State of the Ocean Report for the Pacific North Coast Integrated Management Area (PNCIMA)

J.R. Irvine and W.R. Crawford

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station,
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by

J.R. Irvine[1] and W.R. Crawford[2]

[1]Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, BC
V9T 6N7

[2]Fisheries and Oceans Canada
Science Branch, Pacific Region
Institute of Ocean Sciences
Sidney, BC
V8L 4B2

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ABSTRACT

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As part of a national ecosystem review of large ocean management areas, this report examines the marine ecosystem of the Pacific North Coast Integrated Management Area (PNCIMA). PNCIMA encompasses approximately 102,000 km^2 from the edge of the continental shelf east to the British Columbia mainland. The region extends from the British Columbia-Alaska border south to Bute Inlet on the mainland, across to Campbell River on the east side of Vancouver Island and the Brooks Peninsula on the west side of Vancouver Island. This report updates information from a major 2007 review.

Wet windy winters and drier, relatively calmer summers dominate the seasonal weather, resulting from very different air pressure patterns in the Gulf of Alaska in summer and winter. Frequent winter storms with strong southerly winds (blowing from the south) bring not only high waves, but also warmer waters from the south and deep downwelling and mixing of surface waters. Relatively calmer weather in summer with periods of northerly winds brings calmer seas and allows nutrients from deep waters to reach the surface. Intense rainfall in late autumn and winter along the Coast Mountains provides massive input of fresh water along the eastern side of PNCIMA. Large rivers from the BC interior snowfields and glaciers dominate the fresh water runoff in other seasons, especially in late spring. Although this summer-winter change in weather dominates PNCIMA, there have been variations in the weather over past decades that have impacted PNCIMA.

Some of these variations in the weather and their impacts are listed below. In addition, we summarise recent ecosystem research not necessarily related to changes in weather and climate.

- Two recent winters illustrate the increasingly frequent shifts between strong El Niño (2010 - stronger southerly winds, relatively warmer ocean waters in PNCIMA) and La Niña (2011 - stronger westerly winds, cooler waters) conditions.
- Downwelling winds (from the south or southeast) in PNCIMA were, on average, much stronger since the mid 1990s than in previous decades back to 1950.
- In general, the last two decades have seen warmer, less saline ocean waters.
- Recent declines in sub-surface oxygen concentrations may lead to negative effects on marine species such as groundfish.
- The timing of spring plankton blooms in Queen Charlotte Sound appears to have a major influence on the survival of certain marine birds as well as young salmon.
- PNCIMA provides important habitat for ancient colonies of corals and sponge reef communities; a recently released conservation strategy was designed to protect these rare and sensitive components of our marine ecosystem.
- While many native invertebrate species are harvested, two are doing poorly: Northern abalone are listed as endangered, and Olympia oyster are listed as a species of special concern by COSEWIC.
- Groundfish catches constitute about half of the total groundfish catches within BC with Pacific hake the single largest species catch both coast-wide and within PNCIMA.
- Gadoid (Pacific cod, walleye pollock, Pacific hake) stocks are generally stable or increasing, flatfish, lingcod, sablefish and elasmobranch stocks are stable, while many rockfish species are at low levels of abundance with some being threatened or special concern.
- The region provides essential spawning and rearing habitat for local salmon populations and is also important as a marine migration corridor for more southerly populations. Marine waters are especially important for juvenile salmon during summer and fall.

- Over the last 50 years, numbers of adult pink salmon have increased, while coho salmon and to a lesser extent Chinook salmon numbers have declined.
- Over the past decade, herring biomass in Haida Gwaii has been depressed whereas the biomass in both Prince Rupert and the central coast has remained relatively stable. Herring stocks in Haida Gwaii and the central coast are below cut off levels established to determine if fishing should be allowed.
- After more than a 50-year absence, sardines returned to the west coast of Vancouver Island, Hecate Strait and Dixon Entrance in 1998. The extent of sardine migration into PNCIMA varies among years and is strongly affected by sea surface temperature.
- Many species of marine mammal occur within PNCIMA for at least part of their life history.
- Whaling resulted in significant declines for many baleen whales; blue, sei and North Pacific right whales are listed as endangered under Species at Risk Act while fin and humpback whales are threatened and eastern Pacific grey whales are listed as special concern.
- Three distinct eco-types of killer whales occur in PNCIMA: northern and the southern resident killer whales, transient killer whales, and offshore killer whales. The four populations do not associate with each other although their ranges overlap extensively. Southern residents are listed as endangered under Species At Risk Act while northern residents, transients, and offshore killer whales are listed as threatened.
- PNCIMA is host to a range of introduced shellfish and other invertebrate species, two sponges, and two species of marine fish.
- The reader is referred to the extensive bibliography for more details.

RÉSUMÉ

Irvine, J.R. and Crawford, W.R. 2011. State of the Ocean Report for the Pacific North Coast Integrated Management Area (PNCIMA). Can. Manuscr. Rep. Fish. Aquat. Sci. 2971: xii + 51 p.

Dans le cadre d'un examen effectué à l'échelle nationale et portant sur l'écosystème des zones étendues de gestion des océans, le présent rapport traite de l'écosystème marin de la Zone de gestion intégrée de la côte nord du Pacifique (ZGICNP). La ZGICNP couvre environ 88 000 km^2 à partir du bord du plateau continental à l'est de la partie continentale de la Colombie-Britannique. La région s'étend à partir de la frontière de la Colombie-Britannique et de l'Alaska jusqu'au sud du bras de mer Bute, située dans la partie continentale, en passant par la rivière Campbell, située du côté est de l'île de Vancouver, et par la péninsule Brooks, située du côté ouest de l'île de Vancouver. Le présent rapport vise à mettre à jour les renseignements tirés d'un important examen réalisé en 2007.

Les conditions météorologiques saisonnières de la région sont caractérisées par un hiver humide et venteux et un été plus sec et plus doux. Cela découle de la répartition très différente de la pression atmosphérique présente dans le golfe d'Alaska en été et en hiver. Les tempêtes hivernales fréquentes associées à de forts vents du sud (qui soufflent du sud) ne sont pas seulement responsables de la formation de hautes vagues; elles apportent également de l'eau chaude provenant du sud et créent une profonde plongée et un mélange des eaux superficielles. En été, les conditions météorologiques relativement plus douces, accompagnées de vents du nord, donnent lieu à des mers moins fortes et permettent aux nutriants présents dans les eaux profondes d'atteindre la surface. À la fin de l'automne et en hiver, les fortes précipitations le long de la chaîne Côtière apportent une grande quantité d'eau fraîche le long du côté est de la ZGICNP. Les grandes rivières créées par les champs de neige et les glaciers à l'intérieur de la Colombie-Britannique représentent la source principale d'eau de ruissellement lors des autres saisons, surtout à la fin du printemps. Bien que les différences entre les conditions météorologiques en été et en hiver soient représentatives de la ZGICNP, on a remarqué des variations météorologiques qui ont eu des répercussions sur cette dernière au cours des dernières décennies.

Certaines de ces variations météorologiques, de même que leurs répercussions, sont indiquées ci-dessous. De plus, nous résumons une recherche écosystémique qui n'est pas nécessairement liée aux changements météorologiques et climatiques.

- Les deux derniers hivers indiquent des variations de plus en plus fréquentes entre les conditions fortement marquées par El Niño (2010 – vents du sud plus forts, eaux océaniques relativement plus chaudes dans la ZGICNP) et La Niña (2011 – vents de l'ouest plus forts, eaux plus froides).
- Les vents plongeants (du sud ou du sud-est) dans la ZGICNP ont été, en moyenne, beaucoup plus forts depuis le milieu des années 1990 que durant les années 1950 et les décennies qui suivirent.
- En général, les eaux océaniques ont été plus chaudes et moins salines lors des deux dernières décennies.
- La récente baisse de la concentration d'oxygène sous-marin peut avoir des répercussions négatives sur les espèces marines, comme le poisson de fond.
- La période de prolifération de végétaux planctoniques printanière dans le détroit de la Reine-Charlotte semble jouer un rôle crucial concernant la survie de certains oiseaux marins et de jeunes saumons.
- La ZGICNP représente un habitat important pour les anciennes colonies coralliennes et les communautés récifales d'éponges. Une stratégie de conservation visant à protéger ces espèces rares et fragiles de notre écosystème marin a été élaborée récemment.

- Les stocks de plusieurs espèces d'invertébrés indigènes sont stables et sont pêchés. Néanmoins, COSEPAC a accordé la désignation 'd'espèce en voie de disparition' à l'ormeau nordique et 'd'espèce préoccupante' à l'huître plate du Pacifique.
- La pêche aux poissons de fond représente environ la moitié de la totalité des prises pour cette espèce au sein de la Colombie-Britannique, alors que le merlu du Pacifique représente l'espèce la plus pêchée dans l'ensemble de la côte et au sein de la ZGICNP.
- En général, les stocks de gadidés (morue du Pacifique, goberge de l'Alaska, merlu du Pacifique) sont stables ou en croissance, les stocks de poissons plats, de morues-lingues, de morues charbonnières et d'élasmobranches sont stables, alors qu'un grand nombre d'espèces de sébastes, dont le niveau d'abondance est bas, sont menacées ou représentent des espèces préoccupantes.
- La région représente un important habitat de frai et de grossissement pour les populations de saumon locales, ainsi qu'un couloir de migration marin pour les populations plus au sud. Durant l'été et l'automne, les eaux marines sont particulièrement importantes pour les jeunes saumons.
- Au cours des 50 dernières années, le nombre de saumons roses adultes a augmenté, alors que celui du saumon coho et du saumon quinnat, dans une moindre mesure, a diminué.
- Au cours de la dernière décennie, la biomasse du hareng de Haida Gwaii a diminué, alors que celle de Prince Rubert et de la zone côtière centrale est demeurée relativement stable. Les stocks de harengs de Haida Gwaii et de la zone côtière centrale sont sous le seuil établi qui permet de déterminer si la pêche devrait être permise ou interdite.
- Après une absence de plus de 50 ans sur la côte ouest de l'île de Vancouver, le détroit d'Hécate et l'entrée Dixon, les sardines y sont retournées en 1998. La portée de la migration des sardines au sein de la ZGICNP, qui varie selon les années, est grandement influencée par la température de la surface de la mer.
- Un grand nombre d'espèces de mammifères marins habitent la ZGICNP pendant au moins une période au cours de leur cycle de vie.
- La pêche à la baleine a entraîné une diminution considérable des populations de cétacés à fanons; le rorqual bleu, le rorqual boréal et la baleine noire du Pacifique Nord sont qualifiés d'espèces en voie de disparition en vertu de la *Loi sur les espèces en péril*, alors que le rorqual commun et le rorqual à bosse sont menacés et que la baleine grise du Pacifique Est est qualifiée d'espèce préoccupante.
- Il existe trois écotypes d'épaulards au sein de la ZGICNP : les épaulards résidents du nord et du sud, les épaulards migrateurs et les épaulards du large. Bien que les distances parcourues par ces espèces d'épaulards se chevauchent abondamment, ces quatre populations ne sont pas liées. Les épaulards résidents du sud sont qualifiés d'espèce en voie de disparition en vertu de la *Loi sur les espèces en péril*, alors que les épaulards résidents du nord, migrateurs et du large sont qualifiés d'espèces menacées.
- La ZGICNP abrite une quantité de mollusques et de crustacés, ainsi que d'autres espèces introduites d'invertébrés, deux espèces d'éponges et deux espèces de poissons marins.
- Pour obtenir de plus amples détails, le lecteur doit se référer à la bibliographie complète.

INTRODUCTION

Context and purpose

Canada's Oceans Act states that "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment." Implementation of integrated management planning is central to the new governance and ecosystem based management approach of the Oceans Action Plan (OAP). The OAP identified five priority Large Ocean Management Areas (LOMAs) across Canada for coordination of Integrated Management (IM) efforts. The Pacific North Coast Integrated Management Area (PNCIMA) is one; the others are the Eastern Scotian Shelf, Beaufort Sea, Gulf of St. Lawrence, and Placentia Bay/Grand Banks.

This report updates information on the ecology of the PNCIMA, to provide insight into recent changes in this marine ecosystem since publication of *Ecosystem Overview: Pacific North Coast Integrated Management Area (PNCIMA*) by Lucas et al. (2007a). Their report provides almost 100 pages of ecosystem overview, and is supplemented with eleven appendices, covering the state of knowledge of geology, meteorology and climate, physical and chemical oceanography, plankton, marine plants, invertebrates, groundfish, pelagic fishes, pacific salmon, marine mammals and turtles, and marine birds. The report plus appendices gives almost 1,000 pages of in-depth information.

Our focus here is to point readers to more recent papers and reviews and to present additional information not published elsewhere. We hope our report will provide needed new information for the management processes and decisions in this region of the British Columbia (BC) coast.

Boundaries of the study area

PNCIMA's boundaries were determined primarily on ecological characteristics, and encompass approximately 102,000 km^2. It extends from the outer limit of the foot of the continental slope in the west, to the coastal watersheds in the east. The Canada-United States (US) border for Alaska is the northern boundary. The southern boundary extends from Bute Inlet across to Campbell River on the east side of Vancouver Island and Brooks Peninsula on northwest Vancouver Island (Figure 1).

The southern boundaries of PNCIMA were chosen to lie at points where there are natural changes in oceanographic features. Brooks Peninsula is generally considered to mark the northern end of the California Current System flowing southward along the west coast of Vancouver Island to California and Mexico in summer. Waters to the north of Brooks Peninsula lie in a transition zone between the California Current and the Alaska Current. The latter flows northward and then westward along the coast of Alaska. Although Brooks Peninsula is not a complete barrier to water flowing along the outer BC continental shelf, it is where the continental shelf is narrowest, and in general there is less exchange of shelf waters past this point than at other locations along the BC coast. Quadra Island marks the southern end of the portion of the Inside Passage with strongest tidal currents and narrowest waterways, and also marks the northern end of the wide, slow-flowing Strait of Georgia. Part of the PNCIMA northern limit lies along the Alaska boundary line established between Canada and the US in the 19^{th} century. It also marks the northern side of Dixon Entrance, which therefore provides a natural oceanographic boundary as well.

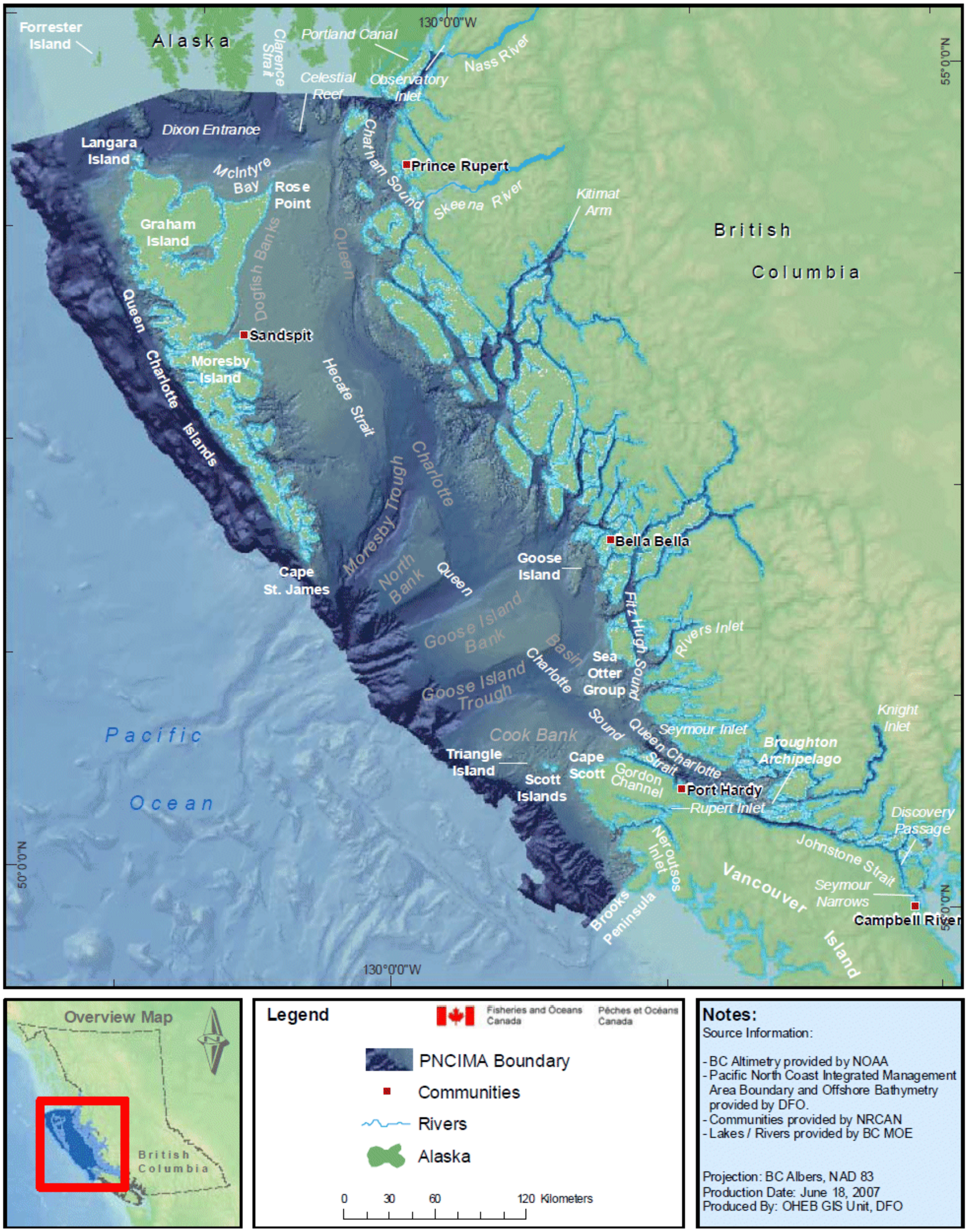


Figure 1. PNCIMA region showing locations and features of BC waters. Figure from Lucas et al. (2007a).

Background material

Lucas et al. (2007a) provide a major overview of the PNCIMA ecosystem:

- Lucas, B.G., Verrin, S., and Brown, R. (editors). 2007a. Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA). *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667. http://www.dfo-mpo.gc.ca/Library/328842.pdf

Appendices to this report cover the topics of meteorology, oceanography, plankton, plants, invertebrates, groundfish, pelagic fishes, Pacific salmon, mammals and turtles, and marine birds:

- Crawford, W., Johannessen, D., Birch, R., Borg, K., and Fissel, D. 2007a. Appendix B: Meteorology and climate. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Crawford, W., Johannessen, D., Whitney, F., Birch, R., Borg, K., Fissel, D., and Vagle, S. 2007b. Appendix C: Physical and chemical oceanography. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Mackas, D., Peña, A., Johannessen, D., Birch, R., Borg, K., and Fissel, D. 2007. Appendix D: Plankton. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Lucas, B.G., Johannessen, D. and Lindstrom, S. 2007b. Appendix E: Marine plants. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Pellegrin, N., Boutillier, J., Lauzier, R., Verrin, S., and Johannessen, D. 2007. Appendix F: Invertebrates. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Fargo, J., MacDougall, L., Pearsall, I. 2007. Appendix G: Groundfish. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Schweigert, J., McCarter, B., Therriault, T., Flostrand, L., Hrabok, C., Winchell, P., and Johannessen, D. 2007. Appendix H: Pelagics. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Hyatt, K., Johannes, M.S., and Stockwell, M. 2007. Appendix I: Pacific Salmon. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- Heise, K., Ford, J., and Olesiuk, P. 2007. Appendix J: Marine mammals and turtles. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.
- McFarlane Tranquilla, L., Truman, K., Johannessen, D., and Hooper, T. 2007. Appendix K: Marine Birds. *In* Ecosystem overview: Pacific North Coast Integrated Management Area (PNCIMA), edited by B.G. Lucas, S. Verrin and R. Brown. *Canadian Technical Report of Fisheries and Aquatic Sciences* 2667.

Recent updates include:

- Cummins, P., and Haigh, R. 2010. Ecosystem status and trends report for North Coast and Hecate Strait ecozone. *DFO Canadian Science Advisory Secretariat Research Document* 2010/045. http://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs70-5-2010-045.pdf

- Ianson, D., and Flostrand, L. 2010. Ecosystem status and trends report: Coastal waters off the west coast of Vancouver Island. *DFO Canadian Science Advisory Secretariat Research Document*. 2010/046. http://publications.gc.ca/collections/collection_2011/mpo-dfo/Fs70-5-2010-046.pdf

The most comprehensive on-line source of information is the Internet site of the *PNCIMA Initiative, (*http://pncima.org/), which maintains a comprehensive list with direct access to many valuable reports and peer-reviewed publications dealing with governance, science, ecology, management, industry and First Nations issues: http://www.pncima.org/site/document-library.html.

The next two reports present information on status and trends of marine species, and on how the PNCIMA ecosystem functions:

- Hall, A. 2008. *State of the Ocean in the Pacific North Coast Integrated Management Area (PNCIMA)*. David Suzuki Foundation. http://www.davidsuzuki.org/publications/downloads/2008/State_PNCIMA_FINAL_COPY.pdf
- Molnar, M., Clarke-Murray, C., Whitworth, J., and Tam, J. 2009. *Marine and coastal ecosystem services: A report on ecosystems services in the Pacific North Coast Integrated Management Area (PNCIMA) on the British Columbia coast,* David Suzuki Foundation http://www.davidsuzuki.org/publications/downloads/2009/marine_ecosystems_report_web.pdf

Two mapping projects in British Columbia delivered on-line products in 2011:

- Pacific North Coast Integrated Management Area Initiative. 2011. *Atlas of the Pacific North Coast Integrated Management Area. http://www.pncima.org/site/atlas.html.* This atlas was produced as a spatial reference document in support of planning processes associated with the PNCIMA Initiative. A total of 63 maps provide information on PNCIMA ecosystem, human impacts and uses, covering both sea and land applications.
- British Columbia Marine Conservation Analysis. 2011: *Marine Atlas of Pacific Canada: a product of the British Columbia Marine Conservation analysis (BCMCA)*. http://www.bcmca.ca/data/ This publication presents maps of aspects of British Columbia coastal waters on topics of oceanography, ecology, shipping, fishing, energy and tourism.

Annual reports of marine climate and life in British Columbia and neighboring waters are published by Fisheries and Oceans Canada. The most recent report is:

- Crawford, W.R., and Irvine, J.R. (editors) 2011. State of physical, biological, and selected fishery resources of Pacific Canadian marine ecosystems in 2010. *DFO Canadian Science Advisory Secretariat Research Document 2011-054* http://www.pac.dfo-mpo.gc.ca/science/psarc-ceesp/osrs/index-eng.htm. This publication is the most recent of twelve annual reports on the state of the Pacific Canadian oceans, with additional material on global oceans and adjacent American waters. These reports will continue to be published annually. Each report comprises a summary of significant scientific observations in the previous year, placed in context of many years of observations. An appendix in the 2011 report contains about 30 individual short summaries of specific aspects of oceanography and marine species, written by the scientists who undertake the research and compile the data.

METEOROLOGY AND OCEANOGRAPHY

More extensive overviews of these topics are provided by Crawford et al. (2007a, 2007b). A good overview of global climate change up to and including the year 2010 is provided by Blunden et al. (2011). We present here a summary of general conditions together with a description of changes in the weather and ocean in the past few years.

Cool wet winters and warmer drier summers dominate the weather of PNCIMA. Winter storms bring massive rainfall, with total annual rainfall of 1560 mm at Cape St. James, increasing to 2600 mm at Cape Scott and much more on coastal mountains. The wettest months are October through January, with monthly average precipitation of 188 mm at Cape St. James, increasing to 327 mm along the mainland coast (~10 mm / day). Extreme daily rainfall can reach 63 mm at Cape St. James, and 319 mm along the coast at McInnes Island. Summers are much drier (74 mm / month at Cape Scott; 121 mm / month along the mainland coast). There is little snowfall at sea level, only 50-70 cm / year, most of which occurs during November-April. (Crawford et al. 2007a)

The summer-winter change in rain is due to changes in weather patterns in the Gulf of Alaska. The Aleutian Low dominates in winter; the North Pacific High in summer. Low pressure in winter is due to the many severe storms that track through the Gulf of Alaska in late autumn and all through the winter. The centre of this Low is the dark purple region in the left panel of Figure 2 and the dark blue region in the right panel, showing conditions in the winters of 2010 and 2011, respectively.

These two recent winters show the extreme differences between strong El Niño conditions in 2010 and strong La Niña conditions in 2011. Average winds in winter blow along the contour lines of constant air pressure (isobars) in Figure 2, with the black arrow showing the typical direction for each winter. The average wind direction in January to March of 2010 was more from the south than in the same months of 2011, and carried more warm air and ocean water into the PNCIMA region.

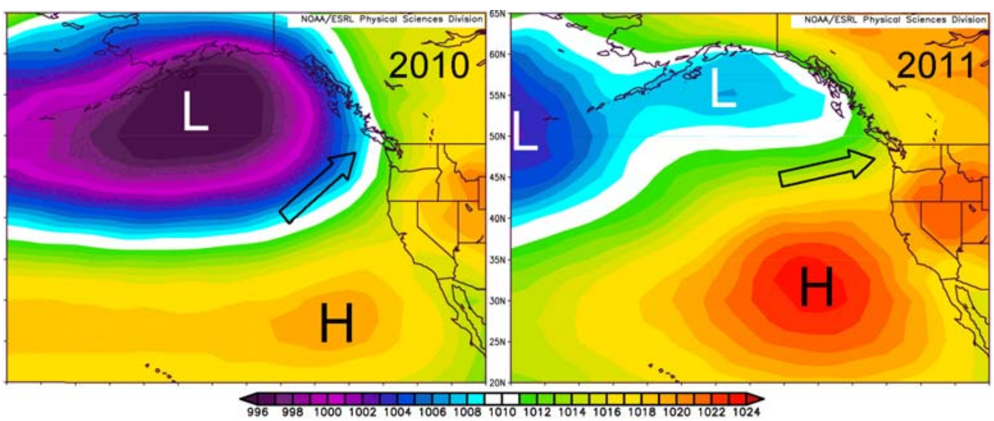


Figure 2. Sea surface air pressure in the Northeast Pacific Ocean and western North America, averaged over the winter months of January to March for the years 2010 and 2011. Contours are at intervals of 1 millibar, with colour scale at bottom. The letter H denotes the North Pacific High Pressure System; 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 west 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 2011 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. Image from US National Oceanic and Atmospheric Administration. Figure from Crawford et al. (2011)

For reasons unknown as yet, winter weather of the entire BC coast has shifted back and forth from warm to cool more regularly with the El Niño – La Niña cycle since 1998 than in the five preceding decades. (The cycling between El Niño and La Niña is denoted ENSO, for El Niño – Southern Oscillation.) El Niño is a warming of the surface ocean along the Pacific Equator, which in turn causes a shift in high altitude winds and weakening of westerlies over the North Pacific Ocean. During La Niña the mid-Pacific equatorial waters are relatively cool compared to average over many years, and North Pacific westerlies increase in speed and tend to cool BC waters in winter to a greater degree than normal. Winters of 2008, 2009 and 2011 were all of the La Niña type, and ocean waters of PNCIMA were cool over these years. The winter of 2010 was a severe El Niño, as noted previously.

Winds inside PNCIMA blow mainly from the south in winter and from the north in mid-summer, with much stronger winds in winter. Northerly winds (blowing from the north) not only bring cooler air to the BC coast, but due to Coriolis force, they also push surface coastal waters away from shore. These surface waters are replaced by nutrient-rich deep water at the surface, providing nutrients for plant life and feeding the entire food chain. For this reason northerly winds are labelled “upwelling winds” and give rise to rich marine life and fisheries. In contrast, southerly winds downwell surface water and keep deep nutrients away from the surface.

For this reason, a long time series of upwelling and downwelling winds informs scientists of reasons for changes in marine species and ecosystems over years, and even decades. Hourston and Thomson (2011) have prepared graphs of these winds by examining time series of a computer simulation of winds along the American and Canadian west coasts since 1950. The computer simulation is called National Center for Environmental Prediction (NCEP), and is provided by the US National Oceanic and Atmospheric Agency (NOAA). Although this simulation often under-represents alongshore winds, it is useful to show qualitative changes in time of such winds. Hourston and Thomson (2011) first extracted from the model output the along-shore winds at sites show in Figure 3, with separate spreadsheets for upwelling and downwelling directions. By plotting in a type of graph called a Hovmuller diagram, they are able to present changes in winds both along the coast and over that past six decades. Figure 3 shows locations of the winds data sites.

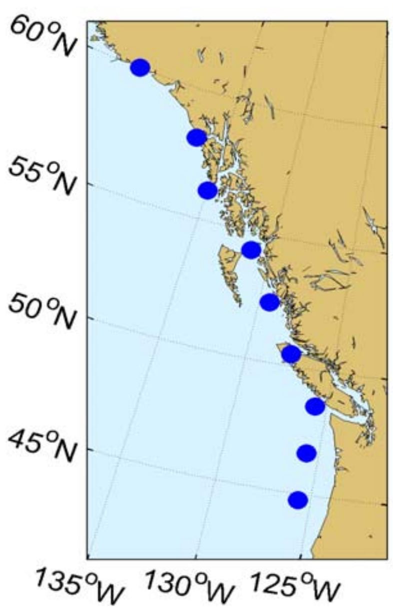


Figure 3. Regions of the BC coast where alongshore winds are sampled from the NCEP re-analyses model. (NCEP is the National Center for Environmental Prediction of the US National Oceanic and Atmospheric Agency, NOAA.) (From Hourston and Thomson 2011)

Figure 4 shows the Hovmuller diagrams that reveal how upwelling and downwelling winds have varied over previous decades. Upwelling winds were weakest on the north coast of Vancouver Island and in Queen Charlotte Sound, Hecate Strait and Dixon Entrance (50°N to 55°N) in the early 1980s, Downwelling winds have been much stronger since 1998 (Figure 4). In general, downwelling winds have been stronger in PNCIMA since the late 1970s, except for the period of about 1988 to 1996.

A separate analysis by Foreman and Merryfield (2011) observes similar changes in time. They examined observed winds at weather buoys along the west coast, and extended their time series back in time by using a time series created by Faucher et al. (1999) to correct geostrophic wind data at each weather buoy location prior to the start of the weather buoy observations. They examined data in decadal intervals for weather buoys west of Gwaii Hanas, rather than in Queen Charlotte Sound and Hecate Strait as studied by Hourston and Thomson (2011). Their results reveal that strongest downwelling winds in the first four months of each year were in the decades of 1979-1988 and 1999-2008.

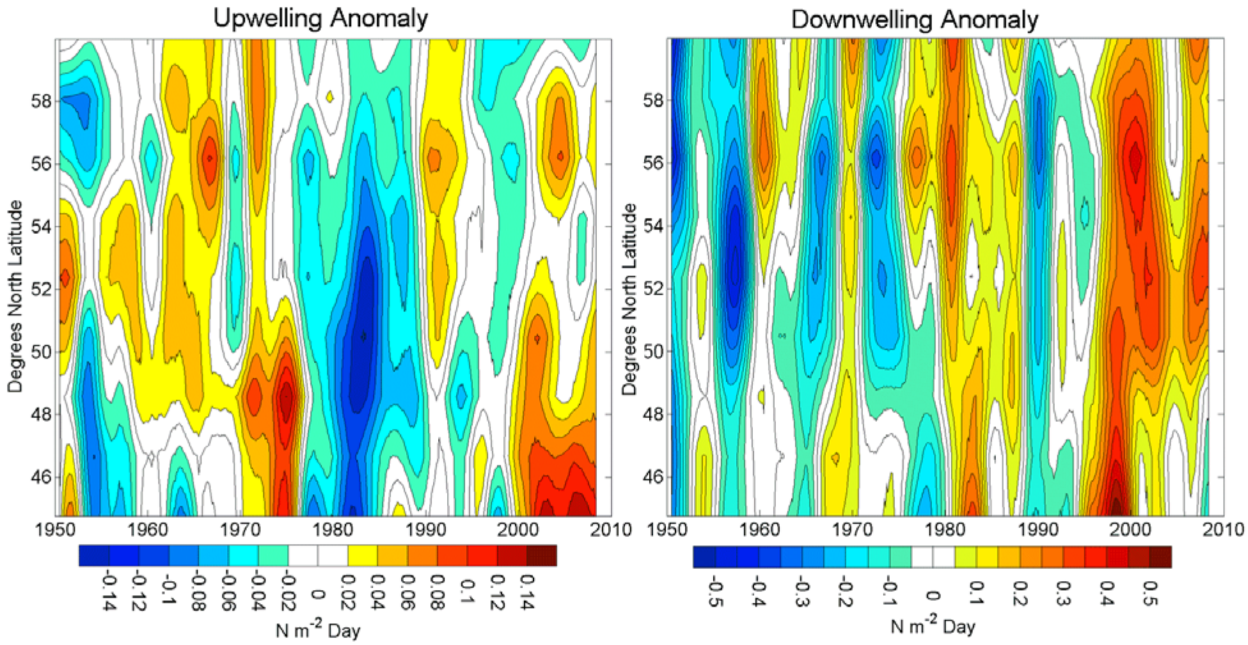
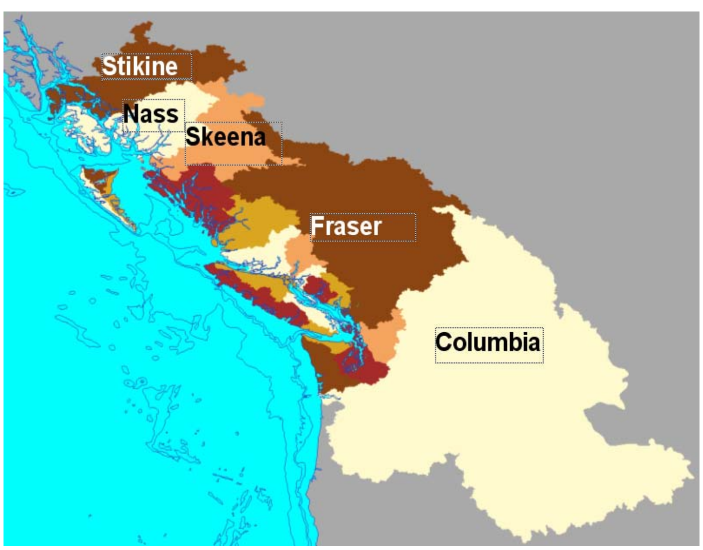


Figure 4. Time series of upwelling (left panel) and downwelling (right panel) winds from 1950 to 2010. Values are presented as anomalies from the local average wind over the full time series, and expressed in unit of wind stress in Newtons / m^2, which is the actual force of the wind on the water. A five-year running average was used to smooth the series. (Adapted from Hourston and Thomson 2011.)

These changes in alongshore winds may have had an impact on marine ecosystems. For example an increase in downwelling winds is a suspected environmental factor in the lack of recovery of the sockeye salmon runs in Rivers Inlet of the BC central coast , following their collapse in the early 1990s (McKinnell et al. 2001). The hypothesis for this salmon stock collapse is that delayed onset of upwelling winds in spring and even early summer might change the distribution and onset of spring plankton blooms, which in turn are prey for larvae and very small fish fed upon by juvenile salmon. There are insufficient data to test this hypothesis. However, there is evidence that plankton distribution spring is a major factor in survival of juvenile seabirds in the Scott Islands, due to shifts in phytoplankton distribution in southern Queen Charlotte Sound (Borstad et al. 2011).



River runoff

Figure 5. Watersheds of British Columbia and USA assessed by Morrison (2011).

As part of a long-term project to determine past and future runoff in BC due to climate variability and change, Morrison (2011) has compiled stream gauge data at most BC locations and, incorporating estimates for ungauged watersheds, determined past fresh water runoff into the ocean averaged over the watersheds of British Columbia that drain into the Pacific Ocean. Figure 5 shows locations of various watersheds, named after its most significant river. Figure 6 presents average annual runoff into the ocean and the runoff for the year 2010.

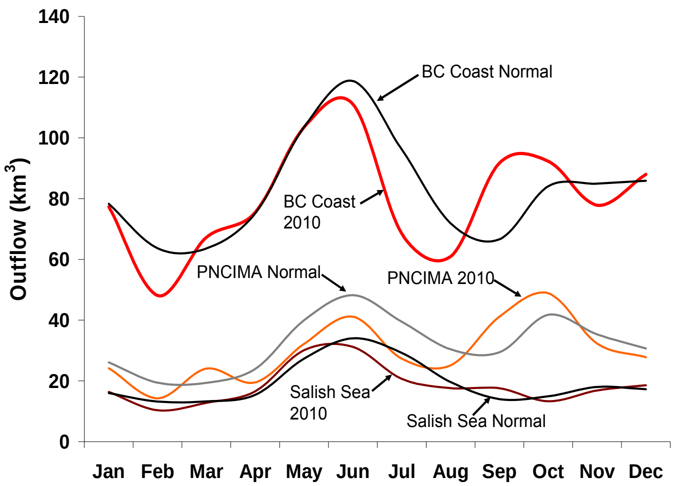


Figure 6. Monthly runoff for regions of British Columbia in 2010 and normal runoff over 1970 to 2010. Figure from Morrison (2011).

All regions have a peak in runoff in May-June due to snow melt, and most have a second peak in autumn due to increased fall precipitation. PNCIMA runoff provides just under one-half the BC runoff in an average year. With warmer winters and changes in precipitation in future decades, the autumn and winter flow is expected to rise relative to summer flow.

Global warming might change runoff over the next decades. One would expect an initial increase in flow as glaciers melt (downwasting), followed by a decrease as the mass of surviving glaciers becomes critically small (terminal retreat). Casassa et al. (2009) suggest that south-central BC glaciers are in terminal retreat, whereas glaciers of northwest BC and the Yukon are downwasting. Stahl and Moore (2006) examined August stream flows of many BC rivers. Their trend analyses suggested no trends in streams in unglacierized basins, but revealed negative trends for glacier-fed rivers, particularly from 1976 to 1996, consistent with the effects of terminal retreat. They do not appear to have distinguished southern and northern BC rivers. Recent studies (Bolch et al. 2010) indicate that glaciers in the central coast of British Columbia lost 1.21% ± 0.27% of their area per year, 1985 to 2005. North coast glaciers lost 0.35 ± 0.15% of their area per year over this same period. A separate studied of volume loss of glaciers (as opposed to areal loss) by Shiefer et al. (2007) determined that recent rate of glacier loss in the Coast Mountains (17.0 km/yr) was approximately double that observed for the previous two decades.

For Pacific salmon (*Oncorhynchus* spp.) it is often the timing and temperature of river flows that is critical to their migration success, especially on their up-river migration as adults. Rand et al. (2006) have determined that these two factors might increase future mortality of sockeye salmon (*O. nerka*) in the Fraser River of southern BC, but similar studies have not been undertaken in any PNCIMA salmon-bearing rivers. Déry et al. (2009) have examined nine streams in BC over the years 1960 to 2006, finding, in general, earlier onset of the spring melt, decreases in summer stream flow, and a delay in the onset of enhanced autumn flows. An exception was Surprise Creek of north-western BC, which is a glacier stream with increasing summer flow. Moore et al. (2009) examined only glacier-dominated rivers of BC, finding that “over recent decades, glaciers in northwest BC and southwest Yukon have lost mass dominantly by thinning with relatively low rates of terminal retreat, and glacier-fed streams in that region have experienced increasing flows.” The opposite trends were found elsewhere in BC.

Sea level rise

A recent study by Thomson et al. (2008) of factors affecting sea level in British Columbia covers most aspects of this topic, including global sea level rise, local vertical ground motion, storms and tsunamis.

The Canadian Hydrographic Service of Fisheries and Oceans Canada monitors levels along the BC coast. Their records are plotted in Figure 7, showing annual deviations of measured sea level from the long-term average at three ports. Both Tofino and Victoria have records that begin in 1910, while the record at Prince Rupert begins in 1912. With records going back about one hundred years, these are the oldest climate time series in BC coastal waters.

Sea level measurements were first established for mariners, and from the very beginning the records used local bedrock as a vertical reference, since the depth of bedrock is a primary concern of mariners. However, when these rocks drop or rise in elevation due to tectonic movement of continental plates or to the ongoing response of Earth’s crust to melting of continental glaciers during the last ice age, the local “average sea level” will change, even if it is not the level of the global ocean that is changing. Readers can see this effect in the time series of sea level in Figure 7, where the record at Tofino indicates local sea level is dropping, even though the absolute elevation of the global ocean has been rising over the past century.

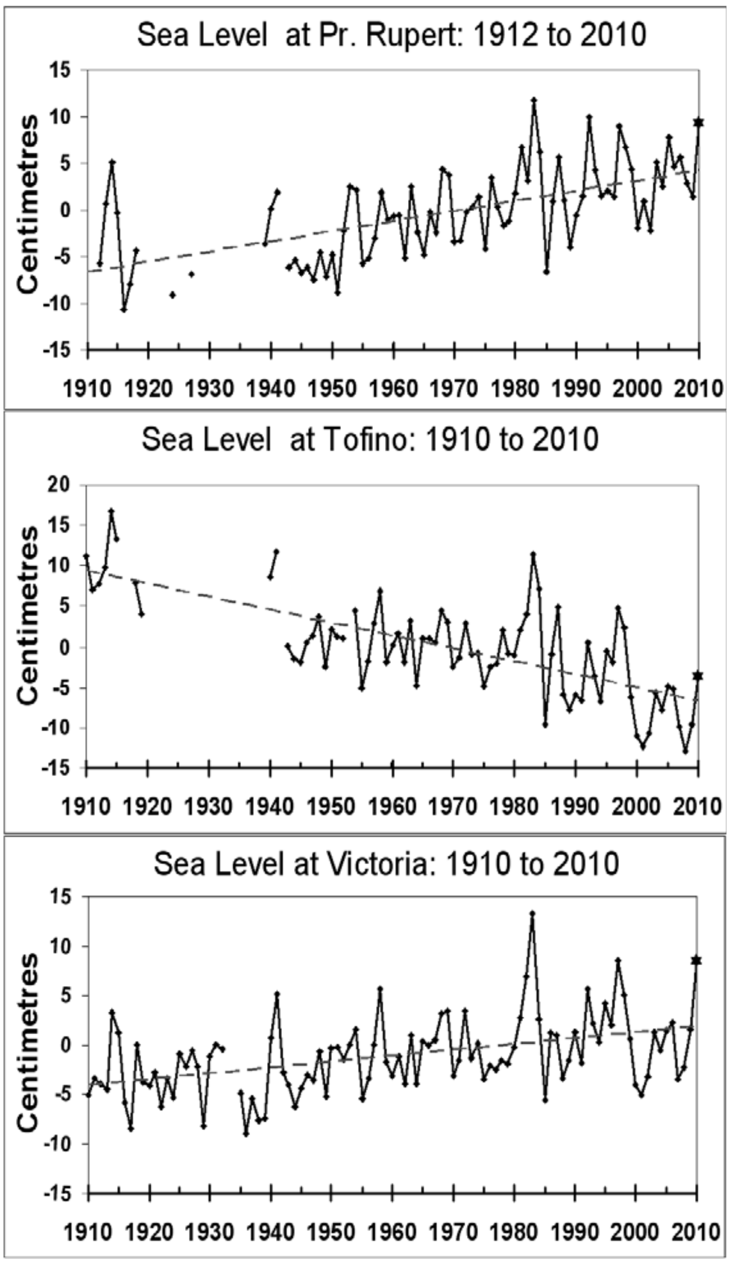


Figure 7. Graphs of annual-average sea levels at three British Columbia ports. Long-term average linear trends are plotted as dashed lines. Figure from Crawford (2011a).

Prevailing winter winds from the west reduced sea levels at these ports in 2000 to 2002, and again in 2008 to 2009. These westerly winds were associated with La Niña conditions, which ended in mid 2009. The shift to El Niño weather in early 2010 brought southerly winds and higher sea levels to the BC coast. As a result, average levels in 2010 were above the long term trend at these ports.

Strong El Niño winters generally bring highest sea levels to the BC coast. The extreme highs in 1982-1983 and 1997-1998 are due to such events.

The linear trends at Prince Rupert, Victoria and Tofino are +11, +6, and -16 cm/century, respectively. By comparison, global sea levels rose by 17± 5 cm in the 20th century, a rate significantly higher than measured at Tofino and Victoria. These differences with the global ocean are due to tectonic motion that is lifting the land (bedrock) faster than sea level is rising, so local sea level is actually dropping at Tofino, and rising more slowly than the global rate at Victoria (Thomson et al. (2008) provide actual numbers for this rate for the entire BC coast). Tofino and Victoria lie on the part of the North American tectonic plate under which the Juan de Fuca plate is sinking, and both gauges are therefore rising slowly. The line along which these two plates meet is called the Cascadia Subduction Zone. The uplift is greater at Tofino because it is closer to the subduction zone.

Prince Rupert lies to the north of Juan de Fuca plate, so its rate of sea level rise of 11 cm/century is closer to the global rate of 17± 5 cm/century. If uncertainties of sea level rise due to climate variability at Prince Rupert are considered, its rate of sea level rise would likely be within the uncertainty of the global rate.

A recent study of this long-term rise in sea level at Prince Rupert (Abeysirigunawardena and Walker 2008) notes that sea level rose more rapidly over the period 1939 to 2003 than over 1919-2003. They also note that El Niño Southern Oscillation (ENSO) forcing exerts significant influence on winter sea level fluctuations at Prince Rupert, while the Pacific Decadal Oscillation (PDO) dominates summer sea level variability, and that interannual and decadal sea level fluctuations were significantly greater than the century-long sea level. (PDO is a pattern of temperature variability over the entire North Pacific Ocean. It is described more fully in the section on climate variability.) Such extreme sea level fluctuations related to ENSO and PDO events should be the immediate priority for the development of coastal adaptation strategies; as they are superimposed on long-term trends, resulting in greater hazard than longer term mean sea level rise trends alone. For example, average sea level in January and February of 1998, during a winter of strong El Niño and positive PDO, was about 30 cm higher than in a typical winter. Any winter storms would bring even higher sea levels to PNCIMA shores.

Satellite observations since 1993 indicate global sea levels are presently rising at a rate of 30 cm per century, suggesting that the rate of sea level rise has accelerated since 1993. The Intergovernmental Panel on Climate Change (Solomon et al. 2007) predicted 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. With long-term global warming, even higher rates of sea level rise are expected after the year 2100. Thomson et al. (2008) examined both global predictions of sea level rise and effects local to British Columbia, concluding that sea level rise in the 21st century at Prince Rupert might be 20 to 30 cm, with a range (90% confidence interval) of 10 to 50 cm. They mention that, with rapid ice sheet melting, the rise of 20 to 30 cm could be 60 cm, a not unrealistic assumption.

The next big Cascadia Subduction Zone earthquake could drop the land at Tofino and along the southwest coast of Vancouver Island by as much as a metre within minutes, and also send a major tsunami toward this newly subsided coast. Estimates of the tsunami wave height are in the range of 1 to 4 m, and remain an estimate because a detailed numerical model of a Cascadia tsunami has not been done for this region.

Abeysirigunawardena and Walker (2008) also examined the highest measured sea level in each year, which is a measure of changes in risks of erosion and flooding at Prince Rupert, with general application to PNCIMA. The linear regression model based on these highest sea levels of each year showed a trend exceeding twice that average annual sea level, suggesting that storms and climate variaibility are combining to raise the winter extreme highs more rapidly that the average annual sea level itself.

Although the shoreline of much of PNCIMA is steep and not generally exposed to strong wave action, it is the northeast shore of Graham Island in Gwaii Hanas that is the region of BC receding most rapidly in time due to waves and sea level rise. The Geological Survey of Canada identifies this eastern coastline as one of the top 3% of Canada’s most sensitive coastlines to climate-changeinduced sea level rise, largely for its low lying, highly erosive, macro tidal shoreline (Walker and Barrie 2007).

Temperature and salinity

Figure 8 presents average sea surface temperature in northern BC and southeast Alaska for summer and winter, based on Foreman et al. (2008). Coldest waters in summer are near the Broughton Archipelago of Queen Charlotte Strait, and in some tidal channels along the east side of Hecate Strait. In general summer waters are cooler in northern parts of PNCIMA and where tidal mixing is strongest. In winter the south-to-north cooling dominates, with warmest waters to the west of Vancouver Island, and coolest in southeast Alaska. However, the range of temperatures in winter is about half that in summer, with a change in winter of only 5^{o} C over the entire south-to-north domain. These images are prepared from a recently computed database of temperature and salinity of all coastal waters, and deep sea waters west to 160°W (Foreman et al. 2008).

Typical values of sea surface salinity are presented in Figure 9. Freshest waters in summer are in inlets, due to runoff from coastal mountains along the east side of Hecate Strait and Queen Charlotte Sound, and from the Skeena and Nass Rivers into eastern Dixon Entrance. In winter, saltier offshore waters penetrate onto the continental shelf, due to strong southerly winds of winter storms.

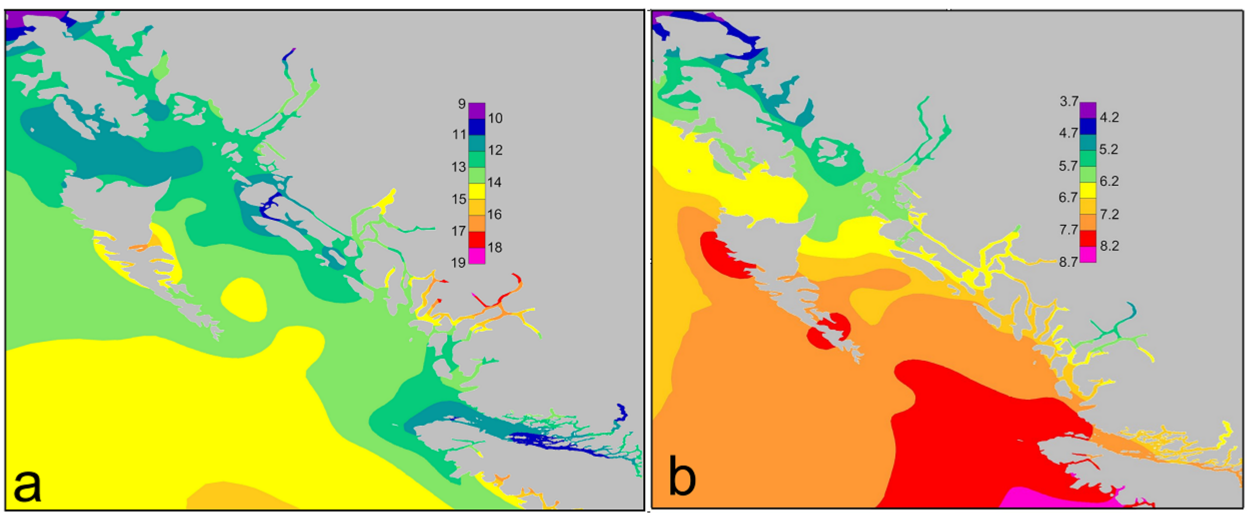


Figure 8. Average ocean surface temperature for (a) summer and (b) winter. Colour contours show ocean temperature in degrees Celsius. Note the changes in temperature scale between (a) and (b).

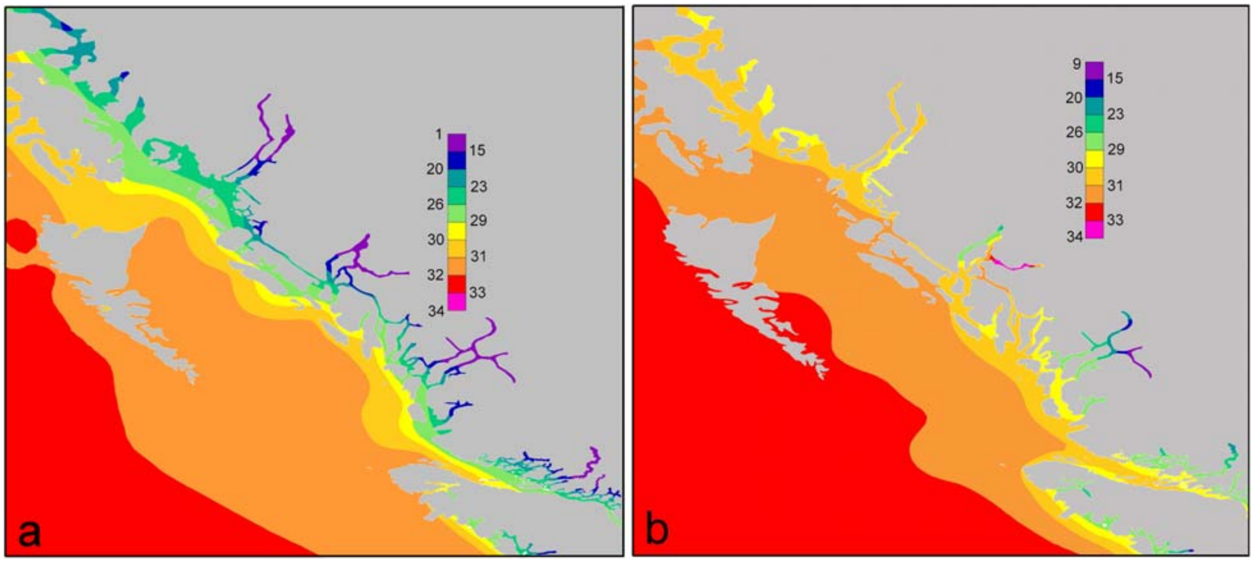


Figure 9. Average ocean surface salinity for (a) summer and (b) winter. Colour contours show ocean salinity, presented as Practical Salinity (S_p) whose units are essentially parts per thousand by mass. Note the changes in salinity scale between (a) and (b). Figures provided by M. Foreman, Institute of Ocean Sciences (personal communication, 2011).

Changes of temperature and salinity in time

Temperature and salinity are measured daily at many locations along the BC coast by Fisheries and Oceans Canada, with most measurements by staff at lighthouses. Figure 10 shows several aspects of changes in temperature at these stations. PNCIMA stations are in the left panel; southern BC stations in the right. Blue and red dots reveal temperatures in 2009 and 2010, respectively, with black arrows connecting these dots revealing the increase in average annual temperature from 2009 to 2010. All stations reported an increase in temperature, ranging from 0.5 to 1^{o} C, due to generally cooler waters during La Niña of 2009 compared to warmer water in the El Niño year of 2010.

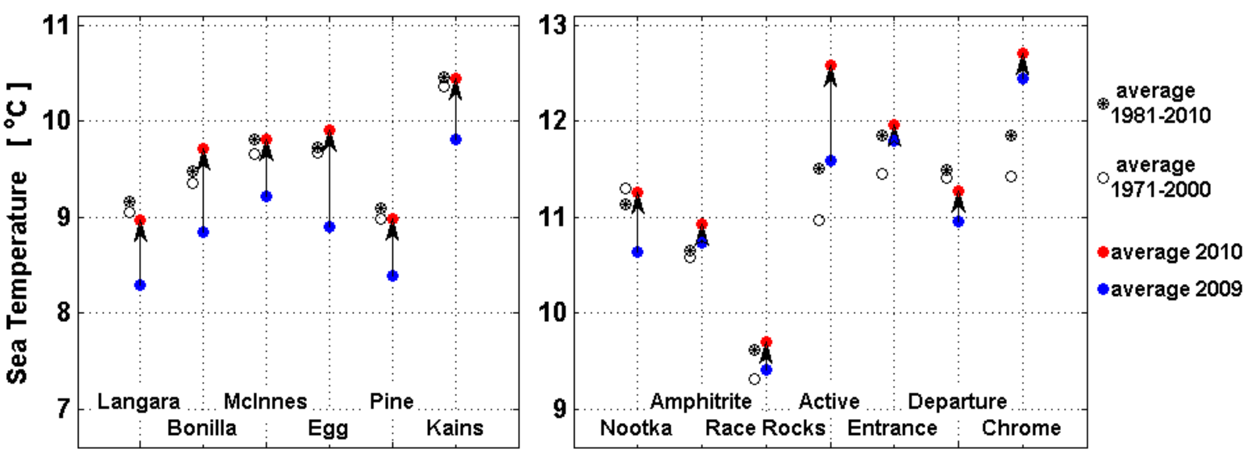


Figure 10. The average daily sea surface temperature in 2009 and 2010 at BC lighthouse stations, and the annual average calculated from two different periods of 30 years of data (1971-2000 and 1981-2010). (From Chandler 2011)

A second feature of Figure 10 is the increase in 30-year averages of ocean temperature. The average temperature over 1971-2000 is about 0.1^{o} C cooler than an average over 1981-2010 at most PNCIMA stations. These 30-year averages are used as climate normals by meteorological agencies of North America. Both Environment Canada and the US NOAA are shifting from a 1971-2000 climate normal to a 1981-2010 climate normal for air temperature. Chandler (2011) presents both in this transition year.

Figure 11 shows the long term changes in temperature at Langara Island off the northwest tip of Graham Island, and at Kains Island off northwest Vancouver Island. Both indicate a general warming from the late 1930s to 2010, although most of the temperature increase takes place between the late 1970s and early 1980s. The temperature scale shows the difference (anomaly) between each individual annual temperature and the long-term average. These temperature trends are similar to those of southern British Columbia. The warm and cool anomalies are generally (but not always) El Niño and La Niña years, respectively.

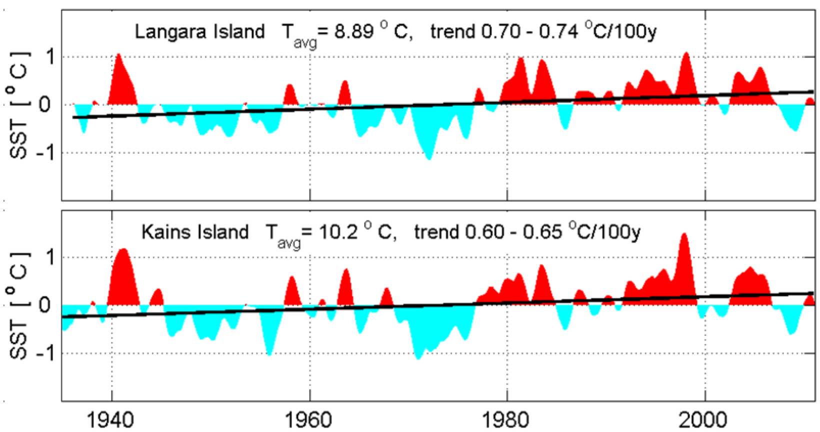


Figure 11. Time series of annual temperature anomaly at Langara and Kains islands. Positive (negative) anomalies from the average temperature at each station are shown in red (blue). The slope of the trend lines assumes a linear change over time, and the 95% confidence intervals of the slopes are given as the range in the trend over 100 years. (Adapted from Chandler 2011)

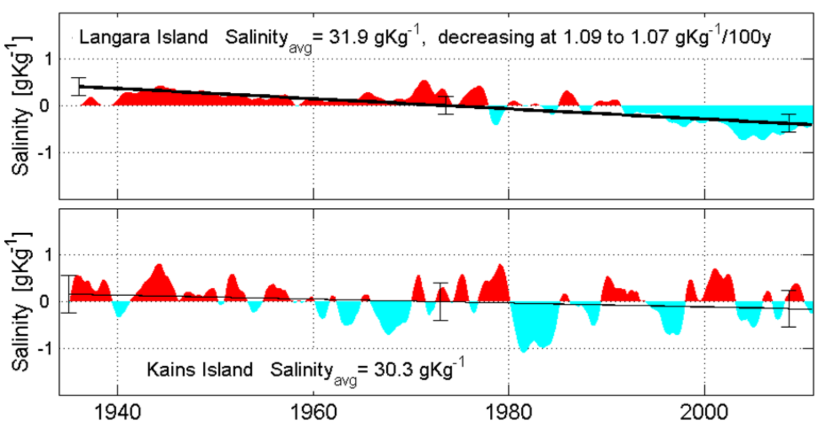


Figure 12. Time series of annual salinity anomaly at Langara and Kains islands. Positive (negative) anomalies from the average salinity at each station are shown in red (blue). The black lines represent the linear relationship between time and salinity; the 95% confidence limits of the slope show a statistically significant decreasing trend at Langara Island, and a negative, but not statistically significant trend, at Kains Island. (Adapted from Chandler 2011.)

Figure 12 reveals the changes in ocean salinity at Langara and Kains islands over the same interval. The decline in salinity at Langara is by far the greatest of any of the 13 stations along the BC coast, and no single factor has been identified to explain it. This decrease in salinity at Langara is almost 1 g of salt / kg of seawater (part per thousand). It began in the late 1970s and accelerated through the 1990s and 2000s. It is unlikely to be related to an increase in river runoff, because Morrison (personal communication) notes no trend in total annual river flow into PNCIMA. The decline is present on all seasons, with a slight but not significantly lower rate of decline in July to September compared to other seasons. Lowest monthly salinities measured in any months were in October and November of 2010, and lowest seasonal averages were all between 2005 and 2010. The extreme years do not appear to follow ENSO variability or to changes in the PDO, another index of ocean temperature change in the Gulf of Alaska. The increase in downwelling winds shown in Figure 4 might be a factor, since such winds would retain fresh water on the continental shelf. However, downwelling winds should increase fresh water retention at all lighthouses in PNCIMA, not just at Langara Island.

We suspect declining salinity at Langara could be attributed to changes in the Aleutian Low, as represented by the North Pacific Index (Trenberth and Hurrell 1995). This low pressure system expanded its area in winter in the late 1970s, and has generally remained larger since then, although with considerable interannual variability. A large Aleutian Low could impact salinity at Langara Island through changes in winter winds and wind-driven ocean currents of the Gulf of Alaska.

Climate variability

The North Pacific Index (NPI) is one of several large-scale indicators of climate variability across the North Pacific Ocean that often help to explain why animal abundances, separated by thousands of kilometres, increase or decrease in unison, or even inversely. Another index of interest in the North Pacific is the Oceanic Niño Index (ONI) which is based on the ENSO cycle of El Niño and La Niña in the equatorial Pacific Ocean. ENSO events affect the waters along the west coast of the Americas causing warmer air and sea temperatures during El Niño and cooler temperatures during La Niña.

In Figure 13 (left), coastal sea temperature anomalies at Kains and Langara islands were positive when the ONI was positive. Although NOI is a tropical index, it accounts for much of the year-to-year variability in coastal BC surface ocean temperatures. An El Niño winter generally brings stronger southerly winds to the BC coast; during La Niña winters the winds tend to be more from the west and cooler. Of note, the North Pacific Index became more negative in the winter of 1977 and, with few exceptions, this shift has persisted to the present. A negative NPI indicates stronger southerly winds along the west coast of Canada, Washington State and Oregon. There are regional differences in how this intensification of storms is expressed in the Northeast Pacific. It seems these winds increased in PNCIMA in the late 1990s, as was noted previously.

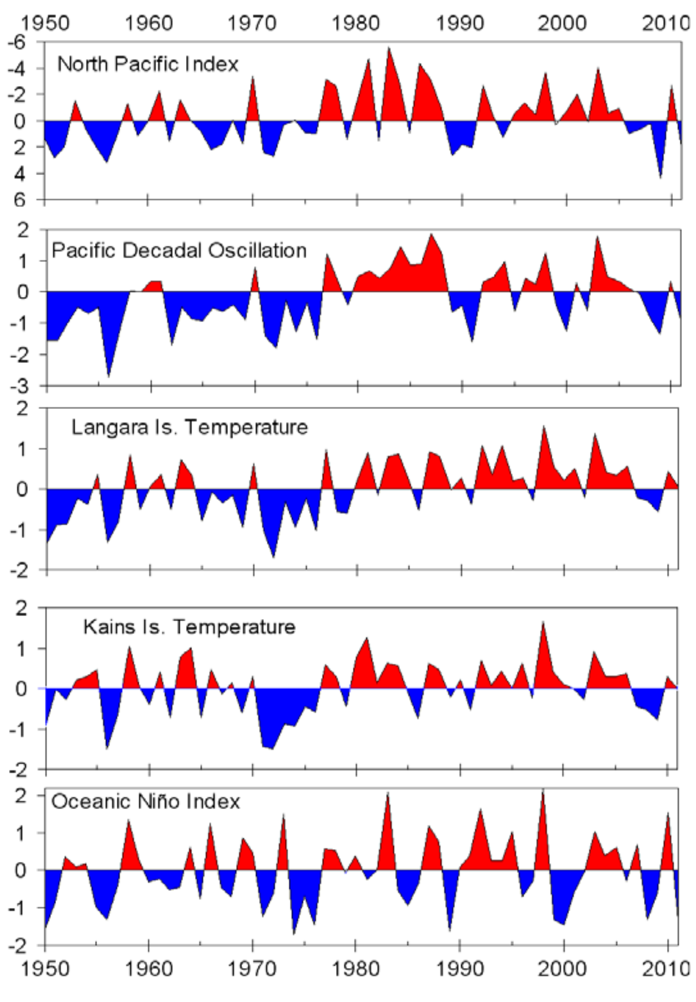


Figure 13. Comparison of anomalies of winter sea surface temperature at Langara and Kains Islands with several climate indices. Each time series is based on an average from November to March, and plotted at the year of January to March. Note that the scale for the North Pacific Index is inverted, because its negative phase aligns with positive values of the other time series.

The Pacific Decadal Oscillation (PDO) index reflects the large-scale ocean surface temperature patterns across the North Pacific Ocean, north of 20° N. It was first identified as a factor to explain long-term changes in salmon catches in the Northeast Pacific Ocean (Mantua et al. 1997). As with the NPI, the PDO reflects much of the decade-to-decade changes in sea temperature anomalies at Kains and Langara islands. Both the ONI and the PDO have been mostly negative for the past four to five years, interrupted only by a brief but strong El Niño in early 2010. It is not surprising, therefore, that winter temperature anomalies at Langara and Kains (Figure 13) were negative through most of these winters.

Dissolved oxygen

A concern in PNCIMA is a continuing decline in bottom-water oxygen concentration (O_2) and its impact on both aquaculture and wild fish. Although surface waters are always rich in dissolved oxygen, waters below 100 to 150 m depth do not gain oxygen directly from the ocean surface. For example, seawater at 250 m below the ocean surface in Queen Charlotte Sound last had contact with the ocean surface decades ago and thousands of kilometres away, and slowly lost O_2 due to decay of organic material. As a result, dissolved O_2 can be as low as 1.5 millilitres per litre (ml/L) on the bottom of Queen Charlotte Sound, and down to zero in some fjords that exchange deep water very slowly with outside waters. Waters of Queen Charlotte Sound, Hecate Strait and Dixon Entrance support diverse bottom life and rich fisheries. Oxygen concentration in these shelf waters is sufficiently low that future declines might alter the distribution of some or many of these species and lead to loss of deep-water habitat. Some of these changes may have already occurred (Whitney and Sinclair, personal communication, 2010).

There have been no previous reviews of oxygen concentration on the PNCIMA continental shelf, so we provide below a detailed account of what is presently known for this region and how waters of the Gulf of Alaska and the BC continental margin influence PNCIMA oxygen concentration. The continental shelf of the North American west coast generally extends from shore to about 200 metres depth. Beyond this the bottom drops much more steeply down to several thousand metres, in a region called the continental slope. The term “continental margin” includes both shelf and slope.

Several papers note declines in North Pacific sub-surface oxygen concentration. Emerson et al. (2004) noted a drop in mid-ocean O_2 from mid 1980s to mid1990s and Whitney et al. (2007) show a decline over 50 years at Ocean Station Papa, located 1500 km west of Vancouver Island. Whitney (2009) prepared a graph of the rate of decline in oxygen concentration from 1987 to 2007 at several deep water regions close to and west of the North American continental shelf, presented in Figure 14. There is a worry that sub-surface oxygen concentrations might continue to decline in future decades along the west coast. The main cause could be the declining O_2 in subarctic waters that is occurring because of reduced ventilation (gas exchange between ocean and atmosphere) of the ocean along the East Asian coast. Whitney (2011) suspects this decline is due to large-scale freshening and possibly warming over the subarctic North Pacific as part of global climate warming.

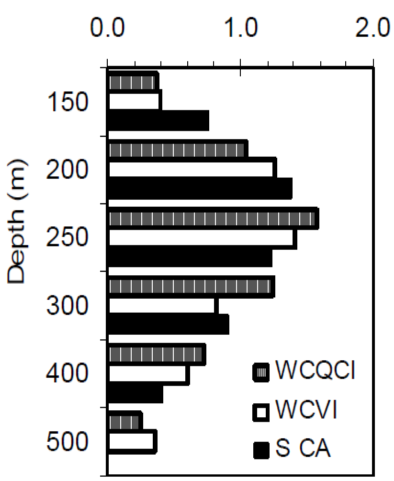


Figure 14. Rate of oxygen loss from 1987 to 2007 at three deep-water locations off the North American west coast. WCQCI: west coast Queen Charlotte Islands (Gwaii Hanas). WCVI: west coast Vancouver Island. SCA: southern California. Units are micromole per year (μM/yr). A decline of 1 μM/yr over 45 years would decrease O_2 by about 1 ml/L. Figure from Whitney (2009).

Figure 15 shows the composition of low-oxygen Pacific Equatorial Water (PEW) in the California Undercurrent along the continental margin between 175 and 225 m depth. This water mass is formed in the eastern tropical Pacific Ocean and is warmer and lower in O_2 than the subarctic water masses of the Northeast Pacific Ocean with which it mixes. The mixing increases O_2 concentration in this undercurrent as it flows northward. Thomson and Krassovski (2010) have determined that at Newport Oregon, PEW comprises a bit more than 40% of local seawater at 200 m depth, whereas in Dixon Entrance the composition is just over 30%. This dilution accounts for the general increase in O_2 of waters of the continental shelf at 175 to 225 metres depth, from Oregon to BC and into Alaska. This dilution and increase in O_2 shows up as a shift in colour of the dots in Figure 15 from red off Oregon to green and blue off Alaska.

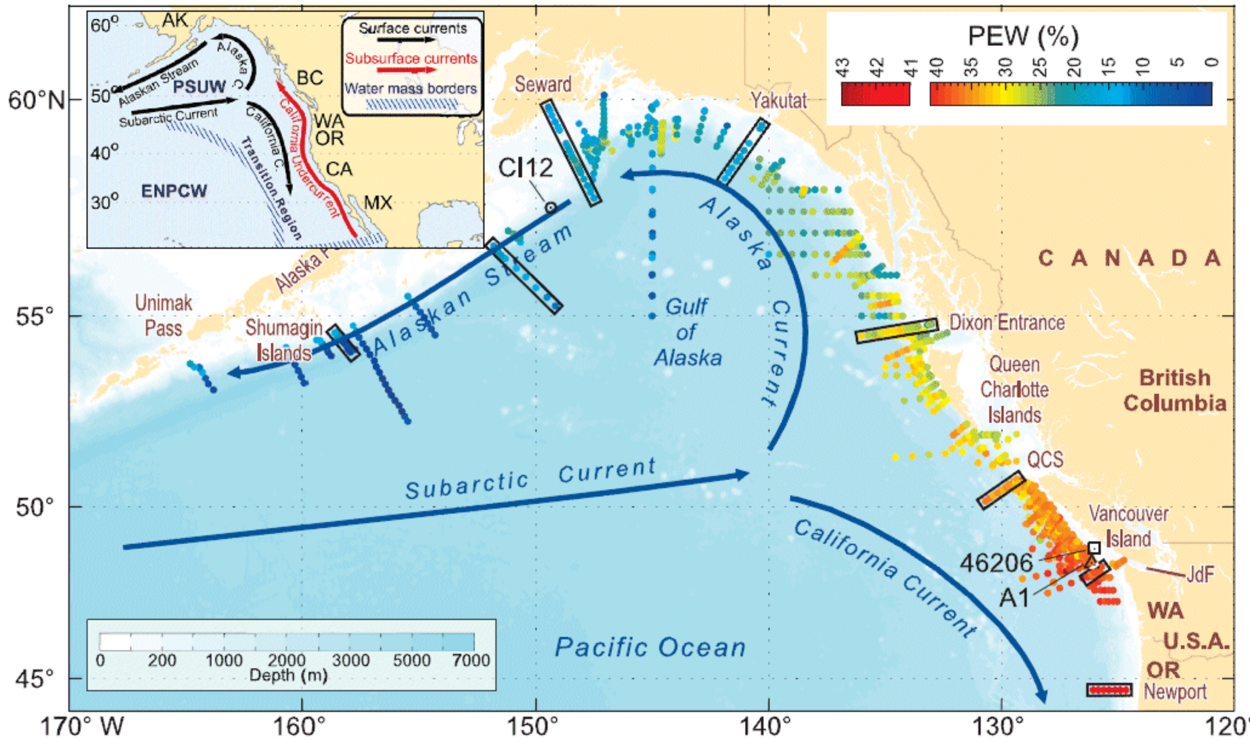


Figure 15. The inset at top left reveals the locations of the main surface currents, as well as the subsurface, northward flowing California Undercurrent (in red). The main panel shows the percent of Pacific Equatorial Water (PEW) at 175 to 225 m depth in regions of the continental margin from Oregon to Alaska in April to October when O_2 levels are lowest. PEW is lower in dissolved oxygen than the waters of the Subarctic, Alaska and California Currents. Figure adapted from Thomson and Krassovski (2010).

Both Emerson et al. (2004) and Whitney (2009) examined observations in deep waters west of the continental shelf, but of greater concern are O_2 levels on the continental shelf itself, which is much richer than the deep-sea regions in biological life below 100 m. Scientists have noticed that O_2 in sub-surface waters on the continental shelf has declined recently to values lower than in previous decades. Bograd et al. (2008) described declines off southern California from 1984 to 2006. Greatest concern is in Oregon, with concentrations since the summer of 2002 less than 0.5 ml/L in waters near shore less than 50 m deep, and mortality of shellfish in this region (Chan et al. 2008). Off Vancouver Island, these relatively shallow, near-shore waters are well oxygenated due oxygen-rich currents flowing out of Juan de Fuca Strait and northward along Vancouver Island. Even at 100 m depth, O_2 is above 2 ml/L and is usually higher. However, at mid shelf off southwest Vancouver Island at about 150 m depth, concentrations as low as 0.7 ml/L were observed in late summer of 2006 and 2009 (Crawford 2011b). A search of historical records determined that the 2006 and 2009 measurements of O_2 were the lowest values there since regular sampling began in 1979. In addition, irregular observations back to the 1930s did not find such oxygen-depleted water.

To search for an historical perspective on O_2 in PNCIMA, we undertook a review of oxygen measurements in most British Columbia waters. Scientists generally look at oxygen in April to September along the US west coast, when bottom waters are lowest in oxygen due to upwelling winds. In Canada the upwelling season starts later in the year, so we investigated separately the O_2 levels in June to September and April to May. We show in Figure 16 the near-bottom oxygen measurements for the BC continental margin south of 52°N out to 1000 m depth. Clearly, oxygen concentrations on the continental shelf are lower in June to September than in April to May. The lowest O_2 inside the 200 m contour is near 48.5°N, 125.3°W in Figure 16A. Essentially no regions shallower than 100 m have O_2 below 1.4 ml/L. In general, oxygen concentrations increase from south to north in Figure 16, attributed to weaker in upwelling winds off northern Vancouver Island, mixing in the California Undercurrent, and an upwelling eddy off southwest Vancouver Island.

Both panels of Figure16 reveal very low O_2 concentrations in some inlets. This is a natural occurrence in deep, fjord-type inlets due to low flushing rates of bottom water, which allows almost all oxygen to be consumed by organic material. Some inlets are almost always oxygen depleted at bottom and even have hydrogen sulfide rather than O_2. Some become anoxic intermittently.

Very few oxygen measurements in summer were taken with traditional sampling methods north of 52°N in PNCIMA. To fill this gap we examined measurements taken in the past few years as part of a program to measure water properties during test fisheries by Fisheries and Oceans Canada in waters of the continental shelf. Oxygen was measured by an electronic sensor at the opening of the trawl net on the ocean bottom. Hecate Strait was sampled with this technique in April and May of 2007 and 2009, with the distribution of O_2 concentrations seen in Figure 17B. Data points elsewhere in Figure 17A are from more traditional sampling methods. All data in July to September in Figure 17B were collected with traditional O_2 sampling.

The distribution of near-bottom O_2 in Hecate Strait in Figure 17 generally follows bottom contours, with concentrations below 3 ml/L generally in waters deeper than 100 m. Even below 200 m the concentration does not fall below 1.4 ml/L. Hypoxia (concentrations less than 1.4 ml/L) is confined to fjord-type inlets, as revealed by the red symbols in Figures 17A and 17B.

Clearly, O_2 concentrations on the Canadian continental shelf are lower off southwest Vancouver Island than farther north in PNCIMA. Although hypoxia is not seen in shelf waters of PNCIMA, there is concern that the trend to lower O_2 west of Gwaii Hanas observed by Whitney (2009) will impact bottom life in PNCIMA in the future. One concern is that even if bottom O_2 levels are not fatal to groundfish, these fish might move to shallower depths where O_2 is more concentrated. Whitney and Sinclair (personal communication) have noted that much of the habitat in PNCIMA lies between 200 and 250 m depth, and if this is a preferred depth for some species, moving to shallower depths would deprive these fish of much of the area of their habitat.

The study of impact of oxygen concentrations on marine life is complicated by the different responses of species to low O_2 concentrations. The level of O_2 at which some species will leave a particular habitat is greater than the concentration that might kill them. Many species can thrive at O_2 levels that seriously impact others. For these reasons the study of impacts of hypoxia is species-dependent.

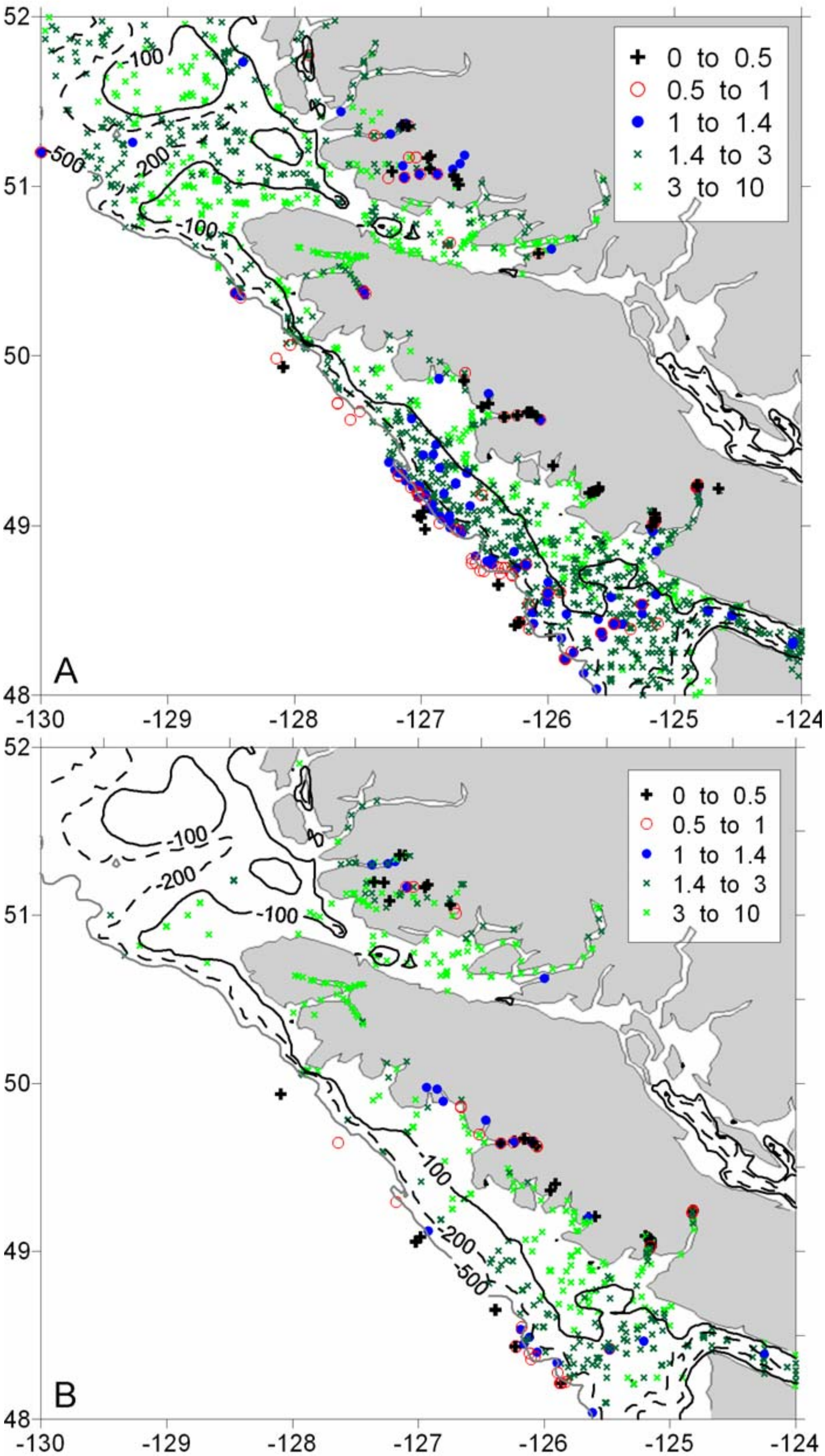


Figure 16. Concentration of oxygen in ml/L within 20 m of the ocean bottom in all historical measurements in Fisheries and Oceans Canada archives for regions south of 52°N. Depth contours are at 100, 200 and 500 m. A: June to September. B: April to May.

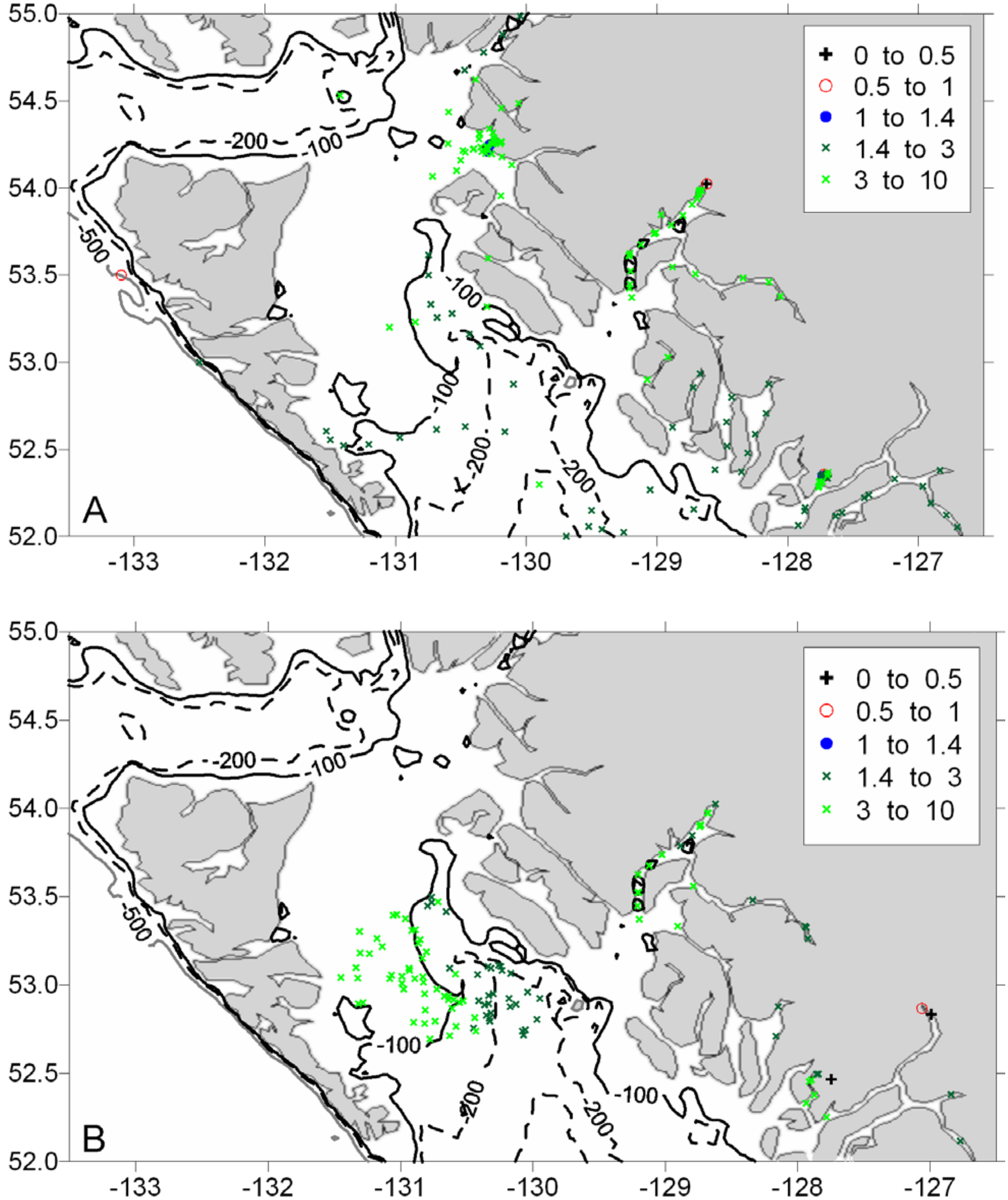


Figure 17. Concentration of oxygen in ml/L within 20 m of the ocean bottom in all historical measurements in Fisheries and Oceans Canada archives for regions north of 52°N. Depth contours are at 100, 200 and 500 m. A: June to September. B: April to May.

Ocean acidification

An alarming trend over the 21st century and beyond will be the increasing acidification of the oceans due to increases in carbon dioxide (CO_2) concentration in ocean waters. Increasing acidification is a threat to organisms that produce calcite and aragonite shells or structures, such as pteropods, corals and shellfish. The full impacts of increasing acidity are not known. Most of this additional CO_2 will be derived from human activities. The most recent publications specific to west coast waters are by Ianson (2007), Nemcek et al. (2008) and Feely et al. (2008). Comprehensive overviews of global oceans are provided by the Royal Society (2005) and Doney et al. (2009).

Figure 18 shows the relative vulnerability of ocean waters to acidification in the future, by plotting the depth below which aragonite and calcite dissolve in seawater, called the saturation depth. Aragonite and calcite are two types of calcium carbonate in almost all shell-producing marine organisms. Shells dissolve more readily than they can form at depths below these saturation depths and some impairment in shell growth can be expected at depths somewhat shallower than the saturation depth.

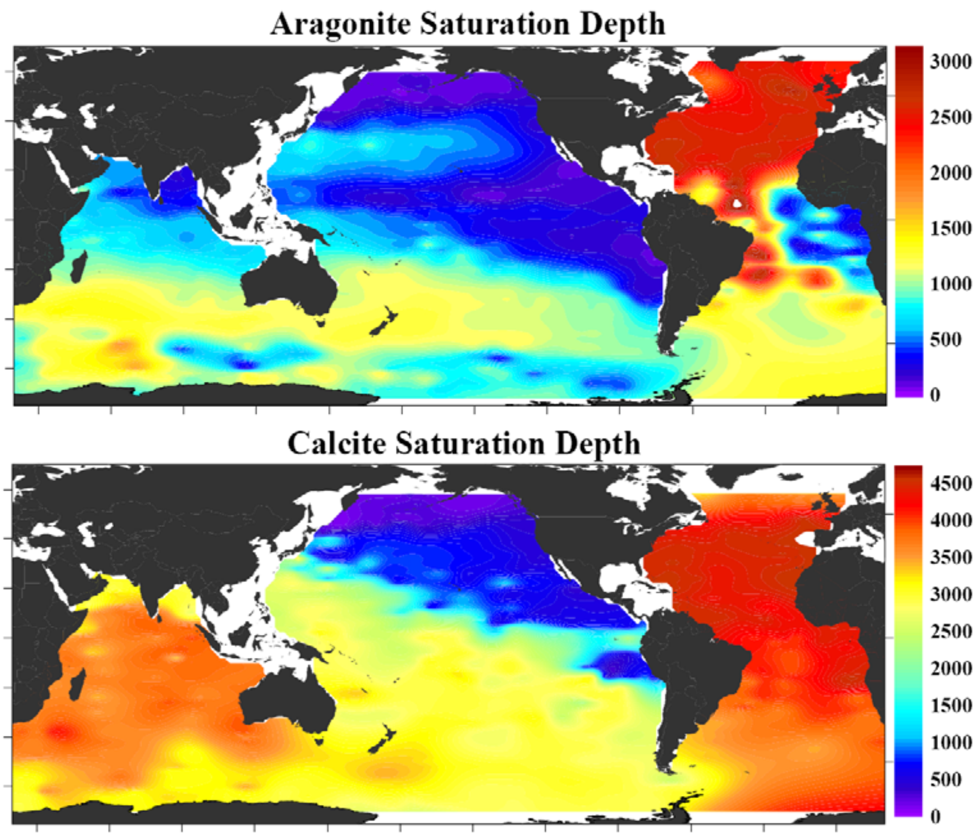


Figure 18. Saturation depth of aragonite and calcite in the global oceans (Feely et al. 2004). Colour scale at right denotes the depth in m. White areas denote regions of little or no data. Figure courtesy of Richard Feely.

Note that the shallowest saturation depths in Figure 18 tend to be in the north and east parts of the Pacific Ocean, generally due to natural processes. (The aragonite saturation depth in the Beaufort Sea of the Canadian Arctic is even shallower, and in at least one recent summer it reached the ocean surface.) The aragonite saturation depth shoaled by between 50 and 200 m in the last century, and is now found at depths of only 100 to 300 m below the ocean surface in deep-sea waters of the

Northeast Pacific Ocean (Feely et al. 2004). Scientists expect the saturation depth to shoal steadily through the next centuries as global atmospheric CO_2 concentrations increase. Pteropods are the organism most vulnerable in waters of the Gulf of Alaska away from the continental shelf. Their shells are aragonite, the more readily dissolved form of calcium carbonate. Several research programs are underway to examine possible impacts on pteropods now.

Summer upwelling along the Canadian west coast causes intermediate depth water from 100 to 200 m below surface to come onto the shelf and up into the ocean surface layer. The upwelled water is high in nutrients and dissolved inorganic carbon (DIC) and so more acidic (lower in pH). However, this DIC is quickly drawn down by primary producers such as phytoplankton, and so the exposure of the shelf to low pH water is expected to be intermittent.

Recently, Nienhuis et al. (2010) and Crim et al. (2011) have examined impacts on abalone and snails in laboratory studies and many studies are ongoing. However, there have been no *in situ* published reports of the effect of this exposure on the local organisms of Canadian west coast continental shelf.

Marine contaminants

Lucas et al. (2007a) did not cover contaminants in their review of the PNCIMA ecosystem, but several valuable reviews were published on this topic at about the same time. Johannessen et al. (2007a) published a summary of marine contaminants in PNCIMA, based largely on extensive details in two reports for northern and southern waters of PNCIMA respectively by Johannessen et al. (2007b) and Haggarty et al. (2003). These three reports, together with their extensive bibliographies, cover topics such as aquaculture, vessel traffic, ports, harbours and marinas, forestry, pulp and paper mills, mining and smelting, ocean dumping, military and coast guard sites, offshore oil and gas, and global contaminants. More recent information specific to waters near Vancouver Island is available in Ianson and Flostrand (2010).

Hall (2008) prepared an overview of the ecosystem of PNCIMA, noting impacts of many marine contaminants. His summary of plastic pollution covers a topic not mentioned in the above reports. Hohn (2011) has written a thorough account of floating plastic at sea, with a major focus on the North Pacific and Southeast Alaska. Molnar and Koshure (2009) have written a thorough review of shipping-related sources of pollution specific to PNCIMA. This review covers present shipping activities as well as future shipping associated with possible development of oil and gas ports in PNCIMA.

Since it is not practicable to summarize recent findings on marine contaminants, a topic that covers a wide range of human activities and impacts within PNCIMA, the reader is referred to the sources listed. We note several recent, ongoing, and proposed events and programs below.

Vessel traffic

Ships and boats can contribute to pollution through releases of wastewater, oil and oily bilge water, through intentional or accidental spills as well as through major spills from collisions. A major category is cruise ships, whose size has increased steadily in time. Johannessen et al. (2007b) state, “Although more stringent regulations are being applied to cruise ship operations, current onboard wastewater treatment methods do not remove many of the contaminants found in pharmaceuticals and personal care products. The degree of enforcement is limited and the level of compliance is unknown.”

On 26 March 2007, the BC ferry M/V *Queen of the North* hit Gil Island on the BC Inside Passage and sank. According to a BC Ministry of the Environment Report (http://www.env.gov.bc.ca/eemp/incidents/2006/queen_north_06.htm), the vessel was loaded with

225,000 L of diesel fuel, 15,000 L of light oil, 3,200 L of hydraulic fluid, and 3,200 L of stern tube oil. Some oil discharged right away, floating to the ocean surface and spreading. Much oil remains aboard the wreck, and there are reports of oil leaks well after the sinking.

This report states that "Wright Sound and surrounding area is rich in marine life. It is a major vessel transportation route of the Inside Passage. The coastal waters are important for First Nations' fisheries and economies. There were minimal impacts on wildlife as the initial large release of product – mostly diesel - quickly evaporated and dispersed during high wind and warm periods shortly after the spill. The ongoing chronic discharges and remaining oil from and in the ferry remain as an environmental concern. A long-term environmental monitoring plan was formulated that will involve members from both the Hartley Bay and Kitkatla First Nations and environmental agencies."

Persistent organic pollutants

Various programs investigate persistent organic pollutants (POPs), organic compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes. POPs have been observed to persist in the environment, to be capable of long-range transport, bio-accumulate in human and animal tissue, bio-magnify in food chains, and to have potential significant impacts on human health and the environment. Some examples of these compounds are polycyclic aromatic hydrocarbons (PAHs) polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs).

Yunker et al. (2011) examined PAHs in sediments and bottom marine life in Kitimat Harbour, partitioning the origin of PAHs among local industry, transportation and natural sources and noting possible effects on marine life. Some of these scientists are presently analyzing sediment samples from southern PNCIMA for PCBs and PBDEs. A separate study of hydrocarbons in sediments in Hecate Strait and along the PNCIMA coast aims to evaluate natural hydrocarbon baseline signatures as well as a variety of anthropogenic contributions to these patterns (Peter Ross, Institute of Ocean Sciences, personal communication, 2011).

Other studies have examined POPs in fish and bears. An earlier study in central and northern PNCIMA and southeast Alaska, examined POPs in grizzly bears whose diet is dominated seasonally by Pacific salmon returning to spawn. Between 70% and 90% of the grizzly's POPs were derived from the salmon they ate (Christensen et al. 2005). These POPs are believed to have entered these salmon in offshore waters of the North Pacific.

Concentrations of PCBs are considered high in many marine mammals of the west coast of North America (http://www.dfo-mpo.gc.ca/science/Publications/article/2006/02-01-2006-eng.htm. The concentration tends to be higher in mammals that eat "higher up the food chain". For example, transient killer whales, which feed mainly on other mammals, have higher PCB concentrations than resident killer whales that dine primarily on salmon.

Recent studies have examined POPs in salmon directly. Ikonomou et al. (2011) examined PBDEs in adult salmon migrating through the Gulf of Alaska, southeast Alaska, and Canadian waters, with one sampling station in Johnstone Strait. Kelly et al. (2011) examined organochlorine pesticides in farmed and wild salmon from British Columbia. Human exposure from a diet of either type of salmon was found to be low relative to United States national average per capita total exposure levels and provisional tolerable daily intakes.

Monitoring conditions at ocean disposal sites

Environment Canada regulates disposal at sea activities through a permitting system administered under the *Canadian Environmental Protection Act (CEPA 1999).* Sites are approved for disposal at sea activities through this permitting process. North of Campbell River, there are three sites that have been recently used for disposal at sea; one of these sites (a location in Brown Passage near

Prince Rupert) has been inactive since 2007, and the other two sites (two locations in the Johnstone Strait) have been inactive since 2008. Environment Canada is responsible for conducting scientific monitoring at sites where disposal activities have been permitted in the past. As part of this ongoing monitoring program, Environment Canada is evaluating environmental quality at some of the previously used sites in the PNCIMA area, including Brown Passage (Scott Lewis, Environment Canada, personal communication, 2011). There are several proposed development projects in the PNCIMA area that could involve large-scale disposal-at-sea activities. Ongoing monitoring represents an opportunity to assess conditions at some of the previously used ocean disposal sites, and to collect baseline data in areas where new sites may be proposed (Scott Lewis, Environment Canada, personal communication, 2011).

Ports, harbours and marinas

These facilities are real or potential sources of oil and polycyclic aromatic hydrocarbon (PAH) contamination and minor levels of sewage. Major industrial ports are located at Kitimat and Prince Rupert. Northern Gateway Pipelines Limited Partnership (Northern Gateway) proposes to construct and operate an oil export pipeline, a condensate import pipeline, and a tank terminal and marine terminal near the town of Kitimat, BC. Pipelines are proposed to carry condensate to Alberta and oil from Alberta. The marine terminal would accommodate transfer of oil into tankers and condensate out of tankers, for shipment to and from offshore ports through the Inside Passage, Hecate Strait, Dixon Entrance and Queen Charlotte Sound. This project, named the Enbridge Northern Gateway Project, began environmental Impact assessment in mid-2011, under the direction of the National Energy Board. Among the aspects of this proposal relevant to marine contaminants are the possibilities of oil and condensate spills at the port near Kitimat and from tankers en route. The largest tanker proposed is rated as a Very Large Crude Container (VLCC) whose maximum size has a capacity for 330,000 m^3 of oil. If approved, the volume and number of vessel transits in this region will increase significantly. Details of this environmental Impact assessment are not available for this State of the Ocean Report, but are expected be made public in late 2011 or in 2012.

Forestry

Impacts of this industry tend to be small compared to southern BC, due to presence of major forest reserves, relatively low use of pesticides and fire retardant chemicals. There are no wood preservative or production facilities (although wood preservation products are used.)

Pulp and paper mills

All Canadian pulp and paper mills underwent significant effluent treatment upgrades in the 1990s such that discharge of solids, chlorinated compounds such as dioxin and furans are now significantly reduced. Some chemicals still released such as wood sugar and plant hormones require additional studies.

Mining and smelting

Johannessen et al. (2007b) reported that some active mining sites were considered at risk for acid rock drainage. Three of these sites used underwater tailings disposal to prevent metal leaching, which has indeed prevented the release of heavy metals into the environment. They specifically mentioned the ALCAN smelter at Kitimat as the main source of PAHs in Kitimat Arm and Douglas Channel. They noted that aluminum smelting continued at Kitimat but contamination levels were not considered to be increasing.

Ocean dumping

Most material dumped is either dredgeate from navigable waters or material from the forest industry.

Military and Coast Guard sites

Although these are potential sources of contaminants, Johannessen et al. (2007b) did not identify current problems.

Offshore oil and gas
This category relates to underwater exploration for hydrocarbons. PNCIMA is believed to hold significant reserves of oil and gas, but at present there is no active proposal to explore.

Global contaminants
Many persistent chemicals can bio-accumulate within organisms and bio-magnify up the food chain. These terms are jargon for the tendency for some chemicals in small organisms to end up stored in the bodies of their predators, and then the next predator, and so on. In many cases the source of pollution can be far from PNCIMA, and even in Asia. Johannessen et al. (2007a) noted that the high level of PCBs in northern BC killer whales is an example of this problem that might be attributed to atmospheric transport. Cadmium levels in some shellfish are likely due to long-range transport through the ocean. Plastics now comprise most of the debris in beaches, and tiny plastic floating particles are a problem when ingested by marine life. Most debris and floating plastic likely arrive from outside PNCIMA waters. Good reviews of the problem in PNCIMA are provided by Hall (2008). We recommend Hohn (2011) for a recent, thorough, readable account of floating plastic at sea.

Aquaculture

Most shellfish and finfish aquaculture locations are shown in maps 46 and 47 of the Pacific North Coast Integrated Management Area Initiative (2011) (http://www.pncima.org/site/atlas.html). The management and regulation of aquaculture in B.C. was transferred from provincial to federal jurisdiction on December 18, 2010. DFO is now responsible for most aspects of the aquaculture industry in B.C., and informs the public through an Internet page dedicated to Aquaculture in British Columbia: http://www.pac.dfo-mpo.gc.ca/aquaculture/index-eng.htm . See the section on Invasive Species later in this report for a description of some aquaculture impacts.

Salmon aquaculture has been the topic of many reviews and studies, more than we can review here. We do note that aspects of this topic are under review by the Commission of Inquiry into the decline of sockeye salmon in the Fraser River (http://www.cohencommission.ca/en/) with several reports investigating impacts of PNCIMA aquaculture on Fraser River sockeye. These fish migrate through PNCIMA on both their seaward passage as juveniles and their return as adults. We direct readers to the Internet site above for access to this recent information. The final report of this commission of inquiry, due in 2012, will provide a good summary of these topics.

MARINE LIFE

Plankton

A review of plankton in PNCIMA is provided by Mackas et al. (2007) in their appendix to the Lucas et al. (2007a) report by Fisheries and Oceans Canada. The category of plankton includes both phytoplankton (plants) and zooplankton (animals).

Phytoplankton
Most of our knowledge of the distribution of phytoplankton derives from measurements of ocean colour by the SeaWiFS and MODIS satellites, both funded by the US National Aviation and Space Agency (NASA). Because the chlorophyll pigments in phytoplankton reflect a specific colour of light, scientists are able to identify the presence of phytoplankton in ocean surface waters. Mackas et al. (2007) present composite images of chlorophyll distribution at the PNCIMA sea surface for months of March, May and September, revealing that Dogfish Banks, Chatham Sound and southeast Queen Charlotte Sound have the greatest biomass of phytoplankton at surface in March to September.

Lower phytoplankton concentrations at the ocean surface are present through late autumn and winter due to low light levels, intense wind mixing, and cooler temperatures.

Recent studies reveal that features of sea-surface phytoplankton abundance in spring in southeast Queen Charlotte Sound, as observed in satellite observations, are critical to seabirds on Triangle Island, and perhaps even to the survival of juvenile salmon migrating through these waters. Borstad et al. (2011) linked the concentration of phytoplankton in surface waters in April near Triangle Island, off northwest Vancouver Island, to the breeding success of rhinoceros auklets on this island. Surprisingly the concentration in March and May is much less critical.

Their conclusion is based on detailed examination of ocean colour data from the SeaWiFS satellite from its launch in 1998 through to 2008, and also on many years of observations of seabirds on this island by scientists of Environment Canada. Figure 19 shows an image of the composite of phytoplankton concentration observed in April of 2007 and 2008. Seabird chick survival was lowest in 2007, the year of lowest phytoplankton biomass in April. Both were highest in 2008.

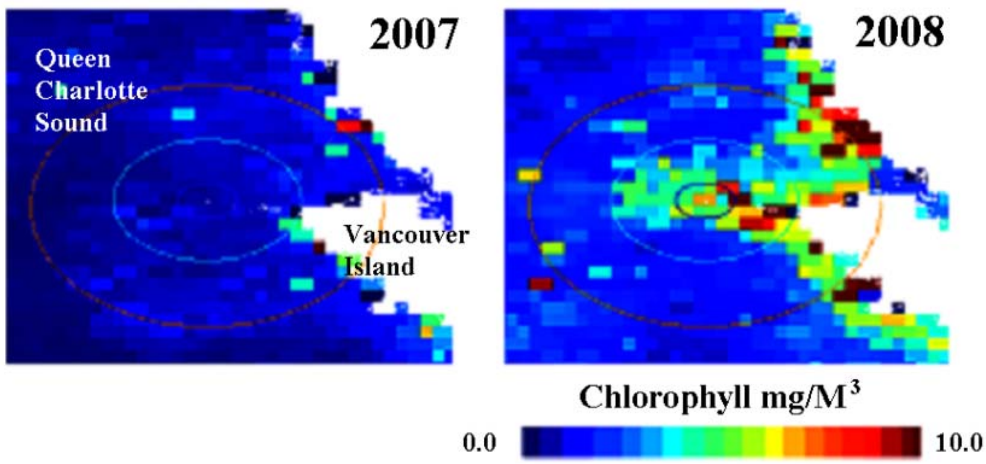


Figure 19. Composite sea-surface chlorophyll time series for Southeast Queen Charlotte Sound for the month of April in 2007 and 2008, shown with 90km, 45km and 15km radius ellipses centered on Triangle Island. Islands of the Goose Island Group are near the region of highest chlorophyll near the BC mainland in 2008. Time series were provided by NASA, based on observations by the SeaWiFS satellite sensor. Figure from Borstad et al. (2011).

By looking at phytoplankton distribution on successive days of satellite images in April for the regions between Triangle Island and Smith Inlet on the BC mainland, they concluded that breeding success is high when a mass of phytoplankton-rich surface water drifts westward from islands of the Goose Island Group to Triangle Island sometime in April. It is likely that this water mass is also rich in zooplankton and fish larvae and even fish juveniles by the time it reaches Triangle Island, providing plentiful feed for seabirds. They believe that seabirds arrive on Triangle Island in late March after a long migration from the south, and require feed from this nearby water mass. Borstad et al. (2011) suspected that if the plankton-rich water arrives after the end of April, it will be too late in the season to benefit seabirds and their chicks. Conditions in March are not important because seabirds are still migrating to the island, and there is seldom a phytoplankton bloom near Triangle Island in this month. This study is one of the first in the world to use satellite measurements of chlorophyll and plankton to predict breeding success of seabirds.

This study also extends to sockeye salmon. Borstad et al. (2011) compared returns of Smith Inlet sockeye salmon over the past decades with the same data series of phytoplankton measured by satellite. Although the results are not as robust as the comparison with seabirds on Triangle Island, there is evidence that ocean-surface phytoplankton concentrations in Queen Charlotte Sound, measured by satellite, correlate with returns of adult sockeye salmon two years later. Irvine et al. (2010) have repeated this comparison with juvenile sockeye salmon migrating from Chilko Lake, which drains into the Fraser River, again with significant correlations.

Zooplankton

Fisheries and Oceans Canada scientists have sampled zooplankton in PNCIMA waters regularly since the 1990s for the two regions labelled Northern Vancouver Island (NVI) and Hecate Strait (Hecate) shown in Figure 20. A third region, SVI, lies off the southwest coast of Vancouver Island (Mackas et al. 2010, 2011).

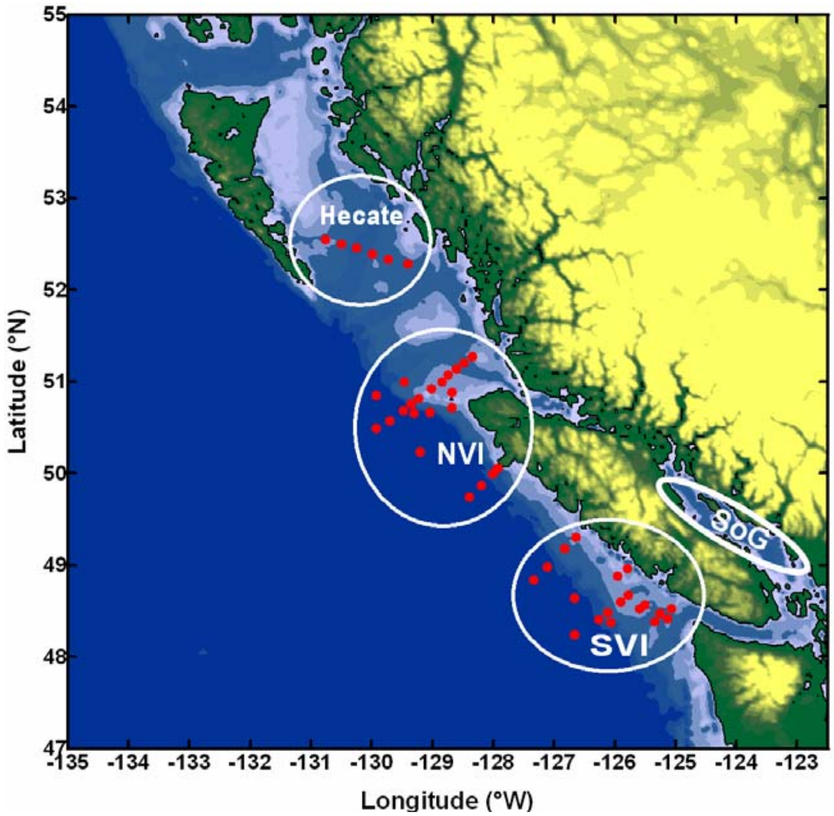


Figure 20. Zooplankton time series sampling locations (red dots) on the BC the continental shelf. The two sampling regions within PNCIMA are Northern Vancouver Island (NVI) and Hecate Strait (Hecate). This map does not include sampling locations in the Salish Sea. Figure from Mackas et al. (2010).

To simplify the reporting of many species of zooplankton, scientists 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 km south of our study areas (either in the California Current and/or further offshore in the North Pacific Central Gyre) (Mackas et al. 2011).

The abundance anomalies of the copepod groups are strongly linked to annual water temperature and circulation anomalies. For example, "southern copepods" reached their highest densities in the

NVI region from 1996-1998 (during and immediately before the 1997-98 El Niño). They subsequently had below-average biomass in the cooler years of 1999-2001 and 2007-2009, and near-average biomass in 2003-2006. This pattern of interannual variability is shared by the other coastal regions, but its intensity varies with latitude: somewhat weaker in the Hecate stations, but much more pronounced along southwest Vancouver Island (SVI). In general, the species composition change in response to years of warm and cool oceans has been greater among all species in SVI than in the two PNCIMA regions (Mackas et al. 2011).

Corals, sponges and sponge reefs

PNCIMA contains many of the cold-water corals and sponges as well as the globally unique hexactinellid (glass) sponge reefs found in BC (Finney and Boutillier 2010). DFO (2010a) recently released its conservation strategy to protect these rare and sensitive components of our marine ecosystem; the following is taken from this strategy.

Some coral colonies may be more than a century old, while some sponge reef communities may have taken thousands of years to develop. For instance, within PNCIMA the Hecate Strait/Queen Charlotte Sound sponge reefs have existed for ~9000 years in channels carved by icebergs. Cold-water corals and sponges host distinctive communities of associated species and sponge reefs that can be important nursery habitat for young rockfish. Recruitment and reproduction for BC coldwater corals and sponges are poorly understood. Readers are encouraged to review DFO (2010a) for a description of:

- The state of knowledge of Canadian Pacific coldwater corals and sponges, including key issues related to their biology;
- Known impacts to coldwater corals and sponges;
- Conservation, management and research objectives and associated strategies and actions;
- Gaps in information and issues where more work is needed;
- Socio-economic and conservation implications with respect to cold-water coral and sponge conservation measures; and
- Management tools to aid in coldwater coral and sponge conservation.

The Living Oceans Society maintains an Internet site devoted to these corals, including descriptions of visits to the colonies in 2009 using manned submersibles (http://www.findingcoral.com/).

Shellfish

The report by Pellegrin at al. (2007) presents an overview of shellfish in PNCIMA. Cummins and Haigh (2010) review more recent information on shellfish; see also the section on invasive species later in this report, as well as recent reports by Fisheries and Oceans Canada on Manila clams (*Venerupis philippinarum*) in the BC Central Coast (DFO 2010b).

Geoducks (*Panopea generosa*) and various other clams (e.g. razor (*Siliqua patula*), butter (*Saxidomus gigantea*), Manila, cockles (*Clinocardium nuttalli*), littleneck (*Protothaca staminea*) and horse clams (*Tresus capax*)) are fished to varying degrees.

Two native species are doing poorly. Northern abalone (*Haliotis kamtschatkana*) abundances remain at low levels due to illegal harvesting and low recruitment. Northern abalone, which occur throughout coastal BC including PNCIMA, are listed as 'endangered' by COSEWIC and SARA (http://www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=603).

In addition, the native Olympia oyster (*Ostrea lurida*), with a few isolated populations within PNCIMA, was recently (May 2011) confirmed as a species of 'special concern' by COSEWIC; it was previously listed as such by SARA in 2003 (http://www.sararegistry.gc.ca/species/speciesDetails_e.cfm?sid=645).

Valuable fisheries occur for pink (*Pandalus jordani*) and sidestripe (*Pandalopsis dispar*) shrimp, as well as red rock (*Cancer productus*), king (*Paralithodes camtschatica*), and especially Dungeness (*Cancer magister*) crabs (Cummins and Haigh 2010).

Groundfish

Workman and Rutherford (2011) recently updated the status of groundfish stocks within PNCIMA and the following is taken from their report, unless otherwise indicated. An earlier summary was provided by Fargo et al. (2007). Catches within PNCIMA constitute about half (2007-2010) of the total groundfish catches within BC (Table 1). Pacific hake (*Merluccius productus*) 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 mt of mixed groundfish was harvested annually within PNCIMA by trawl gear, of which approximately 22,500 mt (51%) was Pacific hake.

The start locations of trawl sets during 2007-2010 (Figure 21) illustrate the major fishing grounds in Queen Charlotte Sound (e.g. Goose Island Gully, Mitchells Gully and Cape St. James), in Dixon Entrance (e.g. near Dundas Island), and off the northwest coast of Haida Gwaii.

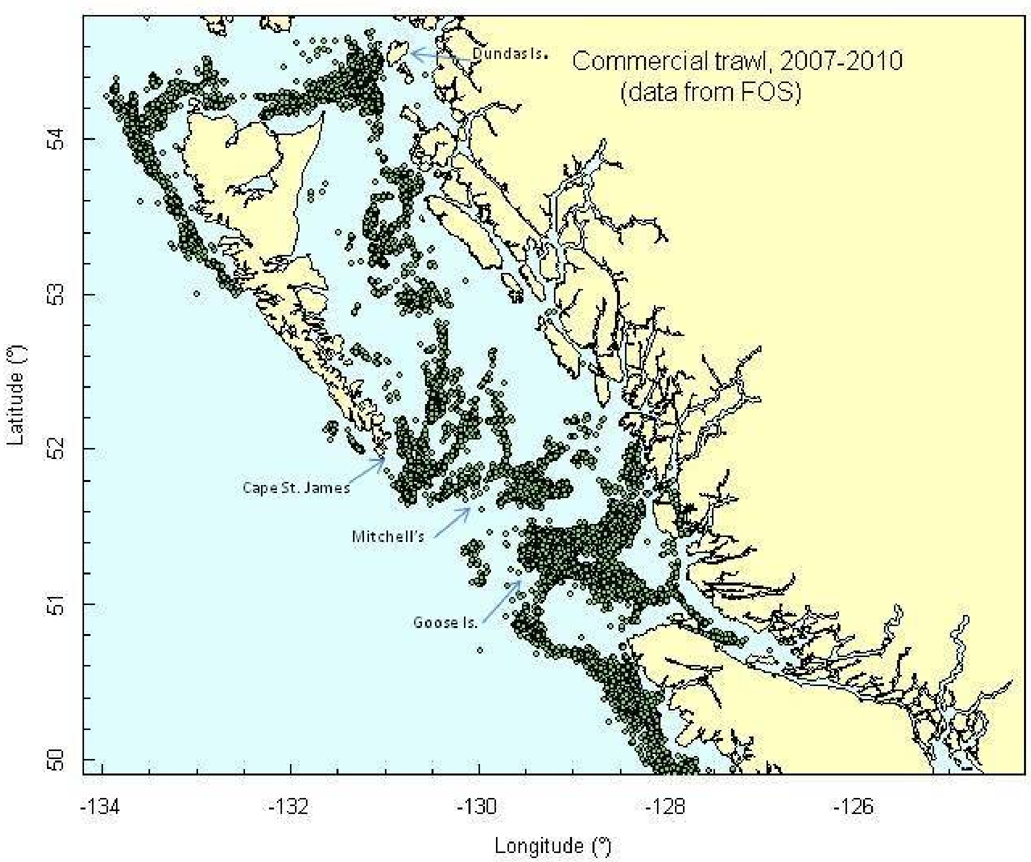


Figure 21. Start locations of all trawl sets (bottom and mid-water) within PNCIMA during 1970-2010. FOS = Fishery Operations System. From Workman and Rutherford (2011).

Groundfish are also taken by a variety of non-trawl gear including long line, hook and line, trap, jig, and troll. The largest catches by non-trawl gear within PNCIMA are of Pacific halibut (*Hippoglossus stenolepis*), sablefish (*Anoplopoma fimbria*) and lingcod (*Ophiodon elongatus*).

In general, within PNCIMA, gadoid (Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), Pacific hake (*Merluccius productus*)) stocks are stable or increasing, flatfish, lingcod, sablefish and elasmobranch stocks appear stable, while many rockfish species are at low levels of abundance with some being listed as 'special concern' or 'threatened' by COSEWIC (COSEWIC 2011). More details on specific groups follow.

Table 1. Average annual catches (mt), 2007-2010, of groundfish landed, released, and total in trawl fisheries within PNCIMA and expressed as a proportion of the catch for the entire BC coast (from Workman and Rutherford 2011).

	Landed (mt)		Released (mt)		Total (mt)	
SPECIES	PNCIMA	Proportion from PNCIMA	PNCIMA	Proportion from PNCIMA	PNCIMA	Proportion from PNCIMA
Pacific hake	22,077.8	0.37	419.2	0.29	22,497.0	0.37
Pacific ocean perch	4,007.8	0.90	108.3	0.77	4,116.1	0.89
Walleye pollock	2,393.4	0.94	236.1	0.87	2,629.5	0.93
Arrowtooth flounder	690.0	0.39	1,484.2	0.75	2,174.2	0.58
Yellowtail rockfish	1,565.2	0.37	59.0	0.65	1,624.2	0.38
Yellowmouth rockfish	1,229.1	0.97	26.4	0.96	1,255.5	0.97
Dover sole	937.1	0.59	108.4	0.66	1,045.5	0.60
Rock sole	836.6	0.98	101.1	0.97	937.6	0.98
Widow rockfish	742.8	0.49	6.9	0.54	749.7	0.49
Silvergray rockfish	540.1	0.87	205.9	0.76	746.0	0.83
Pacific cod	674.7	0.74	28.5	0.53	703.2	0.73
Rougheye rockfish	642.0	0.91	11.3	0.61	653.3	0.90
Lingcod	571.2	0.48	44.1	0.55	615.2	0.48
English sole	442.6	0.80	92.7	0.68	535.3	0.78
Big skate	445.5	0.95	58.6	0.94	504.2	0.95
Redstripe rockfish	351.1	0.76	148.8	0.64	499.9	0.72
Spiny dogfish	8.9	0.02	351.4	0.35	360.3	0.24
Shortspine thornyhead	305.5	0.70	11.9	0.66	317.5	0.69
Rex sole	218.4	0.81	95.5	0.61	313.9	0.74
Canary rockfish	296.6	0.44	0.6	0.33	297.2	0.44
Pacific halibut	0.1	0.04	296.3	0.82	296.4	0.82
Petrale sole	250.4	0.44	14.7	0.37	265.1	0.43
Sharpchin rockfish	93.7	0.67	93.0	0.75	186.7	0.71
Redbanded rockfish	144.9	0.90	1.5	0.59	146.4	0.90
Sablefish	96.4	0.37	48.7	0.48	145.1	0.40
Splitnose rockfish	52.2	0.60	67.6	0.70	119.9	0.65
Longnose skate	46.8	0.32	19.0	0.42	65.8	0.34
Bocaccio	34.9	0.56	28.7	0.65	63.5	0.60
Longspine thornyhead	37.6	0.45	7.2	0.42	44.8	0.44
Other	3.3	1.14	1.4	0.63	1.9	0.59
TOTAL	39,736.6	0.46	4,176.9	0.59	43,910.7	0.47

Rockfish

Slope rockfish are a long-lived species aggregate comprising seven species managed by Fisheries and Oceans Canada using total allowable catch (TAC) limits (Pacific Ocean perch (*Sebastes alutus*), yellowmouth (*S. reedi*), redstripe (*S. proriger*), rougheye (*S. aleutianus*), shortraker (*S. borealis*), shortspine thornyhead (*Sebastolobus alascanus*), and longspine thornyhead (*Sebastolobus altivelis*)) plus half a dozen minor species (e.g. darkblotched (*S. crameri*), sharpchin (*S. zacentrus*), redbanded (*S. babcocki*), and splitnose (*S. diploproa*)), generally distributed on the continental slope between 200 and 1500 m depth. Darkblotched, rougheye, and longspine thornyhead were designated 'special concern' by COSEWIC in 2007 and by SARA in 2009. Yellowmouth rockfish were designated 'threatened' by COSEWIC in 2010; darkblotched were designated 'special concern' by COSEWIC in 2009 but a listing decision under SARA has not been made. Queen Charlotte Sound Pacific Ocean perch have declined to 8-43% of their unexploited equilibrium. Current status of yellowmouth, redstripe, rougheye, shortraker, and shortspine thornyhead stocks is unknown as they have not been assessed since 1999. On average over the last four years 86% of trawl and non-trawl slope rockfish catches coast-wide were taken in the PNCIMA.

Shelf rockfish comprise five species managed by TAC (bocaccio (*S. paucispinis*), canary (*S. pinniger*), silvergray (*S. brevispinis*), widow (*S. entomelas*) and yellowtail (*S. flavidus*)) and a half dozen or more less common species generally distributed between 50 and 300 m depth over the continental shelf. Bocaccio and canary were both assessed by COSEWIC as 'threatened' but have not been designated by SARA. Silvergray are stable or increasing, while the status of widow and yellowtail is unknown. On average over the last four years 46% and 86% of trawl and non-trawl shelf rockfish catch coast-wide were taken in PNCIMA.

Inshore rockfish are comprised of two groups managed by TAC: yelloweye and an aggregate including quillback (*S. maliger*), copper (*S. caurinus*), China (*S. nebulosus*), tiger (*S. nigrocinctus*) and other rockfishes, which tend to be nearshore in depths of 5 – 200 m. COSEWIC has designated yelloweye as 'special concern' and quillback as 'threatened' although neither has been assigned a status under SARA. Although these species were heavily fished during the 1980's and 1990's, fisheries now tend to be small and non-directed. On average over the last four years 82% of inshore rockfish catch coast wide was taken in PNCIMA.

Codfish

Codfishes are comprised of Pacific cod, walleye pollock, Pacific hake and Pacific tomcod (*Microgadus proximus*). Pacific cod are distributed over muddy, sand or gravel bottoms between roughly 10 and 150 m. On average over the last four years 73% of the coast-wide catch of Pacific cod was taken in PNCIMA.

Pacific hake are the single most abundant non-forage marine fish species in BC. The presence of hake in PNCIMA is driven by oceanographic conditions and the 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% (Table 1), but in earlier years, when most of the fishery occurred to the south, the proportion was much lower.

Walleye pollock are traditionally harvested in Queen Charlotte Strait and Dixon Entrance. This species was last assessed in 1997 and current status is unknown. On average over the last four years 93% of the coast-wide catch of walleye pollock has come from PNCIMA.

Flatfish

Six flatfish species within PNCIMA are managed by TAC (Pacific halibut (*Hippoglossus stenolepis*), rock sole (*Lepidopsetta bilineata*), English sole (*Parophrys vetulus*), Dover sole (*Microstomus pacificus*), arrowtooth flounder (*Atheresthes stomias*), and petrale sole (*Eopsetta jordani*)). Halibut are captured by hook and line while the other species are harvested by mixed-species bottom trawls.

Most TAC-managed flatfish species are believed to be at moderate abundance although catches of halibut have been reduced in recent years due to declining abundance. Status of flatfish species taken as non-directed catch in the bottom-trawl fishery, including sand sole (*Psettichthys melanostictus*), rex sole (*Glyptocephalus zachirus*), flathead sole (*Hippoglossoides elassodon*), butter sole (*Isopsetta isolepis*), curlfin sole (*Pleuronichthys decurrens*), and starry flounder (*Platichthys stellatus*), is not well-understood.

Lingcod

An inshore and an offshore stock of lingcod occur; components of each occur within PNCIMA. 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 and only a small recreational fishery exists. Offshore lingcod stocks support medium-sized commercial fisheries for both trawl and hook and line sectors and a small recreational fishery. On average over the last four years 48 and 82% of the non-trawl and trawl catch of lingcod has come from PNCIMA.

Sablefish

Although sablefish are at ~ 18 % of unfished biomass, the stock is projected to rebuild at current reduced levels of harvest. On average over the last four years 40% of the coast-wide trawl and 74% of non-trawl catch was taken within PNCIMA.

Spiny Dogfish

There are no immediate conservation concerns for spiny dogfish (*Squalus acanthias*). Model results suggest the stock has rebuilt from a low point in the 1940s. 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

The principal species, big (*Raja binoculata)* and longnose (*Raja rhina)* skate, were assessed by COSEWIC in 2001 and designated 'not at risk'. On average over the last four years 79% of coast-wide trawl catch and 60% of non-trawl catch of big and longnose skates was taken in PNCIMA.

Pacific salmon

Adult salmon

PNCIMA is home to all seven species (Chinook (*O. tshawytscha)*, coho (*O. kisutch)*, chum (*O. keta)*, pink (*O. gorbuscha)*, and sockeye (*O. nerka)* salmon and steelhead (*O. mykiss)* and cutthroat trout (*O. clarkii)*). The region provides important spawning and rearing habitat for local populations of these species and is also important as a marine migration corridor for more southerly populations en route to and from the Gulf of Alaska (see next section).

Irvine et al. (2011) recently evaluated temporal abundance patterns and status for Pacific salmon within PNCIMA, updating time series examined earlier by Riddell (2004) and Hyatt et al. (2007); the following is taken from them unless otherwise indicated.

Escapement (numbers of adult fish that "escape" marine fisheries and return to freshwater to spawn) data were incomplete, as few streams were assessed every year, and many streams were assessed in only a few years. Despite a reduction in the number of streams assessed over time (Price et al. 2008), Irvine et al. (2011) 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). They in-filled missing escapement estimates for streams by first computing proportions for each stream datum by dividing annual escapement estimates 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 to get back to the original scale.

Commercial catch data from DFO BC catch statistics reports for PNCIMA extended from 1952-2010. To reduce the influence that non-PNCIMIA salmon migrating through PNCIMA might have on the analyses, data from DFO Statistical Areas 2 West, 12, 27, 130 and 142 were ignored (see http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/areas-secteurs/index-eng.htm for map showing areas). Escapement estimates were added to catches to estimate returns for each species).

Temporal abundance patterns for catch and escapement (Figure 22) and total returns (Figure 23) were evaluated by computing linear regressions and testing whether slopes differed from zero. To assess status, mean values during the most recent decade (2000-2009) were compared with mean values for 1952-1999.

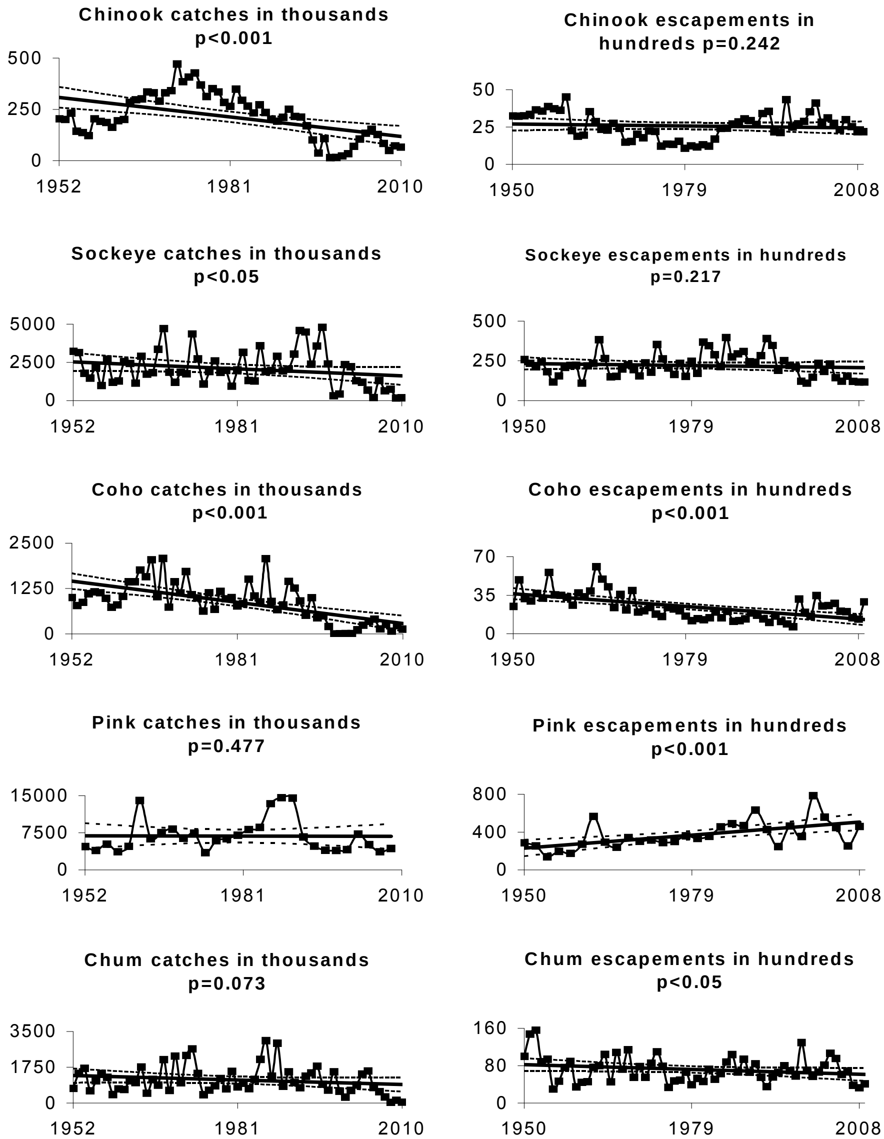


Figure 22. Commercial catch (left hand column) and escapement (right hand column) estimates for Chinook, sockeye, coho, pink, and chum salmon in PNCIMA. Solid lines are linear regression lines (time series slopes) with probability that slope is 0; dashed lines are 95% confidence limits for these lines. From Irvine et al. (2011).

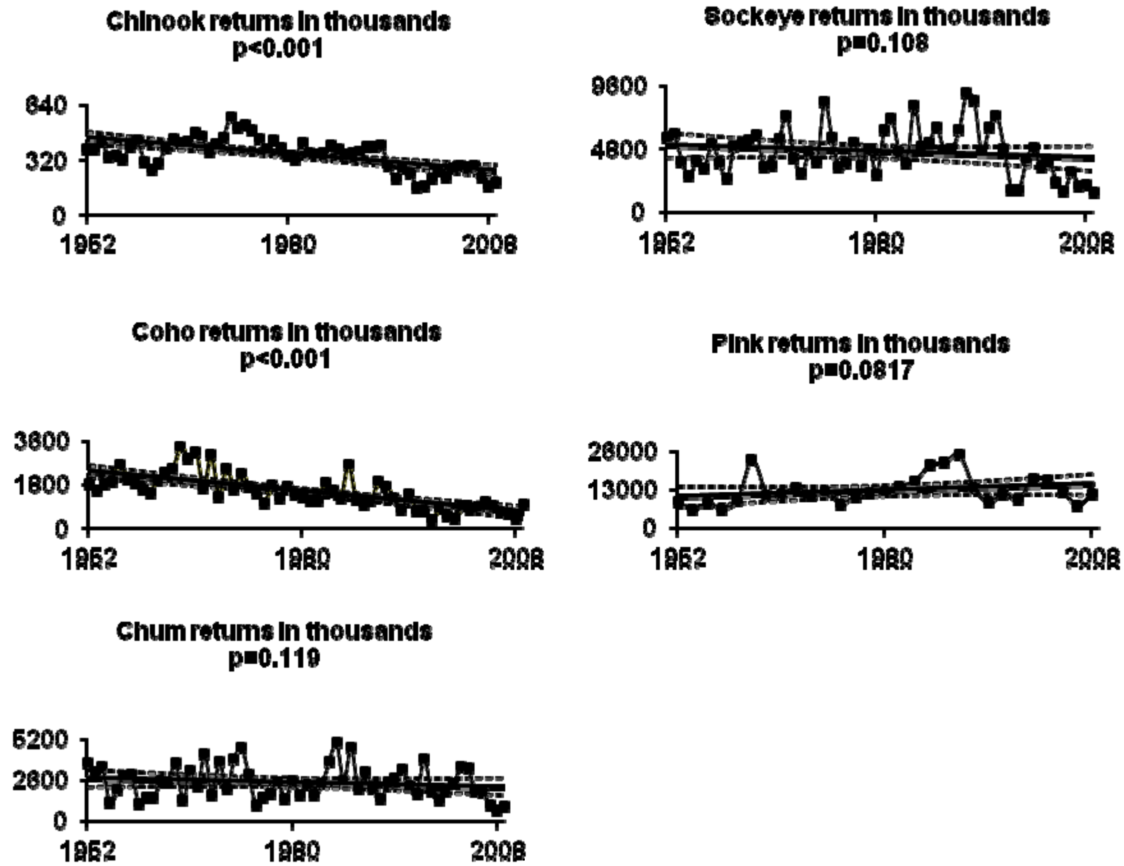


Figure 23. Return estimates (i.e. catch plus escapement) for Chinook, sockeye, coho, pink and chum salmon in PNCIMA. Solid lines are linear regression lines (time series slopes) with probability that slope is 0; dashed lines are 95% confidence limits for these lines. From Irvine et al. (2011).

Results (Figures 22-23, Table 2) imply that pink salmon in PNCIMA are doing relatively well, while coho salmon and to a lesser extent Chinook salmon are doing relatively poorly. These results agree, in general, with those of Riddell (2004) and Hyatt et al. (2007) although these authors examined differences among watersheds. Irvine et al. (2011) found significant declines over the time series 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 mean values during the most recent decade were compared 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 (Table 2).

Hyatt et al. (2011) provide updated information on Rivers and Smith inlets sockeye salmon returns and survivals. Rivers and Smith inlets sockeye salmon supported a valuable fishery within PNCIMA until severe stock declines in the early to mid-1990s forced their closure (e.g. note declines for PNCIMA sockeye salmon catches and returns in Figures 22-23, respectively). Time series assessments permitting partitioning of marine and freshwater production stages (Hyatt et al. 2011) support the view (McKinnell et al. 2001) that the steep decline and low returns of sockeye salmon to Rivers and Smith inlets since the 1990s are due to persistently low marine survival. Fortunately, a strong compensatory response of increased egg-to-fall-fry survival in freshwater accompanied major reductions in spawner abundance for the 1997-2001 and 2005-2008 brood years and buffered Smith Inlet sockeye salmon from even more severe declines.

Table 2. 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 (from Irvine et al. 2011).

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

Juvenile salmon

The following information is provided by John Morris and Strahan Tucker of Fisheries and Oceans Canada (Pacific Biological Station, Nanaimo BC). Juvenile Pacific salmon generally undertake a rapid northwest migration along the continental shelf off the west coast of North America until they reach the Aleutian Islands, where they migrate offshore in the Gulf of Alaska (Hartt and Dell 1986; Groot and Margolis 1991). As such, the PNCIMA ecozone represents an important confluence and feeding zone, where local stocks originating from the central and north coast of British Columbia mingle with southern stocks, such as Fraser River and Barkley Sound salmon that are transiting through this region during their northward migration. Since 2000, the High Seas Salmon Program has been conducting integrated epipelagic surveys during summer and fall that include all areas of PNCIMA (northwest coast of Vancouver Island, Queen Charlotte Strait, Queen Charlotte Sound, Hecate Strait, Dixon Entrance and Haida Gwai). These surveys are designed to assess the effects of ocean conditions on the distribution, migration, growth, and survival of juvenile Pacific salmon. The High Seas Salmon program has also extended this comprehensive sampling to the winter since 2001.

Abundances (expressed as catch per unit effort; CPUE) of juvenile salmon in PNCIMA are generally high in summer and fall and low in winter (Figure 24). However, the five species have different seasonal trends in abundance, reflecting species differences as well as stock-specific timing and patterns of migration. Chinook salmon are least abundant in summer in all areas of PNCIMA, but increase in fall and winter. In summer, over 90% of the Chinook salmon are rapidly transiting Columbia River stocks, as determined from coded wire tag (CWT) recoveries and DNA stock identification analyses (Trudel et al. 2009; Tucker et al. 2011). In fall, respective PNCIMA Chinook stocks dominate catches in all areas and remain resident through winter (Trudel et al. 2009; Tucker et al. 2011). Coho salmon abundances decrease from summer through winter reflecting a pattern of northward migration and dispersion (Figure 24). Coho salmon CWT recoveries suggest that there is a mix of transiting southern stocks and PNCIMA stocks in all seasons (Morris et al. 2007). Furthermore, these coho CWT recoveries demonstrate that there are both fast and slow migrants that either make a rapid and direct migration in summer or disperse slowly and reside on the shelf within PNCIMA over winter (Morris et al. 2007).

Sockeye salmon also decrease in abundance from summer to fall, and they are virtually absent from PNCIMA by winter (Figure 24). DNA stock identification suggests that a mix of stocks is present and that the proportional stock composition changes with the seasons. Fraser River, Barkley Sound and other southern sockeye stocks rapidly migrate northward along the coast through PNCIMA during summer and fall, while juvenile Rivers and Smith inlets sockeye salmon remain as local residents in PNCIMA (Tucker et al. 2009). Rivers and Smith inlets sockeye salmon stocks collapsed over a 20-year period to approximately 0.1% of their initial abundance (Rutherford and Wood 2000; McKinnell et al. 2001). Although the specific cause of the collapse has not been established, it would appear to be due to an extended period of poor marine survival (Rutherford and Wood 2000; McKinnell et al. 2001). This difference in juvenile marine migration behaviour may leave Rivers and Smith inlets sockeye salmon particularly vulnerable to poor ocean conditions, if such developed in the south-central PNCIMA coastal region over an extended period of time.

Juvenile pink and chum salmon enter coastal marine waters in early spring then disperse counter-clockwise along the coast and into the North Pacific Ocean (Heard 1991). Pink and chum salmon have similar life histories during early marine life and both are highly abundant (Figure 24). In PNCIMA, both pink and chum CPUEs were generally high in summer and then decreased to winter, in most years. Pink and chum salmon demonstrated very similar trends in abundance (Figure 24) suggesting that abundances may be driven by physical oceanographic features and processes at the base of the food chain (Tucker, unpublished). The Fraser River is near the southern extent of pink salmon distribution, and produces large numbers of pink salmon smolts only in even-numbered years (Groot and Margolis 1991). However, there is relatively small year-to-year variability in catches of juvenile pink salmon in the PNCIMA ecozone during fall (Figure 24). This suggests then that a large number of pink salmon smolts are produced in the central and north coast of British Columbia during odd years offsetting co-incident low Fraser River production.

Depending on the species and stock, the importance of the PNCIMA region as a rearing and transiting area for juvenile salmon varies on a seasonal basis. Despite these seasonal trends in species and stock abundances, there are important annual differences as well. Total juvenile salmon abundance peaked in summer around 2004-2006 and has since declined (Figure 24). Most of this variability appears to be driven by changes in the abundance of juvenile pink and chum salmon that may be due to an increase in early marine survival and/or smolt production. With the exception of this time period, total juvenile salmon abundance is generally comparable between summer and fall in all years. Winter catches have been lower but more variable than other seasons. Again, shifts are primarily due to high catches of chum salmon during this time.

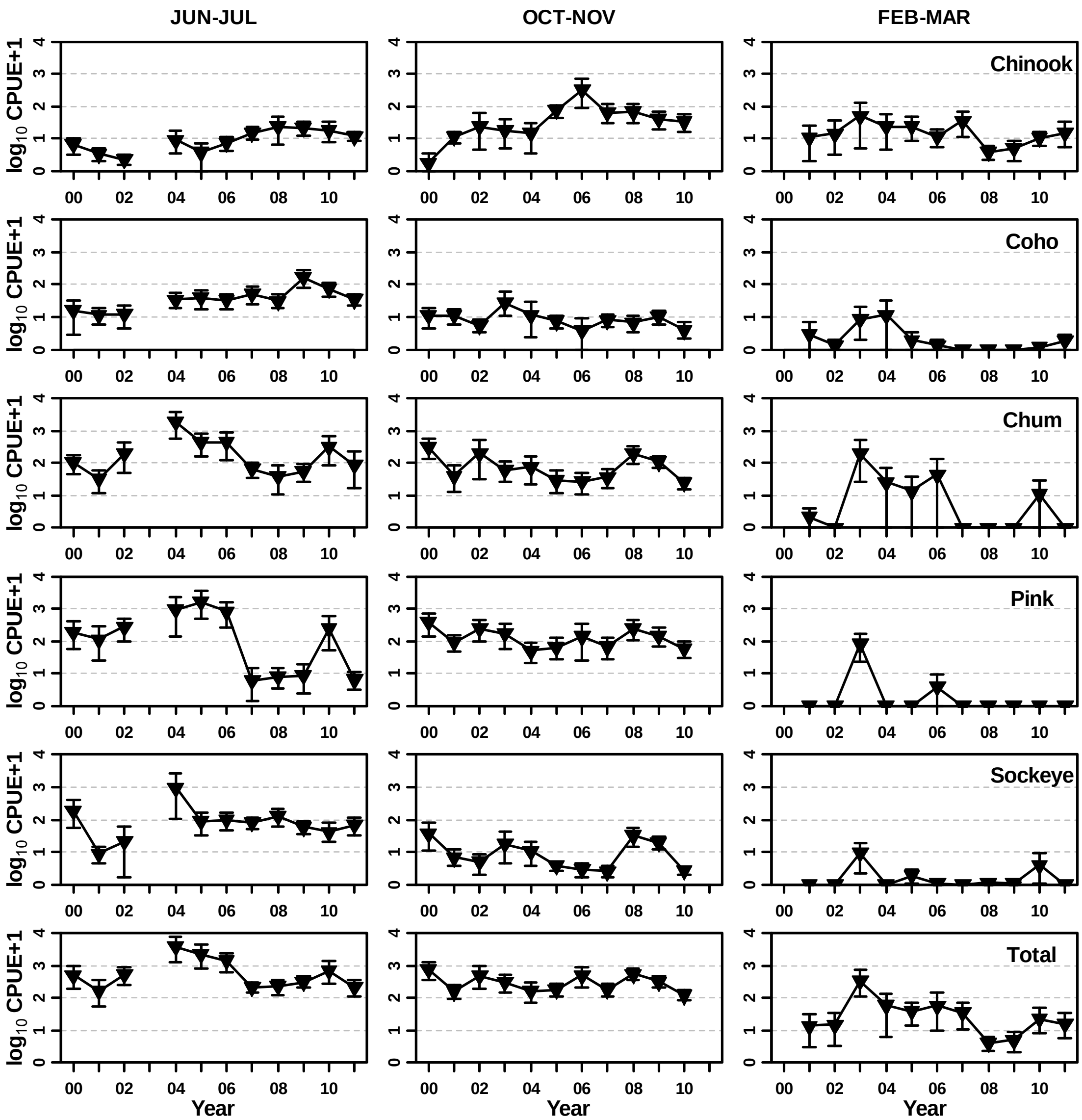


Figure 24. Inter-annual variation in average catch per unit effort (log10(CPUE+1) for juvenile salmon (rows: Chinook, coho, chum, pink, sockeye and total juvenile salmon) in PNCIMA by months (columns). Average CPUE and 95% confidence intervals were obtained by bootstrap approximations.

Herring

Unless indicated otherwise, the following is from the recent review by Schweigert et al. (2011), which updated information from Schweigert et al. (2007). Model estimates of Pacific herring (*Clupea harengus pallasii*) biomass provide an index of herring population trends for five major fishing stocks in BC, including three within PNCIMA: Prince Rupert (PRD), Haida Gwaii (HG) and the central coast (CC) (Figure 25). Exploitable herring biomass in PNCIMA represents a combination of migratory stocks from the HG, PRD and CC areas. Over the past decade, herring biomass in HG 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 (Figure 26). 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. Recruitment to the CC stock has been less regular but the 'good' year-classes that have occurred were very strong. Indications are that the recent recruitments (2003-2006 year-classes) were 'poor' or 'average', resulting in declines of all three stocks (Figure 26). Recruitment in 2010 (i.e., 2006 year-class) increased slightly for PRD, but remained poor for the CC and HG. Weight-at-age has declined since the mid-1970s for herring from PRD, HG, and CC, similar to other areas in BC.

Herring biomass declines have occurred throughout BC during the last decade, despite a precautionary harvest policy. This suggests that factors other than fishing are influencing herring population trends. Specific reasons are uncertain but may include changes in food supply and quality, predator abundance, and competition (Schweigert et al. 2011). These reductions in herring biomass have implications for herring predators, such as other fish, marine mammals and seabirds.

Additional information is provided by DFO (2011). Perry and Schweigert (2008) examined the carrying capacity of herring stocks in BC. They found that the Strait of Georgia and the west coast of Vancouver Island have the highest carrying capacities, at 1.5–2.3 t km^{-2} $year^{-1}$, whereas the BC populations within the Hecate Strait ecosystem were at 0.3–0. t km^{-2} $year^{-1}$. These differences generally match the overall differences in primary productivity (phytoplankton growth rate) noted by Ware and Thomson (2005).

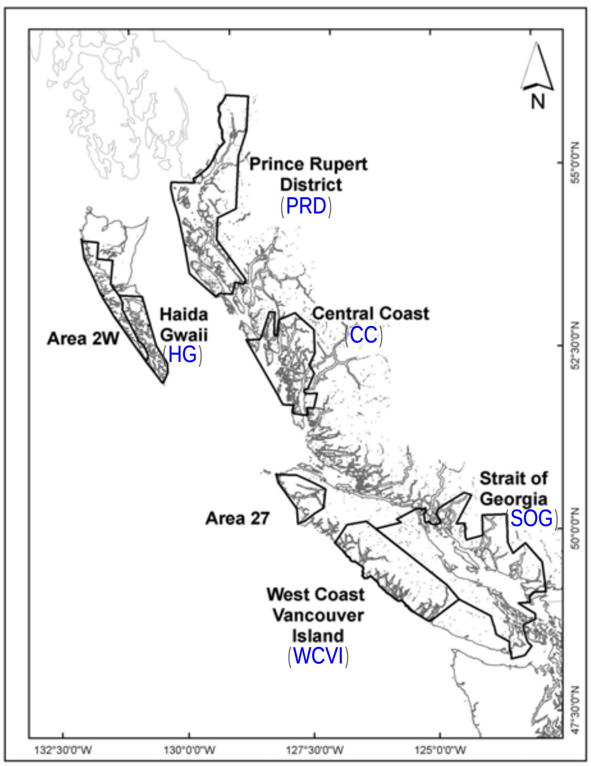


Figure 25. Location of the five major (Strait of Georgia, west coast of Vancouver Island, Prince Rupert, Haida Gwaii, and the Central Coast) and two minor (Area 2W and Area 27) Pacific herring fishing stocks in British Columbia. From Schweigert et al. (2011).

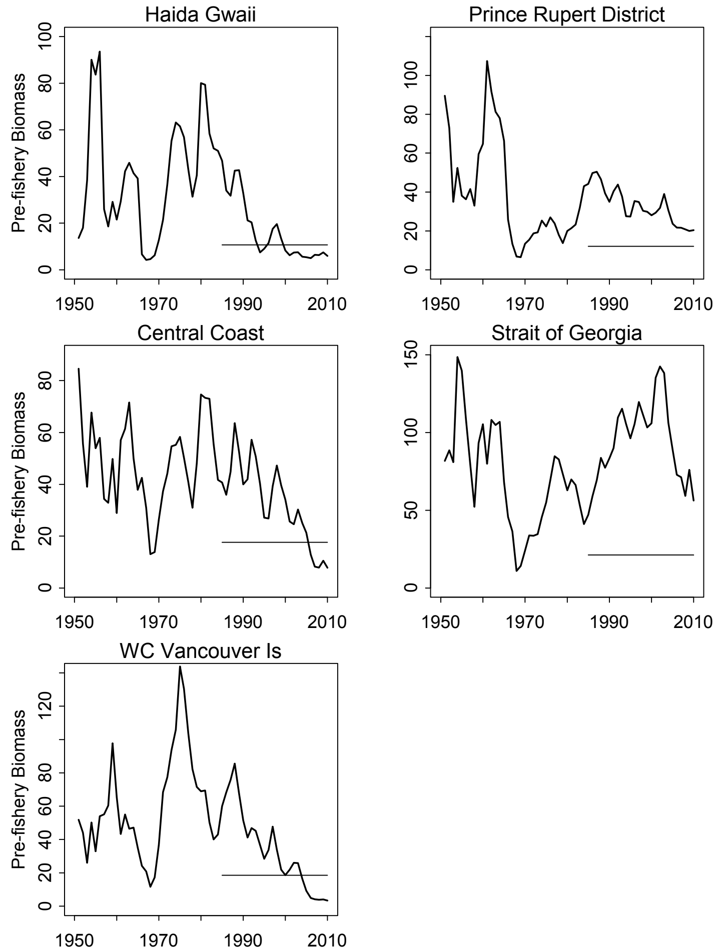


Figure 26. Pre-fishery biomass (solid line) of Pacific herring in the five major fishing stock areas in BC. The horizontal line represents the fishing cut-off threshold. Commercial fishing is closed when the estimated pre-fishery biomass is below this threshold value. From Schweigert et al. (2011).

Sardines

Flostrand et al. (2011a, 2011b) describe the recent history of Pacific sardines (*Sardinops sagax*) in BC waters. Sardines 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 (WCVI), Hecate Strait and Dixon Entrance by 1998. The extent of sardine migration into PNCIMA varies among years and is strongly affected by SST (Jake Schweigert, PBS, personal communication, Sept 2011). In 2010, WCVI survey catches of sardine were much lower than the previous three survey years. 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 recruitment for the 2006-2009 year-classes was moderately low.

Sharks

A survey of sharks in PNCIMA was reported by Williams et al. (2010) based on observations during a survey designed to study marine mammals. Their data indicated that at least 10 000 pelagic sharks were concentrated in 10% of a section of the Queen Charlotte Basin during the summers of 2004 to 2006. Approximately half of these were likely salmon sharks (*Lamna ditropis*), at a time of year when pregnant salmon sharks return from Alaska. No salmon sharks were observed in an autumn survey. It was unclear if these sharks congregated primarily to feed on returning salmon or for other reasons. The authors suspect other factors prevail, but sharks do indeed feed on salmon.

Marine mammals

Heise et al. (2007) provided a detailed review of information on marine mammals including baleen and toothed whales as well as seals, sea lions and sea otters that was updated somewhat by Cummins and Haigh (2010). Most recently, Nichol et al. (2011) reported on baleen whales based on recent publications of DFO ship surveys, acoustic monitoring work and recent results regarding population abundance and structure from photo-identification (Ford et al. 2010a, 2010b; Calambokidis et al. 2009). The following is from Nichol et al. (2011) or Linda Nichol (PBS, personal communication, Oct 2011) unless indicated otherwise.

Blue (*Baleonoptera musculus*), sei (*B. borealis*), and North Pacific right (*Eubalaena japonica*) whales are listed as endangered under SARA, fin (*B. physalus*) and humpback (*Megaptera novaeangliae*) whales as threatened. Historical whaling in the North Pacific caused drastic population declines from which these species are still recovering. As yet there have been no sightings or acoustic detections of North Pacific right whales in BC waters, and only two sightings of sei whales.

Blue whales remain rare in BC waters but there have been 10 photo-identification matches between blue whales in BC and California waters. These matches suggest re-establishment of historic feeding grounds in BC and also that blue whales in BC and California are part of the same eastern Pacific population. Blue whales tend to be seen in BC during cool ocean years that favour euphausiids that blue whales feed on.

Eastern Pacific grey whales (*Eschirichtius robustus*) were reduced to near extinction by the late 1800’s but have since recovered to near pre-whaling abundances and are listed as special concern under SARA. Humpback whales are now the most frequently sighted baleen whale in BC. Although still below historic levels, ~2,100 humpback whales were estimated in BC in 2006. The population (number of animals migrating from breeding grounds to forage in BC waters) is estimated to be increasing at about 4% per year (Ford et al. 2009). Habitats off the southeast coast of Haida Gwaii, Langara Island in Dixon Entrance, and around Gill Island in Squally and Whale Channel were identified as important for humpback whales (Nichol et al. 2010).

During the coastal whaling era, fin whales were the most abundant large baleen whale in BC but they remain relatively uncommon. Sightings of fin whales during DFO surveys averaged 1.61 whales per 100 km from 2002 to 2008 (482 animals in total). This compares with the humpback whale sighting rate of 10.58 individuals/100 km during the same period. Acoustic monitoring, which provides seasonal occurrence information, suggests that fin whales may be present much of the year along the BC coast exhibiting a more diffuse migration pattern than other baleen whale species.

Northern latitude waters such as the BC coast provide foraging habitat for baleen whales that migrate between warmer latitude breeding areas and high latitude feeding areas. Baleen whales consume large volumes of tiny prey, feeding on zooplankton and small fish. North Pacific right whales feed on copepods, fin and sei whales feed on euphausiids, copepods and schooling fish, and humpback whales feed on euphausiids and schooling fish such as herring and sardine. Nichol et al. (2011) cite several studies that speculate on how the reduction in plankton consuming whales as a result of whaling may have contributed to the shifts in dominant fisheries in the Bering Sea and Gulf of Alaska during the 1970s and 1980s. Continued recovery of large baleen whales may result in restructuring of marine ecosystems within PNCIMA and elsewhere.

Three distinct eco-types of killer whales (*Orcinus orca*) occur in PNCIMA: northern and southern resident killer whales, transient killer whales, and offshore killer whales. The four populations do not associate with each other although their ranges overlap extensively. Southern residents are listed as ‘endangered’ under SARA while northern residents, transients, and offshore killer whales are listed as ‘threatened’ (COSEWIC 2008).

During the summer and fall, the distribution of both northern and southern resident killer whales is closely linked to that of their preferred prey. Changes in the relative strength of major salmon runs results in corresponding shifts in the areas where killer whales are found (Ford and Ellis 2006). In 2006 there were 87 individuals in the southern resident killer whale population, and 244 whales in the northern resident population (COSEWIC 2008). There is evidence that resident killer whale abundance may be limited by availability of their primary prey, Chinook salmon (Ford et al. 2010c; Ford and Ellis 2006; Ford et al. 1998). Critical habitat for northern resident whales was identified in Johnstone Strait and two additional areas were identified as potential critical habitat because of their seasonal importance, Fitzhugh Sound and the connecting channels around King Island, and further north the waters of Caamano Sound and the connecting channels around Gil Island (Ford 2006, COSEWIC 2008). These areas are all within PNCIMA.

There are an estimated 243 whales in the west coast transient population (Ford et al. 2007). Transients hunt marine mammals. From the mid-1970s to mid-1990s this population grew rapidly (~ 6%/yr), coinciding with dramatic increases in the abundance of harbour seals (*Phoca vitulina*) and Steller sea lions (*Eumetopias jubatus*) in BC coastal waters, and perhaps reflective of movement of adults into nearshore areas (Ford et al. 2007). Growth in the population since 1990 (~ 2%/yr) has been due to recruitment (Ford et al. 2007).

Human encounters with offshore killer whales are relatively rare compared to encounters with the other eco-types. Offshore killer whales are observed most frequently off the outer coast but occasionally travel in inside waters. Photo-identifications made during 86 encounters with offshore killer whales from 1988 to 2008 yielded a total of 288 unique individuals (CRP-DFO unpublished data). Because this total only includes animals with distinctive markings, 288 is a minimum estimate of number of offshore killer whales. The diet of offshore killer whales is not well understood but fatty acid profiles from blubber samples indicate that they are fish eaters although the signature is very different from that of salmon eating resident killer whales (Herman et al. 2005).

Additional cetacean species encountered during ship surveys between 2002 and 2008 on the BC coast (including PNCIMA) are; minke whales, sperm whales, Baird’s beaked whales, Pacific white sided dolphins, Dall’s porpoise, harbour porpoise, northern right whale dolphin, Risso’s dolphin, Cuvier’s beaked whale and false killer whale.

Williams and O’Hara (2010) modeled ship traffic data and whale distribution for regions of the coast where they had survey data for fin, humpback and killer whales: Hecate Strait, Queen Charlotte Sound, Dixon Entrance, Queen Charlotte Strait and Johnstone Strait. High strike risk areas for these species occur where whales and ships are concentrated. Williams and O’Hara (2010) concluded ship strike risk was highest for killer whales in Johnstone Strait, for humpback whales in Queen Charlotte and Johnstone straits, and for fin whales, in Dixon Entrance.

Trends in the population size and distribution of BC’s recovering sea otter population (*Enhydra lutris*) were described by Nichol et al. (2009). Sea otters are a non-migratory coastal species occupying habitat < 50m deep. Within PNCIMA, sea otters are established from Brooks Peninsula northward to the Scott Islands and eastward into Queen Charlotte Strait. Along Vancouver Island the population grew at 8.4% per year from 1995 to 2008 and 4,110 sea otters counted in 2008 represent a minimum population estimate. There were 32% of the animals counted within the portion of PNCIMA off Vancouver Island. Sea otters also occur in the central BC coast, an area entirely within PNCIMA. In that region, 602 sea otters were counted in 2008, the result of an estimated annual increase of 11.4% from 1990 to 2008. Significant range expansions were recorded in 2008 to the southeast and to the north, notably along the outer coast of Aristazabal Island near the entrance to Caamano Sound.

Invasive species

The following information, provided by Graham Gillespie and Thomas Therriault of Fisheries and Oceans Canada (Pacific Biological Station, Nanaimo BC), supplements a recent review of aquatic invasive species in BC (Therriault et al. 2011). Soft shell clams (*Mya arenaria*) were introduced from the east coast of North America to California in the 1880s and subsequently dispersed throughout the BC coast, including Haida Gwaii. Manila clams (*Venerupis philippinarum*), spread from unintentional introductions in the south and are found as far north as Laredo Inlet and have been abundant enough to support a commercial fishery near Bella Bella since the early 1990s (Gillespie 2007). Bivalve surveys also noted the non-indigenous Japanese wireweed, *Sargassum muticum*, throughout BC, including Haida Gwaii (Gillespie 2007).

Pacific oysters were imported from Japan for aquaculture beginning in the 1910s (Quayle 1988). These oysters are common in southern BC but have limited distribution within PNCIMA at Desolation Sound, Klaskish and Klaskino Inlets and Quatsino Sound (Gillespie 2007). These initial introductions for aquaculture in the north and central coasts did not result in establishment of populations (Quayle 1988), but there is recent evidence of successful reproduction and settlement in Skidegate Inlet, Haida Gwaii (Gillespie 2007).

The European green crab, *Carcinus maenas*, arrived in BC as larvae from southern populations in 1998/99 (Gillespie et al. 2007). Green crabs are currently distributed throughout the west coast of Vancouver Island, including Klaskino Inlet and Quastsino Sound in southern PNCIMA. However, larval dispersal and environmental niche models suggest this species could spread in PNCIMA (Therriault et al. 2008).

There are at least two non-indigenous sponges in the PNCIMA area, the boring sponge *Cliona* sp. and *Scypha* spp. (Gartner 2010). Additional subtidal invaders in PNCIMA include bryozoans, ascidians, and the invasive caprellid amphipod, *Caprella mutica*, which recently has been confirmed in BC (Frey et al. 2009). There are three non-indigenous bryozoans within the PNCIMA area, including *Alcyonidium polyoum*, *Bowerbankia gracilis*, and *Schizoporella japonica* (Gartner 2010). Of these, *A. polyoum* appears the most common. Of the three invasive ascidians, *Botrylloides violaceus* (violet tunicate) appears to be the most widespread in the PNCIMA area based on limited observations (Gartner 2010). A second botryllid tunicate, *Botryllus schlosseri* (golden star tunicate) also occurs within PNCIMA. The third non-indigenous ascidian, *Ciona savignyi* (transparent tunicate), a deeper water species has been reported from the PNCIMA area (Lamb and Hanby 2005).

In addition to the numerous non-indigenous invertebrates, two non-indigenous marine fish also have been recorded from PNCIMA: the American shad, *Alosa sapidissima*, and the Atlantic salmon, *Salmo salar*. American shad were introduced in California in the 1870s and have since spread in marine waters through BC and Alaska to Russia (Hart 1973, Mecklenberg et al. 2002). Hart (1973) indicated they were encountered uncommonly in Rivers Inlet and in catches of schooling fishes away from river mouths. American shad are commonly encountered in research trawl surveys off the west coast of Vancouver Island, Queen Charlotte Sound and Hecate Strait.

Atlantic salmon became a wide-spread aquaculture species in marine net pens in BC and Washington after 1980 (Mecklenberg et al. 2002). Escapees have been captured in commercial and recreational fisheries and scientific monitoring programs in both marine and freshwater (McKinnell et al. 1997); successful natural reproduction has been documented in the Tsitika River on northern Vancouver Island (Volpe et al. 2000).

Monitoring activities in PNCIMA for invasive species have been rather *ad hoc* to date and the establishment of longer-term, directed monitoring programs could identify additional invasive species within this relatively large body of water. Potential introduction vectors within PNCIMA include recreational boating, commercial shipping, and aquaculture-related transfers. There are various introduced species just south of PNCIMA that may spread north, and become established within PNCIMA, should environmental conditions become favourable for them. In addition, the expansion of the Port of Prince Rupert and potential development of a natural gas depot in Kitimat could see an increase in non-indigenous propagules from overseas.

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