Marine Environmental Quality in the Pacific North Coast Integrated Management Area (PNCIMA), British Columbia, Canada: A Summary of Contaminant Sources, Types, and Risks

D.I.Johannessen, J.S.Macdonald, K.A.Harris, and P.S.Ross

Fisheries and Oceans Canada
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C.,
Canada
V8L 4B2

2007

Canadian Technical Report of Fisheries and Aquatic Sciences 2716

Fisheries and Oceans Pêches et Océans

Canada

Canadian Technical Report of
Fisheries and Aquatic Sciences 2716

2007

MARINE ENVIRONMENTAL QUALITY IN THE PACIFIC NORTH COAST INTEGRATED MANAGEMENT AREA (PNCIMA), BRITISH COLUMBIA, CANADA: A SUMMARY OF CONTAMINANT SOURCES, TYPES, AND RISKS

by

D.I. Johannessen, J.S. Macdonald, K.A. Harris, and P.S. Ross

Fisheries and Oceans Canada
Institute of Ocean Sciences
P.O. Box 6000
Sidney, B.C.
Canada
V8L 4B2

Cat. No. Fs 97-6/2716E ISSN 0706-6457

Correct citation for this publication:

Johannessen, D.I., Macdonald, J.S., Harris, K.A., and Ross, P.S. 2007. Marine environmental quality in the Pacific North Coast Integrated Management Area (PNCIMA), British Columbia, Canada: A summary of contaminant sources, types and risks. Can. Tech. Rep. Fish. Aquat. Sci. 2716: xi + 53 p.

Table of Contents

Table of Figures

Table of Tables

Abstract

Johannessen, D.I., J.S. Macdonald, K.A. Harris, P.S. Ross. 2007. Marine environmental quality in the Pacific North Coast Integrated Management Area (PNCIMA), British Columbia, Canada: A summary of contaminant sources, types, and risks. Can. Tech. Rep. Fish. Aquat. Sci. 2716: xi + 53 p.

Under the terms of Canada's Oceans Act (1997), Fisheries and Oceans Canada has embarked on an approach to Ecosystem-Based Management (EBM) which aims to protect the structure, function, and quality of marine ecosystems from human impacts. This report aims to provide the reader with an overview of the contaminant sources, types, and risks in the Pacific North Coast Integrated Management Area (PNCIMA) as these relate to marine environmental quality (MEQ), and builds on two previously published reports generated for sub-regions of the PNCIMA, namely the central coast (Haggarty *et al.* 2003) and the north coast and Queen Charlotte Islands (Johannessen *et al.* 2007).

The PNCIMA includes 102,000 km^2 of ocean, covering roughly two-thirds of the BC coast. While sparsely populated (3.3% of BC's total population), the PNCIMA is faced with a growing list of threats to MEQ. The PNCIMA extends from the southern end of Johnstone Strait and the Brooks Peninsula on Vancouver Island northwards to the British Columbia (BC) - Alaska border and includes the marine area out as far as the base of the continental slope, and the Queen Charlotte Islands (Figure 1.1). The region is rugged, with a steep, glaciated mainland covered in dense rainforest and bisected by numerous fjords and inlets, while the coast is dominantly rocky and strewn with islands. The influence of two semi-permanent atmospheric pressure cells (the Aleutian Low and the North Pacific High) over the Pacific Ocean provides this area with some of the highest rainfall amounts in Canada, along with mild winters and cool summers.

The remote location and low population would suggest that there are few anthropogenic stresses in the area. However, a number of human activities take place in the area that can affect MEQ. Key among the past and present activities are aquaculture, vessel traffic, ports / harbours / marinas, forestry, pulp and paper, mining / smelting, ocean dumping, Coast Guard / military sites, oil and gas, and global pollutants. In many cases, source control and regulations have mitigated some of these activities, including a reduction in the by-production of dioxins and furans by pulp mills, the elimination of polychlorinated biphenyls (PCBs) and many organochlorine (OC) pesticides, and restrictions on the use of tributyltin on ship hulls as an antifoulant. However, a number of emerging threats to MEQ in the PNCIMA reflect growing industrial sectors, and include the potential exploration and extraction of offshore oil and gas, a significant increase in cruise ship traffic, expanding port facilities, and the expanding aquaculture sector.

Résumé

Johannessen, D.I., J.S. Macdonald, K.A. Harris, P.S. Ross. 2007. Qualité de l'environnement marin dans la Zone de gestion intégrée de la côte nord du Pacifique (ZGICNP), Colombie-Britannique, Canada: Résumé des sources et des types de contaminants et des risques dans ce domaine. Can. Tech. Rep. Fish. Aquat. Sci. 2007: xi + 53 p.

Dans le cadre de la Loi sur les océans (1997) du Canada, Pêches et Océans Canada a choisi une démarche de gestion écosystémique qui vise à protéger la qualité des écosystèmes marins. Le présent rapport a pour but de fournir aux lecteurs un tour d'horizon des sources et des types de contaminants et des risques en la matière dans la Zone de gestion intégrée de la côte nord du Pacifique (ZGICNP) en ce qui a trait à la qualité de l'environnement marin (QEM); il s'appuie sur deux rapports publiés antérieurement sur les sous-régions de la ZGICNP, à savoir la côte centrale (Haggarty *et al.* 2003) et la côte nord et les îles de la Reine-Charlotte (Johannessen *et al.* 2007).

La ZGICNP comprend approximativement 177 000 km^2 de terres et 102 000 km^2 d'eaux océaniques et couvre environ les deux tiers des côtes de la C.-B. Bien qu'elle soit très peu peuplée (3,3 % de la population totale de la C.-B.), la ZGICNP fait face à un nombre croissant de menaces à la QEM. La ZGICNP va de l'extrémité sud du détroit de Johnstone et de la péninsule Brooks sur l'île de Vancouver à la frontière entre la C.-B. et l'Alaska et englobe la zone marine qui s'étend jusqu'à la base de la pente continentale ainsi que les bassins hydrologiques adjacents à cette zone de même que les îles de la Reine-Charlotte (figure 1.1). Il s'agit d'une région accidentée où la partie continentale sculptée par les glaciers est recouverte d'une forêt humide dense et entaillée de nombreux fjords et bras de mer alors que le littoral, parsemé d'îles, est principalement rocheux. L'influence de deux vastes zones de pression atmosphérique semi-permanentes (la dépression des Aléoutiennes et l'anticyclone du Pacifique nord) au-dessus de l'océan Pacifique vaut à cette région d'avoir parmi les plus élevés des indices pluviométriques du Canada et de connaître des hivers doux et des étés frais.

On pourrait supposer que du fait de son isolement et de sa faible population, cette région subit peu de stress anthropiques. Il s'y produit toutefois diverses activités humaines qui peuvent altérer la QEM. Les principales activités passées et présentes incluent les suivantes : aquaculture, trafic maritime, ports / marinas, exploitation forestière, fabrication de pâtes et papiers, exploitation minière / fonderies, rejet en mer, sites des forces militaires et de la Garde côtière, exploitation pétrolière et gazière et enfin, polluants planétaires. Dans bien des cas, les mesures de contrôle à la source et la réglementation ont permis d'atténuer les effets de certaines de ces activités, notamment une réduction de la production secondaire de dioxines et de furanes dans la fabrication des pâtes et papiers, l'élimination des diphényles polychlorés et de nombreux autres pesticides organochlorés et des restrictions sur l'emploi du tributylétain à titre de d'agent antisalissures pour les coques de navires. En revanche, diverses menaces naissantes pour la QEM reflètent la croissance des secteurs industriels dans la ZGICNP et comprennent notamment la possibilité de l'exploration et de l'extraction pétrolière et gazière en mer, une augmentation importante de la circulation de navires de croisière, l'expansion des installations portuaires et le développement du secteur de l'aquaculture.

ACKNOWLEDGEMENTS

This project was funded through the Oceans Action Plan (Fisheries and Oceans Canada). The authors are grateful to the advice and assistance of numerous persons, including Bev Agar, Robin Brown, Jon Chamberlain, Kelly Francis, Greg Mallette, Dwight McCullough, Patrick O'Hara, Pam Olson, Glen Rasmussen, Adrian Rowland, Dixie Sullivan, Andrew Thomson, and Ian Wade.

Executive Summary

Pursuant to the passing of Canada's Oceans Act in 1997, Fisheries and Oceans Canada has embarked on steps to adopt Ecosystem-Based Management (EBM). An understanding of Marine Environmental Quality (MEQ) represents an integral component of this process, requiring an understanding of ecoregions, ecosystem processes, information on the state of the environment, and those human activities that may impact on environmental quality. Contaminants released from point sources or introduced to the environment from diffuse processes represent significant threats to MEQ in coastal waters, and the Pacific North Coast Integrated Management (PNCIMA) is no exception. Despite a low population density, the PNCIMA is host to some important human activities.

Reviews of contaminant sources, types, and risks have been previously completed for the central British Columbia (BC) coast (Haggarty *et al.* 2003) and for the northern BC mainland coast and Queen Charlotte Islands (Johannessen *et al.* 2007). Together these areas comprise the newly designated Pacific North Coast Integrated Management Area (PNCIMA - Figure 1.1). The general area captured by the PNCIMA comprises marine waters extending from the southern end of Johnstone Strait and the Brooks Peninsula on Vancouver Island northwards to the British Columbia (BC) - Alaska border and includes the marine area out as far as the base of the continental slope, and the Queen Charlotte Islands. While adjacent terrestrial watersheds are not covered by the PNCIMA, it is recognized that land-based threats to PNCIMA MEQ may be significant, and efforts will be needed to work with agencies and stakeholders in such areas. Hence, we include such sectors here as forestry and agriculture, with pesticides, run-off, siltation and stream cover representing important threats to the viability of countless salmon runs.

This report aims to summarize the major contaminant risk categories in the PNCIMA by drawing from numerous types of information sources, including the scientific literature, technical reports, consultant reports, and other relevant publications and documents. While we make no claim to be exhaustive, we have attempted to capture the widest possible range of contaminant issues in such a way as to broadly describe the state of these threats in the PNCIMA, and to identify emerging concerns. Due to a lack of information and data from the PNCIMA, we occasionally draw on experiences from other parts of the world so as to predict or empower a local understanding of priority concerns in the PNCIMA.

In this report, we describe a top ten list of contaminant sources in the PNCIMA, without listing them in any particular order. These threats to MEQ comprise both point source and non-point source (diffuse) contaminants which arise either from local activities within the PNCIMA (e.g. aquaculture, vessel traffic), or external inputs from broader scale activities (e.g. global pollutants from Asia via air or ocean currents). The cumulative impacts of multiple contaminant sources may represent a significant threat to the MEQ in the PNCIMA. It is our view that in order for EBM to be effective, consideration of both internal and external threats should be considered.

1. **Aquaculture.** The PNCIMA includes the Broughton Archipelago and its 28 finfish farms. Apart from this area, however, there is very little finfish or shellfish aquaculture in the PNCIMA relative to the southern areas of the Province. Both

forms of aquaculture may expand northward in the future, although current deliberations may not support this expansion. The presence of pesticides and other persistent pollutants in fish used in the production of feed has caused some near and far field contamination from both feces and feed. This, together with the disruption of natural habitats, represents a significant issue in the southern portion of the PNCIMA which may increase in the future.

2. **Vessel Traffic.** The PNCIMA is host to significant levels of shipping traffic due to the presence of year-round ice-free deep water ports and ready access to Asia and other markets. Chronic, low-level oil pollution resulting from engine leakage and oily bilge water represents a threat to wildlife. It has been estimated that chronic oiling is killing as many marine birds as are killed by catastrophic oil spills. Cruise ships generally travel through the inside passage. While traffic has not increased significantly in recent years, the capacity of modern cruise ships has more than doubled. The estimated 1.5 million passengers (more than 10 times the population of the PNCIMA) travelling along the BC coast in 2004 will likely continue to increase in the future. Although more stringent environmental 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.

3. **Ports/Harbours/Marinas.** Industrial ports exist at Prince Rupert and Kitimat. Prince Rupert's port is currently undergoing expansion to accommodate larger container ships and a higher volume. Kitimat is currently developing a liquefied natural gas (LNG) port and may become the terminus of a crude oil pipeline for the export of crude oil and import of condensate. There are also numerous smaller ports, small craft harbours (operated both by the Department of Fisheries and Oceans and by private interests), and marinas in the PNCIMA. Each of these is a source of oil and polycyclic aromatic hydrocarbon (PAH) contamination, and minor levels of sewage. The demand for both commercial and recreational harbours is increasing.

4. **Forestry.** The PNCIMA encompasses some of the largest stands of old growth forest in the Province, much of which is protected by land reserves. Consequently there is some security from contamination by pesticides, fire retardant chemicals, wood preservatives, fuel storage/transfer facilities, and accumulations of wood debris at log dumps and sorting sites. Harvesting and silviculture that does occur in the PNCIMA has not used large amounts of pesticides, and the damp coastal rainforests are less susceptible to forest fires. The area has no wood preservative production facilities, although wood preservation products are used.

5. **Pulp and paper mills.** Four mills exist in the area, though two of them have operated intermittently. All Canadian pulp mills underwent significant effluent treatment upgrades in the 1990s such that discharge of solids, discharge of oxygen demand, and chlorinated compounds such as dioxins and furans are now significantly reduced. However, a number of other chemicals are still released, including plant hormones, wood sugars, and others. Some have been shown to cause endocrine disruption and may have other effects. Contamination from pulp

and paper processing is not thought to be increasing within the PNCIMA, but the effects of their contaminants require further investigation.

6. **Mining and smelting.** Of the few active mining and exploration sites and abundant former sites in the PNCIMA, 12 locations are considered a risk for acid rock drainage and the associated mobilization of mobile heavy metals. Three of these locations used underwater tailings disposal systems designed to prevent metal leaching by placing the tailings in low or zero oxygen content water. Environmental monitoring of these sites suggests that this approach has prevented the release of heavy metals into the environment. The majority of mining sites in the area are currently inactive, but recent increases in metal prices have caused an exploration boom, and this portion of the BC coast is considered highly prospective. The ALCAN aluminium smelter at Kitimat has been implicated as the main source of PAHs in Kitimat Arm and Douglas Channel. Significant PAH concentrations have been detected in sediments and in biota, but the determination of impacts from this contamination remains elusive. Aluminium smelting continues but contamination levels are not believed to be increasing.
7. **Ocean Dumping.** Ocean dumping is monitored and permitted by Environment Canada. 11 sites are currently active and the majority of the material dumped is produced by the forest industry or is dredgeate from navigable waters. Material dredged from harbours must be examined for contamination before ocean dumping is permitted.
8. **Military/Coast Guard sites.** There are three former military sites in the PNCIMA: CFS Masset, RCAF Alliford Bay, and RCAF Prince Rupert. The extent to which these sites represent a threat to local MEQ is unclear. The Coast Guard maintains four Search and Rescue stations, 23 lighthouses, and numerous navigational aids in the PNCIMA. Lighthouses and navigational aids have been associated with historical contamination due to transformer leakage of PCBs and local disposal of batteries containing cadmium and mercury. The Coast Guard is involved in an ongoing assessment and a remediation of these sites.
9. **Offshore Oil and Gas.** Should the existing moratorim on offshore oil and gas exploration and extraction be lifted, new threats to MEQ would emerge. Oil and gas exploration and development would lead to increased vessel traffic and increased risk of chronic oiling, oil spills, air pollution, noise pollution, and pollution associated with drilling muds.
10. **Global Contaminants.** Recent research has shown that pollutants can travel long distances from their sources, within air masses or with ocean currents. Many of these pollutants accumulate in remote environments previously considered to be pristine. Many persistent chemicals can bioaccumulate within organisms and biomagnify up the food chain to levels much higher than in the surrounding environment. Some compounds that are a threat to human health are subject to international restrictions, but a number of emerging (unregulated) contaminants are being increasingly detected in the environment. Pollution regulations require environmental impact assessments which can take considerable time, particularly

when dealing with compounds that elicit impacts. This issue is becoming more significant as industrial expansion occurs globally, and particularly in Asia.

In addition to these categories, activities that may represent localized threats to MEQ include agriculture, tourism, and human settlements, all of which can be considered relatively minor in the PNCIMA at the present. Pesticides and fertilizers associated with agricultural activities are unlikely to have a significant impact on the marine environment. Effects are more likely in localized areas including salmon streams or estuaries. The PNCIMA is very attractive to recreational boaters, charter fishing camps, kayakers, hikers, and whale watching excursions, and a few studies have documented an increase in boat traffic from recreational and commercial tourism in the PNCIMA. Possible impacts include the chronic release of petrochemical products and noise pollution. The PNCIMA is relatively remote and sparsely populated, accounting for approximately 3.3% of BC's population (approximately 130 000 residents). Centres such as Prince Rupert, Terrace, Kitimat, and Campbell River may create localized contamination from sewage outfalls, storm drains, surface water runoff, and industrial effluents.

While our top ten list of contaminant threats to MEQ in the PNCIMA are largely based on an understanding of past and present activities, we have attempted to gauge emerging threats within each of the categories, as well as new threats, for which little information from the PNCIMA is available. In this regard, we note the increasing threats posed to MEQ by increasing cruise ship traffic, the potential for offshore oil and gas exploration and development, expanding port facilities, and a burgeoning aquaculture sector.

1 Introduction

Marine Environmental Quality (MEQ) represents one of the key elements of Canada's Oceans Act (1997). An understanding of threats to MEQ is required by managers as they strive to adopt Ecosystem-Based Management (EBM). Such an understanding can only be built by combining existing information on the local environment, knowledge from elsewhere, and from research and monitoring. The Pacific North Coast Integrated Management Area (PNCIMA) comprises two previously described sub-regions, for which MEQ information is available.

This report is intended to summarize these two previously published reports on MEQ in Canada's Pacific waters. The first report covered the contaminant issues in the formerly named "central coast" area of BC (Haggarty *et al.* 2003). This area was initially chosen as the first Large Ocean Management Area (LOMA) on the Pacific coast. As the integrated management process progressed, it was determined that the LOMA should be expanded to cover the PNCIMA (Figure 1.1). This necessitated the production of a report on MEQ issues for an additional portion of the coast to include the north coast and Queen Charlotte Islands (Johannessen *et al.* 2007). This report provides a succinct summary of these two reports, describing the contaminant types, sources and risks in the PNCIMA.

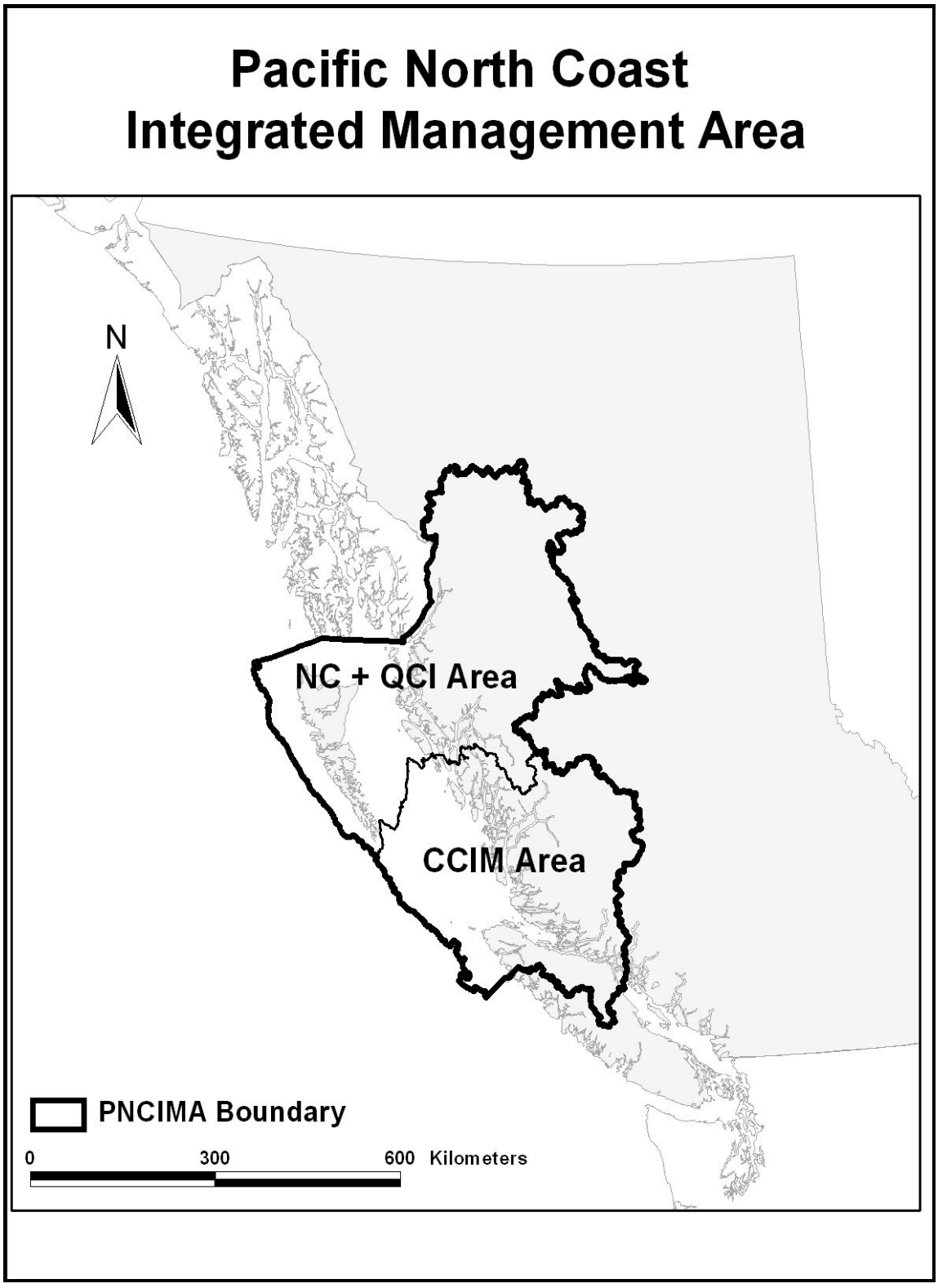

Figure 1.1 The boundary of the PNCIMA comprises the Central Coast Integrated Management Area (CCIM) and the North Coast (NC) and Queen Charlotte Island (QCI) sub-areas, for which other MEQ Technical Reports have been developed.

2 Study Area

2.1 Area and Population

The PNCIMA includes approximately 102,000 km^2 of ocean, covering roughly two-thirds of the BC coast (Figure 2.1). While the adjacent terrestrial watersheds are not technically included as part of the PNCIMA, we address terrestrial issues in this report as they may have direct and significant bearing on MEQ; this watershed comprises approximately 177,000 km^2 of land. The area is sparsely populated; the largest community is Campbell River with a population of about 31 000. Based on settlement populations and estimates for unincorporated areas, the PNCIMA had a population of approximately 135,000 in 2001, representing approximately 3.3% of the BC total (data from Statistics Canada). The populations in the four largest settlements (Campbell River, Prince Rupert, Terrace and Kitimat) are many times smaller than those in communities further south (Figure 2.2).

2.2 Physiography

The PNCIMA coastline is predominantly fjords carved into the granitic Coast Mountains, created by the last of several glaciations 12 000 years ago. Shores tend to be rocky and steep with beaches restricted to sheltered areas adjacent to estuaries. The outer coastal areas are exposed to the open ocean, but sheltered areas occur behind islands and reefs, and the intersecting straits and channels provide a wide variety of exposures and habitats. Most of the settlements are only accessible by water and air, with limited road access. The Skeena and Nass watersheds extend into the interior plateau in the northeast portion of the PNCIMA (Figure 2.1). These rivers provide the single largest freshwater and sediment sources on this portion of the coast; the Skeena is one of the largest estuaries in BC.

2.3 Climate

The PNCIMA is in a coastal temperate zone characterized by mild temperatures and high rainfall due to the Pacific Ocean, prevailing wind patterns, and the orographic effect of the coastal mountains. Weather conditions are influenced by the relative size and position of the Aleutian Low and North Pacific High pressure systems. During winter, the Aleutian Low dominates, bringing storms and strong southeast to southwest winds across the Pacific. During summer the North Pacific High dominates with lighter winds mostly from the northwest. Rainfall is highest on the mainland near the coast, with limited mountain rainshadow effects on the eastern coasts of the Queen Charlotte and Vancouver islands. This mild and wet climate supports temperate rainforests along the coast.

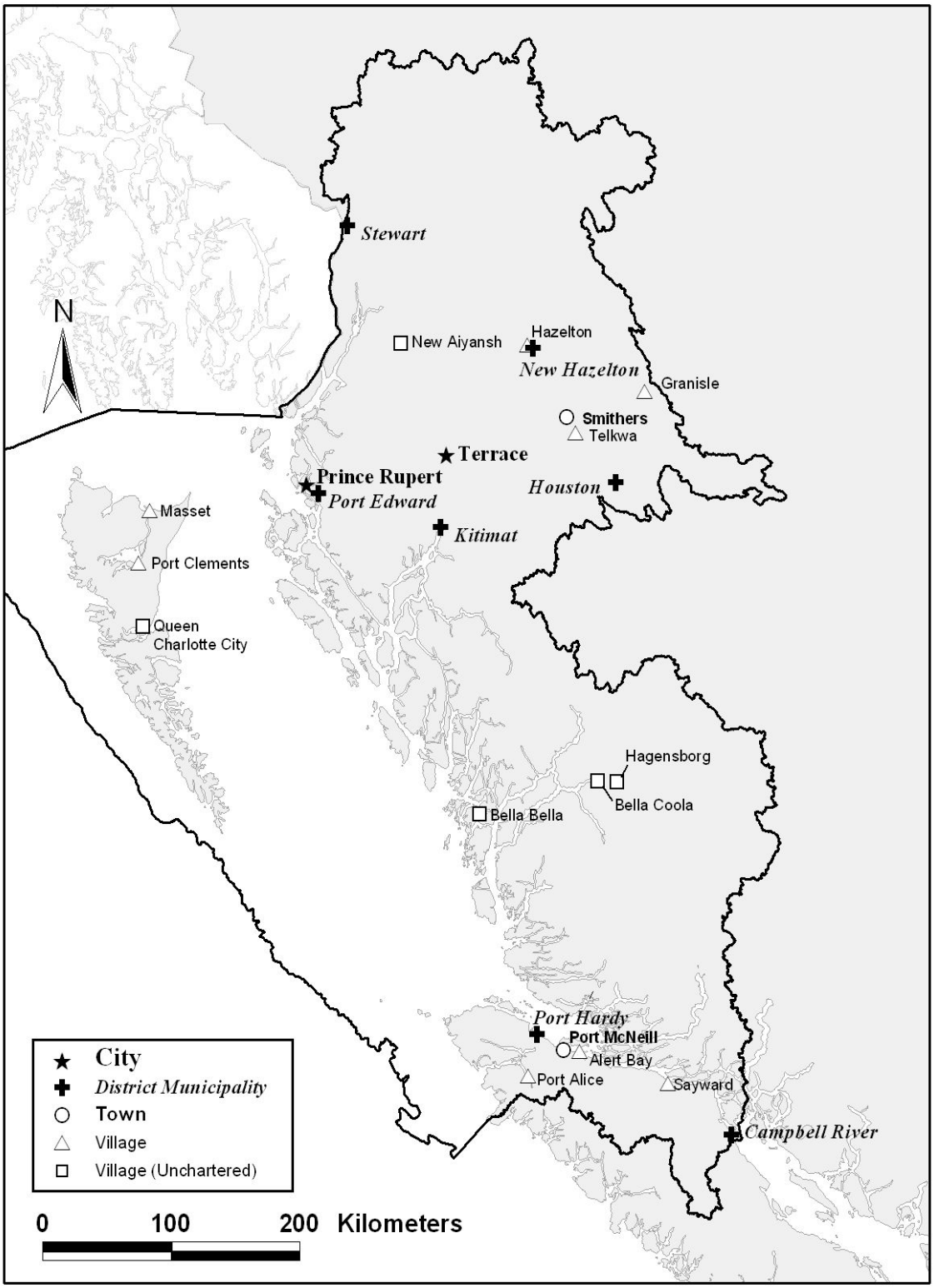

Figure 2.1 Location and type of major settlements within the PNCIMA.

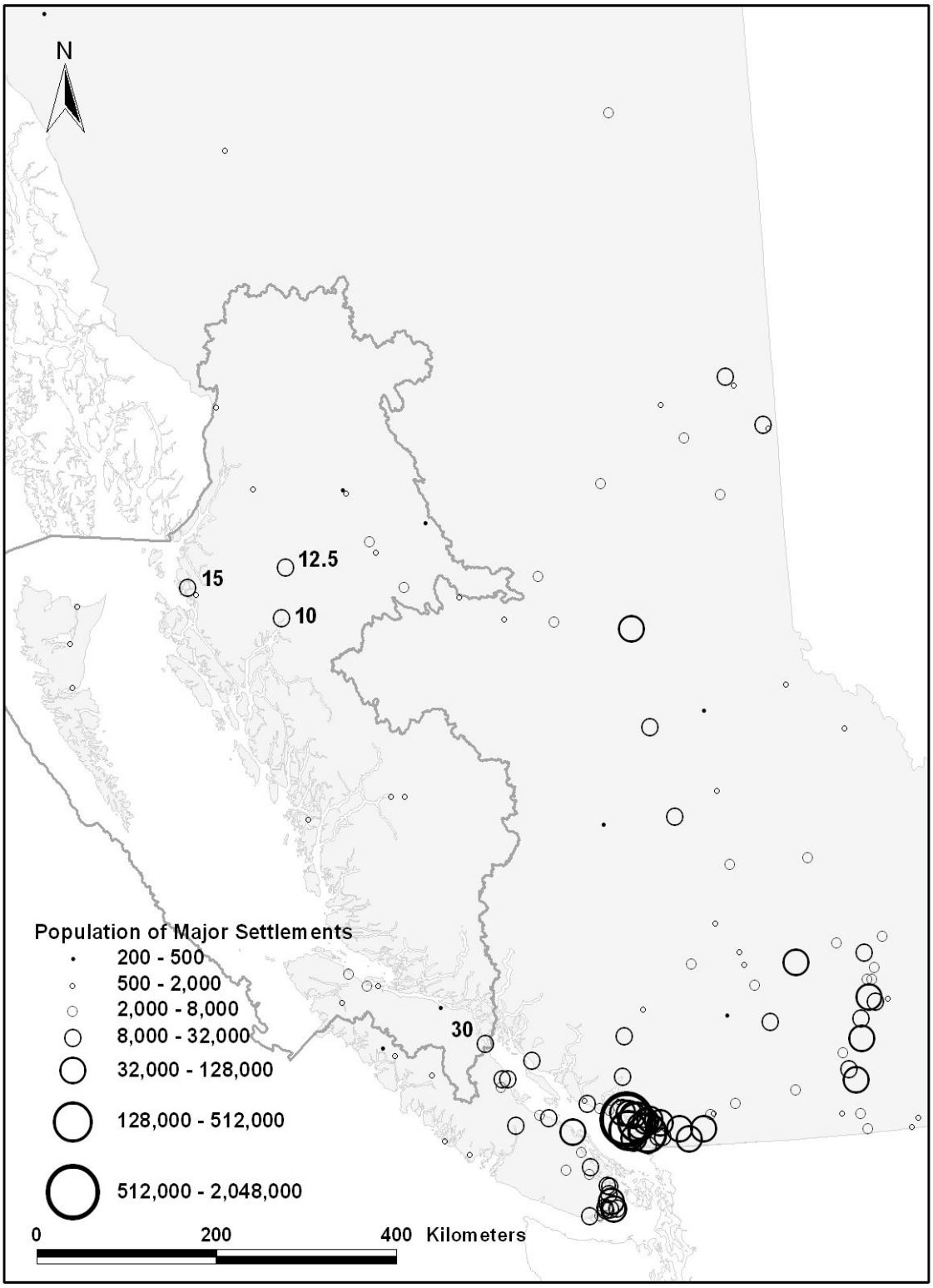

Figure 2.2 Circle size illustrates the relative populations of major settlements in the PNCIMA and much of the rest of BC. Bold numbers indicate thousands of people in the four major settlements in the PNCIMA as of 2001 (map created using data from Statistics Canada).

2.4 Oceanography

The marine currents in the PNCIMA are controlled by three main factors: wind conditions, freshwater inputs, and bathymetric controls on tidal currents. The wind conditions are generally dictated by the location of the atmospheric high pressure systems described in section 2.3. In winter, winds are strong and from the southeast to southwest, with surface currents predominantly northwards throughout the PNCIMA. Lighter summer winds have less influence and allow freshwater inputs from land and bathymetric effects on tides to exert more control on current patterns. Throughout the year, estuarine circulation is a significant factor both in the coastal inlets, and in waters on the continental shelf. This results in a constant movement of relatively warm, brackish surface waters away from the coast, replaced by the upwelling of cool, saline, nutrient rich, deep waters. Variations in this occur where islands, channels, capes and underwater canyons affect the direction of the currents. Significant wind and tidal mixing also occur where waters are shallow, where islands and rocks are abundant, and around points of land.

Haida eddies, formed during the winter off the southern tip of the Queen Charlotte Islands, move westward in an anti-cyclonic pattern away from the coast (Crawford 2002), and represent a phenomenon which could influence the transport and fate of contaminants. They can be over 200km in diameter and as much as 2km deep, and may transport as much water as the combined volumes of Hecate Strait and Queen Charlotte Sound (Whitney and Robert 2002). An overview of ecosystem features for the PNCIMA can be viewed in Fig. 2.3.

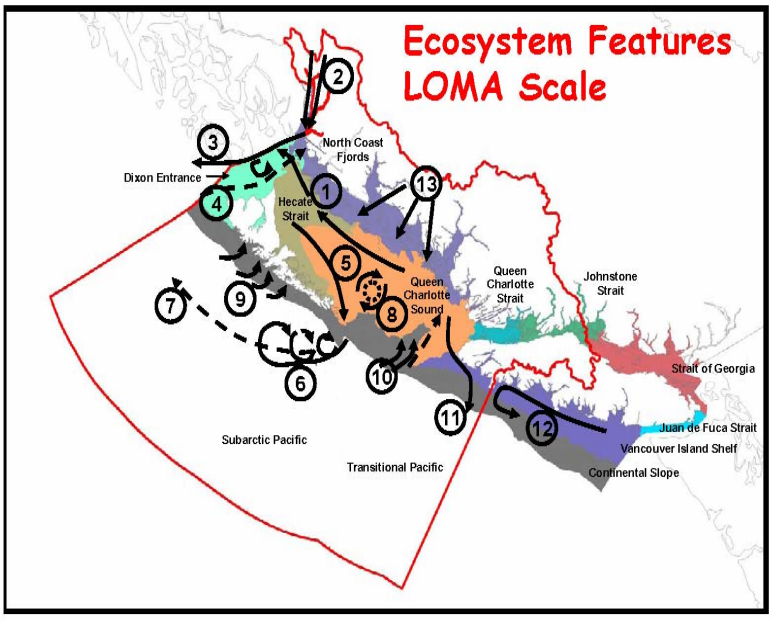

Figure 2.3 Ecosystem features in the PNCIMA (from J. Mathias, DFO Oceans Directorate, unpublished report “Rationale for the LOMA Boundary” 2003).

2.5 Biology and ecology

The PNCIMA is home to a wide variety of marine plant and animal species; threats to MEQ in this area can have repercussions for human society and for the regional economy. A 'healthy PNCIMA' is therefore key to the future prosperity and well-being of its citizens, as well as the citizens of British Columbia and Canada.

Fisheries and Oceans Canada has identified 15 Ecologically and Biologically Significant Areas (EBSAs) in the PNCIMA, with a total area of 45 182 km^2 (44.3% of the PNCIMA; Clarke and Jamieson 2006). EBSAs have been defined using an evaluation of five dimensions (uniqueness, aggregation, fitness consequences, naturalness, and resilience) and three categories of physical features (oceanographic features, bottleneck areas, and sponge bioherms). They are intended to identify areas worthy of enhanced protection. The Coast Information Team (CIT) has also identified important ecological elements found in the PNCIMA. Established by the provincial government, First Nations, environmental groups, and forest products companies to provide information on the region, the CIT highlights the importance of estuaries, kelp beds, seabird colonies, archipelago/fjord terrain, and intertidal flats with abundant invertebrates and resident and migratory waterbirds (Rumsey *et al.* 2003). The PNCIMA is also home to globally unique hexactinellid sponge bioherms, estimated to have existed in Queen Charlotte and Hecate Straits for 8 500 – 9 500 years (Department of Fisheries and Oceans 2000). These sponges are long-lived and are extremely sensitive to physical disturbance due to their fragile body structure and sedentary nature (Clarke and Jamieson 2006).

The varied habitat types in the PNCIMA support a wide variety of marine life. Rocky reefs are used by fish such as rockfish, greenlings, sculpins, lingcod, and wolf eel, as well as numerous invertebrate species. Rocky habitats also support prawns (*Pandalus platyceros*) caught in a commercial trap fishery (Ardron *et al.* 2002). Sand and gravel habitats are used by commercially caught species such as Dungeness crab (*Cancer magister*), English sole (*Pleauronectes vetulus*), rock sole (*Pleuronectes bilineata*), and Pacific cod (*Gadus macrocephalus*). Nearshore sandy and gravel habitats are particularly important nursery habitats for juvenile fishes (e.g. for English sole). Important prey items utilizing this habitat include sandlance (*Ammodytes hexapterus*), herring (*Clupea harengus pallasi*), demersal fishes (cottids, gobies, pricklebacks and gunnels) and various types of shrimp, crabs, amphipods, polychaete worms and mollusks. Sand and gravel bottoms are particularly important for sandlance, a major prey item of fishes and seabirds (Ardron *et al.* 2002; Haggarty *et al.* 2003). Muddy sediments are important rearing and adult habitats for several species of pandalid shrimps (humpback shrimp, spiny pink shrimp, pink shrimp, sidestripe shrimp). Bottom fish that use muddy sediments include flathead sole (*Hippoglossoides elassodon*), pollock (*Theragra chalcogramma*), Pacific tomcod (*Microgadus proximus*), and the dwarf wrymouth (*Lyconectes aleutensis*). These species feed on invertebrates, including pandalid shrimp (Ardron *et al.* 2002; Haggarty *et al.* 2003).

The PNCIMA is home to a rich array of marine life, due in large part to the consistent upwelling of cold, nutrient-rich waters and strong tidal mixing. It supports several breeding seabird populations, including ancient murrelets, black oystercatchers, auklets, cormorants, gulls, pigeon guillemots, puffins, and storm petrels, many of which breed nowhere else in Canada (Rumsey *et al.* 2003). Offshore habitats provide feeding sites for

pelagic birds like the Black-footed albatross, Sooty Shearwater, jaegers, Northern Fulmar, phalaropes, and gulls, and the coastline supports shorebirds such as plovers, sandpipers, and killdeers {Booth, 1998 1239 /id}. Species such as blue heron and bald eagles also depend on a healthy marine environment, as do waterfowl including swans, geese, dabbling ducks, sea ducks (harlequin, long-tailed, scoters, buffleheads, goldeneyes, and mergansers), and divers (loons, grebes, and cormorants) {Booth, 1998 1239 /id}. Marine fish species inhabiting the PNCIMA include seven salmonid species, eulachon, herring, groundfish, and species that inhabit shallow habitat (rocky reefs, eelgrass beds, and kelp forests) (Haggarty *et al.* 2003).

The PNCIMA is also home to a wide variety of marine mammal species, including northern resident killer whales, grey whales, Pacific white-sided dolphin (*Lagenorhynchus obliquindens*), Dall's porpoise (*Phocoenoides dalli*), harbour porpoise (*Phocoena phocoena*), harbour seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), and sea otters (*Enhydra lutris*). Other marine mammals found in the PNCIMA include the offshore and transient killer whales, humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus*), sei (*Balaenoptera borealis*), sperm (*Physeter catodon*), minke (*Balaenoptera acutorostrata*), and northern right whales (*Eubalaena glacialis*), California sea lions (*Zalophus californianus*), and Northern fur seals (*Callorhinus ursinus*).

A number of socioeconomic sectors rely on a healthy marine environment in the PNCIMA. Both fishing and ecotourism fall within the top five industries dominating the economy of the PNCIMA (Rumsey *et al.* 2003). The area supports commercial fisheries for salmon (coho, pink, Chinook, sockeye, chum, and steelhead), invertebrates (clams, octopus, scallops, prawns, shrimp, urchins, sea cucumber, and crab), and groundfish (including flounder, hake, herring, lingcod, pollock, and rockfish). There are also recreational fisheries for salmon, halibut, rockfish, and lingcod, as well as an aboriginal subsistence fishery. Each year, the PNCIMA hosts thousands of visitors to its approximately 17 marine parks and nine terrestrial parks and recreational areas, which provide camping, wildlife viewing, and hunting opportunities (http://www.livingoceans.org/marine_planning/pncima.shtml). Other ocean-based recreation in the PNCIMA includes whale watching, saltwater angling (through both fishing lodges and charters), boating and sailing, scuba diving, and guided kayak trips. The region also includes the traditional territories of 26 First Nations in four linguistic groups: Haida (2), Coast Tsimshian (5), Heiltsuk-Wuikala (3), Coast Salish (1), and Kwakwala (14). The total aboriginal population is about 26,000 (Rumsey *et al.* 2003).

3 Aquaculture

The majority of finfish aquaculture operations in BC cultivate Atlantic salmon (Salmo salar) using open-net pen cage arrays. In 2003 there were 136 licensed fish farm tenures in the Province, of which 77 (~50%) were in the PNCIMA (Figure 3.1), with the highest density of farms (28 tenures) located in the Broughton Archipelago (between the northern end of Vancouver Island and the mainland). In the same period, there were 24 shellfish farm tenures located within the PNCIMA accounting for only 5% of the BC total. A high number of shellfish farm tenures were located slightly outside the south-eastern PCNIMA boundary in the Strait of Georgia. Although both forms of aquaculture have expanded

production considerably over recent years in BC, any further development of these industries in the northern area of the PNCIMA is currently uncertain (Ministry of Employment & Investment (Economics Branch) *et al.* 2000).

Finfish aquaculture farms release organic waste material into the environment in the form of waste feed particles, fecal material, and dissolved constituents (Chamberlain *et al.* 2005). In addition, organisms that grow on and/or foul the net cage structures can frequently be dislodged and released into the environment (Haggarty et al, 2003). Carcasses are generally collected and removed from the farms for on-land disposal – under exceptional circumstances Environment Canada may issue a permit for release of carcasses into the marine environment. The release of finfish farm waste material may decrease dissolved oxygen levels in the surrounding water body and has the potential to increase the suspended particulate matter loading and dissolved concentrations of nitrogen, phosphorus and other nutrients. Increased levels of these nutrients may contribute to eutrophication events and increased frequency of harmful algal blooms (Sutherland *et al.* 2001; Nash 2000; Haggarty *et al.* 2003). The fate of the waste material that deposits onto the seabed, and its effects on benthic biogeochemical processes, are well documented (Chamberlain *et al.* 2005; Wildish and Pohle 2005) and can lead to smothering of benthic organisms and increased nutrient concentrations, which can stimulate plankton and algal growth and microbial decomposition. The increased microbial activity can reduce oxygen levels leading to hypoxic/anoxic conditions, where sulphate reduction is the dominant metabolic process, and production of free sulphides, which can be toxic to benthic infauna (Holmer et al., 2001) and increase the bioavailability of heavy metals (Levings et al., 2002). These effects can be mitigated to some degree by selection of farm sites that are in dispersive and well swept areas and through good husbandry practices (e.g. minimal waste feed rates). Advances in diet formulation may also reduce the impact of finfish aquaculture on the environment. In extremely sensitive environments, closed containment systems may eliminate the output of organic waste, but economic constraints must be dealt with.

Chemicals are also introduced into the marine environment from finfish aquaculture operations. Fish feed manufacturers may add chemotherapeutants to reduce the incidence of infection and may inadvertently introduce persistent organic pollutants to their products through the use of marine-based protein and lipid sources. In addition, disinfectants (such as iodophors and chlorine), pesticides (such as Emamectin Benzoate, Ivermectin, and Azamethiphos), wood preservatives (such as pentachlorophenol (PCP), chromated copper arsenate (CCA), and creosote), and antifouling compounds (generally copper-based paints) have, at some point, all been applied at fish farm sites in Canada during the development of the industry (Haya et al., 2001). Limited research has detected slightly higher levels of organohalogen contaminants (e.g. PCBs) in farmed Atlantic than in wild salmon, but the concentrations were 3 to 7 fold lower than levels of concern established by Health Canada (Ikonomou *et al.* 2007). Similarly, studies to examine the environmental effects of Emamectin Benzoate around finfish farms in Scotland detected very low concentrations of the compound and concluded that there was no evidence of toxic impacts on organisms in either the water column or sediments (Wildish and Pohle 2005). Further research is needed to determine possible sub-lethal, synergistic (multiple compounds together causing higher toxicity), and/or cumulative effects of the aforementioned compounds on the local ecosystem in the PNCIMA.

Pesticides are generally not used in shellfish aquaculture (Jamieson *et al.* 2001), and the industry relies to a large extent on natural sources of food. Antibiotics and antifouling agents are used occasionally and there is a concern that the use of antibiotics could result in drug resistant strains of pathogenic bacteria (Boyd 1999). Even with expansion, shellfish aquaculture is unlikely to provide as large a contaminant risk as finfish sites. However, when intertidal shellfish leases are actively managed with gravel additions, cultivation, and antipredator netting, community level impacts and reductions in biodiversity may occur. There are many knowledge gaps that need attention.

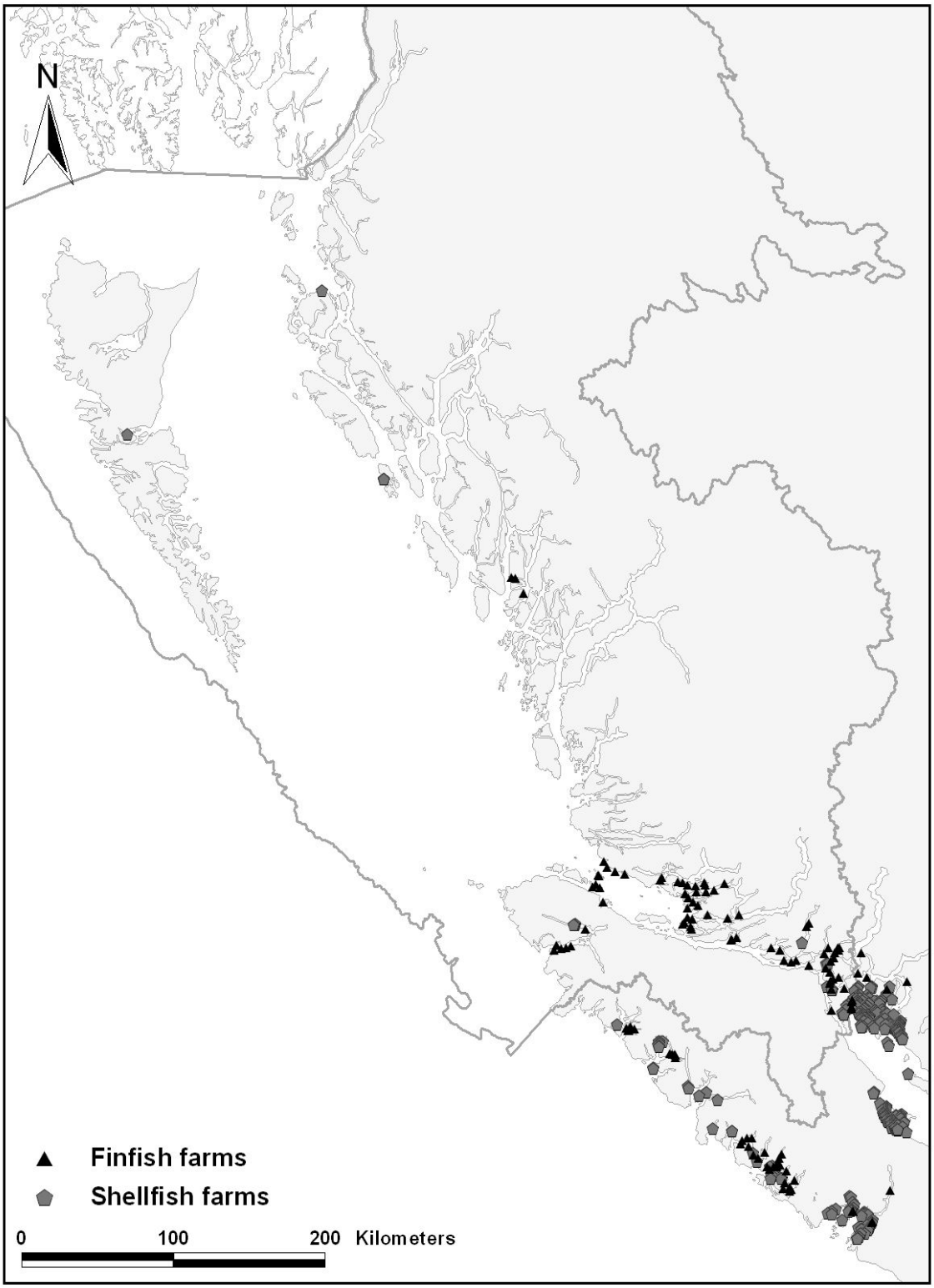

Figure 3.1 Location of finfish and shellfish aquaculture tenures in the PNCIMA as of 2003 (map created using data from the BC Ministry of Food and Fisheries).

4 Vessel Traffic

56% of all coastal traffic on the BC coast is passenger related and a further 29% is towboats (Haggarty *et al.* 2003; Johannessen *et al.* 2007, Table 4.1), and while marine traffic density is greatest on the southernmost portion of the coast, nearshore protected routes through the PNCIMA are used by thousands of vessels annually (Figure 4.1).

Contaminant issues associated with marine traffic include the discharge of sewage, grey water, oily bilge water, shipboard solid wastes, and release of antifouling compounds from ablative coatings. Sound pollution from engine exhaust, propellers, and depth sounders increases with marine traffic and may have a significant impact on marine mammals that depend on echolocation for prey location and for communication. The extent to which this pollution is affecting killer whales in PNCIMA is not known, although noise and disturbance is cited as a significant conservation concern for threatened northern resident killer whales and endangered southern resident killer whales (Joyce *et al.* 2005).

Cruise ships do not make up a large percentage of the total vessel traffic, however, due to their size and high passenger volumes, they are a potential source of large amounts of many contaminants. With an average crew and passenger total of 2,000 per ship, they generate a significant amount of waste and sewage (Nowell and Kwan 2001). Recently the number of ships visiting most BC ports has decreased, but total passenger visits have doubled, indicating an increase in vessel capacity (BC Ministry of Environment *et al.* 2006). Close to 1.5 million passengers transited the PNCIMA in 2004, travelling between Vancouver or Seattle and Alaska (Fisheries and Oceans Canada 2005). Environmental regulations for cruise ships have become more stringent and sewage treatment is now common (International Council of Cruise Lines 2001; Transport Canada 2005). However, their treatment procedures do not remove contaminants such as pharmaceuticals and personal care products. In addition, Canada is thought to be less stringent than the US in enforcing its regulations (Nowell and Kwan 2001), and ships may dump waste in waters in which they are less likely to be caught and prosecuted (Haggarty *et al.* 2003). Because of the routes frequented, released contaminants can end up in relatively shallow waters and fairly close to sensitive shorelines (Figure 4.2).

Table 4.1 Annual vessel movements by vessel type from 1996-97 to 2003-04 for the coast of BC (table from BC Ministry of Environment *et al.* 2006).

Vessel type	Vessel description	Average number of vessels/year	Percent of total
Tankers	Carrying liquid cargo, primarily oil	2,739	<1
Chemical	Tankers carrying liquid chemicals, including petroleum and natural gas	1,278	<1
Cargo	Bulk cargoes such as cars, grain, ore, etc.	29,253	7
Tugs	Towing or pushing barges	117,319	29
Fishing	Catching, processing, or transporting fish under the Fisheries Act	11,078	3
Passenger	Ferries and cruise ships	229,095	56
Other	All vessels not in other categories	19,541	5
Total		410,301	100

Source: MCTS, Canadian Coast Guard.

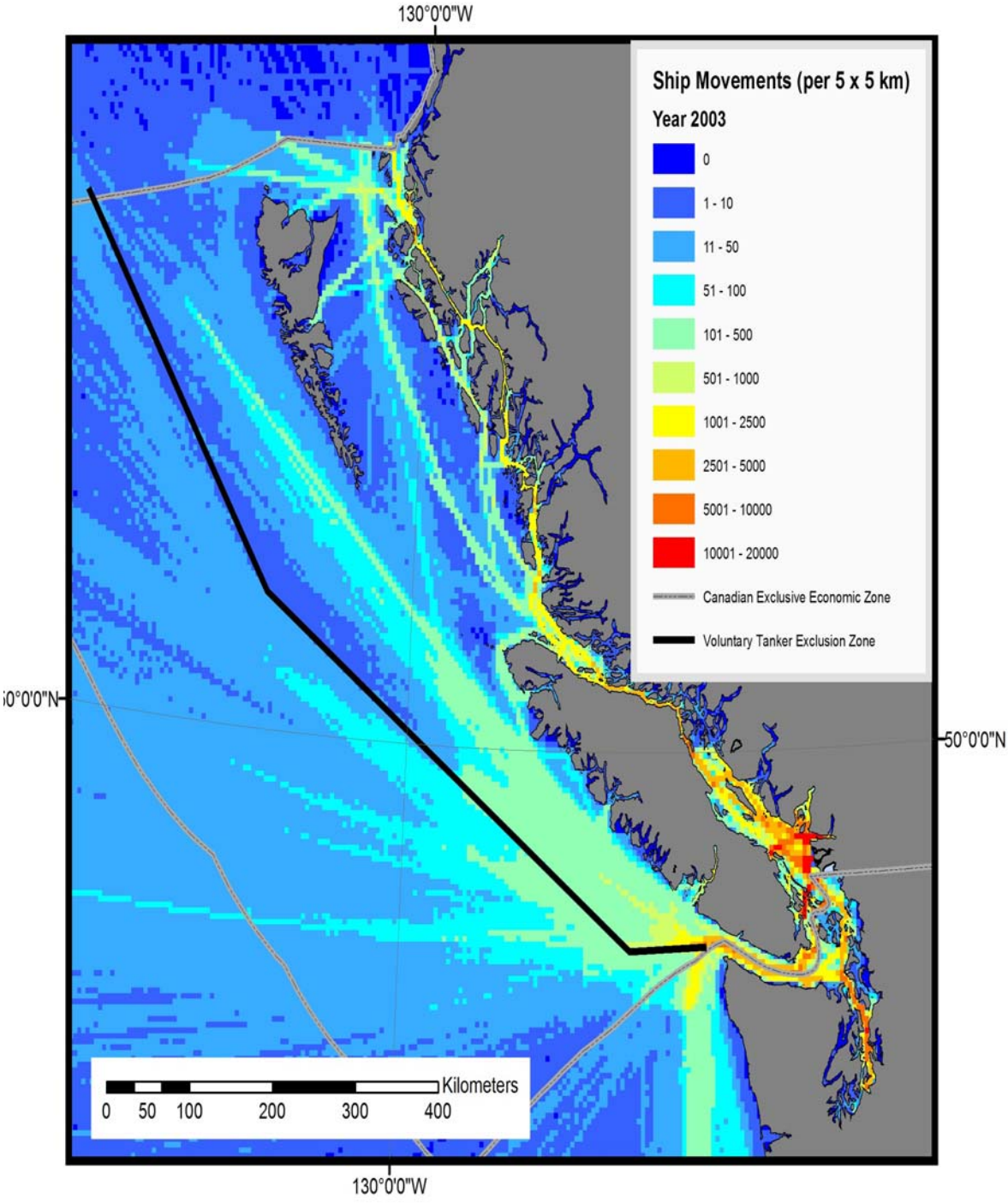

Figure 4.1 Map of marine vessel traffic density based on inter-grid (5 km by 5 km) movement on the BC coast in 2003 (figure provided by P. O'Hara, Environment Canada, 2007, with data from DFO Marine Communications and Traffic Services).

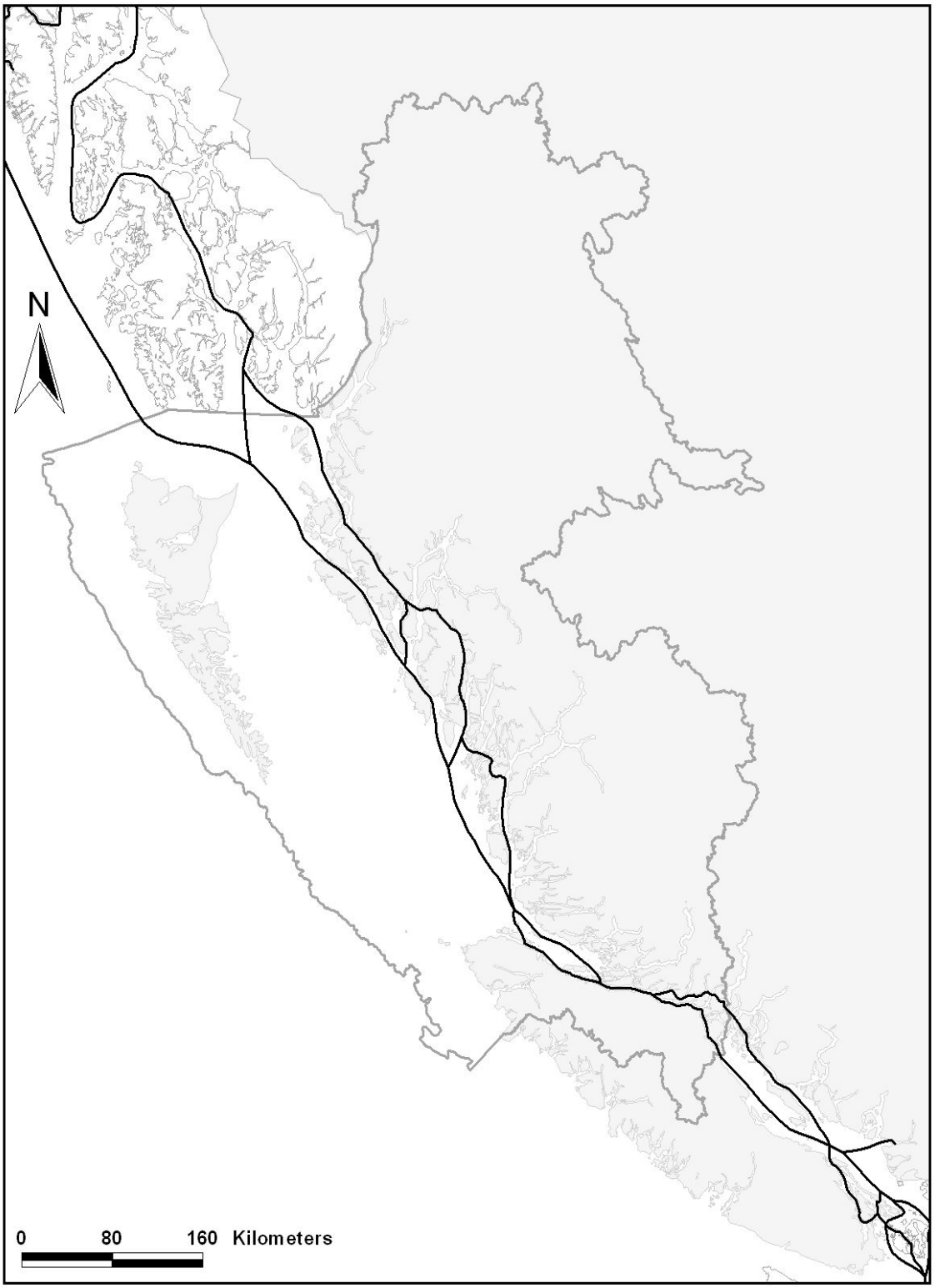

Figure 4.2 Cruise ship routes along the BC coast (map created using data from the BC Offshore Oil and Gas Team, Ministry of Energy and Mines http://www.offshoreoilandgas.gov.bc.ca/).

5 Ports, Harbours and Marinas

A number of contaminant issues are associated with vessels and the locations in which they tie up or are repaired. Creosote, chromated copper arsenate, and pentachlorophenol (PCP) are commonly used wood preservatives on docking facility building materials (ENKON Environmental Limited 2001). PCP in particular has been found in elevated levels in many parts of the BC coastal environment, including Campbell River's harbour, and is thought to originate from wood preservatives (Yunker *et al.* 2002). Antifouling paints containing copper and tributyltin (TBT) are used to prevent the colonization by marine organisms of the hulls of boats, ships and wooden structures. These compounds build up in harbours and marinas, especially near ship repair facilities (Haggarty *et al.* 2003). TBT has toxic effects including endocrine disruption causing imposex in molluscs (Pierce *et al.* 1998). In many countries including Canada, TBT has since been banned for use on vessels less than 25m in length, and many larger vessels such as ferries, cruise ships, and naval vessels, have also phased out its use (Science Advisory Panel 2002; Haggarty *et al.* 2003). Despite the ban, continued TBT contamination of large industrial harbours, such as Prince Rupert and Vancouver, suggests that this antifoulant is leaching from vessels arriving from countries where TBT is still used (Pierce *et al.* 1998; Stewart and Thompson 1997; Stewart and Thompson 1994; Haggarty *et al.* 2003). Copper-based antifouling paints, which leach copper to the environment, are now commonly used instead of TBT. Harbours are also sites of spills from fuel docks, release of bilge water, and engine exhaust, all sources of polycyclic aromatic hydrocarbons (PAHs). BC harbours have PAH concentrations that are up to 260 times those detected at non-harbour sites (Kay 1989). Ballast water released in harbours may be the most important vector for the introduction of some invasive species and sewage discharge from vessels can create localized biochemical oxygen demand (BOD) but is frequently insignificant relative to sewage from adjacent terrestrial sources.

The PNCIMA has two major industrial ports, Prince Rupert and Kitimat. Vessel traffic has declined recently at Prince Rupert likely due to its limited capacity for large container and cruise ships. As a result, a new cruise ship dock was completed in 2004 and a new high volume container terminal is under construction (Johannessen *et al.* 2007). The expected increase in traffic may increase the risk of environmental contamination. Kitimat is a privately owned industrial port serving the ALCAN aluminum smelter, the Eurocan paper mill, and the Methanex methanol plant which may reopen to import methanol and condensate (Johannessen *et al.* 2007). Enbridge Inc. is currently considering Kitimat as an export destination for liquid crude oil and Galveston LNG has proposed a liquefied natural gas receiving, regassification, and export terminal 15km south of Kitimat (Fisheries and Oceans Canada 2005). These expansions to the port of Kitimat increase the risk of environmental contamination.

The PNCIMA also has 35 small craft harbours, some run by DFO and some by private harbour authorities, as well as numerous marinas, boat launches, and anchorages (Figures 5.1 – 5.3). Smaller vessels no longer contribute to TBT contamination, but problems associated with sewage discharge, PAHs from engine leaks and combustion, and chemicals associated with boat maintenance still exist at some of these locations.

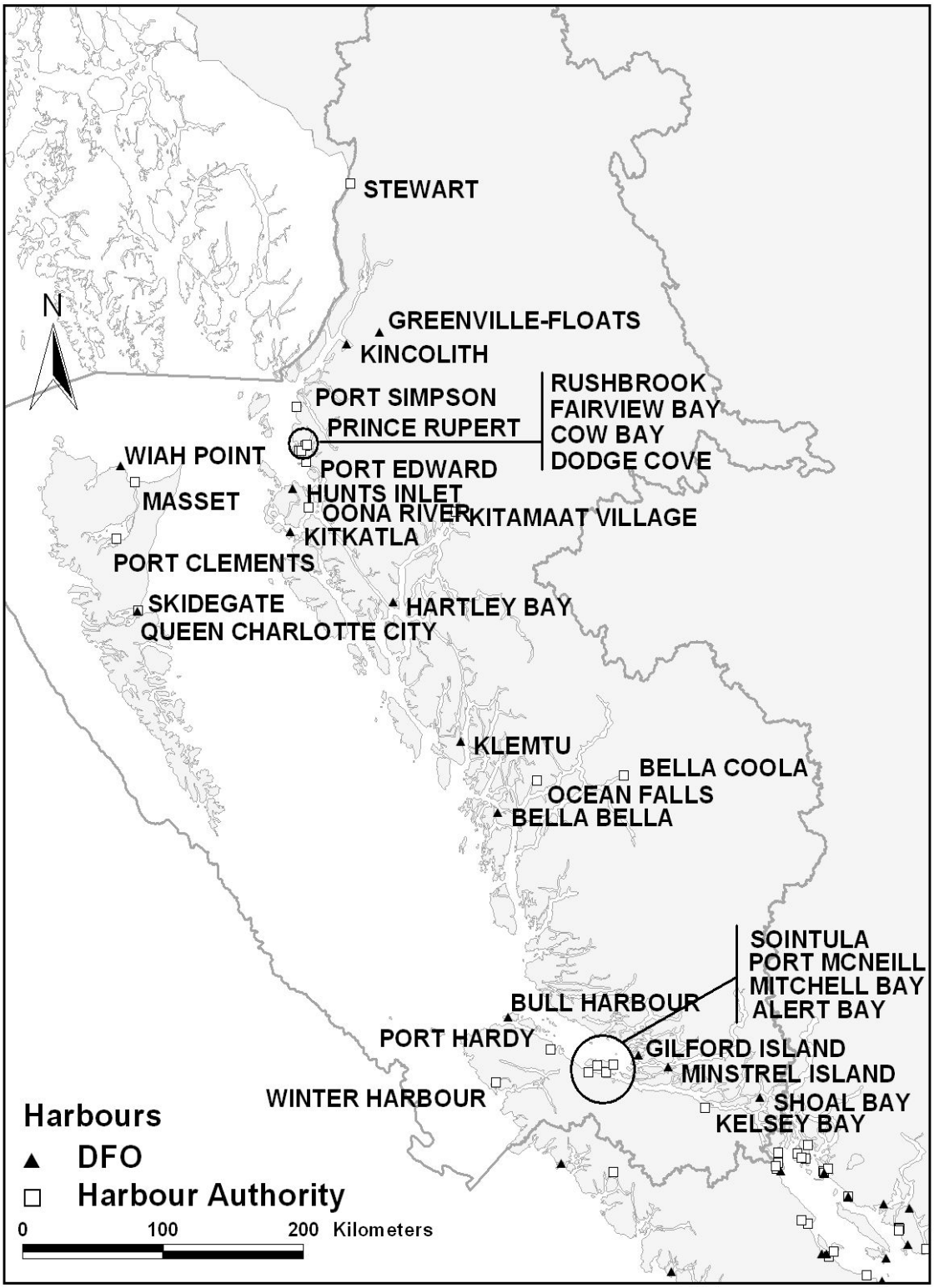

Figure 5.1 Locations and names of small and large craft harbours in the PNCIMA (map created using data from the BC Ministry of Sustainable Resource Management).

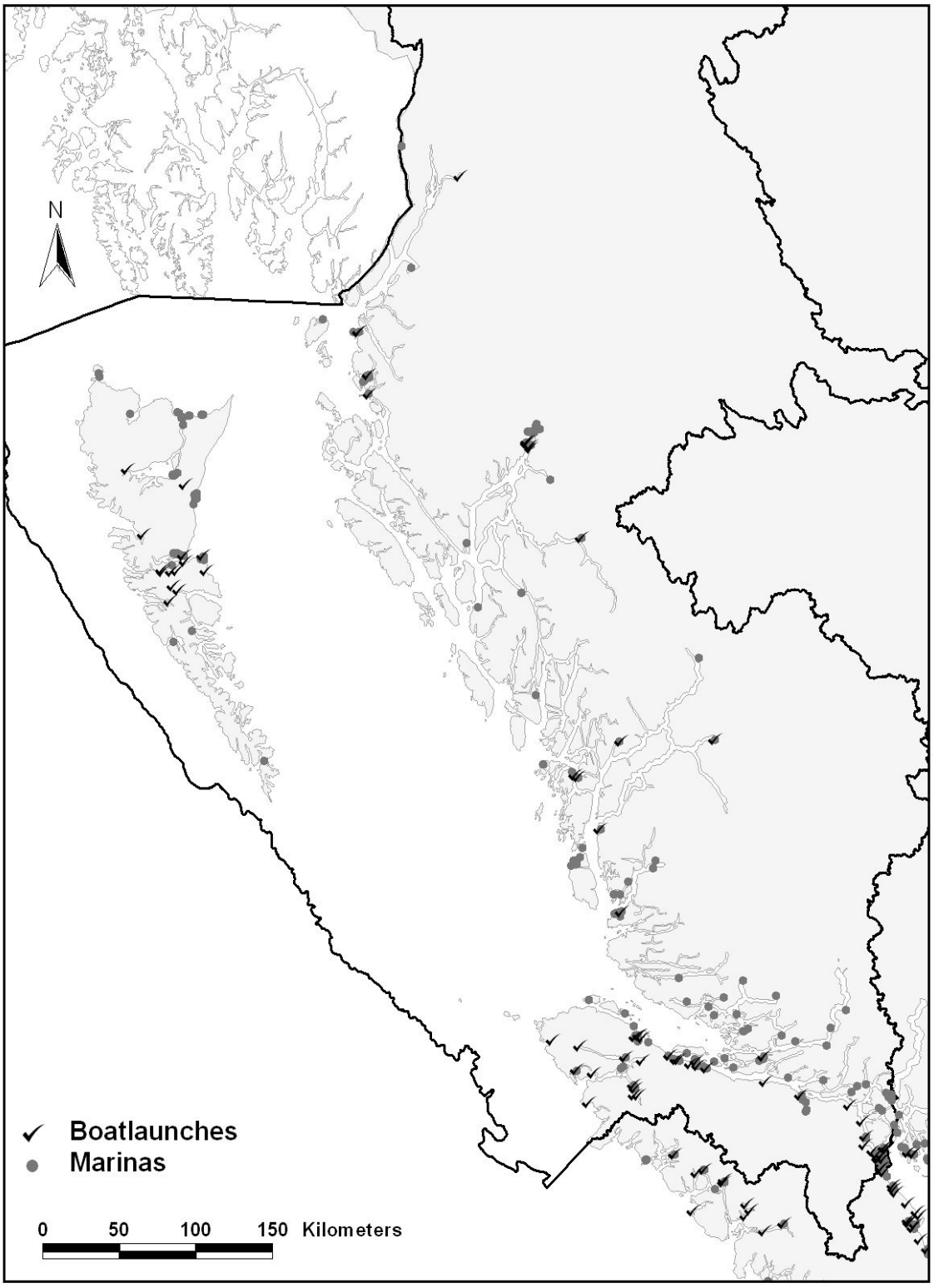

Figure 5.2 Location of marinas and boat launches in the PNCIMA (map created using data from the BC Ministry of Sustainable Resource Management).

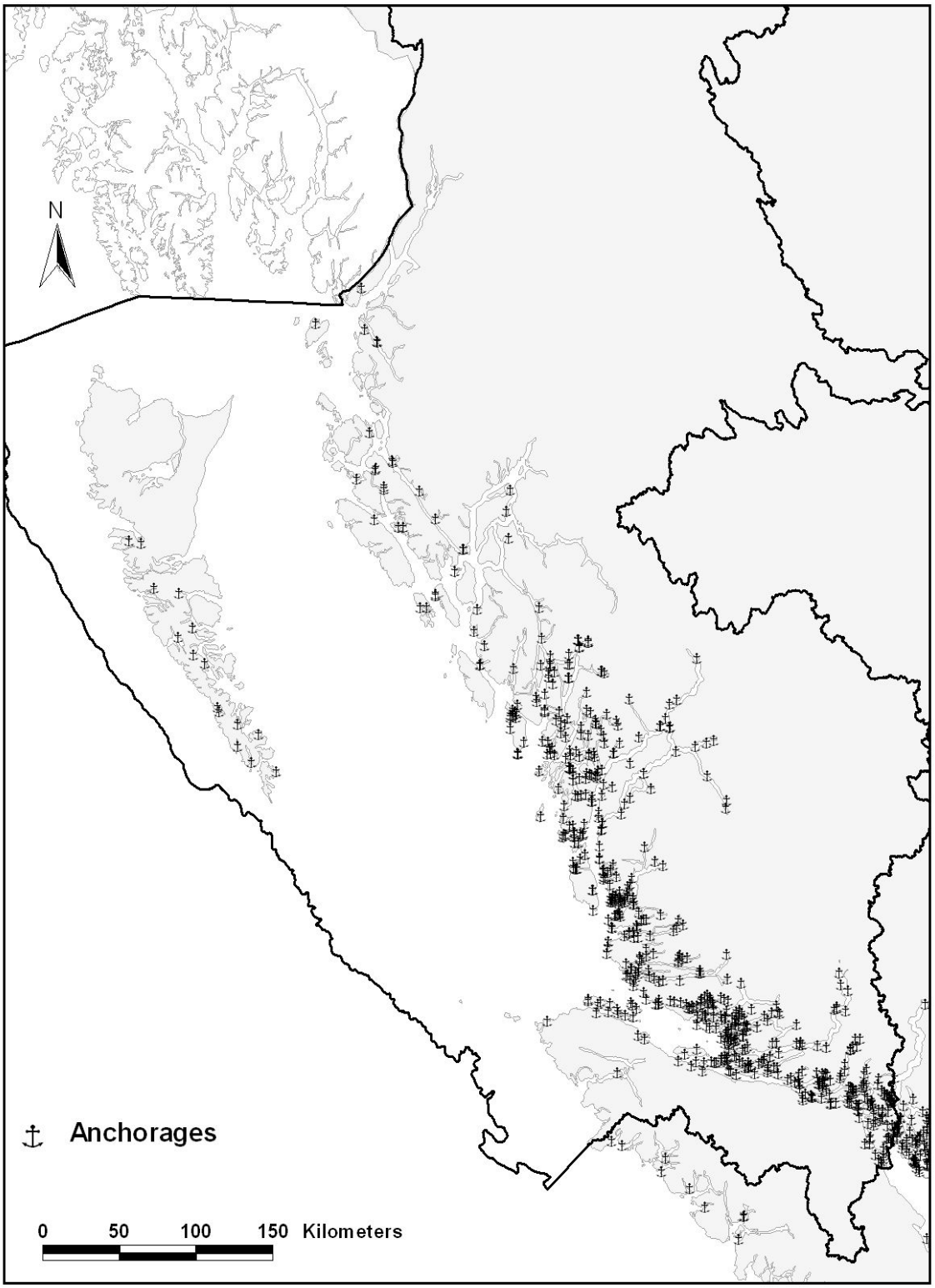

Figure 5.3 Locations of anchorages in the PNCIMA (map created using data from the BC Ministry of Sustainable Resource Management).

6 Forestry

Forestry is an important industry in the PNCIMA, where large tracts of surrounding watersheds are licensed for tree farming (Figure 6.1). However, coastal forestry operations have experienced an economic downturn in recent years.

Pesticides used in the forest industry in BC include insecticides to exterminate a variety of bark beetles and herbicides to inhibit the growth of undesirable plants during silviculture. Use of all insecticides and most herbicides has declined recently (data from the National Forestry Database Program http://nfdp.ccfm.org/index_e.php). However, glyphosate use remains highly variable from year to year, and triclopyr use increased steadily from 1991 to 1998. Both of these compounds have short half-lives and relatively low toxicity to aquatic organisms, dependent on the form of the compound and its purity. Additions to the active compound can have greater toxicity (Haggarty *et al.* 2003; Johannessen and Ross 2002). Current pesticide use by forestry operations in the PNCIMA is unlikely to have widespread environmental impact.

In addition to water, both fire suppressant foams and fire retardant chemical salts are used in the PNCIMA (Johannessen and Ross 2002). Chemical salts have very low toxicity, but the surfactants used in the foams to increase bubble strength (Gaikowski *et al.* 1996) are more toxic. The toxicity of salt formulations increases dramatically with the addition of sodium ferrocyanide, used to inhibit the corrosion of the fire fighting equipment. When exposed to sunlight, these formulations produce cyanide, which can kill fish (Norris *et al.* 1983; Little and Calfee 2000; Burdick and Lipschuetz 1950). Fire control chemicals have yet to be linked to aquatic animal mortalities in the PNCIMA, and sub-lethal effects have not been well investigated.

Wood preservatives and anti-sapstain compounds are not likely a significant issue in the PNCIMA. Creosote, and less frequently chromated copper arsenate (CCA), are used by industry to preserve wood. The chromium, copper, and arsenic found in CCA are all toxic substances (Johannessen and Ross 2002). Creosote is a complex chemical mixture, and when used to preserve dock pilings, its toxicity is localized to a small portion of the surrounding environment, particularly if it is allowed to “age” before use (Hutton and Samis 2000). The majority of wood preservative facilities in BC are found south of the PNCIMA, within the Fraser and Georgia basins where wood product use is highest. Furthermore, the implementation of “best practices” methodologies at wood preservative facilities in the 1990s has resulted in an estimated 90% decrease in the discharge of contaminated effluent (EC 1998). Anti-sapstain compounds are used by lumber mills as short term means to prevent fungal growth and staining on lumber. Through the implementation of best practices at the 14 sawmills in the PNCIMA, the risk of anti-sapstain contamination of the marine environment is minimal.

Marine environments throughout the PNCIMA are commonly used for log sorting and transportation. Ease of road access and a need for protected waters frequently results in log dumps being located in sensitive estuarine habitats where log grounding at low tide, prop wash, and creation of log debris from handling causes compaction, scouring, and smothering of the benthos. Wood sugars and other naturally occurring organic compounds, in combination with microbial decomposition of the wood debris, are a source of a variety of leachates which can be toxic to aquatic life (Frankowski and Hall

1999) and can result in depressed oxygen levels. Dry land log sorts have been developed to address some of these impacts and to reduce the exposure of logs to the ambrosia beetle (which may excavate wide tunnels in the exposed surfaces of logs floating in salt or fresh water, resulting in degradation of wood quality (http://www.nrcan-rncan.gc.ca/cfs-scf/science/)), but water runoff must be managed to avoid contamination of adjacent marine habitats. Attempts to develop better log handling practices continue so as to reduce or eliminate environmental impacts (White 2001).

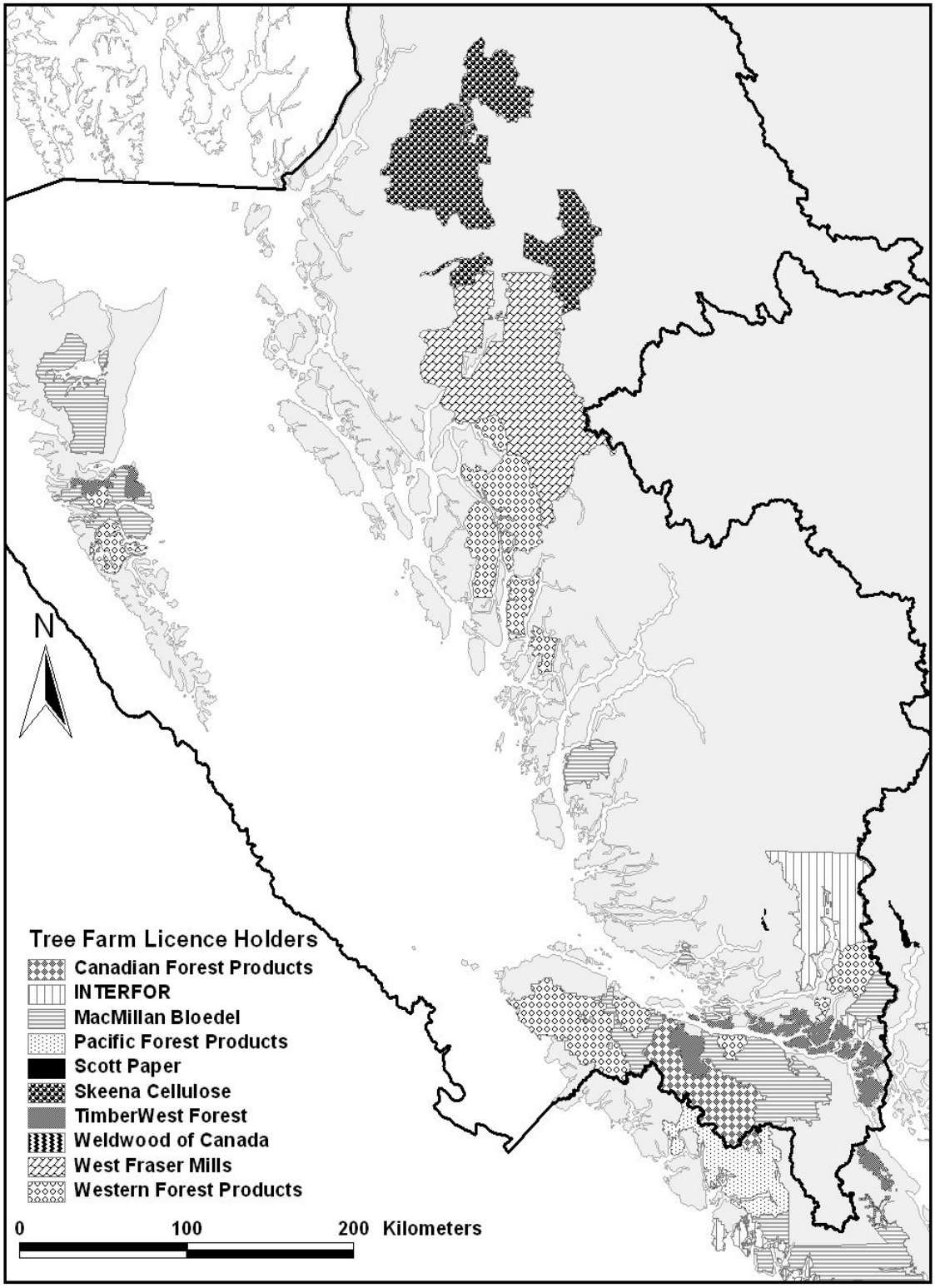

Figure 6.1 Location and ownership of tree farm licences in the PNCIMA as of 1997 (map created using data from the BC Ministry of Forests).

7 Pulp and Paper

There are four active pulp mills in the PNCIMA (Figure 7.1), with two on Vancouver Island (Western Pulp Ltd. in Port Alice and Norske Skog Canada in Elk Falls just north of Campbell River) and two on the northern mainland coast (Skeena Cellulose in Prince Rupert and Eurocan in Kitimat). BC's pulp and paper industry has recently experienced an economic downturn, and both Western Pulp and Skeena Cellulose have undergone recent closures and have been re-opened under new ownership.

In the 1960s and 1970s pulp mill effluent was a major source of fine particles (reported as total suspended solids or TSS) and biochemical oxygen demand (BOD), whereby bacterial decomposition or chemical oxidation of the effluent's organic component depletes the oxygen in the mill's receiving waters. Depleted oxygen levels caused mass mortalities in local aquatic biota adjacent to pulp mills on a regular basis (Waldichuk 1961; Waldichuk 1963; Packman and Bradshaw 1977; Beak Consultants 1970; Beak Consultants 1974; Packman 1977). Mills have also been responsible for the presence of chlorinated organic compounds in both atmospheric and aqueous discharge as a by-product of the bleaching process and the burning of salt laden wood. Among these compounds are the highly toxic dioxins and furans, which bioaccumulate in organisms and biomagnify through the food chain (Harding and Pomeroy 1990; Servos *et al.* 1996; Yunker and Cretney 1995; Colodey *et al.* 1990; Yunker and Cretney 2000b; Yunker and Cretney 2000a; Yunker *et al.* 2002). In the 1980s and 1990s, the addition of secondary treatment for effluent and a change from liquid chlorine to chlorine dioxide gas for pulp bleaching reduced TSS and BOD levels to well below regulatory limits and nearly eliminated dioxins and furans in mill effluent across Canada (McGreer and Belzer 1999). Dioxin and furan levels in the hepatopancreas of crabs in the vicinity of pulp mills has shown a steady decline since these changes were made (Figure 7.2) and the standard test for mill effluent toxicity, 96 hour exposure of fish to effluent, changed from 50% survival prior to the changes, to 100% survival afterwards (Hagen *et al.* 1997b; McGreer and Belzer 1999), underscoring the net positive effect of regulatory changes to source chlorine on aquatic animal health.

However, despite the improvement, pulp mill effluent continues to contain metal contaminants, natural plant compounds including hormones, other chlorinated compounds, and surfactants (Hewitt and Servos 2001; Fox 2001; Yang and Randall 1996; Hodson *et al.* 1992; Kiparissis *et al.* 2001). Little information exists on the environmental effects of many of these compounds. In the past the focus has been on acute toxicity, hence the reliance on short exposures to full effluent concentration. However, there is growing evidence that exposure to diluted effluent concentrations over the long-term can cause sub-lethal effects in aquatic organisms, ultimately causing mortality or impaired reproductive ability with community and population level consequences. Given the variety of substances used in, and produced by, pulp mill processes, they can not yet be discounted as a source of potentially significant contaminants.

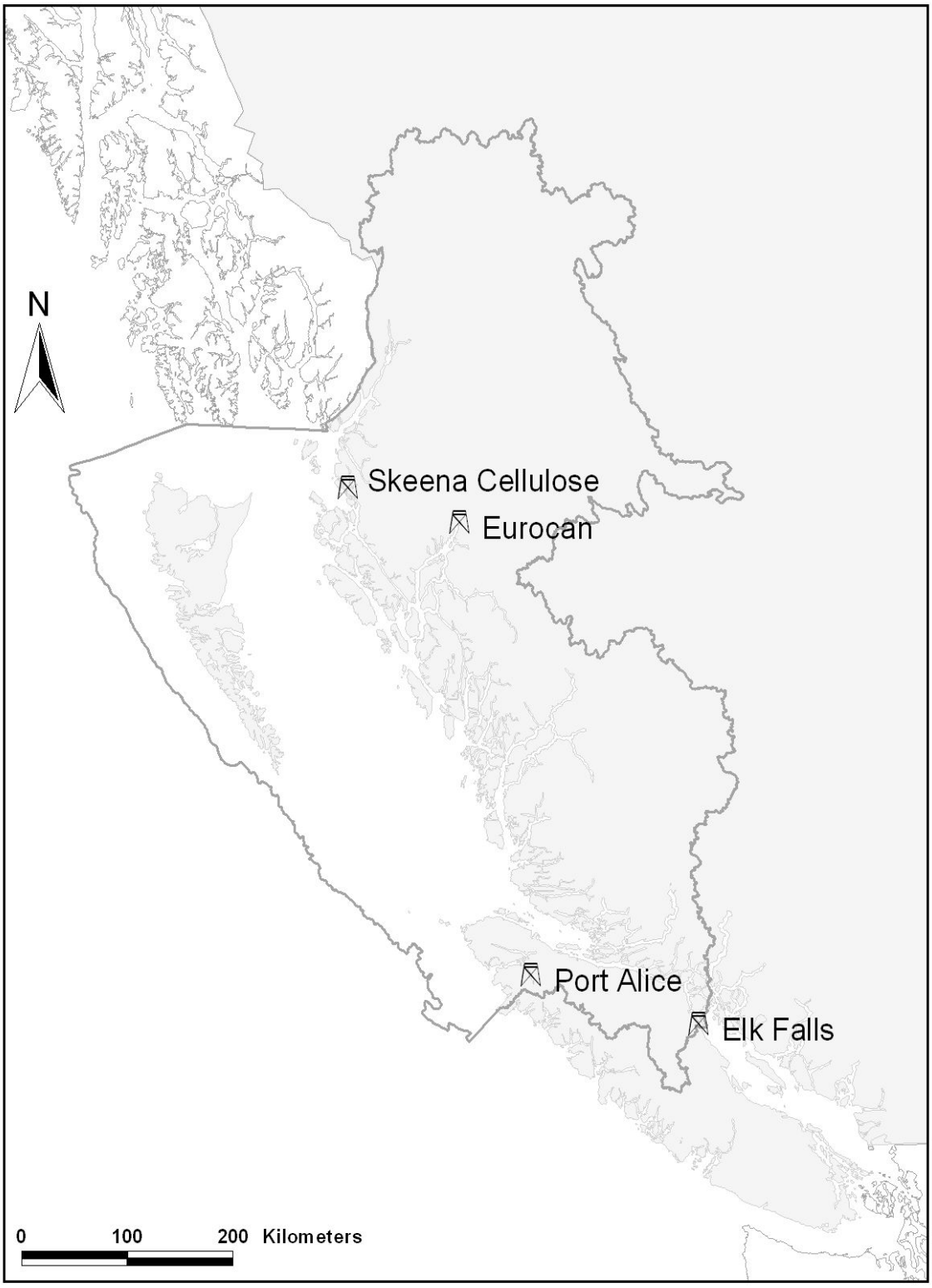

Figure 7.1 Location of the four active pulp and paper mills in the PNCIMA.

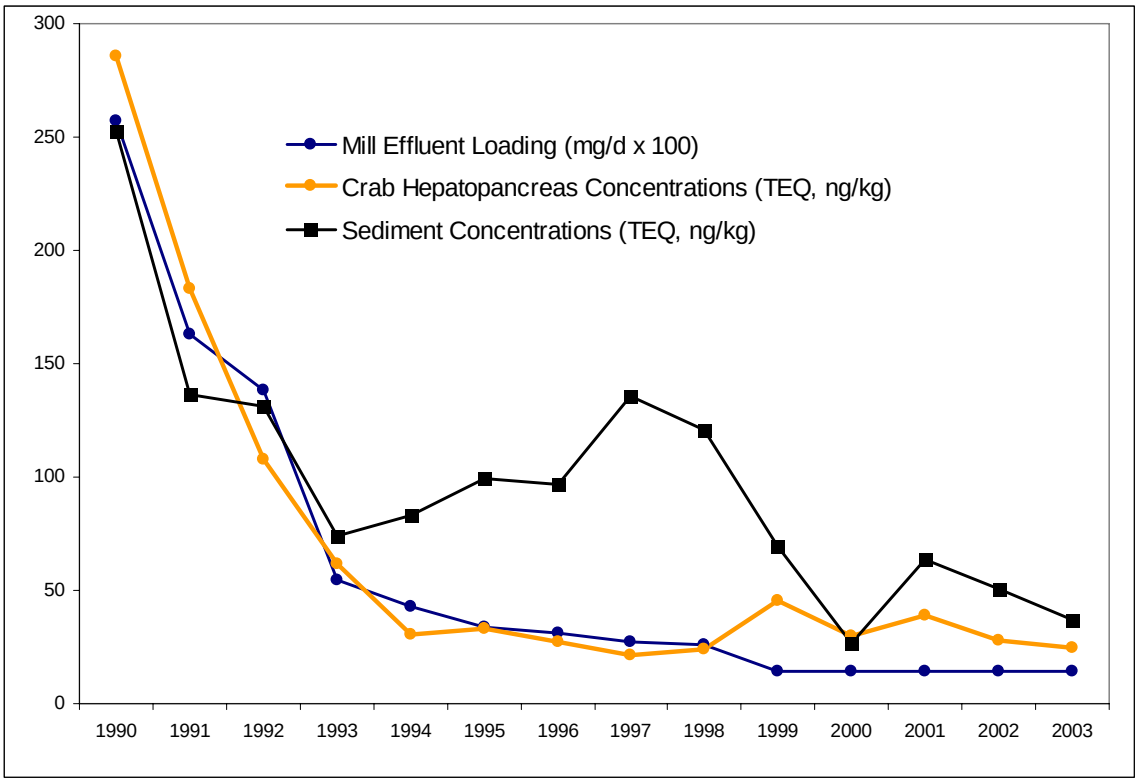

Figure 7.2 Dioxin and furan concentrations detected in pulp mill effluents, crab hepatopancreas, and sediments near mill outfall decreased between 1990-2003 (graph from BC Ministry of Environment *et al.* 2006).

8 Mining/Smelting

Much of the southern and northern portions of the PNCIMA has been prospected for mineral claims and have a long history of mining activity including operations at Island Copper and Kitsault (Figures 8.1 and 8.2). Mines operating in the PNCIMA include a copper mine (Myra Falls), a coal mine (Quinsam Coal), and three industrial mineral mines (Anyox Slag Heap: silica; Benson Lake: limestone; and Tsitika Stone: granite/building stone). Twelve sites are a risk to produce acid rock drainage and heavy metal leachate but monitoring has been sufficient at only six of them to evaluate environmental impact (Ministry of Water Land and Air Protection 2002).

Acid rock drainage (ARD) is the single largest environmental problem facing the mining industry (O'Kane *et al.* 1997). Acidic compounds are produced when sulphide minerals in rocks are exposed to water and air. Many metals become soluble under acidic conditions and leach into the surrounding environment. Most metal mines and some coal mines are susceptible to ARD depending on the amount and type of rock surface area exposed to weathering by blasting and crushing. Increased acidity and concentrations of dissolved metals such as copper, zinc, and cadmium can be toxic to biota (Ministry of Water, Land and Air Protection2003).

Three mine sites (Island Copper, Kitsault, and Tasu) dispose of tailings in deep, low-oxygen water in an attempt to avoid ARD. Sediments at these sites have elevated metal

levels but the levels in the biota are not lethal, suggesting that the disposal techniques have immobilized the metals or decreased their biological accessibility. Metal leaching and ARD levels at Myra Falls and Quinsam Coal meet current guidelines. However, monitoring is limited to 96 hour lethality tests and does not consider sublethal or long term effects. At Anyox, metal mining and smelting has left a large quantity of slag on the shore and intertidal areas, which is now being mined for the silica. Weathering by tidal and wave action has resulted in elevated heavy metal concentrations in the sediments and biota in a wide area away from this site.

The only active smelter in the PNCIMA is the aluminum smelter at Kitimat, owned and operated by Alcan. In the early stage of its operation, the primary environmental concern was the release of large amounts of fluoride (Brewer *et al.* 1979; Hocking *et al.* 1980; Bell and Kallman 1976). However, emission controls and changes in the smelting process have significantly reduced the release of fluoride. An ongoing concern is the release of polycyclic aromatic hydrocarbons (PAHs), produced both by the smelting process and by the handling of pitch and coke on-site (Simpson *et al.* 1998). PAHs comprise a large number of compounds, a number of which are known to be toxic. Several studies have detected elevated PAH concentrations in both marine biota and sediments in the Kitimat Arm area, but none of these studies have clearly linked exposure to the health effects exhibited by the organisms (Erickson *et al.* 1979; Paine *et al.* 1996; Simpson *et al.* 1996; Eickhoff *et al.* 2003a; Eickhoff *et al.* 2003b).

Heavy metal contamination in the PNCIMA from past, present, and future activities remains a risk to marine environmental quality, particularly considering the recent rise in base metal prices and the associated exploration boom.

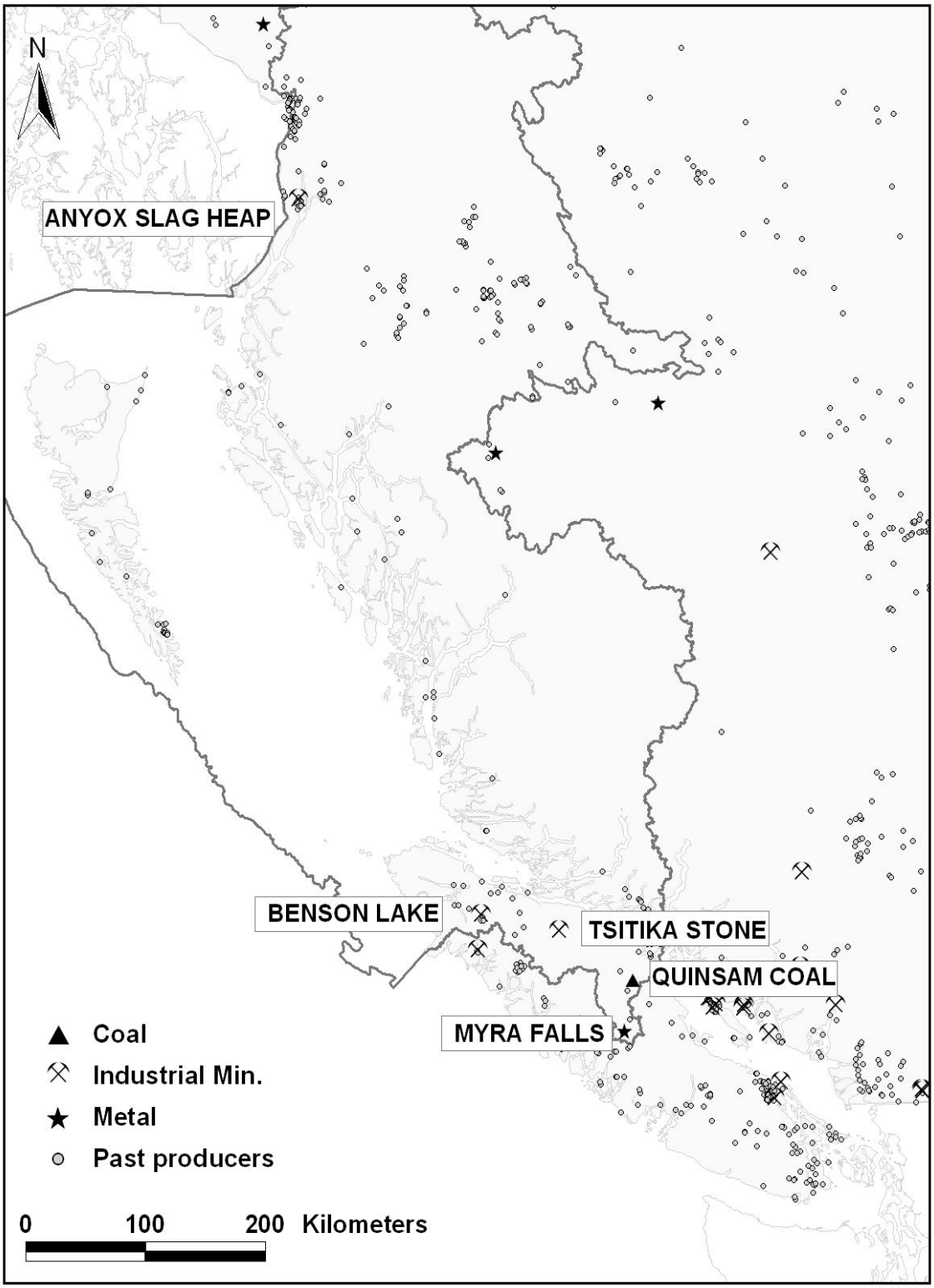

Figure 8.1 Active and historical mine sites in the PNCIMA (map created using data from the BC Ministry of Energy and Mines, http://www.em.gov.bc.ca).

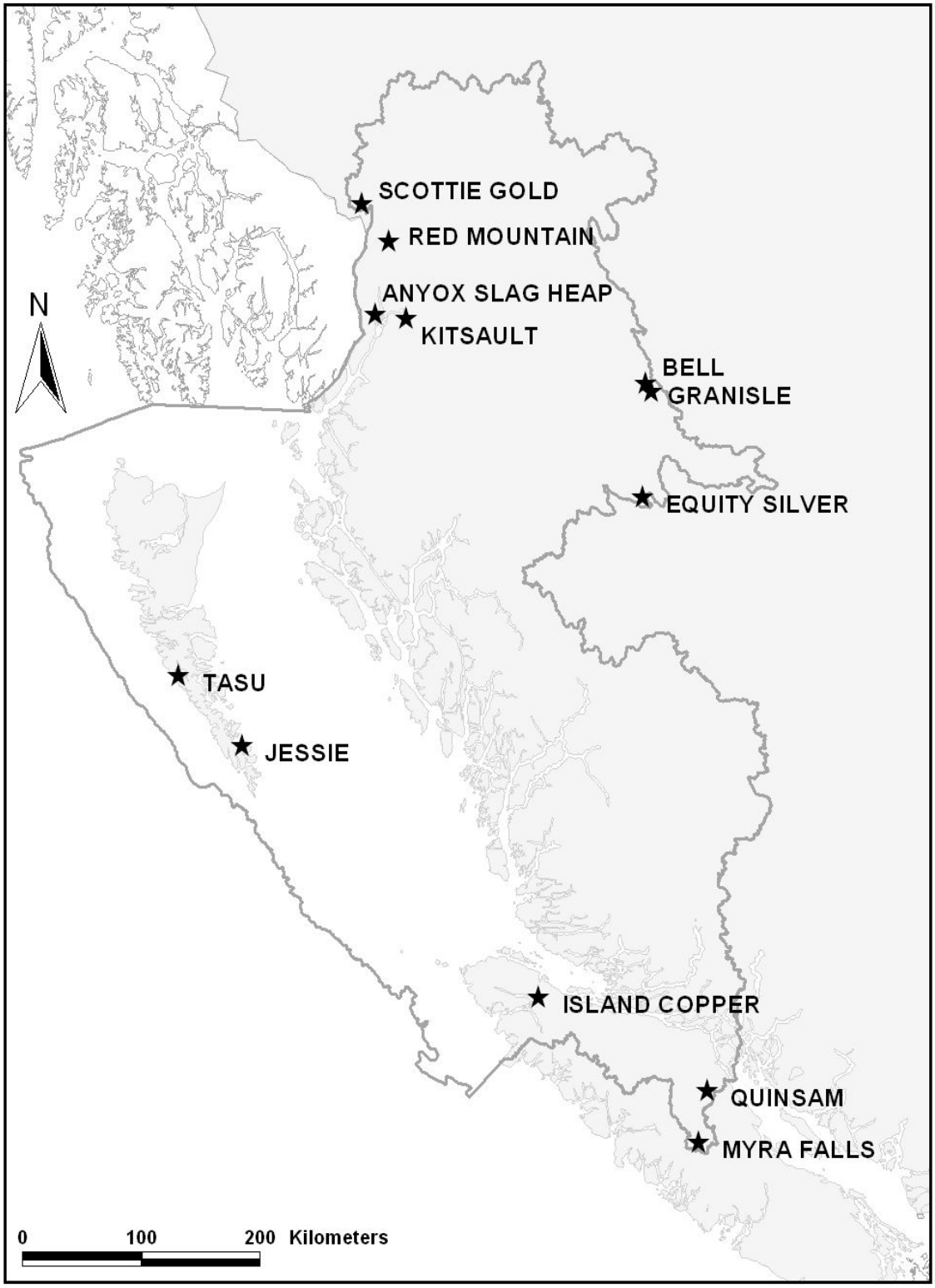

Figure 8.2 Several mine sites, both active and decommissioned, are thought to present a risk of acid rock drainage and heavy metal leaching in the PNCIMA (map created using data from the Ministry of Water Land and Air Protection 2002).

9 Ocean Dumping

There are 11 active and 27 historic ocean dump sites in the PNCIMA (Figure 9.1). Permitting for dumping materials at sea is governed by *The Ocean Dumping Control Act*, which has become part VI of the *Canadian Environmental Protection Act* (CEPA). It applies to the disposal at sea of dredged material and inert, inorganic, and uncontaminated organic material, fish waste, inert, bulky items such as concrete, steel or other matter, vessels or other structures, and to the incineration of materials at sea (Environment Canada and Pacific and Yukon Region 2003). CEPA Part VI also applies to the loading of wastes onto ships, aircraft, platforms, or other artificial structures for disposal at sea (Environment Canada 2003). A few types of ocean discharge are covered by separate legislation, including offshore mineral exploration and development, discharge during the normal operation of ships and other craft, and effluent from land-based sources such as pipelines (Environment Canada and Pacific and Yukon Region 2003).

Prior to receiving permits from Environment Canada, all material to be dumped must undergo chemical testing (Haggarty *et al.* 2003). While dumping of hazardous material is prohibited, materials containing 'acceptable' levels of metals may be approved. Consequently, some ocean dumpsites have elevated levels of mercury, cadmium, lead, zinc, and copper (Haggarty *et al.* 2003). The forest products industry frequently uses ocean dumps to dispose of wood wastes, and material generated from dredging of channels, harbours, marinas, bridges, wharves, and ferry terminals to maintain navigable waters is often disposed of at sea (Sullivan 1987).

Due to the permitting and monitoring of this activity, ocean dumping is not considered to be a major source of contaminants in the PNCIMA.

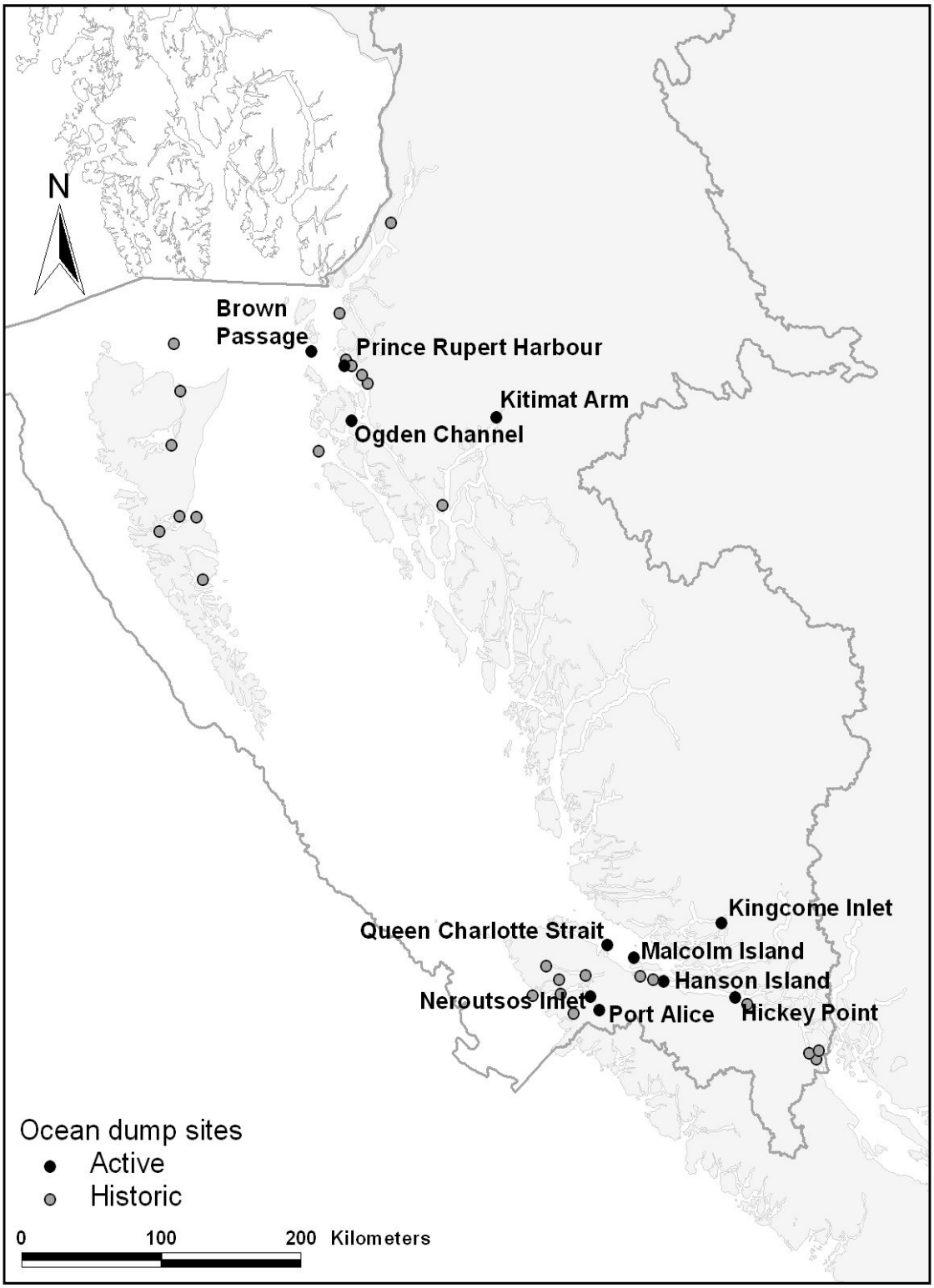

Figure 9.1 Active and historic ocean dump sites in the PNCIMA (map created using data from Johannessen *et al.* 2007)).

10 Coast Guard/Military

The Canadian Coast Guard (CCG) maintains four Search and Rescue stations, 23 lighthouses, and numerous navigational aids in the PNCIMA. Ships likely contribute ship-based pollutants to the marine environment as discussed in section 4 and in Haggarty *et al*. (2003). Staffed lighthouses used large quantities of mercury as a stable base for their beacons, and large quantities of discarded lead acid batteries are currently being recovered from the water adjacent to many aids to navigation (Haggarty *et al.* 2003, Figure 10.1). In addition, since 1965, lead weights, lithium batteries, and other substances have been deposited into the ocean at Canadian Forces Maritime Experimental and Test Ranges at Nanoose Bay near Nanaimo (Office of the Auditor General of Canada 2003). An environmental assessment carried out in 1996 did not gather enough information to determine the impacts of these substances on local marine populations, but a recent review of this assessment by Fisheries and Oceans Canada stated that steps should be taken to assess and mitigate potential environmental damage (Office of the Auditor General of Canada 2003). The CCG is responsible for many of marine contaminant issues on the BC coast, but has since recognized this issue and is working to rectify it.

Currently, there are no active Canadian forces bases in the PNCIMA. Three military sites on the north coast were stood down following World War II; CFS Masset, RCAF Alliford Bay, and RCAF Prince Rupert (http://www.rcaf.com/stations/). A myriad of discarded chemicals may remain on these sites but await the completion of adequate environmental assessments for a reliable inventory. A 2003 report by the Auditor General of Canada (2003) found that the Department of National Defence did not always comply with provisions of the *Fisheries Act* and as a consequence fish habitat has been lost.

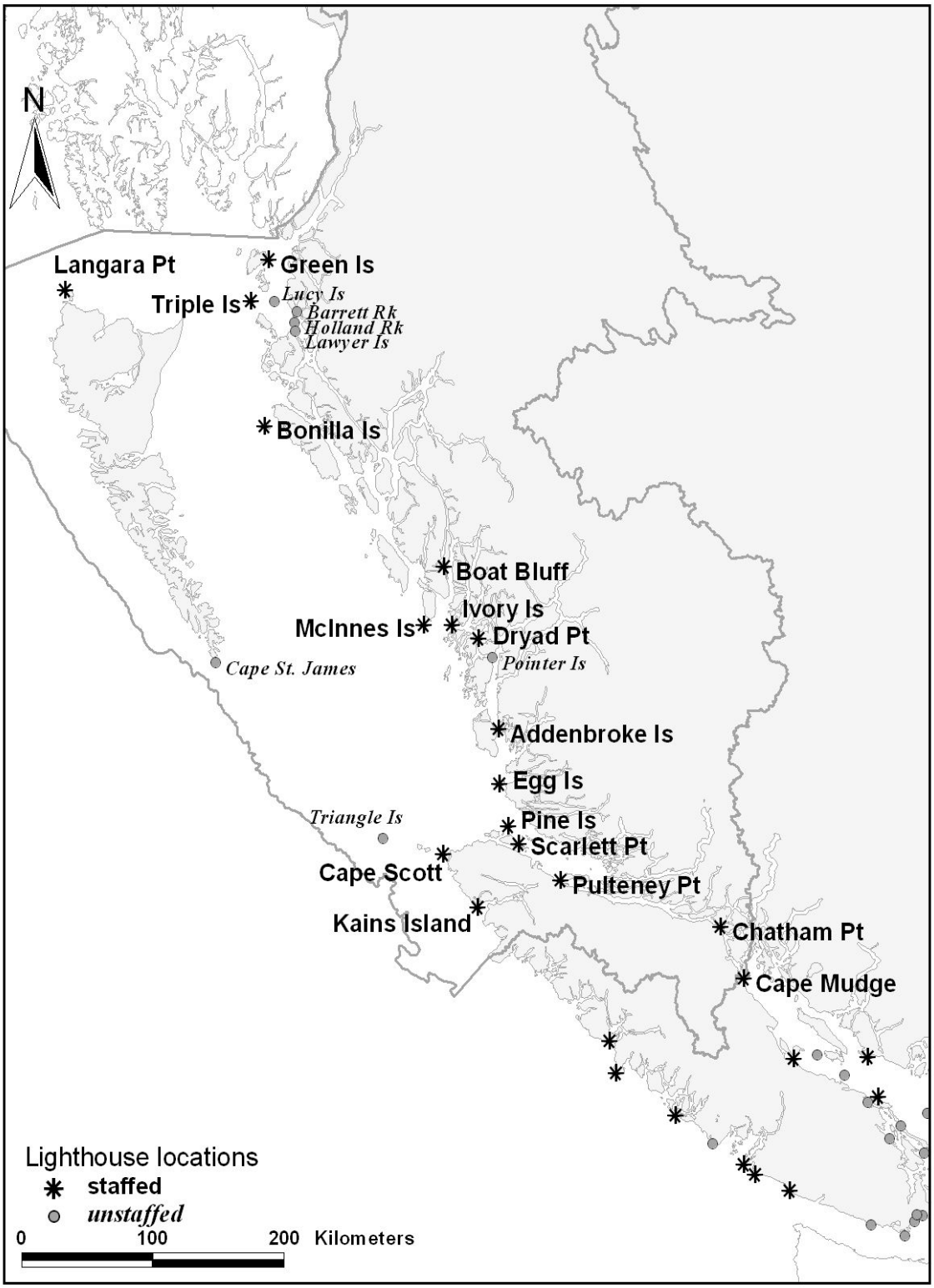

Figure 10.1 Staffed and unstaffed lighthouses in the PNCIMA (map created using data from http://www.fogwhistle.ca/bclights/index.php).

11 Oil and Gas

Of the four sedimentary basins off the BC coast that could contain reserves of oil and gas, the Queen Charlotte Basin, which underlies most of the PNCIMA, has the best prospects (Woodsworth 1991; Hannigan *et al.* 2001) (Figure 11.1). Exploration began with 14 test wells in the offshore portion of the Queen Charlotte Basin in the late 1960s, followed by environmental impact reviews in the early 1980s (Canada Oil and Gas Lands Administration and BC Ministry of Energy 1984; West Coast Offshore Exploration Environmental Assessment Panel 1986; Chevron Canada Resources Ltd. 1982; Petro-Canada 1983; Planning and Assessment Branch (BC Ministry of Environment) 1983) (http://www.offshoreoilandgas.gov.bc.ca/). However, the *Nestucca* (1988, 227 000 gallons) and *Exxon Valdez* (1989, 11 000 000 gallons) oil spills led to provincial and federal moratoria on oil exploration in the region. Recently, the provincial and federal governments have begun to revisit these moratoria in light of new technologies and the rising price of oil and gas, prompting another series of environmental reviews {Birtwell, 2002 378 /id;Strong, 2002 113 /id;Jacques Whitford Environment Limited, 2001 1461 /id;Jamieson, 2003 1630 /id;Crawford, 2002 1035 /id;Cretney, 2002 1383 /id;Cretney, 2002 1384 /id;Cretney, 2002 1385 /id;Cretney, 2002 833 /id;Hall, 2004 1121 /id;Simon Fraser University, 2000 200 /id;Whiticar, 2000 199 /id;Whiticar, 2001 365 /id}. The reviews by Strong *et al.* and by Hall *et al.* concluded that the moratoria could be lifted on the condition that a large number of scientific knowledge gaps be filled prior to any exploration or development activities.

Offshore exploration, development, and production of oil and gas resources pose the risk of chronic oiling and catastrophic oil spills, noise pollution (particularly due to seismic surveys during exploration), drilling mud and produced water effluent, and increased shipping. Haggarty *et al.* (2003) is one of the few summaries of the environmental effects of drilling mud and produced water contamination. Drilling mud is a liquid product which varies in composition with drill site but usually consists of a water, diesel, or mineral oil base and very fine bentonite microparticles to form a stable colloidal suspension that has a slightly greater density than water. Various other components are added to the mud to achieve or accentuate certain properties, including barite (for extra density), tannins and lignosulfonates (for thinning), caustic soda (pH control), biocides (corrosion control), and carboxymethyl cellulose or starch (for gelling and filter cake properties) (West Coast Offshore Exploration Environmental Assessment Panel 1986). For the most part, drilling mud additives are not highly toxic but the mud can smother benthic organisms (Cranford *et al.* 1999; Gordon Jr. *et al.* 2000).

Produced water represents the largest volume waste stream from offshore oil and gas production activities. Produced water is extracted from the well along with oil and gas. It consists of formation water, which occurs naturally in the geological formation, injection water, which enters during the drilling process, condensed water (gas production) or seawater (oil production), which are injected to maintain reservoir pressure, and technological water, which is treated with chemicals such as emulsion breakers, corrosion inhibitors, and biocides. The formation water component of production water is brine derived from the major ions found in seawater. However, depending on the nature of the formation, it may also contain a number of metal and organic constituents including

hydrolysis metals, heavy metals, and organic chemicals such as petroleum hydrocarbons, nutrients, radionuclides, and treating chemicals.

To date, the federal moratorium remains in place and the provincial moratorium has been lifted. While exploration has not found significant pools of oil or gas, there are indications of oil seeps and tar and gas deposits on both the Queen Charlotte Islands (Hamilton and Cameron 1989), and in waters offshore (Barrie 1988).

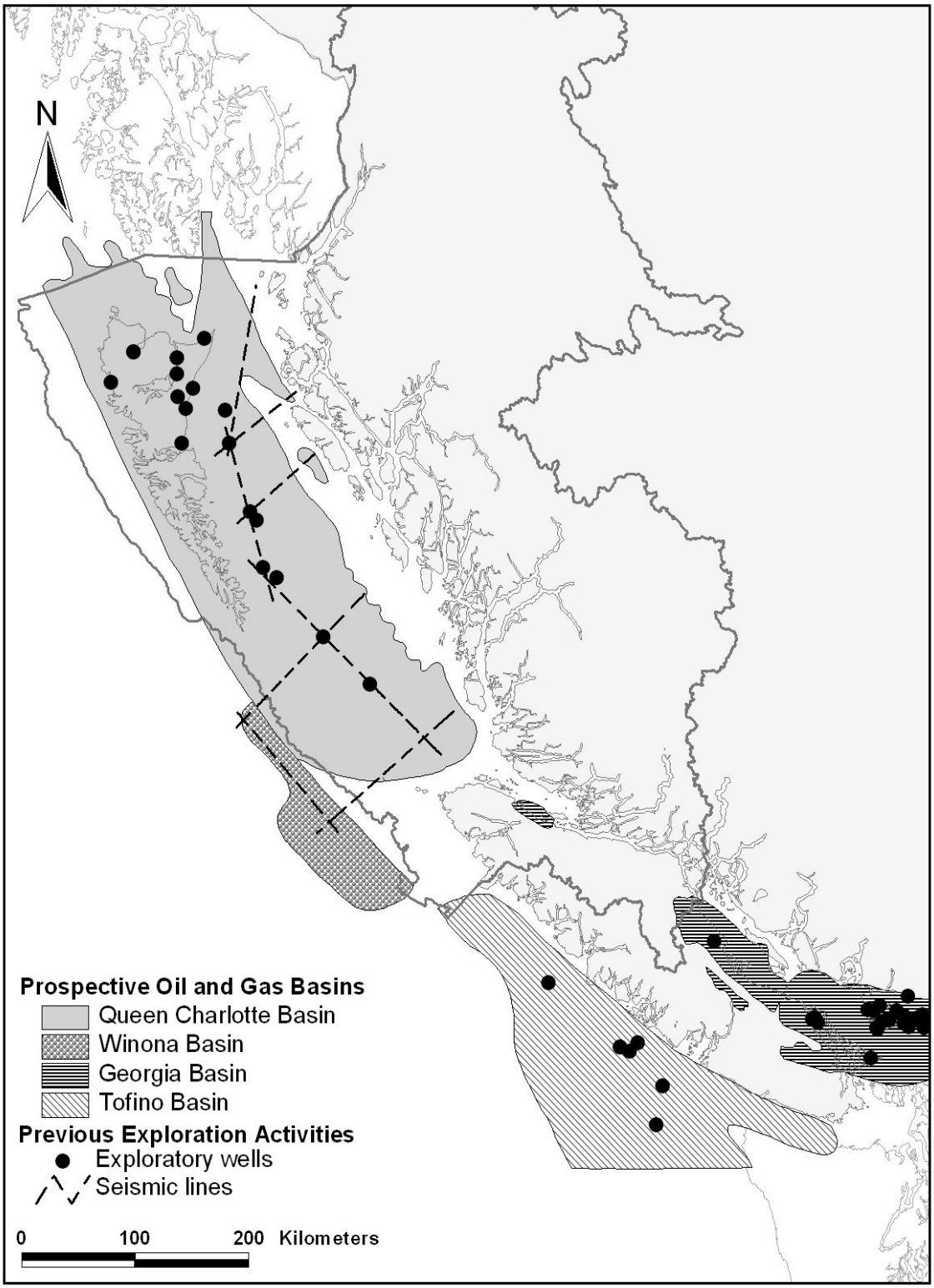

Figure 11.1 There are four main prospective basins on BC's west coast. Also shown are land-based and offshore oil exploration wells (map created using data from the BC Offshore Oil and Gas Team, Ministry of Energy and Mines).

12 Global Pollutants

Many pollutants are highly persistent, remaining in the environment for long periods and undergoing long range transport by atmospheric circulation, ocean currents or while incorporated into the fats and proteins of migratory animals. Consequently, remote wilderness far removed population centres may be at the receiving end of a complex mixture of industrial, agricultural and other chemicals, leading to water, sediment and food web contamination. Spawning salmon are one vehicle by which POPs from open ocean food webs are transported to the west coat of North America (Ewald *et al.* 1998; O'Neill *et al.* 1998). In addition, the continued use of POPs in parts of Asia can result in their deposition in North America via atmospheric delivery (Wilkening 2001).

Therefore, legacy POPs remain a potential contaminant issue in the PNCIMA, despite its remote nature and sparse human population. Exposure to these chemicals may lead to adverse health effects in local biota. A number of factors influence the movement of chemicals away from source and their accumulation in food webs, including their volatility, solubility in waters (or lipids), and their persistence (half-life) in the environment. Global pollutants of concern today typically comprise those chemicals considered as persistent, bioaccumulative and toxic (PBT chemicals). Such chemicals can readily move into remote regions, such as the PNCIMA, do not degrade quickly, accumulate in aquatic food webs, and cause endocrine disruption in biota.

Species that are vulnerable to the accumulation of high levels of PBT compounds and their associated effects include those at the top of aquatic food webs, such as fish-eating seabirds, seals, whales, and terrestrial species relying on marine foods. While marine mammals inhabiting more industrial waters are vulnerable to chemical contamination, researchers readily detect industrial chemicals such as PCBs in those inhabiting more remote areas. For example, while harbour seals sampled in the Strait of Georgia had 2.5 mg/kg PCBs, those sampled in Queen Charlotte Strait had approximately 1.4 mg/kg PCBs (Ross *et al.* 2004). While male southern resident killer whales averaged 146 mg/kg PCBs, male northern resident killer whales can still be considered heavily contaminated at 37 mg/kg PCBs (Ross *et al.* 2000). These killer whales rely almost exclusively on salmon (with a strong preference for Chinook salmon) and can be considered as ‘integrating’ contaminant signals from the North Pacific habitat of their prey. Grizzly bears in British Columbia have also been shown to accumulate PBT contaminants associated with their consumption of Pacific salmon (Christensen *et al.* 2005). Such work underscores the ‘global nature’ of PBT contaminants, and the vulnerability of the PNCIMA to externally-derived contaminants.

PBT contaminants have been associated with a number of adverse health effects in high trophic level wildlife, including immunotoxicity and endocrine disruption (Ross *et al.* 1996; Grasman *et al.* 1996). These in turn have led to population-level impacts such as increased disease-associated mortality, reproductive impairment, and behavioural abnormalities (Luebke *et al.* 1997; Helle *et al.* 1976; Hunt and Hunt 1977). In the NE Pacific Ocean, harbour seals inhabiting the heavily contaminated Puget Sound have been shown to be suffering from adverse health effects (Mos *et al.* 2007; Mos *et al.* 2006; Tabuchi *et al.* 2006). Northern resident killer whales are ‘threatened’ under the terms of SARA, with PCBs and other POPs representing a significant conservation concern (Ross

2006). The extent to which PBT contaminants are affecting the health of biota in the PNCIMA is not known.

Certain human consumer groups are also vulnerable, including subsistence-oriented peoples such as the Inuit and coastal First Nations (Kuhnlein and Chan 2000; Mos *et al.* 2004). Preventing the entry of PBT contaminant into the global environment represents a key aim of the Stockholm Convention on Persistent Organic Pollutants. These include polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (dioxins), polychlorinated dibenzofurans (furans), hexachlorobenzene (HCB), pentachlorophenol (PCP), and organochlorine pesticides such as DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, mirex, lindane, and toxaphene (Johannessen and Ross 2002). Concentrations of some 'legacy' POPs have decreased in BC (Hagen *et al.* 1997a; Ministry of Environment 2000), but many of these compounds continue to accumulate at high latitudes and high altitude sites, including in snow and lakes on BC mountains (Macdonald *et al.* 2002; Blais *et al.* 1998; Campbell *et al.* 2000).

While chemicals with PBT properties are generally disfavoured under the current regulatory paradigm in industrialized nations, MEQ in PNCIMA faces the following threats:

- 'legacy' PBT contaminants that will continue to elicit health effects in vulnerable species such as killer whales;
- PBT contaminants that are considered 'legacy' in the Canada and the USA, but are still used in Asia and are subject to LRTAP into the PNCIMA;
- PBT contaminants that are not yet regulated in Canada and/or the USA, such as polybrominated diphenylethers (PBDEs);
- Non-PBT contaminants, such as currently used pesticides, that may adversely affect salmon in natal streams or other biota in coastal and estuarine areas;
- Mercury (Hg), a natural element that bioaccumulates in aquatic food webs and is being anthropogenically enhanced in the biosphere as a result of emissions from coal-fired generating stations and other industrial activities.

Of the new PBT contaminants, the following list highlights emerging threats to MEQ in PNCIMA and elsewhere:

- Brominated flame retardants are a large group of chemicals used largely in the manufacture of various foams and plastics to reduce their flammability. By far the most commonly used compounds in this group are the PBDEs. Environment concentrations of these compounds are increasing at an exponential rate, even in remote areas such as the Arctic and the remote BC coast (Ikonomou *et al.* 2002; Betts 2002b; Betts 2002a; Johannessen and Ross 2002). Many of these new compounds are highly bioaccumulative and are endocrine disruptors, thereby representing a significant emerging threat to PNCIMA's killer whales (Ross 2006). Regulators in Canada, the USA and Europe are considering bans on PBDE products that remain on the market (Johannessen and Ross 2002).

- Alkylphenol ethoxylates are a group of chemical surfactants used in a number of applications including detergents, pesticides, personal care products (shampoos), and pulp mill additives (Warhurst 1995; Government of Canada *et al.* 1999; Johannessen and Ross 2002). Although only a few of these chemicals have been studied, a number are known to be endocrine disruptors and some degrade into more toxic compounds when exposed to secondary sewage treatment (Harris *et al.* 2001; Jobling and Sumpter 1993; Johannessen and Ross 2002).
- Fluorinated organic compounds (FOCs) are another large group of surfactants used to manufacture a wide variety of materials. Perfluorooctane sulphonate (PFOS) has been widely detected in the global environment, as well as in biota (Johannessen and Ross 2002). Levels of PFOS in Arctic ring seal blood have declined since a phase-out of this compound by the manufacturer 3M (CBC.ca News 2006a). However, concern over this group of chemicals continues to grow: federal regulators recently moved to block the import of products which contain chemicals that can break down to form perfluorinated carboxylic acids (PFCAs) (CBC.ca News 2006b).
- Phthalate esters are used as softeners in plastics as well as in personal care products, pesticides, lubricants, and wood finishes (Johannessen and Ross 2002). These compounds can be lethally toxic and are also of concern as confirmed or suspected endocrine disruptors at very low concentrations (Jobling *et al.* 1995; Myers 2002).
- Currently-used pesticides are available for agricultural, forestry and urban applications. In some cases, either the active ingredient or the adjuvant possesses properties that are toxic to salmonids (Tierney *et al.* 2006a; Tierney *et al.* 2006b; Scholz *et al.* 2000), leading to population-level declines (Fairchild *et al.* 1999).

The remoteness of much of the PNCIMA does not ensure protection from highly persistent and mobile contaminants. The prevailing winds ensure that contaminants released from Asia will reach the PNCIMA coastline within 5-8 days. A build-up in snowpack, glaciers, coastal sediments and salmon-bearing streams may render ecosystem health vulnerable in the future. Such concerns highlight the importance of national legislation and international treaties to prevent the wanton release of contaminants that end up in remote aquatic food webs.

13 Conclusions

This report was designed to assess the risk to marine environmental quality from contaminants in the Pacific North Coast Integrated Management Area, based on existing scientific literature. Limitations of this approach include:

- Information on past contamination issues is often lacking or is outdated as scientific research in the area has been limited in recent years.
- Current or expected changes in human activities in the area, such as increases in cruise ship activity and aquaculture, have not yet been assessed in the literature.

- Modern analytical techniques have revealed a number of contaminant concerns in other parts of the world, but these techniques have rarely been applied to this portion of the BC coast.
- There is insufficient scientific research to enable adequate MEQ assessments and therefore the delivery of Ecosystem-Based management.

Despite these limitations, this report attempts to qualitatively assess contaminant risks in the area while highlighting the areas and topics where more information is most needed. Based on the information that is available, we have identified a number of specific issues or activities present a risk of significantly affecting marine environmental quality in PNCIMA:

- Current and planned upgrades to the Prince Rupert and Kitimat ports involve short term issues with port construction and long term issues with increased industrial port activity and vessel traffic.
- Increasing cruise ship size has resulted in ever increasing numbers of people travelling up and down the BC coast. 2004 saw an estimated 1.5 million passengers travelling the inside passage. The various waste products and effluents from this mobile population are likely to affect the ecosystem, particularly those substances not removed by current wastewater treatment methods.
- ALCAN currently operates an Aluminum smelter in Kitimat. The immediate environment around this smelter has been shown to be significantly contaminated by polycyclic aromatic hydrocarbons (PAHs). The smelter has been implicated as the main source of this pollution. However, while elevated PAH levels have been found in biota and those biota exhibit signs of impaired health, a direct link between the health effects and the PAHs has not been clearly demonstrated.
- Mining was a significant activity in the area in the early part of the 20th Century, but much of this activity had ceased by the late-middle of the century. Twelve mine sites (active and former) are considered to be at risk of producing acid rock drainage, but this assessment is based largely on reports of bedrock and ore characteristics, rather than sampling of the environment.
- Elevated levels of heavy metals have been detected in the region of Observatory Inlet. This contamination has been linked to the ongoing erosion of a slag heap from the former Anyox copper smelter, which was deposited on the adjacent shore and intertidal zone. Leaching from the mine's tailings pile, located a short distance away, may also be contributing to the detected heavy metal concentrations. To date, biological effects of this contamination have not been shown.
- Increased concentrations of some persistent organic pollutants (POPs) have been observed in marine organisms around the world, both in industrialized and remote environments. These POPs have been associated with population-level impacts in certain areas, although the impacts in remote populations are less clear. Many "legacy"c POPs have been banned or regulated in industrialized nations, but their longevity in the environment means they are often still an issue,

especially higher in the food chain. In addition, nations that have not banned their use continue to be a global source for these contaminants.

- Finfish aquaculture is currently very active in the southernmost portion of the PNCIMA. Activity is limited in the north coast but both finfish and shellfish aquaculture are expected to expand significantly in upcoming years. Multiple operations in restricted waters are the most likely conditions to produce significant risk of environmental contamination. These conditions are likely to occur in the restricted waters of protected inlets and fjords as aquaculture activity expands.
- Offshore oil and gas exploration and development is not currently permitted in the area but existing federal and provincial moratoria are under review and could be lifted in the future. Rising prices for oil and gas increase the pressure to lift these restrictions. Should this activity commence, the risk of contamination, particularly from chronic and acute oil spills, would increase greatly.

Currently available information suggests that the following issues and activities present a relatively low risk of affecting marine environmental quality in the PNCIMA for the reasons given:

- Agriculture is not a prevalent activity in the area.
- Forestry is significant but there are limited contaminant issues related to this activity. The industry's pesticide use is fairly low. Forest fire fighting has the potential to contaminate streams, but large scale effects from this have not been noted in the area to date and the use of chemicals in fire fighting is regulated. The build-up of woody debris both on land and on the bottom of inlets is a known contaminant issue. However, there is little indication that this is currently a problem and, assuming modern 'best practices' are used, it is unlikely to become a larger problem in the future.
- Ocean dumping is an activity which requires a permit and dumping activity has been low in recent years. While port expansions in the area may cause a brief rise in this activity, regulations reduce the risk of improper disposal of contaminated material.
- Mine tailings have been disposed of into deep, anoxic coastal basins at Alice Arm, Tasu Sound, and Rupert Inlet. All three sites underwent environmental monitoring during and after tailings disposal. This work suggests that there has been little environmental effect beyond the initial smothering of benthic organisms in the immediate area.
- Tourism is unlikely to be a significant source of contaminants, with the notable exceptions of associated increases in vessel traffic, the effluents associated with the growing cruise ship industry, and the huge numbers of people it brings through the area.
- The relatively low population of the area as a whole suggests that urban runoff and related contaminant issues are likely to be localized and much less of an issue than in the highly populated coastal areas to the south.

This assessment could be improved and expanded if further and/or more recent information were available, particularly in the following areas:

- The effect of various levels of contamination on biota and ecosystem function is often poorly understood. The PNCIMA contains three examples of known environmental contamination (elevated concentrations of heavy metals from mining, PAHs from smelting and POPs from global sources).
- A study of past and present mining activities in the area would make it possible to develop a list of sites requiring remediation or monitoring.
- Given the expected increase in vessel traffic and the potential for oil and gas development, further work on marine oil detection, movement, fate, effects, and mitigation strategies in this area would be highly relevant.
- A number of emerging pollutants have only recently been recognized. More information on the environmental effects of various 'new' pollutants such as pharmaceuticals, personal care products, hormones (artificial and natural), and persistent organic pollutants is required.
- Levels of cadmium and mercury are known to be high in some organisms along the BC coast. The sources of these contaminants and their effects on biota are not clear, but fish consumption advisories, closures, and important bans by trading partners highlight the importance of human health and socio-economic considerations.
- Four pulp and paper mills operate in the area. Operational changes in the 1990s greatly reduced dioxin and furan emissions. However, the process of paper production results in the by-formation of numerous chemicals, such as plant hormones. Investigations into the effects of these chemicals are ongoing.

This report provides a summary of current scientific information on contaminant issues in the PNCIMA. These conclusions are intended to provide some qualitative guidance on the relative importance of these risks, and outline gaps in knowledge which prevent the accurate assessment of contaminant risks in the area.

References

Ardron, J. A., Lash, J, and Haggarty, D. 2002. Modelling a network of marine protected areas for the Central Coast. Living Oceans Society. http://www.livingoceans.org/documents/LOS_MPA_model_v31_web.pdf.

Barrie, J. V. Surficial Geology of Hecate Strait, British Columbia Continental Shelf. 1988. Open File 1682, Geological Survey of Canada.

BC Ministry of Environment, Fisheries and Oceans Canada, University of Victoria, University of British Columbia, and Environment Canada. 2006. Alive and Inseparable: British Columbia's Coastal Environment. British Columbia Ministry of Environment. http://www.env.gov.bc.ca/soe/bcce/.

Beak Consultants. 1970. Eurocan Pulp and Paper Co. Ltd., Environmental Survey - 1969-1970. Appendix 5: Air Quality Survey. Project K4007.

Beak Consultants. 1974. Biological survey of the Kitimat River, September, 1973. Project J5057.

Bell, L. M. and Kallman, R. J. 1976. The Kitimat River Estuary - Status of Environmental Knowledge to 1976. Special Estuary Series. No. 6. Environment Canada. Vancouver, BC.

Betts, K. S. 2002a. Flame-proofing the Arctic. Environ.Sci.Tech.News (September 1) **36**: 188A-192A.

Betts, K. S. 2002b. Rapidly rising PBDE levels in North America. Environ.Sci.Tech.News (September 1) **36**: 50A-52A.

Birtwell, I. K. and McAllister, C. D. 2002. Hydrocarbons and their Effects on Aquatic Organisms in Relation to Offshore Oil and Gas Exploration and Oil Well Blowout Scenarios in British Columbia, 1985. Canadian Technical Report of Fisheries and Aquatic Sciences. 2391. Fisheries and Oceans Canada.

Blais, J. M., Schindler, D. W., Muir, D. C. G., Kimpe, L. E., Donald, D. B., and Rosenberg, B. 1998. Accumulation of persistent organochlorine compounds in mountains of Western Canada. Nature **395**: 585-588.

Booth, J., Coastal and Ocean Resources Inc., Clover Point Cartographics. 1998. Study to identify preliminary representative marine areas in the Queen Charlotte Sound Marine Region. Report prepared for National Parks, Parks Canada.

Brewer, R. C., Brodie, J. B., Kornder, L. D., Papenbrock, W., and Wallace, W. G. 1979. Environmental effects of emissions from the Alcan smelter at Kitimat, B.C.: Report of the Alcan surveillance committee. British Columbia Ministry of Environment. Victoria, BC.

Burdick, G. E. and Lipschuetz, M. 1950. Toxicity of ferro- and ferricyanide solutions to fish: determination of the cause of mortality. Trans.Am.Fish.Soc. **78**: 192.

Campbell, L. M., Schindler, D. W., Muir, D. C. G., Donald, D. B., and Kidd, K. A. 2000. Organochlorine transfer in the food web of subalpine Bow Lake, Banff National Park. Can.J.Fish.Aquat.Sci. **57**: 1258-1269.

Canada Oil and Gas Lands Administration and BC Ministry of Energy, Mines and Petroleum Resources. 1984. Technical Evaluation of the IEEs for Offshore Petroleum Exploration North of Vancouver Island.

CBC.ca News. 2006a. Contaminant Levels Drop in Seals After Scotchguard Change. CBC.ca News. http://www.cbc.ca/story/science/national/2006/05/24/pfos.html.

CBC.ca News. 2006b. Ottawa to Limit Non-stick, Stain-repellent Chemicals. CBC.ca News. http://www.cbc.ca/story/science/national/2006/06/20/pfca.html.

Chamberlain, J., Stucchi, D., Lu, L., and Levings, C. D. 2005. The suitability of DEPOMOD for use in the management of finfish aquaculture sites, with particular reference to Pacific Region. Canadian Science Advisory Secretariat Research Document. 035. Fisheries and Oceans Canada.

Chevron Canada Resources Ltd. 1982. Initial Environmental Evaluation for Renewed Petroleum Exploration in Hecate Strait and Queen Charlotte Sound. 1 (Sections 1-3).

Christensen, J. R., MacDuffee, M., Macdonald, R. W., Whiticar, M., and Ross, P. S. 2005. Persistent organic pollutants in British Columbia grizzly bears: Consequence of divergent diets. Environ.Sci.Technol. **39**: 6952-6960.

Clarke, C. L. and Jamieson, G. S. 2006. Identification of Ecologically and Biologically Significant Areas for the Pacific North Coast Integrated Management Area: Phase II. Fisheries and Oceans Canada.

Colodey, A. G., Harding, L. E., Wells, P. G., and Parker, W. R. 1990. Effects of pulp and paper mill effluents and their constituents on estuarine and marine environments in Canada: A brief review. Regional Program Report. 90-08. Environment Canada, Environmental Protection.

Cranford, P. J., Gordon Jr., D. C., Lee, K., Armsworthy, S. L., and Tremblay, G-H. 1999. Chronic toxicity and physical disturbance effects of water- and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). Mar.Environ.Res. **48**: 225-256.

Crawford, W., Cretney, W., Cherniawsky, J., and Hannah, C. 2002. Modelling oceanic fates of oil, drilling muds and produced water from the offshore oil and gas industry, with application to the Queen Charlotte Basin. Canadian Science Advisory Secretariat. 2002/120. Fisheries and Oceans Canada.

Crawford, W. R. 2002. Physical Characteristics of Haida Eddies. J. Oceanography **58**: 703-713.

Cretney, W., Burd, B., Wright, C., Crawford, W., Cherniawsky, J, Bravender, B, Fargo, J, Lauzier, R, Nichol, L, Vagle, S, Yunker, M., Hamilton, T., Rodden, D, and Rogers, G. 2002a. Knowledge gaps and risks of concern for BC marine environments from offshore oil & gas exploration, development, production, transportation and decommissioning. Pacific Scientific Advice Review Committee - Working Paper. H2002-01.

Cretney, W., Crawford, W. R., Masson, D., and Hamilton, T. 2002b. Physical Oceanographic and Geological Setting of a Possible Offshore Oil and Gas Industry in the Queen Charlotte Basin. Canadian Science Advisory Secretariat Research Document. 2002/004. Fisheries and Oceans Canada. http://www.pac.dfo-mpo.gc.ca/sci/psarc/.

Cretney, W., Sinclair, A., Wright, C., and Burd, B. 2002c. Role of Modelling in Ecological Risk Assessment and Ecological Risk Management with Emphasis on the Offshore Oil and Gas Industry. Canadian Science Advisory Secretariat Research Document. 2002/125. Fisheries and Oceans Canada. http://www.dfo-mpo.gc.ca/csas/Csas/English/Research_Years/2002/2002_125_E.htm.

Cretney, W., Yunker, M., and Yeats, P. 2002d. Biogeochemical Benchmarks for Source Identification of Contaminants from an Offshore Oil and Gas Industry. Canadian Science Advisory Secretariat Research Document. 2002/129. Fisheries and Oceans Canada.

Department of Fisheries and Oceans. 2000. Hexactinellid sponge reefs on the British Columbia continental shelf: geological and biological structure. DFO Pacific Region Habitat Status Report. 2000/02. Fisheries and Oceans Canada.

Eickhoff, C. V., Gobas, F. A. P. C., and Law, F. C. P. 2003a. Screening pyrene metabolites in the hemolymph of Dungeness crabs (*Cancer magister*) with synchronous fluorescence spectometry: method development and application. Environ.Toxicol.Chem. **22**: 59-66.

Eickhoff, C. V., He, S. X., Gobas, F. A. P. C., and Law, F. C. P. 2003b. Determination of polycyclic aromatic hydrocarbons in Dungeness Crabs (*Cancer magister*) near an aluminum smelter in Kitimat Arm, British Columbia, Canada. Environ.Toxicol.Chem. **22**: 50-58.

ENKON Environmental Limited. 2001. Survey of pesticide use in British Columbia: 1999. 1004-005. Environment Canada; Ministry of Environment, Lands and Parks. Surrey, British Columbia.

Environment Canada. 2003. Ocean Disposal. Environment Canada. http://www.ns.ec.gc.ca/epb/wastemgmt/dispos.html. 2006.

Environment Canada and Pacific and Yukon Region. 2003. Ocean disposal sites in the Pacific and Yukon region. http://www.pyr.ec.gc.ca/EN/ocean-disposal/english/sitemap_e.htm. 2006.

Erickson, P., Fowler, B., Brown, D., Heath, B., and Thompson, K. 1979. Hydrocarbon levels in the marine environment of Kitimat Arm and its seaward approaches. Seakem Oceanography Ltd. Sidney, BC.

Ewald, G., Larsson, P., Linge, H., Okla, L., and Szarzi, N. 1998. Biotransport of organic pollutants to an inland Alaska lake by migrating sockeye salmon (*Oncohrynchus nerka*). Arctic **51**: 40-47.

Fairchild, W. L., Swansburg, E. O., Arsenault, J. T., and Brown, S. B. 1999. Does an association between pesticide use and subsequent declines in catch of Atlantic salmon (*Salmo salar*) represent a case of endocrine disruption? Environ.Health Perspect. **107**: 349-358.

Fisheries and Oceans Canada. 2005. Marine Use Analysis of the Pacific North Coast Integrated Management Area (PNCIMA) - In Preparation.

Fox, G. A. 2001. Effects of endocrine disrupting chemicals on wildlife in Canada: past, present and future. Water Qual.Res.J.Can. **36**: 233-251.

Gaikowski, M. P., Hamilton, S. J., and Buhl, K. J. 1996. Acute toxicity of three fire-retardant and two fire-suppressant foam formulations to the early life stages of rainbow trout (*Oncorhynchus mykiss*). Environ.Toxicol.Chem. **15**: 1365-1374.

Gordon Jr., D. C., Cranford, P. J., Hannah, C. G., Loder, J. W., Milligan, T. G., Muschenheim, D. K., and Shen, Y. 2000. Modelling the transport and effects on scallops of water-based drilling mud from potential hydrocarbon exploration on Georges Bank. Canadian Technical Report of Fisheries and Aquatic Sciences. 2317. Fisheries and Oceans Canada.

Government of Canada, Environment Canada, and Health Canada. 1999. Canadian Environmental Protection Act 1999: priority substances list assessment report: nonylphenol and its ethoxylates. Catalogue No. En 40-215/3E.

Grasman, K. A., Fox, G. A., Scanlon, P. F., and Ludwig, J. P. 1996. Organochlorine-associated immunosuppression in prefledgling Caspian Terns and Herring gulls from the Great Lakes: An ecoepidemiological study. Environ.Health Perspect.Suppl. **104**: 829-842.

Hagen, M. E., Colodey, A. G., Knapp, W. D., and Samis, S. C. 1997a. Environmental response to decreased dioxin and furan loadings from British Columbia coastal pulp mills. Chemosphere **34**: 1221-1229.

Hagen, M. E., Golodey, A. G., Knapp, W. D., and Samis, S. C. 1997b. Environmental response to decreased dioxin and furan loadings from British Columbia coastal pulp mills. Chemosphere **34**: 1221-1229.

Haggarty, D. R., McCorquodale, B., Johannessen, D. I., Levings, C. D., and Ross, P. S. 2003. Marine environmental quality in the central coast of British Columbia: A review of contaminant sources, types and risks. Canadian Technical Report of Fisheries and Aquatic Sciences. 2507. Fisheries and Oceans Canada.

Hall, J, Addison, R. F, Dower, J, and Jordaan, I. 2004. Report of the Expert Panel on Science Issues Related to Oil and Gas Activities, Offshore British Columbia. Expert Panel Report. RSC.EPR 04-1. The Royal Society of Canada. Ottawa, Ontario, Canada. http://www.rsc.ca.

Hamilton, T. and Cameron, B. E. B. 1989. Hydrocarbon Occurrences on the Western Margin of the Queen Charlotte Basin. B. Can. Petrol. Geol. **34**: 443-460.

Hannigan, P. K, Dietrich, J. R, Lee, P. J, and Osadetz, K. G. 2001. Petroleum Resource Potential of Sedimentary Basins on the Pacific Margin of Canada. Geological Survey of Canada Bulletin 564.

Harding, L. E. and Pomeroy, W. M. 1990. Dioxin and furan levels in sediments, fish, and invertebrates from fishery closure areas of coastal British Columbia. Regional Data Report. 90-09. Environment Canada, Environmental Protection. North Vancouver, BC.

Harris, C. A., Santos, E. M., Janbakhsh, A., Pottinger, T. G., Tyler, C. R., and Sumpter, J. P. 2001. Nonylphenol affects gonadotropin levels in the pituitary gland and plasma of female rainbow trout. Environ.Sci.Technol. **35**: 2909-2916.

Helle, E., Olsson, M., and Jensen, S. 1976. DDT and PCB levels and reproduction in ringed seal from the Bothnian Bay. Ambio **5**: 188-189.

Hewitt, M. and Servos, M. 2001. An overview of substances present in Canadian aquatic environments associated with endocrine disruption. Water Qual.Res.J.Can. **36**: 191-213.

Hocking, M. B., Hocking, D., and Smyth, T. A. 1980. Fluoride distribution and dispersion processes about an industrial point source in a forested coastal zone. Water Air Soil Pollut. **14**: 133-157.

Hodson, P. V., McWhirter, M., Ralph, K., Gray, B., Thivierge, D., Carey, J. H., Van der Kraak, G., Whittle, D. M., and Levesque, M-C. 1992. Effects of bleached kraft mill effluent on fish in the St. Maurice River, Quebec. Environ.Toxicol.Chem. **11**: 1635-1651.

Hunt, G. and Hunt, M. 1977. Female-female pairing in western gulls (*Larus occidentalis*) in Southern California. Science **196**: 1466-1467.

Hutton, K. E. and Samis, S. C. 2000. Guidelines to protect fish and fish habitat from treated wood used in aquatic environments in the Pacific Region. Canadian Technical Report of Fisheries and Aquatic Sciences. 2314. Fisheries and Oceans Canada.

Ikonomou, M. G., Rayne, S., Fischer, M., Fernandez, M. P., and Cretney, W. 2002. Occurrence and congener profiles of polybrominated diphenyl ethers (PBDEs) in environmental samples from coastal British Columbia, Canada. Chemosphere **46**: 649-663.

International Council of Cruise Lines. 2001. Cruise industry waste management practices and procedures. International Council of Cruise Lines.

Jacques Whitford Environment Limited. 2001. British Columbia Offshore Oil and Gas Technology Update. JWEL Project No. BCV50229. BC Ministry of Energy and Mines. Victoria, B.C.

Jamieson, G. and Davies, J. 2003. State of Knowledge of Marine Ecosystems of the Northern BC Coast in Oil and Gas Lease Areas. Canadian Science Advisory Secretariat Research Document. 2004/009. http://sci.info.pac.dfo.ca/PSARC/resdocs/03-habitat-wp.htm.

Jobling, S., Reynolds, T., White, R., Parker, M. G., and Sumpter, J. P. 1995. A variety of environmentally persistent chemicals, including some phthalate plasticizers, are weakly estrogenic. Environ.Health Perspect. **103**: 582-587.

Jobling, S. and Sumpter, J. P. 1993. Detergent components in sewage effluent are weakly oestrogenic to fish: An in vitro study using rainbow trout (*Oncorhynchus mykiss*) hepatocytes. Aquat.Toxicol. **27**: 361-372.

Johannessen, D. I., Harris, K. A., MacDonald, S., and Ross, P. S. 2007. Marine Environmental Quality in the North Coast and Queen Charlotte Islands, British Columbia, Canada: A Review of Contaminant Sources, Types and Risk. Canadian Technical Report of Fisheries and Aquatic Sciences. 2717. Fisheries and Oceans Canada.

Johannessen, D. I. and Ross, P. S. 2002. Late-run sockeye at risk: An overview of environmental contaminants in Fraser River salmon habitat. Canadian Technical Report of Fisheries and Aquatic Sciences. 2429. Fisheries and Oceans Canada.

Joyce, M., Barrett-Lennard, L., Bain, D., Balcomb, K, Borrowman, J., Durban, J., Ellis, G., Ford, J., Garrett, C., Hall, A., Jeffries, S., Jones, L., Norberg, B., Olesiuk, P., Osborne, R., Paynter, R., Reader, B., Ross, P., Spong, P., Trites, A., Wallace, S., Wiles, G., Williams, R., and Riddell, B. 2005. DRAFT: National Recovery Strategy for Northern and Southern Resident Killer Whales (*Orcinus orca*). Fisheries and Oceans Canada.

Kay, B. H. 1989. Pollutants in British Columbia's marine environment: A status report. A state of the environment report. SOE report; 89-1. Canada. Environmental Protection. Pacific and Yukon Region. West Vancouver, BC.

Kiparissis, Y., Hughes, R., and Metcalfe, C. 2001. Identification of the isoflavinoid genistein in bleached kraft mill effluent. Environ.Sci.Tech. **35**: 2423-2427.

Kuhnlein, H. V. and Chan, H. M. 2000. Environment and contaminants in traditional food systems of northern indigenous peoples. Annu.Rev.Nutr. **20**: 595-626.

Little, E. E. and Calfee, R. D. 2000. The effects of UVB radiation on the toxicity of fire-fighting chemicals. Report prepared for USDA Fire Service. Missoula, MT. 1-71.

Luebke, R. W., Hodson, P. V., Faisal, M., Ross, P. S., Grasman, K. A., and Zelikoff, J. T. 1997. Aquatic pollution-induced immunotoxicity in wildlife species. Fundam.Appl.Toxicol. **37**: 1-15.

Macdonald, R. W., Mackay, D., and Hickie, B. 2002. Contaminant amplification in the environment. Environ.Sci.Technol. **36**: 457-462.

McGreer, E. R. and Belzer, W. 1999. Contaminant Sources. *In* Gray, C. and Tuominen, T. (*eds.*). Health of the Fraser River Aquatic Ecosystem, Volume 1. Environment Canada, Vancouver. DOE FRAP 1998-11. 7-22.

Ministry of Environment, Lands and Parks. 2000. Environmental trends in British Columbia 2000. Victoria, British Columbia.

Ministry of Water Land and Air Protection. 2002. Environmental Trends in British Columbia 2002. Environmental Trends in British Columbia. Ministry of Water, Land and Air Protection. Victoria, BC. http://wlapwww.gov.bc.ca/soerpt.

Ministry of Water, Land and Air Protection. 2003. Metal leaching and acid rock drainage. http://wlapwww.gov.bc.ca/soerpt/9mitigation/minesites.html.

Mos, L., Jack, J., Cullon, D., Montour, L., Alleyne, C., and Ross, P. S. 2004. The importance of marine foods to a near-urban First Nation community in coastal British Columbia, Canada: Towards a risk-benefit assessment. J.Toxicol.Environ.Health, Part A **67**: 1-18.

Mos, L., Morsey, B., Jeffries, S. J., Yunker, M. B., Raverty, S., De Guise, S., and Ross, P. S. 2006. Chemical and biological pollution contribute to the immunological profiles of free-ranging harbor seals. Environ.Toxicol.Chem. **25**: 3110-3117.

Mos, L., Tabuchi, M., Dangerfield, N., Jeffries, S. J., Koop, B. F., and Ross, P. S. 2007. Contaminant-associated disruption of vitamin A and its receptor (RARα) in free-ranging harbour seals (*Phoca vitulina*). Aquat.Toxicol. **81**: 319-328.

Myers, J. P. 2002. Our Stolen Future: About Phthalates. http://www.ourstolenfuture.org. 2006.

Norris, L. A., Lorz, H. W., and Gregory, S. V. 1983. Influence of forest and rangeland management on anadromous fish habitat in western North Amercia. General Technical Report PNW-149. Pacific Northwest Forest; USDA Forest Service.

Nowell, L. and Kwan, I. 2001. Cruise control - Regulating cruise ship pollution on the Pacific coast of Canada. West Coast Environmental Law. http://www.wcel.org/wcelpub/2001/13536.pdf.

O'Kane, M., Mchaina, D. M., Stoicescu, J., Januszewski, S., Haug, M. D., and Bews, B. E. 1997. Managing for closure at the Myra Falls operation - The design of a soil cover system for long term ecological and physical stability. http://www.okane-consultants.com/.

O'Neill, S. M., West, J. E., and Hoeman, J. C. 1998. Spatial trends in the concentrations of polychlorinated biphenyls (PCBs) in chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) in Puget Sound and factors affecting PCB accumulation: Results from the Puget Sound Ambient Monitoring Program. The Puget Sound Water Quality Authority. 312-328. Seattle, Washington.

Office of the Auditor General of Canada. 2003. National Defence — Environmental Stewardship of Military Training and Test Areas. http://www.oag-bvg.gc.ca/domino/reports.nsf/html/20030407ce.html. Chapter 7.

Packman, G. A. 1977. Environmental surveillance in the vicinity of the Canadian Cellulose Co. Ltd. pulp mill at Prince Rupert, British Columbia. EPS 5-PR-77-8. Aquatic Programs and Contaminants Control Branch, Marine Studies Group, Environmental Protection Service, Pacific Region.

Packman, G. A. and Bradshaw, V. 1977. Environmental surveillance of Kitimat Arm, British Columbia. EPS 5-PR-77-7. Aquatic Programs and Contaminants Control Branch, Marine Studies Group, Environmental Protection Service, Pacific Region.

Paine, M. D., Chapman, P. M., Allard, P. J., Murdoch, M. H., and Minifie, D. 1996. Limited bioavailability of sediment PAH near an aluminum smelter: contamination does not equal effects. Environ.Toxicol.Chem. **15**: 2003-2018.

Petro-Canada. 1983. Offshore Queen Charlotte Islands Initial Environmental Evaluation. (1).

Pierce, R. C., Whittle, D. M., and Bramwell, J. B. 1998. Chemical contaminants in Canadian aquatic ecosystems. Fisheries and Oceans Canada.

Planning and Assessment Branch (BC Ministry of Environment). 1983. A Preliminary Environmental Assessment of Offshore Hydrocarbon Exploration and Development. *In* Langford, R. W (*eds.*). BC Ministry of Environment. Victoria, BC. 1-334.

Ross, P. S. 2006. Fireproof killer whales: Flame retardant chemicals and the conservation imperative in the charismatic icon of British Columbia. Can.J.Fish.Aquat.Sci. **63**: 224-234.

Ross, P. S., De Swart, R. L., Van Loveren, H., Osterhaus, A. D. M. E., and Vos, J. G. 1996. The immunotoxicity of environmental contaminants to marine wildlife: A review. Ann.Rev.Fish Dis. **6**: 151-165.

Ross, P. S., Ellis, G. M., Ikonomou, M. G., Barrett-Lennard, L. G., and Addison, R. F. 2000. High PCB concentrations in free-ranging Pacific killer whales, *Orcinus orca*: effects of age, sex and dietary preference. Mar.Pollut.Bull. **40**: 504-515.

Ross, P. S., Jeffries, S. J., Yunker, M. B., Addison, R. F., Ikonomou, M. G., and Calambokidis, J. 2004. Harbour seals (*Phoca vitulina*) in British Columbia, Canada, and Washington, USA, reveal a combination of local and global polychlorinated biphenyl, dioxin, and furan signals. Environ.Toxicol.Chem. **23**: 157-165.

Rumsey, C., Ardron, J., Ciruna, K., Curtis, T., Doyle, R., Ferdana, Z., Hamilton, T., Heinemeyer, K., Iachetti, P., Jeo, R., Kaiser, G., Narver, D., Noss, R., Sizemore, D., Tautz, A., Tingey, R., and Vance-Borland, K. 2003. Draft: An Ecosystem Spatial Analysis for Haida Gwaii, Central Coast and North Coast British Columbia. Coast Information Team. 1-184.

Scholz, N. L., Truelove, N. K., French, B. L., Berejikian, B. A., Quinn, T. P., Casillas, E., and Collier, T. K. 2000. Diazinon disrupts antipredator and homing behaviors in chinook salmon (*Oncorhyncus tshawytscha*). Can.J.Fish.Aquat.Sci. **57**: 1911-1918.

Science Advisory Panel. 2002. The impact of cruise ship wastewater discharge on Alaska waters. Alaska Department of Environmental Conservation. http://www.state.ak.us/.

Servos, M. R., Munkittrick, K. R., Carey, J. H., and Van der Kraak, G. J. 1996. Environmental fate and effects of pulp and paper mill effluents. St. Lucie Press, Delray Beach, Florida.

Simon Fraser University. 2000. Exploring the Future of Offshore Oil and Gas Development in BC: Lessons from the Atlantic. Exploring the Future of Offshore Oil and Gas Development in BC: Lessons from the Atlantic. Simon Fraser University, Burnaby, BC. 2000.

Simpson, C. D., Harrington, C. F., Cullen, W. R., Bright, D. A., and Reimer, K. J. 1998. Polycyclic aromatic hydrocarbon contamination in marine sediments near Kitimat, British Columbia. Environ.Sci.Technol. **32**: 3266-3272.

Simpson, C. D., Mosi, A. A., Cullen, W. R., and Reimer, K. J. 1996. Composition and distribution of polycyclic aromatic hydrocarbon contamination in surficial marine sediments from Kitimat Harbour, Canada. Sci.Total Environ. **181**: 265-278.

Stewart, C. and Thompson, J. A. J. 1994. Extensive butyltin contamination in southwestern coastal British Columbia, Canada. Mar.Pollut.Bull. **28**: 601-606.

Stewart, C. and Thompson, J. A. J. 1997. Vertical distribution of butyltin residues in sediments of British Columbia harbours. Environ.Tech. **18**: 1195-1202.

Strong, D. S, Gallagher, P, and Muggeridge, D. 2002. British Columbia Offshore Hydrocarbon Development: Report of the Scientific Review Panel. Report of the Scientific Review Panel. BC Ministry of Energy and Mines.

Sullivan, D. L. 1987. Compilation and assessment of research, monitoring, and dumping information for active dump sites on the British Columbia and Yukon coasts from 1979 to 1987. 87-02. Environment Canada, Conservation and Protection.

Tabuchi, M., Veldhoen, N., Dangerfield, N., Jeffries, S. J., Helbing, C. C., and Ross, P. S. 2006. PCB-related alteration of thyroid hormones and thyroid hormone receptor gene expression in free-ranging harbor seals (*Phoca vitulina*). Environ.Health Perspect. **114**: 1024-1031.

Tierney, K. B., Ross, P. S., Jarrard, H. E., Delaney, K. R., and Kennedy, C. J. 2006a. Changes in juvenile coho salmon electro-olfactogram during and after short-term exposure to current-use pesticides. Environ.Toxicol.Chem. **25**: 2809-2817.

Tierney, K. B., Taylor, A. L., Ross, P. S., and Kennedy, C. J. 2006b. The alarm reaction of coho salmon parr is impaired by the carbamate fungicide IPBC. Aquat.Toxicol. **79**: 149-157.

Transport Canada. 2005. Pollution Prevention Guidelines for the Operation of Cruise Ships Under Canadian Jurisdiction. TP 14202 E. Transport Canada Marine Safety.

Waldichuk, M. 1961. Observations in marine waters of the Prince Rupert Area, particularly with reference to pollution from the sulphite pulp mill on Watson Island, September 1961. Manuscript Report Series. 733. Fisheries Research Board of Canada.

Waldichuk, M. 1963. Effects of sulfite wastes in a pratially-enclosed marine system in British Columbia. Presented in part at the 36th Annual Meeting of the Water Pollution Control Federation in Seattle, Washington, October 6-10, 1963. Nanaimo, BC.

Warhurst, A. M. 1995. An environmental assessment of alkylphenol ethoxylates and alkylphenols. Friends of the Earth Scotland, Friends of the Earth. Bonnington Mill, Edinburgh. http://www.foe.co.uk/resource/reports/ethoxylates_alkylphenols.pdf.

West Coast Offshore Exploration Environmental Assessment Panel. 1986. Offshore Hydrocarbon Exploration: Report and Recommendations of the West Coast Offshore Exploration Environmental Assessment Panel. Environment Canada. Vancouver, BC.

White, E. 2001. An Overview of Water Based Log Handling on the North Coast of British Columbia. Background Report. Triton Environmental Consultants Ltd.

Whiticar, M. J. 2000. Climate Change and Potential Impact of Hydrocarbon Exploitation in Queen Charlotte Basin, BC. Exploring the Future of Offshore Oil and Gas Development in BC: Lessons from the Atlantic. Simon Fraser University, Burnaby, BC.

Whiticar, M. J. 2001. Offshore Potential and Impacts of Petroleum in Queen Charlotte Basin, BC. "The Dawning of a New Era - The Future of Offshore Oil and Gas in British Columbia: A Comprehensive Examination of the Issues". School of Earth & Ocean Sciences, University of Victoria, Vancouver, BC.

Whitney, F. A. and Robert, M 2002. Structure of Haida Eddies and Their Transport of Nutrient from Coastal Margins into the NE Pacific Ocean. J. Oceanography **58**: 715-723.

Wildish, D. J. and Pohle, G. W. 2005. Benthic macrofauna changes resulting from marine finfish; Handbook of environmental chemistry. *In* Hargrave, B. T. (*eds.*). Environmental effects of finfish mariculture. Springer, Berlin. 275-304.

Wilkening, K. E. 2001. Trans-Pacific air pollution: scientific evidence and political implications. Water Air Soil Pollut. **130**: 1825-1830.

Woodsworth, G. J. 1991. Evolution and Hydrocarbon Potential of the Queen Charlotte Basin, British Columbia. Geological Survey of Canada Paper. 90-10. Geological Survey of Canada.

Yang, R. and Randall, D. J. 1996. Effects of tetrachloroguaiacol (TeCG) on the osmoregulation of adult coho salmon (*Oncorhynchus kisutch*). Bull.Environ.Contam.Toxicol **56**: 788-795.

Yunker, M. B. and Cretney, J. 1995. Chlorinated dioxin trends between 1987 and 1993 for samples of crab hepatopancreas from pulp and paper mill and harbour sites in British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences. 2082. Fisheries & Oceans Canada.

Yunker, M. B. and Cretney, W. J. 2000a. Bioavailability of chlorinated dibenzo-*p*-dioxins and dibenzofurans to dungeness crab (*Cancer magister*) at marine pulp mill sites in British Columbia, Canada. Environ.Toxicol.Chem. **19**: 2997-3011.

Yunker, M. B. and Cretney, W. J. 2000b. Concentration dependency of biota-sediment accumulation factors for chlorinated dibenzo-*p*-dioxins and dibenzofurans in dungeness crab (*Cancer magister*) at marine pulp mill sites in British Columbia, Canada. Environ.Toxicol.Chem. **19**: 3012-3023.

Yunker, M. B., Cretney, W. J., and Ikonomou, M. G. 2002. Assessment of chlorinated dibenzo-*p*-dioxin and dibenzofuran trends in sediment and crab hepatopancreas from pulp mill and harbour sites using multivariate- and index-based approaches. Environ.Sci.Technol. **36**: 1869-1878.