the Strait of Georgia. Offshore Pacific Hake are highly migratory, spawning off southern California and Baja during winter months (February), and feeding off Oregon, Washington, and BC during the summer. Pacific Hake have not been assessed by COSEWIC. Pacific Hake is the single largest groundfish fishery on the west coast of North America usually yielding 50,000 – 300,000 metric tonnes annually. The offshore population is prone to large fluctuations in abundance due to high variability in recruitment (Forrest 2011 *et al*. else where in this research document). This stock is assessed annually and managed jointly by Canada and the US under the Canada/US Pacific Hake/Whiting Treaty. The current stock assessment (PFMC, 2011) indicates strong evidence of a recent large recruitment event (2008), which should result in stock size increases over the next several years. Presence in PNCIMA is driven by oceanographic conditions and age (size) structure of the population; larger older fish are able to migrate further north each summer than smaller at age or younger fish, and during warm years more fish of all sizes and ages often migrate further northward. Over the last 4 years the average proportion of the BC Pacific Hake catch within PNCIMA has been 37% but historically, when most of the fishery occurred off the lower west coast of Vancouver Island, may have been as low as 0%.

Walleye Pollock is traditionally harvested in Queen Charlotte Strait and Dixon Entrance. This species was last assessed in 1997 and current status is unknown. Walleye Pollock is managed as three separate stocks in BC, 4B (SoG), 5A/B-Area12, and 5CD. Walleye Pollock have not been reviewed by COSEWIC. On average over the last four years 93% of the coastwide catch of Walleye Pollock has come from PNCIMA.

Flatfish

Six flatfish species within PNCIMA are managed using total allowable catches (TACs): Pacific Halibut, Rock Sole, English Sole, Dover Sole, Arrowtooth Flounder, and Petrale Sole. Pacific Halibut are captured by hook and line fisheries while all other flatfish species are harvested by the mixed-species bottom trawl fishery. Fisheries range in size from small to moderate, with Pacific Halibut, Dover Sole, Arrowtooth Flounder, and Rock Sole yielding the highest catches. Most TAC-managed flatfish species are believed to be at moderate abundance and have had constant TACs for several years. One exception is Pacific Halibut for which catches were reduced in recent years due to declining abundance. The most recent Pacific Halibut stock assessment (Hare 2010) indicated a slight increase in biomass between 2008 and 2010 after several years of continued declines. Rock Sole, English Sole, and Petrale Sole (Starr *et al*. 2006, Starr 2009a, 2009b) were last assessed in 2007, at which time biomass levels for all species were characterized as being within safe biological limits. A 2001 assessment for Arrowtooth Flounder also showed the stock to be within safe biological limits. High directed fishing for this species in 2005 – 2006 resulted in declines in survey indices but Arrowtooth Flounder is still one on the most abundant species on the BC coast. Dover Sole has not been assessed since 1999, at which time abundance was deemed stable.

Several additional flatfish species are taken as non-directed catch in the bottom-trawl fishery, including Sand Sole, Rex Sole, Flathead Sole, Butter Sole, Curlfin Sole, and Starry Flounder. Catches have historically been considered small enough that a TAC has not been applied, and none of these species have been subject to a formal stock assessment. A recent examination of survey trends from Hecate Strait between 1984 and 2003 indicated that both relative biomass and occupied area were higher in 2003 compared to 1984, suggesting that catch levels at that time were not negatively affecting population dynamics for any of these species. No flatfish species have been identified as being a conservation concern by COSEWIC or SARA.

Lingcod

Lingcod in BC are characterized as two separate populations, both of which occur within PNCIMA: an inshore stock within the Strait of Georgia, Johnstone Strait, and Queen Charlotte Strait (i.e., all waters between Vancouver Island and the BC mainland) and an offshore population which comprises four discrete stocks: 3C, the lower west coast of Vancouver Island, 3D, the upper west coast of Vancouver Island, 5AB, Queen Charlotte Sound and 5CDE which includes Hecate Strait, Dixon Entrance and the west coast of the Haida Gwaii. Inshore Lingcod populations are currently rebuilding after a severe reduction in biomass between the 1940s and 1980s. Commercial fishing on inshore stocks has been closed since 1990. Only a small recreational fishery exists (5000 - 7000 fish per year). A 2004 assessment of Lingcod in the Strait of Georgia and Johnstone Strait (Logan *et al*. 2004) indicated that abundance had increased from the historic low levels of the late 1980's, but that they were still overfished. Stock status in Queen Charlotte Strait is unknown due to limited data. Offshore Lingcod stocks were recently assessed (King *et al*. 2011) using a Bayesian surplus production model, all four stocks were determined to be above their target reference point of B_{msy}. These stocks support medium-sized commercial fisheries for both trawl and hook and line sectors. A small recreational fishery also exists. Lingcod in BC have not been identified as a conservation concern by COSEWIC or SARA. On average over the last four years 48 and 82% of the non-trawl and trawl catch of lingcod has come from PNCIMA

Sablefish

Sablefish in BC are currently managed as a single coastwide stock. This population is currently the only one assessed and managed under a Management Strategy Evaluation framework. The most recent assessment (Cox *et al*. 2010) found Sablefish to be at ~ 18 % of unfished biomass and below the target reference point of B_{msy}, however the stock is projected to rebuild at the present reduced levels of harvest. Sablefish in BC have not been identified as a conservation concern by COSEWIC or SARA. On average over the last four years 40% of coastwide trawl and 74% of non-trawl catch was taken within PNCIMA

Spiny Dogfish

Spiny Dogfish are currently managed as two stocks, an inside stock within the Strait of Georgia and an outside coastwide stock (Baja California to Alaska). Spiny Dogfish are currently under review by COSEWIC. The Convention on International Trade in Endangered Species (CITES) reviewed the status internationally and did not list the species. Spiny Dogfish were last assessed in 2010 (Gallucci *et al*. 2011) and at that time it was concluded that there was no immediate conservation concern from the current levels of fishing pressure. Model results suggest the stock has rebuilt from a low point in the 1940s and currently may be above, at or below management reference points. Spiny dogfish are one of the most abundant species in both bottom trawl and hook and line fisheries independent surveys. On average over the last four years 23% of the trawl and 9% of the non-trawl catch was taken in PNCIMA.

Skates

Big Skate and Longnose Skate are the principal species targeted; a dozen or more less common species may also be incidentally harvested. Quotas exist for only Big and Longnose Skates in area 5C/D (HS) only. Big and Longnose Skates were assessed by COSEWIC in 2001 and designated 'Not at Risk'. On average over the last four years 79% of coastwide trawl catch and 60% of non-trawl catch of Big and Longnose Skates was taken in PNCIMA

In General

- During the last 4 years roughly 51 % of BC's trawl and 67% of BC's non-trawl catch has come from PNCIMA.
- In general the gadoid (Pacific Cod, Walleye Pollock, Pacific Hake) stocks are stable or increasing
- Most rockfish species are at low levels of abundance with many being listed as Special Concern or Threatened by COSEWIC
- Flatfish stocks appear to be stable
- Lingcod stocks appear to be stable
- Sablefish stocks appear to be stable at low abundance
- Elasmobranch (e.g. Spiny Dogfish) stocks appear stable
- Harvest advice for many species is out of date and there is a clear need for updated information on stock status
- There is also a clear and ongoing need for resource monitoring through fisheries independent surveys

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SALMON IN PNCIMA – PINK ARE DOING WELL WHILE COHO ARE DOING POORLY

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We evaluated temporal abundance patterns and status for salmon within the Pacific North Coast Integrated Management Area in central and northern British Columbia (PNCIMA), updating time series examined earlier by Riddell (2004) and Hyatt *et al*. (2007). Escapement (numbers of adult fish that "escape" and return to freshwater to spawn) data from the DFO NuSeds database extended from 1950-2009 while commercial catch data from DFO BC catch statistics reports extended from 1952-2010. To reduce the influence that non-PNCMIA salmon migrating through PNCIMA might have on our analyses, we ignored catch data from DFO Statistical Areas 2 West, 12, 27, 130 and 142 (http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/areas-secteurs/index-eng.htm). Escapement data were from all watersheds within PNCIMA (i.e. Statistical Areas 1-12 and 27).

Escapement data were incomplete, as few streams were assessed every year, and many streams were assessed in only a few years. To ensure that these data were as complete as practicable, for each species we identified a base set of streams with escapement estimates during most years (40, 70, 75, 112, and 109 streams for Chinook, Sockeye, Coho, Pink, and Chum Salmon respectively). We infilled missing escapement estimates (*Y*) for streams in our base data sets by first computing proportions for each stream datum by dividing by the maximum escapement of that stream across all filled years. Missing data were filled with the average of these proportions for their stream and then multiplied by the stream maximum again to get back to the original scale according to:

$$Y_{ij} = y_i \max\left(\frac{1}{n}\sum_{i}^{n}\left(\frac{y_{ij}}{y_i \max}\right)\right)$$

where y_{ij} is the escapement in the *i*th stream and *j*th year and *n* is the number of streams. We estimated the total escapement to PNCIMA by species (i.e. expanded escapements to base set to include streams outside our base set) by multiplying by a scaling factor, *S* estimated by $S = Eij(M/m)$, where E_{ij} is the original escapement, *M* is the sum of the median escapements of every stream for a species, and *m* is the sum of the median escapements of streams used in the base set of streams for that species. These scaled escapements were then added to catch to estimate returns.

Temporal abundance patterns (Figs. 1-2) were evaluated by computing linear regressions and testing whether slopes differed from zero. To assess status, we compared mean values during the most recent decade (2000-2009) with mean values for 1952-1999.

Results (Figs. 1-2, Table 1) imply that Pink Salmon are doing relatively well, while Coho Salmon and to a lesser extent Chinook Salmon are doing relatively poorly. Declines over the time series were significant for Coho Salmon catches, escapements, and returns, Chinook Salmon catches and returns, and Chum Salmon escapements. Pink Salmon was the only species with significant increases (escapements only). When we compared mean values during the most recent decade with historical means, recent catches and returns were lower for each species except Pink Salmon. Pink Salmon was also the only species with significantly higher escapements during the most recent decade compared to earlier. These results agree, in general, with those of Riddell (2004) and Hyatt *et al*. (2007) although these authors examined differences among watersheds. To improve our understanding of intraspecific patterns, we plan to extend our analyses by looking at temporal patterns for individual salmon Conservation Units.

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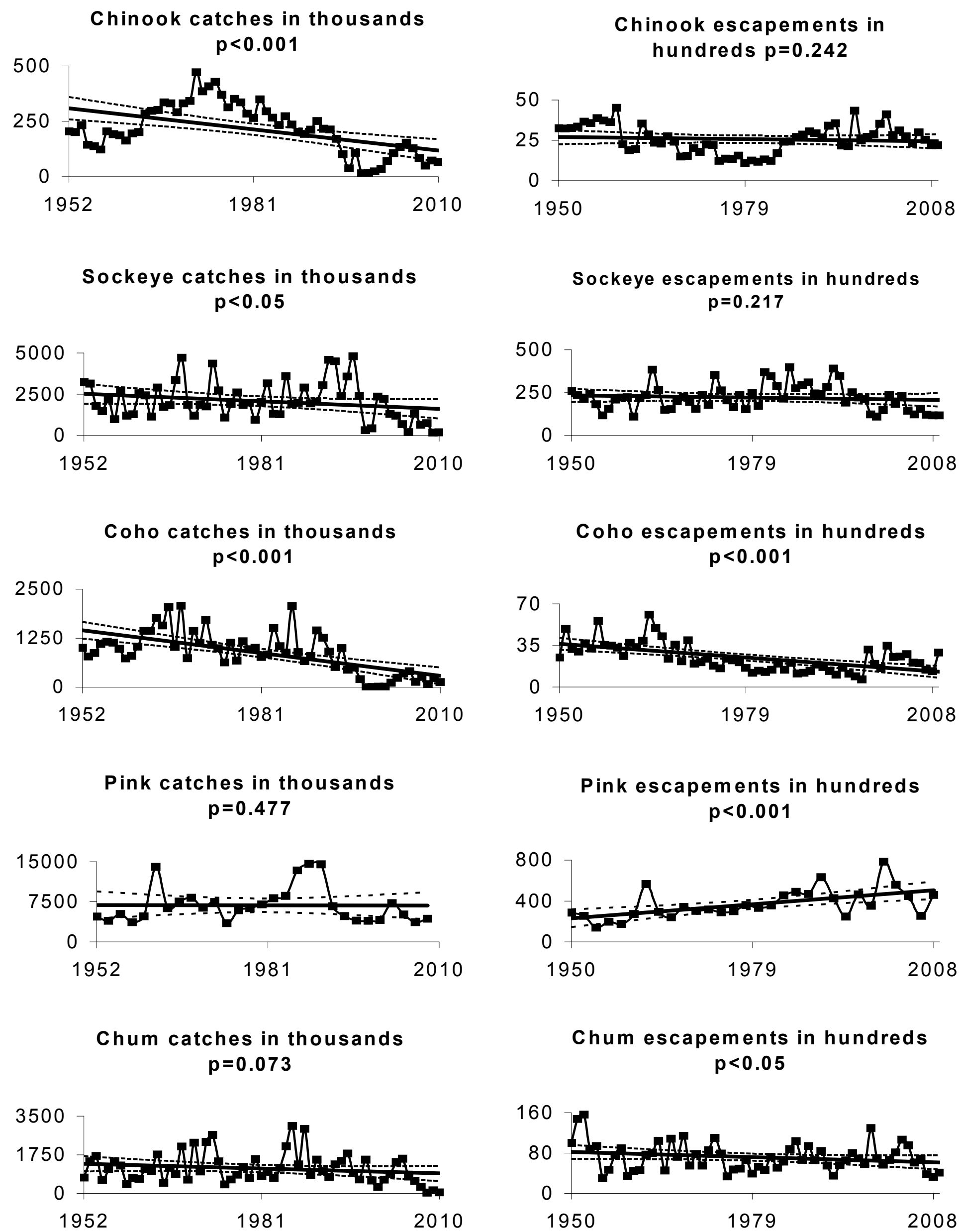
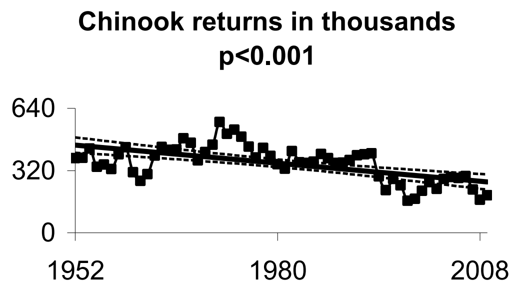
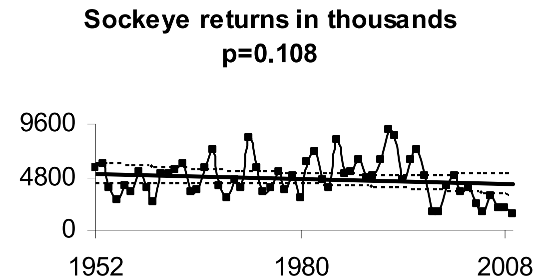
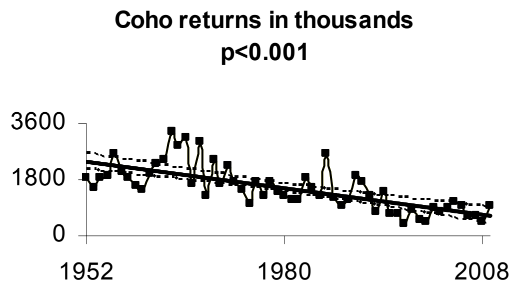
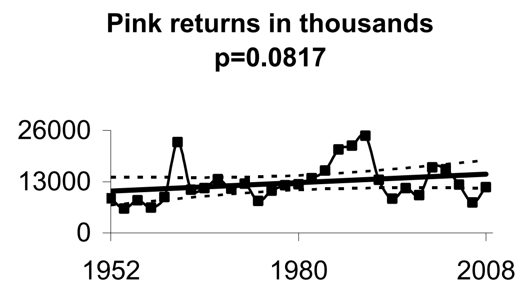


Figure 1. Commercial catch (left hand column) and escapement (right hand column) estimates for Chinook, Sockeye, Sockeye, Coho, Chum, and Pink Salmon in PNCIMA. Solid lines are linear regression lines (time series slopes) with probability that slope is 0; dashed lines are 95% confidence limits for these lines.









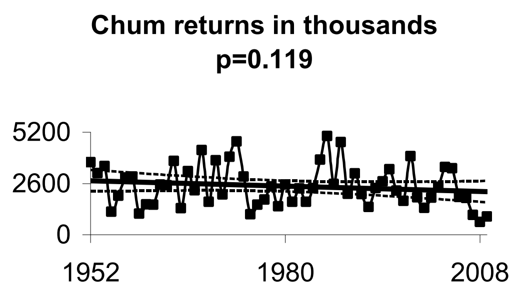


Figure 2. Return estimates (i.e. catch plus escapement) for Chinook, Sockeye, Sockeye, Coho, Chum, and Pink Salmon in PNCIMA. Solid lines are linear regression lines (time series slopes) with probability that slope is 0; dashed lines are 95% confidence limits for these lines.

	Recent Means			Time Series Slopes		
	Catch	Escapement	Returns	Catch	Escapement	Returns
Chinook	↓	↔	↓	↓	↔	↓
Sockeye	↓	↓	↓	↓	↔	↔
Coho	↓	↔	↓	↓	↓	↓
Pink	↔	↑	↔	↔	↑	↔
Chum	↓	↔	↓	↔	↓	↔

Table 1. Statistical results comparing recent means with historical means (first three columns of table) and linear slopes with 0 (last three columns). Symbols indicate when recent means (or slopes) are less than (↓), greater than (↑), or not different than (↔) historical means (or 0) for Chinook, Sockeye, Coho, Pink, and Chum Salmon.

SOCKEYE SALMON INDICATOR STOCKS –REGIONAL OVERVIEW OF TRENDS AND 2010 RETURNS

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Studies by Mueter *et al*. (2002a, 2002b) and Pyper *et al*. (2005) suggest associations between Pacific salmon survival and coastal environmental variables (*upwelling index, sea surface temperature [SST], and sea surface salinity [SSS]*) are strongest at local spatial scales (<500-800 km intervals) for adjacent stocks and exhibit little to no co-variation at scales larger than 1000 km. Correlation scales for SST in summer most closely matched the correlation scales for salmon survival. Regional averages of SST appeared to be better predictors of survival than large-scale measures of SST variability (*e.g.* the Pacific Decadal Oscillation, Mueter *et al*. 2002b). Thus, regional-scale variations in coastal SST's may reflect processes causing co-variation in survival rates of neighbouring stocks. Therefore, neighbouring stocks may exhibit stronger similarities in survival and production variations than widely separated stocks. In addition, geographical overlap of salmon species during freshwater and early marine life stages appear more important in determining shared environmental effects on survival rates than life history differences between species (Pyper *et al*. 2005).

Comparisons of forecasts and observed returns of sockeye salmon returning to major rivers and fisheries in BC have been completed annually by DFO personnel for decades (Fig. 1). Given the observations above, production trends for major sockeye populations or stock aggregates (*i.e.* "indicator-stocks") may reflect environmental changes and production trends for other salmon species originating from coastal-areas constituting separate production domains. Trend comparisons (1970-2010) among sockeye indicator-stocks permit the following generalizations:

- Return variations are large with maximum annual returns at 10-90 times minimum returns.
- Maximum returns for all sockeye indicator stocks from the north coast to the Fraser occurred during the early 1990s in association with the powerful 1989 La Niña event 2-3 years earlier.
- The 2008 La Niña event was followed in 2010 by record to near-record high returns of Vancouver Is. (Barkley), Fraser River (Chilko) and Columbia River (Okanagan) indicator stocks in a dramatic reversal of their recent, sub-average, return trends (Fig. 1 and Williams *et al*. 2011).
- Although sockeye returns to Smith Inlet and Long Lake on the Central Coast remained far below average, total returns in 2010 were twice that predicted (Fig. 4) suggesting survival favourable conditions for juvenile salmon during the 2008 La Niña year of sea-entry throughout Central to South Coast areas of British Columbia.
- North Coast and Transboundary stocks declined from the early 1990s peaks shared among all indicator stocks, but have remained closer to their all-year average return values than more southerly stocks during the early 1990s to 2010 interval.
- Sockeye indicator-stocks entering continental shelf areas under stronger oceanic influences (*i.e. areas 3 and 4 of Fig. 1*) appear more responsive to alternating La Niña-like (*anomalously cool, survival favourable*) and El Niño-like (*anomalously warm, survival less favourable*) conditions (*see detailed analysis for WCVI and Central Coast areas below*) than stocks entering more protected estuarine waters (*i.e. areas 1, 2, and 5 of Fig. 1*).
- Increased returns of Central Coast (Long Lake) and WCVI (Barkley Sound) sockeye in 2010 were anticipated by pre-season forecasts. By contrast, Georgia Basin (Fraser-Chilko) and Columbia (Okanagan) returns and survival rates were higher than predictions.

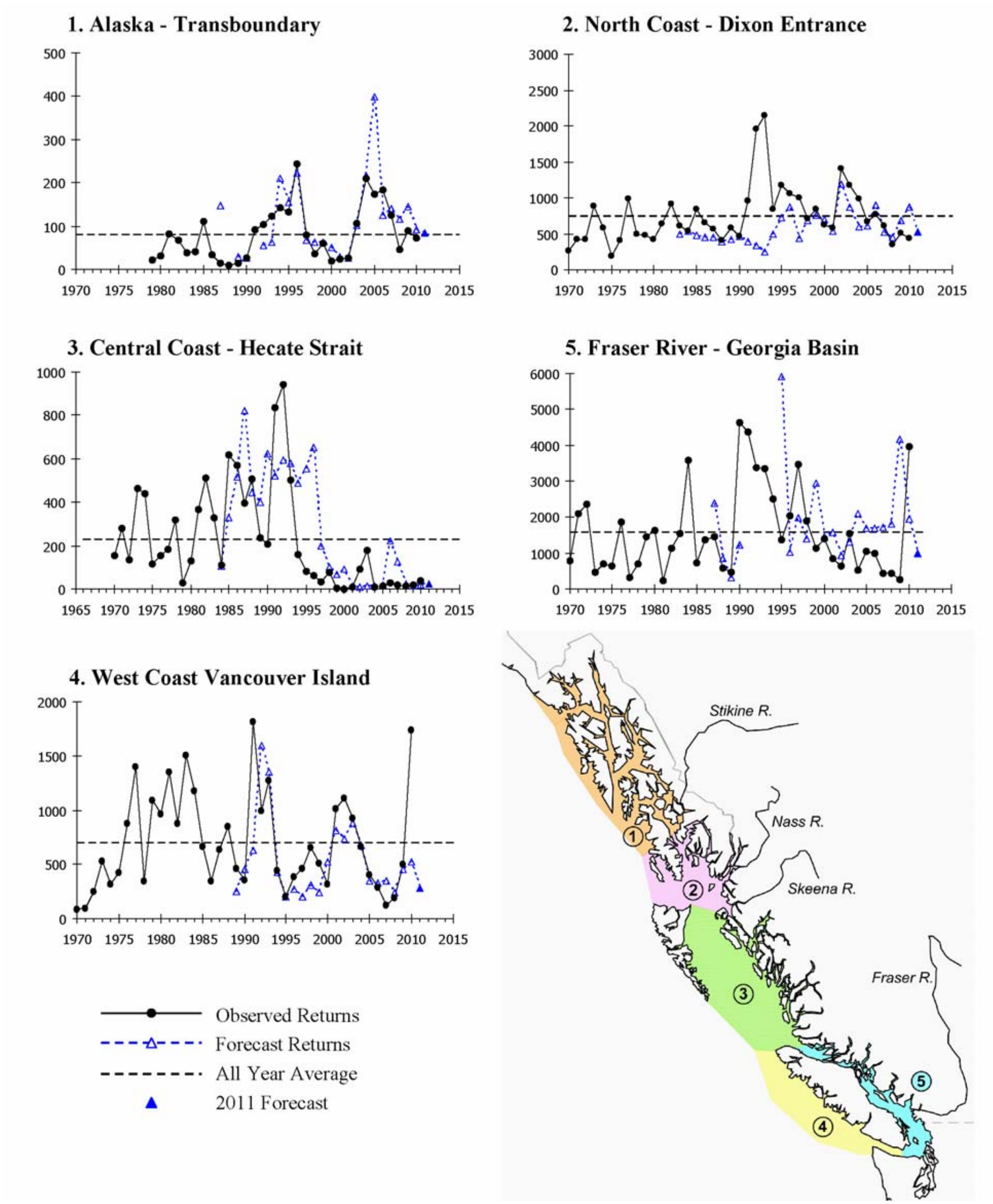

Figure 1. Trends in the total returns and forecasts for British Columbia Sockeye index stocks including: 1. Tahltan, 2. Nass, 3. Smith Inlet, 4. Barkley Sound, and 5. Chilko Sockeye Salmon. Y-axis represents returns in thousands of fish.

- Moderate to strong El Niño and La Niña events (NOAA Fisheries) are associated (2-3 years after juvenile sockeye sea entry) with either below or above multi-year, average adult-returns respectively (Figs. 2 and 4). These variations coincide more closely with marine survival rate changes associated with "warm" versus "cool" ocean conditions than with freshwater survival variations (Fig. 3 and Hyatt unpublished data).
- Survival favourable conditions in 2008-2009 sea-entry years for Central and South Coast stocks plus freshwater survival increases at Long L. (Fig. 3b) anticipate return rates well above formal predictions (Fig. 1) for Smith Inlet, Barkley Sound and perhaps Chilko sockeye in 2011.

West Coast Vancouver Island

Barkley Sound Sockeye Salmon: Rapid stock rebuilding between 2008-2011

Barkley Sound (BkSd) sockeye on the west coast of Vancouver Island exhibit annual recruitment variations that alter abundance patterns by more than a factor of ten within intervals as short as 2-3 years (Fig. 2). Since 1998 successful predictions of multiyear intervals of stock collapse (late 1980's, mid-1990's, 2004-2007) and recovery (early 1990's, 2001-2003, 2009-2010) due to these variations have relied on a simple two-state, "survival-stanza", model (SStM, Hyatt and Luedke 1999). SStM forecasts rely on the concept that continental-shelf ecosystems alternate between two states which support either high or low marine survival of these juvenile sockeye (Hyatt and Steer, 1988). Thus, "La Niña-like" conditions (*SST < 30 yr average during smolt migration, low northward transport, average to below average sea level*) are associated with relatively high marine survival (set at 5 %) and "El Niño-like" conditions (*SST > 30 yr average, elevated sea level, high northward transport*) with lower marine survival (set at 2.5 %).

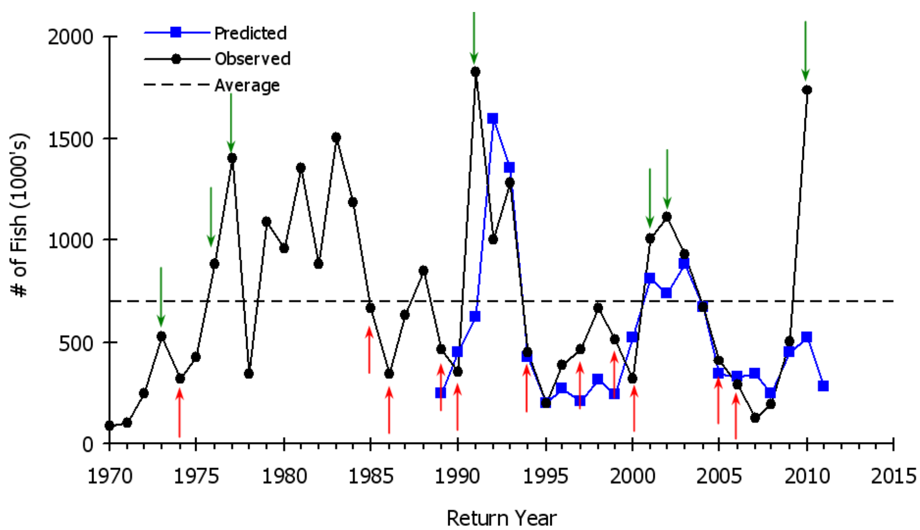

Figure 2. Returns and forecasts of Barkley Sound sockeye salmon 1970-2010. Arrows indicate La Niña (green, cool ocean) or El Niño (red, warm ocean) events classified by NOAA as moderate to strong (www.ggweather.com/enso/oni.htm). Arrows are aligned with adult returns two years after the sea entry year in which juvenile salmon experienced a given ENSO event.

NOAA's Northwest Fisheries Science Center (Ocean Ecosystem Indicators accessible at: http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/g-forecast.cfm) has tracked La Niña-like and El Niño-like conditions in the Northern California Current (NCC) system that extends to the WCVI since 1998. The NOAA series of indicators form a "report card" for factors potentially associated with annual changes in marine survival of salmon during their sea-entry year into the NCC system (see Peterson 2011 elsewhere in this Research Document). Although the suite of indicators employed have not been adapted for formal use in our forecasting system to date, a familiar "stop-light" classification matrix provides information to anticipate whether marine survival potential is above average (principally green), average (mixture of green, amber) or well below average (principally red). Reference to this matrix suggests that marine survival rates and associated returns for Barkley Sound Sockeye that make sea-entry in the NCC system should have followed a trajectory with a trough in the year 2000, a peak during return years 2001-2004, followed by a trough between 2005 to at least 2007, and finally a peak in 2010. The good correspondence between these expectations and observed returns is not surprising given our pre-existing knowledge of high and low marine survival states associated with La Niña and El Niño-like conditions (Hyatt and Steer 1988). However, the range of indicators tracked by NOAA offers additional information that may allow us to modify our two-state marine survival model into a future, multi-state model for improved performance.

2010 Observations:

Barkley Sound sockeye salmon returns rebuilt rapidly between 2008 and 2010 in line with SStM model forecasts (Fig. 2). Higher average marine survivals experienced by WCVI juvenile salmon during their 2007 and 2008 ocean entry years (adult returns in 2009-2010) were generally anticipated by negative SST and La Niña indices respectively (DFO 2008, DFO 2009, DFO 2010). However, smolt-to-adult survival rates of between 12% to 20% (Hyatt *et al* unpublished observations) for Barkley Sound sockeye associated with the 1989 and 2008 La Niña, sea-entry years suggest the two-state SStM forecasts might benefit from modification to account for higher than predicted marine survival rates of Barkley sockeye given moderate to strong La Niña events.

Outlook for 2011 and beyond:

In spring 2007-2009 sea surface temperature anomalies at Amphitrite Point, the NOAA, ENSO index and NOAA "report card" all reflected conditions that changed rapidly from ENSO-neutral (2006) to a very strong La Niña event (Hyatt *et al*. 2007, DFO 2007, DFO 2008). Thus, 2007-2009 sea-entry year <u>return rates</u> for Barkley Sound sockeye and possibly several other salmon stocks (all WCVI origin sockeye stocks, Carnation Creek coho, Robertson Creek coho, and Chinook) are expected to exhibit significant, short-term, improvement. Increases in marine survival will permit a period of stock rebuilding for WCVI coho (2008-2010) and sockeye (2009-2011). by contrast, the recurrence of a moderate to strong El Niño in late summer 2009 and especially spring 2010 anticipate declines of Barkley Sound juvenile salmon survival in sea-entry year 2010, adult coho returning in 2011, and adult sockeye returning in 2012.

<u>Central Coast – Queen Charlotte Sound:</u>

Rivers and Smith Inlet Sockeye Salmon: Returns above 2010 average forecast, as anticipated (DFO 2008) and expected to perform above forecast again in 2011.

Rivers and Smith Inlet sockeye supported one of the most valuable fisheries on the Central Coast of BC until severe stock declines in the early to mid-1990s forced their closure. Time series assessments permitting partitioning of marine versus freshwater production stages (Author's data, Fig. 3) support the view (McKinnell *et al*. 2001) that the steep decline and low returns of sockeye to Rivers and Smith Inlets since the 1990s are due to persistently low marine survival. By contrast, a strong compensatory response of increased egg-to-fall-fry survival in freshwater (Smokehouse River, Canoe Creek, and Long Lake, Fig. 3B) accompanied major reductions in spawner abundance for the 1997-2001 and 2005-2008 brood years and buffered Smith Inlet sockeye from even more severe declines (Fig.4). Returns to Smith Inlet in 2010 remained strongly sub-average, as in 2004-2007. However, higher than average survival rates for juvenile sockeye originating from 2004 brood-year adults supported returns in 2010 of roughly double the pre-season forecast (Fig. 4).

Production trends for Central Coast sockeye initially appeared to share little in common with stocks from other areas and especially given the precipitous decline and persistently low marine survival rates of Smith Inlet sockeye starting with the 1990 sea entry year (Fig. 3a).

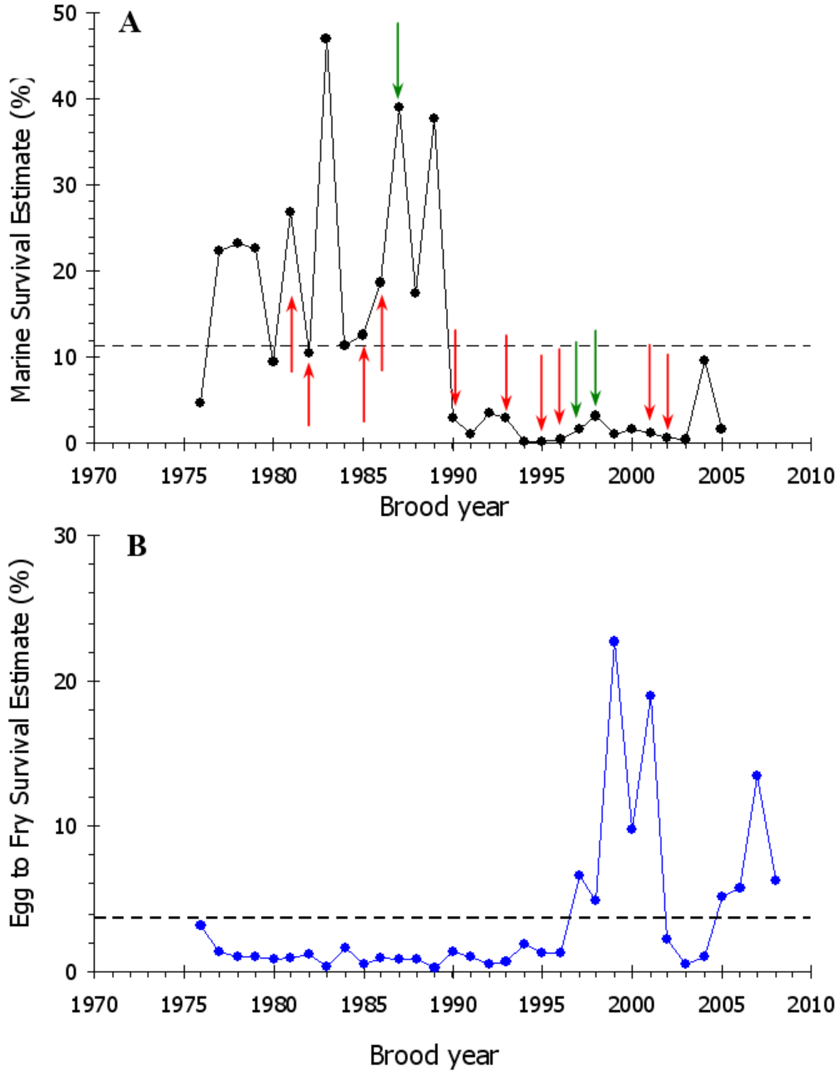

Figure 3. Trends in ***A.*** *marine (smolt-to-adult) and* ***B.*** *freshwater (egg-to-fall-fry) survival of 1976-2008 brood year sockeye salmon from Smith Inlet (Long Lake). Arrows in A. indicate marine survivals associated with moderate-to-strong (NOAA Fisheries, 2011) La Niña (green, cool ocean) or El Niño (red, warm ocean) events during the spring of sea-entry (i.e. Brood Year +2) for juvenile salmon.*

However, in spite of between stock differences in average trends, there are some indications that both Barkley Sound and Central Coast index stocks (Fig. 1) reflect signature effects of alternating El Niño and La Niña like events on production variations (*i.e. shared peaks in 88, 91-93, 98, 02-03 associated with relatively cool SSTs during smolt migrations two years earlier; shared troughs in 89-90, 95-97, 05-07 associated with relatively warm SSTs two years earlier*). Thus, it is likely that alternating “warm” and “cold” ocean conditions create common marine mechanisms controlling some of the production variations for salmon stocks in the relatively open coastal waters of Barkley Sound (WCVI) and Queen Charlotte Sound (Central Coast). Application of a non-stationary, multi-state, survival model (SStM, Hyatt and Steer 1988) triggered by changes in SST has yielded useful forecasts of variations in Barkley Sound sockeye returns compared to the stationary models applied to Smith Inlet sockeye over a comparable interval (*compare panels 3 and 4 in Fig. 1*). Central Coast survival rates are expected to improve in the near term under a variable-state, survival model (*e.g.* Borstad *et al* 2011). Furthermore, events resulting in above average, freshwater survival for juvenile sockeye originating from the 2005-2008 brood years (Fig. 3B) are likely to be reflected by 2-4 times more adults returning to Smith Inlet in 2011 than suggested by the current formal forecast (Fig.4), which is based on return rates averaged over the most recent 5 year interval.

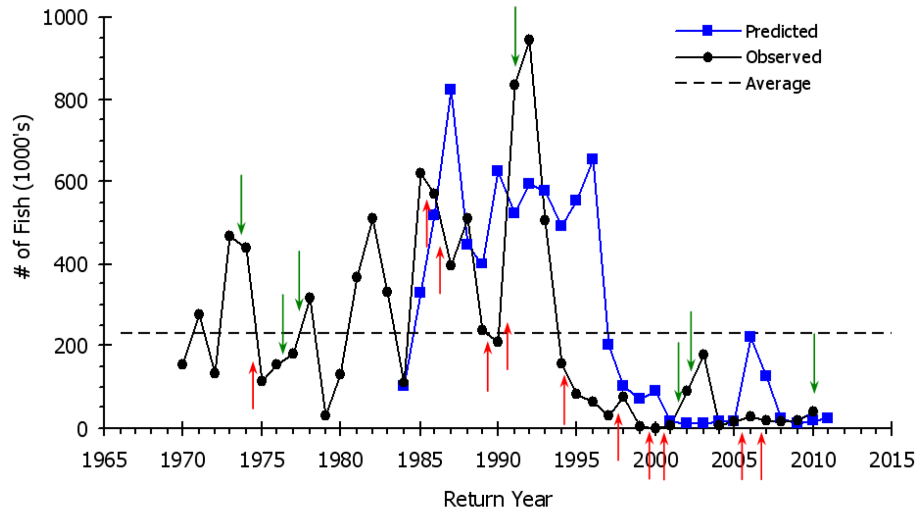

Figure 4. Returns and forecasts of Smith Inlet sockeye salmon, 1970-2010. Arrows indicate adult returns two and a half years (i.e. due to split of adult returns after either two or three years at sea) after moderate-to-strong La Niña (green, cool ocean) or El Niño (red, warm ocean) events.

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