Marine Environmental Quality in the North Coast and Queen Charlotte Islands, British Columbia, Canada: A Review of Contaminant Sources, Types, and Risks

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2007

Canadian Technical Report of Fisheries and Aquatic Sciences 2717

Fisheries and Oceans | Pêches et Océans

Canada

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Cat. No. Fs 97-6/2717 ISSN 0706-6457

Correct citation for this publication:

Johannessen, D.I., Harris, K.A., Macdonald, J.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 risks. Can. Tech. Rep. Fish. Aquat. Sci. 2717: xii + 87 p.

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Abstract

Johannessen, D.I., Harris, K.A., Macdonald, J.S., 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 risks. Can. Tech. Rep. Fish. Aquat. Sci. 2717: xii + 87 p.

This report on British Columbia's North Coast (NC) is one in a series of three written in support of Canada's Oceans Act and its implementation in British Columbia's coastal waters. It is a companion report to the earlier one by Haggarty *et al*. (2003) on marine environmental quality in British Columbia's Central Coast (CC). Together, these two reports form the basis for a third summary report which encompasses the revised and presently described Pacific North Coast Integrated Management Area (PNCIMA; Johannessen *et al.* 2007). This NC report reviews contaminant sources, types, and risks for the northern mainland coast of BC and the Queen Charlotte Islands. This region encompasses the northern portion of the steep and rugged coastal fjordlands including the Skeena and Nass watersheds, as well as the less mountainous but similarly rugged coastline of the Queen Charlotte Islands. The marine area covers the continental shelf and slope waters of Dixon Entrance, most of Hecate Strait, and the waters off the west coast of the Queen Charlotte Islands, roughly a third of BC's coastal waters. This area is among the least populated in BC, with only ~ 80,000 residents (about 2% of BC's total). However, the area supports significant human activities such as mining and smelting operations, fishing activities, and abundant marine traffic. In addition, it is subject to various global transport mechanisms that bring persistent pollutants into the area. Existing literature suggests that current risks to marine environmental quality include shipping traffic, which produces chronic oil releases among other wastes; metal contamination from existing and previous mining activities, particularly in the Alice Arm area; hydrocarbon contamination, particularly in the area around the Kitimat smelter; pulp mill effluents in Kitimat and Prince Rupert; potential contamination due to port related activities in Prince Rupert and Kitimat; and possible contamination issues related to past practices at military and coast guard sites. Emerging issues for the area include potential oil and gas exploration, a rapidly expanding cruise ship industry, and possible growth in the aquaculture industry.

Résumé

Johannessen, D.I., Harris, K.A., Macdonald, J.S., Ross, P.S. 2007. Qualité de l'environnement marin le long de la Côte nord et des îles de la Reine-Charlotte, Colombie-Britannique, Canada : Examen des sources et des types de contaminants et des risques dans ce domaine. Can. Tech. Rep. Fish. Aquat. Sci. 2717: xii + 87 p.

Ce rapport sur la côte nord (CN) de la Colombie-Britannique fait partie d'une série de trois rapports préparés à l'appui de la Loi sur les océans du Canada et de sa mise en œuvre dans les eaux côtières de la Colombie-Britannique. Il accompagne le précédent rapport publié par Haggarty et coll. (2003a) concernant la qualité de l'environnement marin sur la côte centrale (CC) de la Colombie-Britannique. Ces rapports sont tous deux à la base d'un troisième rapport sommaire qui couvre la toute nouvelle Zone de gestion intégrée de la côte nord du Pacifique décrite à présent (PNCIMA; Johannessen *et al.* 2007). Ce rapport sur la CN examine les sources et les types de contaminants ainsi que les risques afférents le long du littoral nord de la partie continentale de la C.-B. et des îles de la Reine-Charlotte. Cette région englobe la partie nord des terres entaillées de fjords abrupts et accidentés notamment les bassins hydrographiques des rivières Skeena et Nass ainsi que le littoral des îles de la Reine-Charlotte tout aussi accidenté bien que moins montagneux. La zone marine couvre les eaux de la plateforme et de la pente continentales de l'Entrée Dixon, la majeure partie du détroit d'Hécate et les eaux situées à l'ouest des îles de la Reine-Charlotte, soit environ un tiers des eaux côtières de la C.-B. Cette zone figure parmi les régions les moins peuplées de la province puisqu'elle compte seulement ~ 80 000 résidents (approximativement 2 % de la population totale de la C.-B.). Toutefois, cette zone est le siège d'importantes activités humaines telles que mines et fonderies, pêcheries et intense trafic maritime. En outre, elle est assujettie à divers mécanismes de transport planétaire qui y amènent des polluants persistants. Selon les écrits existants, les risques pour la qualité de l'environnement marin comprennent le trafic maritime qui est responsable de déversements chroniques de produits pétroliers entre autres rejets; une contamination par les métaux en provenance d'activités minières actuelles et antérieures, notamment dans la zone du bras Alice; une contamination par les hydrocarbures, particulièrement dans la zone proche de l'aluminerie de Kitimat; les effluents d'usine de pâtes à papier à Kitimat et à Prince Rupert; une contamination éventuelle liées aux activités portuaires à Prince Rupert et à Kitimat; et de possibles enjeux de contamination liée, dans certains sites, aux anciennes pratiques des forces armées et de la garde côtière. Les nouvelles questions d'actualité pour cette zone comprennent, entre autres, la possibilité d'exploration pétrolière et gazière, l'expansion rapide de l'industrie des croisières et le développement éventuel du secteur de l'aquaculture.

Acknowledgements

This project was funded through the Oceans Action Plan (Fisheries & Oceans Canada). The authors are grateful for the advice and assistance of numerous persons, including Bev Agar, Robin Brown, Les Burridge, Jon Chamberlain, Wayne Fairchild, 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 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 North Coast of British Columbia is no exception. Despite a low population density, the NC is host to some important human activities.

This report represents a companion document to our previous report on the Central Coast (Haggarty *et al.* 2003). Today, Fisheries and Oceans Canada recognizes the formerly named Central Coast and North Coast as a single management area, now referred to as the Pacific North Coast Integrated Management Area (PNCIMA). This report (NC) and the previous report (CC) can be considered as detailed evaluations of information available for their respective areas, while a summary of both reports is presented elsewhere (Johannessen *et al.* 2007).

Marine environmental quality concerns exist around a number of human activities taking place on BC's north coast and Queen Charlotte Islands. Current literature and available information suggest that there are risks to MEQ from a number of activities. We present here a 'top ten' list of threats to MEQ in the North Coast and Queen Charlotte Islands, although they are not presented in any particular order.

1. **Vessel traffic**. Shipping and transportation activity in the northern coastal area has not increased significantly in recent years and has in some cases declined. However, recently completed upgrades to the Prince Rupert port and proposed and ongoing additions at the Prince Rupert and Kitimat ports are expected to cause increases in tanker traffic. Increased cruise ship size has caused a rise in the total numbers of people travelling through the area.

2. **Ports.** Both of the major industrial ports in the area, Prince Rupert and Kitimat, are undergoing or have proposed upgrades and additions. Risks of pollution in the area are predicted to increase as a result of the increased activity these expansions will create.

3. **Forestry**. Forest activities of concern to marine environmental quality, aside from pulp and paper milling, including pesticide application, fire suppression, and chemicals produced by large volumes of decomposing woody material. Despite an active forest industry in the area, forest pesticide use in BC is not considered significant and the use of most chemicals is decreasing. In relation to drier interior and northern areas, forest fires are less common in the coastal rainforest so chemicals used in fire fighting are not likely to be a significant contamination issue. The build-up of woody debris, either in the bottom of inlets or on adjacent land, is the most likely source of chemical contaminants. However, there is no evidence that this is a significant problem and implementation of best practices should reduce the risk of pollution from woody debris.

4. **Pulp and paper mills**. Two pulp and paper mills are currently in operation in the study area: Skeena Cellulose in Prince Rupert and Eurocan in Kitimat. While operational changes in the 1990s led to a reduction in dioxin and furan emissions, other chemicals of concern are known to exist in mill effluent, the environmental effects of which remains uncertain. For this reason, pulp and paper mill activity remains a concern.

5. **Mining and smelting**. Nine mining sites have been identified by the province as a potential risk for acid rock drainage and associated elevated levels of mobile heavy metals. The extraction of silica from one of these sites - the Anyox slag heap - represents the only mining activity currently occurring in the area. However, this slag heap has been identified as a significant source of heavy metals, resulting from active weathering of the slag. The Kitsault and Tasu mines used sub-marine mine tailings disposal methods in the past. Studies suggest that in both cases this method prevented significant mobilization of heavy metals from the tailings. Finally, a recent upturn in metal prices has sparked an exploration boom in BC, increasing the chance that new mining operations will be established in the area. The ALCAN Aluminum smelter at Kitimat has been implicated as the source of significant polycyclic aromatic hydrocarbon (PAH) contamination in that area. The smelting process produces PAHs both from emissions from the smelter process itself, and from the handling of hydrocarbon rich materials at the Kitimat port.

6. **Aquaculture**. Aquaculture activity is not currently significant in the north coast area, but northward expansion of this industry is expected. In cases where multiple sites are located in sheltered and restricted waters, pollution issues can be a concern.

7. **Military and Coast Guard sites**. Military and coast guard sites have frequently been found to be sites of significant contamination in Canada. There are currently no active Canadian forces bases in the north coast area, but three military sites were 'stood down' following World War II. The extent to which environmental assessment was carried out at these sites was not found by this survey. The Canadian Coast Guard is responsible for four staffed and five unstaffed lightstations and two search and rescue stations located in the study area. Again, historical contaminant issues, such as the improper disposal of batteries containing cadmium and mercury, exist. The coast guard is currently working to assess these sites and mitigate identified problems.

8. **Global pollutants.** Persistent organic pollutants (POPs) are long-lived in the environment, biomagnify through food webs to top predators, and are subject to atmospheric transport which can result in their global distribution. Some of the older POPs have shown declines, but many are still a concern. In addition, new POPs are being utilized as the global chemical industry develops new compounds to serve a variety of purposes. These contaminants have been found in a variety of BC environments and are of concern in the study area.

9. **Offshore oil and gas.** Offshore oil and gas exploration is not currently permitted in the study area; however, existing moratoria are under review. Significant

pollution issues relating to exploration and extraction include chronic and acute oil spills, increased vessel traffic, air pollution, and noise pollution, and the release of drilling mud and produced water to the marine environment.

10. **Ocean dumping.** Ocean dumping may introduce toxic compounds to local food webs or smother benthic biota. At present, there are four ocean dumping sites in the north coast and Queen Charlotte Islands, but these are thought to be largely used for disposal of inert dredging materials.

From this information it is clear that two of the main areas of concern in terms of marine contamination on the north coast are Prince Rupert and Kitimat. Ports at these centres are host to important industrial activity and are transportation and shipping hubs. In addition to these hotspots, the Alice Arm/Granby Bay area is of concern due to the leaching of heavy metals from the Anyox slag heap. Other possible threats to MEQ not captured in our categories of concern include agriculture (limited in the region).

1 Introduction

1.1 Purpose and Scope of the Report

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 local environmental information, environmental process knowledge from elsewhere, and a commitment to continue research and monitoring in the future. The North Coast (NC) had previously been designated as one of the Pacific Region's designated integrated management areas, which was later superseded by the creation of a single 'Pacific North Coast Integrated Management Area (PNCIMA)'.

This report on the North Coast is intended to serve as a companion report to one previously published on the formerly named Central Coast (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). The reader is referred to a third report which synthesizes our findings for both former areas, and provides guidance on MEQ issues in the PNCIMA (Johannessen *et al.* 2007).

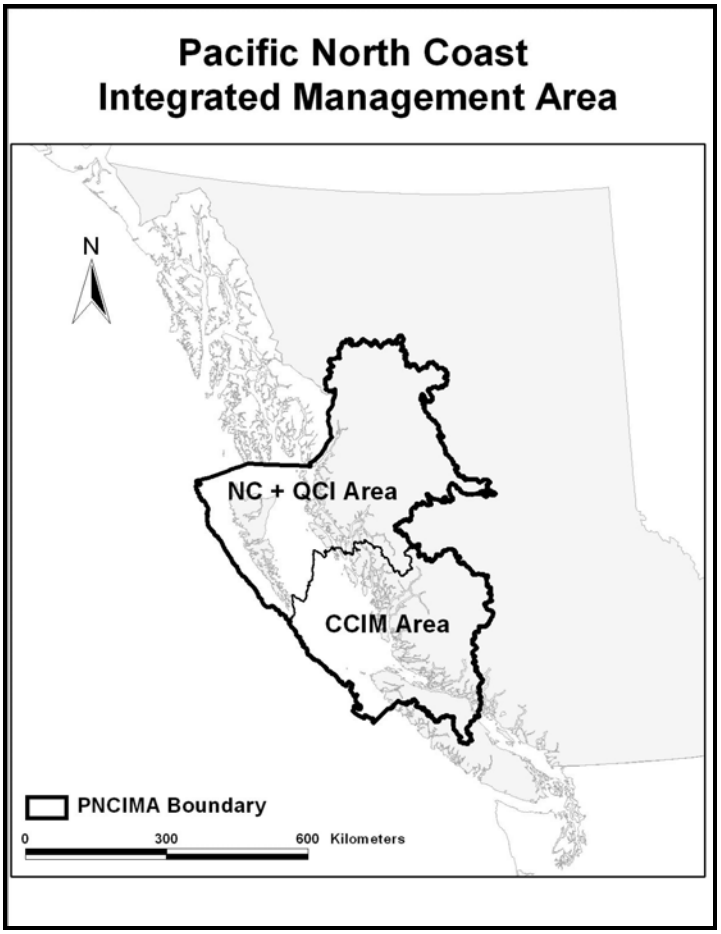

Figure 1.1 Location of the two sub-areas for which MEQ reports have been developed, and which together make up the PNCIMA. This report covers the northern sub-area (North Coast and Queen Charlotte Islands).

The information in this report is organized according to the human activities which are a source of contamination. The topics are not listed in any particular order. Some are discussed only briefly where the information is generalized to the BC coast and was covered in the central coast report (Haggarty *et al.* 2003). Furthermore, the central coast report discussed contaminant toxicity in detail. This information is no different for the same contaminants on the north coast and has changed little in recent years so this report will focus on the sources of contaminants and their relative importance at local and coastal scales.

2 Overview of the North Coast and Queen Charlotte Islands Environment

2.1 Area and Population

The north coast and Queen Charlotte Islands cover approximately 51,000 km^2 of ocean (Figure 2.1). While adjacent terrestrial watersheds are not technically included as part of the area, we address terrestrial issues in this report as they may have direct and significant bearing on MEQ; these watersheds comprises approximately 109,000 km^2 of land. The area's population as of 2001 was estimated at approximately 80,000, about 2% of the provincial total (data from Statistics Canada). The concentration of the area's population is in three main settlements, Prince Rupert, Terrace and Kitimat (Figure 2.2).

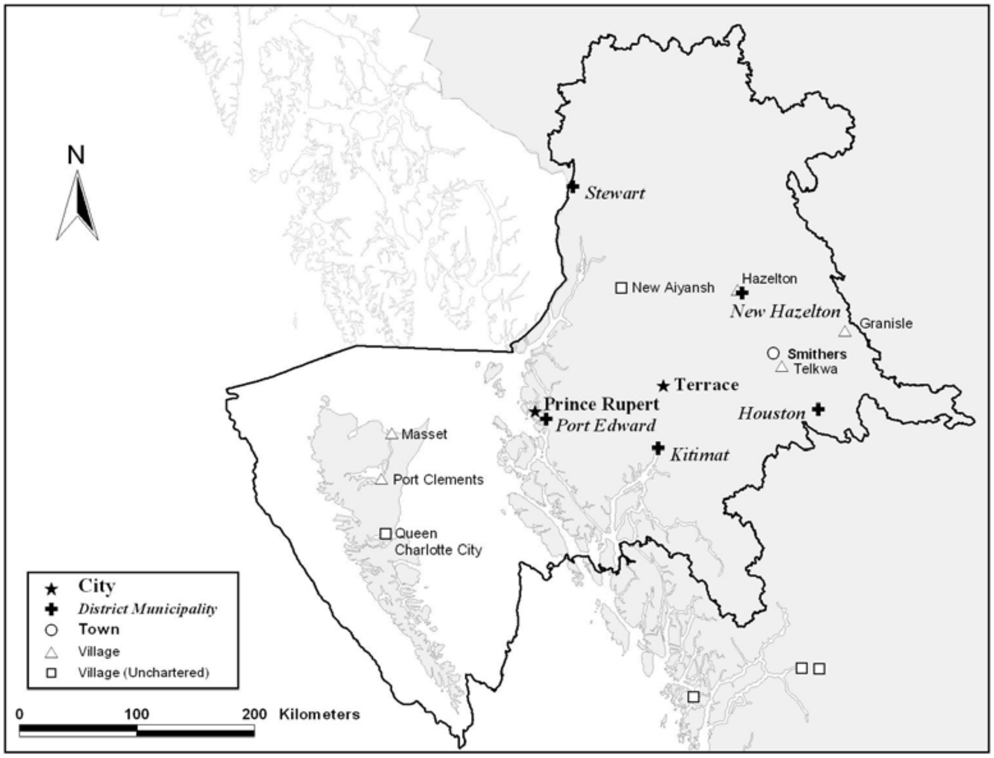

Figure 2.1 Location and type of major settlements on the north coast and Queen Charlotte Islands.

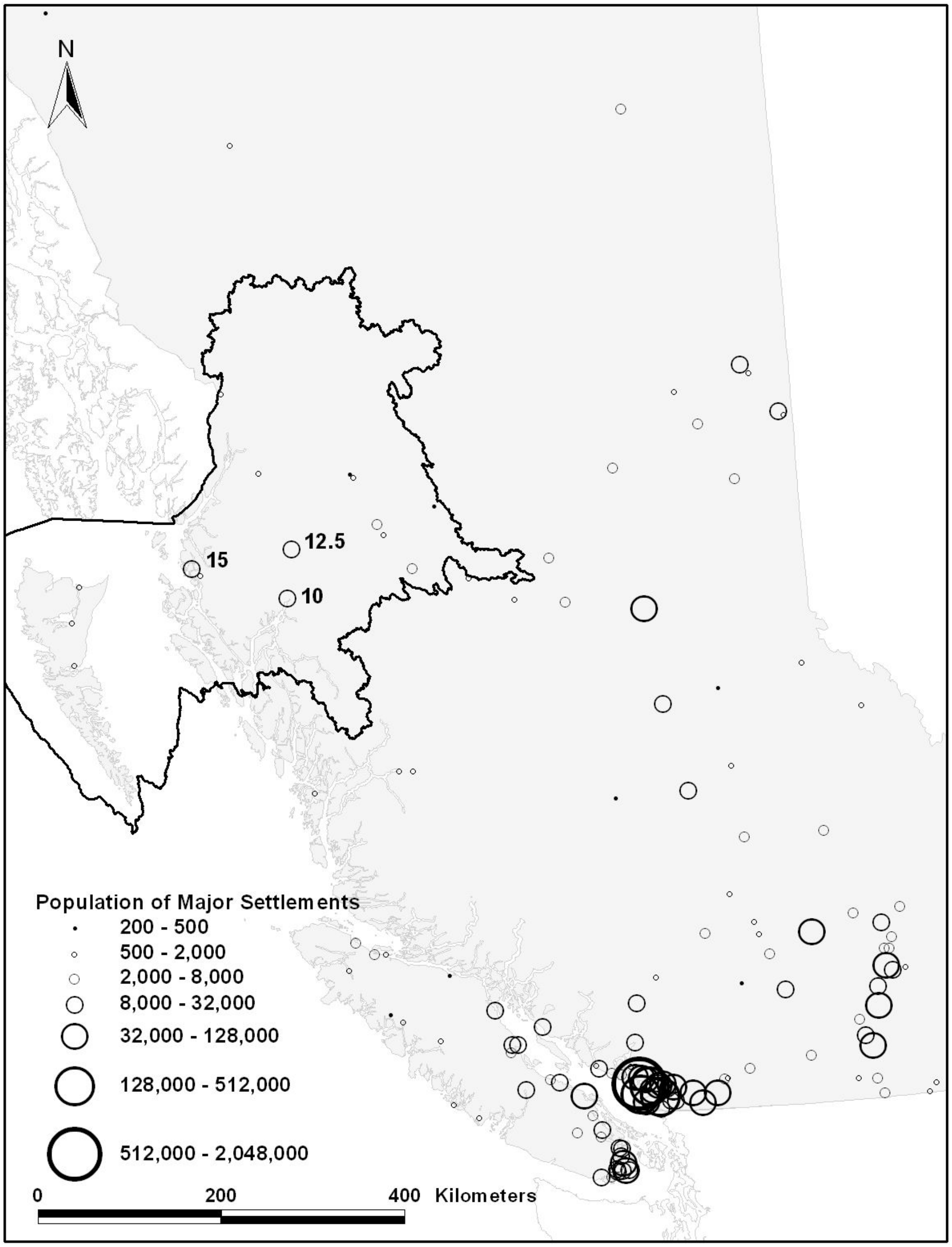

Figure 2.2 Relative populations of settlements on the North Coast and Queen Charlotte Island as well as much of the rest of BC. Bold numbers indicate the population (thousands of people in 2001) of the three main settlements located in the study area (data from Statistics Canada).

2.2 Physiography

The north coast and Queen Charlotte Islands encompass several physical environments, including the exposed outer coast of the Queen Charlotte Islands, the semi-protected waters of Hecate Strait and Dixon Entrance, the protected waters of the channels and inlets along the mainland coast, the Coastal Range mountains, and the high elevation Interior Plateau.

The western side of the Queen Charlotte Islands, with its narrow continental shelf, is the most exposed and wave pounded section of the BC coast: storms coming across the Pacific Ocean often make landfall here. The low lying mountain ranges on the Queen Charlotte Islands produce only minor orographic effects (high rainfall on the windward (west) side and rainshadows on the lee side) and no permanent snow or ice. While precipitation occurs frequently, there is little accumulation and winters are mild. Local rivers have relatively small watersheds at low elevation, resulting in rainfall-dominated discharge. This means that peak river flows coincide with peak rainfall, which occurs between fall and late winter. The majority of the islands have been glaciated and, like much of the BC coast, are dominated by rocky shorelines cut by narrow, deep inlets. One exception is the northeast corner of Graham Island, where sand beaches dominate and a huge, shallow, sandy bank forms much of the floor of northwestern Hecate Strait.

The north coast mainland is protected not only by the presence of the Queen Charlotte Islands, but also by many low-lying, smaller islands and deep, narrow straits and channels, resulting in mild winters and frequent rainfall. The mainland itself shows the effects of glaciation on a high elevation, granitic mountain range, resulting in long, deep, steep-sided inlets carved into the Coast Mountains. The orographic effect is significant of these high coastal mountains is significant, resulting in some of Canada's highest recorded rainfall volumes in coastal communities. At higher elevations, snow and ice accumulate, resulting in meltwater discharge peaks in spring in larger rivers such as the Nass and Skeena. These rivers rank second and third respectively in BC in terms of discharge, with each delivering about a third of the volume discharged by the Fraser River.

2.3 Climate

The North Coast and Queen Charlotte Islands represent 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 Islands. This mild and wet climate supports temperate rainforests along the coast.

2.4 Oceanography

The marine currents in the PNCIMA are controlled by three main factors: wind conditions, freshwater input, and topographic controls. The wind conditions are primarily dictated by two atmospheric pressure systems over the Pacific Ocean. The North Pacific High dominates in summer and produces mild winds from the northwest. Its influence is stronger along southern portions of the coast. The Aleutian Low dominates in winter and produces strong winds from the southwest, bringing winter storms across the Pacific. The result is that wind tends to be the dominant surface current control in the winter, pushing water north through Hecate Strait and northwest out of Dixon Entrance. In the summer, winds have less effect on currents, and topography and freshwater driven estuarine circulation dominate. This results in a general seaward flow of surface waters (both at a basin wide scale, and within inlets and channels) and landward flow of bottom waters. Due to topographic effects, large scale eddies are common in southern Hecate Strait and Dixon Entrance. These eddies cause the retention of water (and anything in the water, such as plankton or pollutants) within coastal waters. Water mixing is strongest around narrow channels, shallow areas, and points of land such as the three corners of the Queen Charlotte Islands.

Another phenomenon of particular significance to this part of the BC coast is the formation in late winter of the Haida Eddies off of the southern tip of the Queen Charlotte Islands. These eddies are anti-cyclonic and tend to move westward away from the coast (Crawford 2002). They can be over 200 km in diameter and up to 2 km deep, and may transport as much water as the combined volumes of Hecate Strait and Queen Charlotte Sound (Whitney and Robert 2002). These eddies can move quantities of contaminants significant distances.

2.5 Biology and ecology

Fisheries and Oceans Canada has identified 15 Ecologically and Biologically Significant Areas (EBSAs) in the newly designated Pacific North Coast Integrated Management Area, which comprises the North Coast and Queen Charlotte Islands, with a total area of 45,182 km^2 (44.3% of the PNCIMA). EBSAs, the result of 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), identify areas worthy of enhanced protection. The Coast Information Team (CIT) has also identified important ecological elements found in the North Coast. Established by the provincial government, First Nations, environmental groups, and forest products companies to provide information on the PNCIMA, included in which is the North Coast, 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 North Coast is also home to globally unique hexactinellid sponge bioherms, which, due to their fragile body structure and sedentary nature, are extremely sensitive to physical disturbance (Clarke and Jamieson 2006). They are estimated to have existed in Queen Charlotte and Hecate Straits for 8,500 – 9,500 years (Department of Fisheries and Oceans 2000).

The wide variety of marine life found in the North Coast can be largely attributed to the numerous habitat types. These include, but are not limited to, rocky reefs, sand and gravel habitat both off- and nearshore, and muddy sediments. They provide important nursery and foraging habitat for fish and invertebrate species, many of which are important in commercial fisheries or as prey for higher trophic level species. The species present and the habitat types they utilize are summarized elsewhere (Johannessen *et al.* 2007).

In addition to varied habitat types, the consistent upwelling of cold, nutrient-rich waters along the North Coast, in conjunction with strong tidal mixing, makes it an ideal environment for a vast assemblage of marine life. It provides near- and offshore breeding and foraging habitat for several species of seabird, many of which breed nowhere else in Canada (Rumsey *et al.* 2003; Booth *et al.* 1998), and the coastline supports shorebirds such as plovers, sandpipers, and killdeers (Booth *et al.* 1998). Other bird species, including blue heron, bald eagles, swans, geese, dabbling ducks, sea ducks (harlequin, long-tailed, scoters, buffleheads, goldeneyes, and mergansers), and divers (loons, grebes, and cormorants) also depend on a healthy marine environment (Booth *et al.* 1998). Marine fish species inhabiting the North Coast 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 North Coast is home to 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*). Less common are 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*).

There are many human socioeconomic sectors that rely on a healthy marine environment. The region includes the territories of several First Nations, whose traditional way of life hinges upon a thriving marine environment. Both fishing and ecotourism are important sectors of the North Coast economy (Rumsey *et al.* 2003). The area supports recreational and aboriginal subsistence fisheries, as well as commercial fisheries for salmon, invertebrates, and groundfish. Marine and terrestrial parks provide camping, wildlife viewing, and hunting opportunities for the thousands of visitors to the North Coast annually (http://www.livingoceans.org/marine_planning/pncima.shtml). The North Coast also provides opportunities for whale watching, saltwater angling (through both fishing lodges and charters), boating and sailing, scuba diving, and guided kayak trips.

3 Vessel Traffic

Residents of and visitors to BC's north coast and Queen Charlotte Islands rely on marine vessels, both for shipping (moving cargo) and for transportation (moving people). Vessels employed include oil tankers, container and cargo ships, barges, ferries, cruise ships, and fishing and recreational vessels (Haggarty *et al.* 2003). The north coast of BC sees a significant amount of vessel traffic, especially due to large ports at Kitimat and Prince Rupert (Figure 3.1). However, the vessel traffic statistics maintained by the Canadian Coast Guard for the Prince Rupert Area of Responsibility illustrate a general decrease in shipping traffic, aside from ferry traffic, on the north coast since 2003 (Table 3.1). Decreases in large tanker, cargo, and container ship traffic, however, may be reversed as the port at Prince Rupert is upgraded to handle new, larger ships.

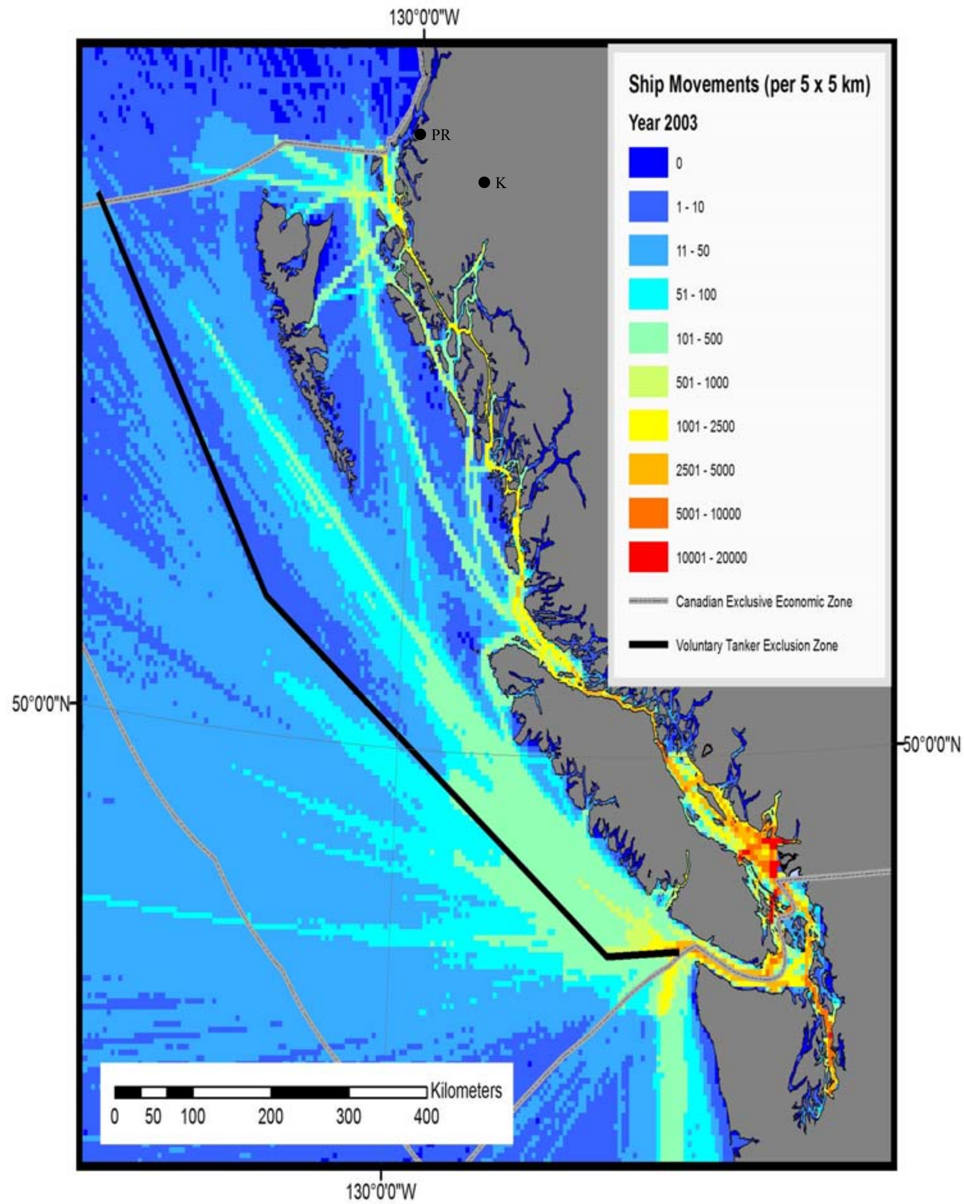

Figure 3.1 Map of marine vessel traffic density based on inter-grid (5 km by 5 km) movement on the BC coast in 2003 (figure provided by P. O'Hara, University of Victoria, 2007); PR: Prince Rupert, K: Kitimat

Table 3.1 Vessel Traffic Statistics (VTS) for the Prince Rupert Area of Responsibility from 2003-2006. VTS represent inbound, outbound, and transiting vessels (personal communication, I. Wade, MCTS, Canadian Coast Guard, 2006).

MOVEMENTS BY VESSEL TYPE	PRINCE RUPERT 2003-2004	PRINCE RUPERT 2004-2005	PRINCE RUPERT 2005-2006
Tanker<50000 DWT	58	12	31
Tanker>50000 DWT	85	59	40
Chemical Tanker	170	81	44
LPG/LNG Carrier	54	165	93
Cargo – General	758	741	467
Cargo – Bulk	1255	1534	1167
Container	641	471	490
Tug	638	608	617
Tug with oil barge	906	795	762
Tug with chemical barge	2	18	0
Tug with Tow	6311	6403	5315
Government	2270	2279	2131
Fishing	2380	2231	1831
Passenger Vessels	1726	1848	1694
Other Vessels >20m	667	783	702
Other Vessels<20m	56	49	82
Sub-Total Movements	17977	18077	15466
Ferry	3163	15115	15013
Grand Total Movements	**21140**	**33192**	**30479**

3.1 Chronic Oiling

Chronic oiling may be caused by natural seepages, sewage, atmospheric input, and runoff from land, but chronic oil pollution as a result of marine vessel traffic has received much attention (Haggarty *et al.* 2003). Chronic inputs contribute more oil to the marine environment than do acute spills (reviewed in Haggarty *et al.* 2003), and are thought to have a greater effect on bird populations (Sloan 1999). In addition, a review of the effects of spill volume on seabird mortality found that, in general, volume is not predictive of mortality and that other factors, such as seabird density, wind velocity, wave action, and distance to shore may be equally important in determining ultimate mortality (Burger 1993). Of all sources of oil pollution, ships are more likely to release oil in areas in which it is likely to come into contact with marine wildlife. In addition, ship-derived oil pollution tends to concentrate at the surface in the form of slicks, which, as oil pollution is currently understood, have the greatest impact on a per unit basis in terms of acute mortality. Oil in slick form contaminates seabird plumage, leading to ingestion via preening (toxic effects), and interferes with the water-resistant characteristics of the plumage, leading to hypothermia and loss of buoyancy (personal communication, P. O'Hara, University of Victoria, 2006).

Oil may be released as a result of accidental spills or leakage, or may be released intentionally. Intentional releases may occur through the dumping of oily bilge water and through tank washings, although this is legally required to take place offshore and currently, is not thought to be of major concern. Research based upon the proportion of oiled seabird carcasses found on surveyed beaches along Newfoundland's Avalon Peninsula estimated that between 1998 and 2000, approximately 300 000 seabirds died annually in a small region off the peninsula as a result of chronic oiling (Wiese and Robertson 2004). On the west coast, the proportion of oiled seabird carcasses found along surveyed comparable beaches (in terms of proximity to shipping lanes and dense seabird aggregations, and prevailing wind and oceanographic conditions favouring carcass deposition) is similar to the proportion found along the Avalon Peninsula. In addition, the west coast is characterized by dense seabird aggregations, high biodiversity, and important foraging areas, and many of these areas overlap with regions of intense shipping. For these reasons, it is believed that mortality rates for various regions in the BC exclusive economic zone (see Figure 3.1) may be similar to those estimated for the small area off the Avalon Peninsula (personal communication, P. O'Hara, University of Victoria, 2006). Much less is known about the density and foraging habitat of seabirds on BC's north coast and current impacts of ship-source oil pollution on these populations. Furthermore, with the predicted increase in tanker and cruise ship traffic as a result of upgrades to the Prince Rupert port and industrial activity at the Kitimat port (see Section 4.2), chronic oiling can be expected to increase in the near future and pose a greater risk in terms of environmental contamination.

3.2 BC Ferries

Ferry traffic accounts for most of the vessel activity on the north coast, and while other passenger vessels such as cruise ships are less common, their effect is thought to be substantial due to their size and the large number of passengers they bring to the area (Table 3.1). These vessels pose similar pollution concerns, so for brevity, are discussed in detail in the Cruise ships section only.

There are two BC Ferries routes that serve the north coast: route 10, which travels from Port Hardy to Prince Rupert, and route 11, which travels from the Queen Charlotte Islands to Prince Rupert (Figure 3.2). Route 10 has the capacity for 115 vehicles and 375 to 650 passengers per vessel, and route 11 has the capacity for 80 vehicles and 544 passengers and crew per vessel (Fisheries and Oceans Canada 2005). Following the sinking of the Queen of the North in 2006, the only vessel currently serving this route is the Queen of Prince Rupert. While ferries pose similar marine contamination issues as cruise ships, BC Ferries is in the process of upgrading its sewage systems to the Hydroxyl CleanSea® Sewage system, a system that uses bio-oxidation to deal with sewage, grey water, and oily bilge water. It does not use chlorine, and for this reason, sewage produced by BC Ferries vessels is not likely to be of major concern in the future (Haggarty *et al.* 2003). While BC Ferries is the main provider of passenger and vehicle ferry service in the north coast, there are also private ferry operators. These include the

Digby Island ferry, connecting Digby Island with Prince Rupert, and the Alaskan State ferry system.

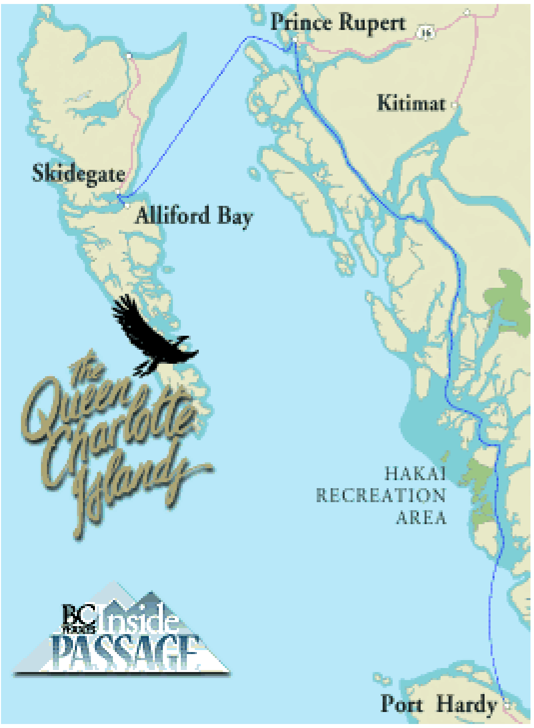

Figure 3.2 BC ferry routes for the northern BC coast (figure from http://www.bcferries.com/schedules/maps/maps-insidepass.html)

3.3 Cruise Ships

Every year, the scenic beauty of the Pacific north coast attracts passengers to cruise ships departing ports such as Seattle and Vancouver en route to Alaska (Table 3.2). These ships travel through the north coast area via the Inside Passage Marine Highway (Fisheries and Oceans Canada 2005) (Figure 3.3). Cruise ships destined for or travelling via the north coast may be divided into two classes: large vessel cruise ships, which carry more than 500 passengers (usually between 1200 and 2800 passengers) and stop only at the port of Prince Rupert; and pocket cruises, which carry up to 500 passengers and stop at many ports throughout the north coast (Fisheries and Oceans Canada 2005).

Table 3.2 Number of vessels and passengers travelling from Vancouver or Seattle to Alaska in 2004 (Fisheries and Oceans Canada 2005)

Port of Embarkation	Number of Sailings	Passengers
Vancouver	286	929 976
Seattle	148	550 000
TOTAL	334	1 479 976

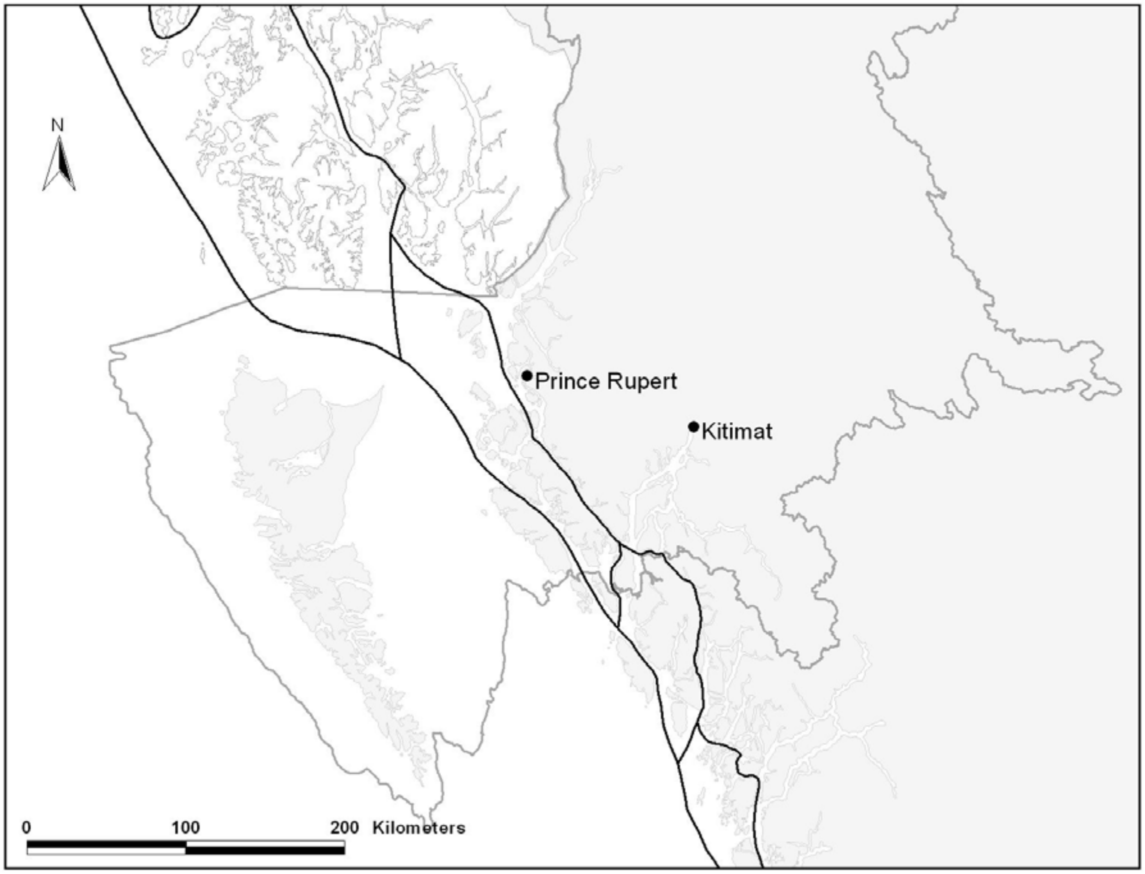

Figure 3.3 Cruise ship routes along the BC coast (data from the BC Offshore Oil and Gas Team, Ministry of Energy and Mines).

Cruise lines have faced criticism in the past for their environmental record (Ocean's Blue Foundation 2003 as cited in; Haggarty *et al.* 2003). A report by the United States General Accounting Office (2000) documented both accidental and intentional instances of illegal dumping by cruise ships between 1993 and 1998, resulting in fines in the millions of dollars. In 2000, Royal Caribbean Cruises Ltd. and Holland America Line Westours Inc. were convicted of illegally polluting the Inside Passage and were fined $6.5 million and $2 million respectively (Nowell and Kwan 2001). In response, the International Council of Cruise Lines has adopted waste management practices with which all of its members must comply (International Council of Cruise Lines 2005). Transport Canada released a revised set of guidelines in 2005 for the prevention of pollution by cruise ships (Transport Canada 2005).

Waste produced by cruise ships can be divided into eight categories (Haggarty *et al.* 2003):

1. Sewage (also called blackwater):

   Sewage from cruise ships is more concentrated than municipal sewage because less water is used to dilute it. A week-long cruise will typically generate an estimated 800 000 litres of sewage (Haggarty *et al.* 2003), and during peak cruise season (May to September in B.C.) an estimated 9.5 million litres of sewage is produced daily (Nowell and Kwan 2001). Aside from its organic content, blackwater may contain pharmaceuticals, many of which have poorly characterized environmental effects. The *Fisheries Act* prohibits the deposition of "deleterious substances" into fish bearing water, and Canadian law specifies a limited number of no-discharge zones for sewage, but none of these zones are located in the north coast (Nowell and Kwan 2001). Discharge of disinfected sewage is permitted at a distance of more than three nautical miles from land, and sewage that has not been disinfected may be discharged at a distance of more than 12 nautical miles from land at a 'moderate' rate when the ship is travelling at a speed of at least four knots (Transport Canada 2005).

2. Grey water:

   Grey water includes wastewater from sinks, showers, galleys, and laundry facilities. It is not usually treated, and can add up to four million litres of discharge per ship (based on a seven day cruise). Grey water may contain organics, petroleum hydrocarbons, oils, greases, metals, suspended solids, nutrients, coliform bacteria, and personal care products (Nowell and Kwan 2001). In its 2002 report, the Science Advisory Panel (2002) concluded that dilution and vigorous mixing would effectively control pollution from black and grey water, but recommended that discharges not be made when the ship is stationary, within half a nautical mile of shellfish beds, within one nautical mile of shore, or within protected bays or inlets with low tidal exchanges. In 2005, Transport Canada (2005) released guidelines which clearly indicate to cruise ship operators the procedures they must implement in order to comply with Canadian legislation. They state that, except in an emergency, the discharge of grey water should take place only when the ship is travelling at a speed of at least six knots, is not in port, and is at least four nautical miles from shore.

3. Oil pollution:

   Bilge water may include oil and fuel from on-board spills and wastes from engines and machinery. The *Canada Shipping Act* requires "zero discharge" of oily bilge water, and Transport Canada requires that bilge water discharged into the Canadian inland waters be processed, and that the filtering device be fitted with a stopping device that will automatically stop discharge when the oil content exceeds 15 parts per million (Transport Canada 2005; Nowell and Kwan 2001). In addition, each discharge must be recorded.

4. Hazardous wastes:

   Hazardous wastes include dry cleaning by-products (which contains perchlorethylene), waste (such as silver) from photo and x-ray processing laboratories, paint waste and solvents, print shop wastes, deodorizers and disinfectants (such as chlorine and formaldehyde), and batteries. The *Canada Shipping Act*, as well as Transport Canada (2005), provide regulations on the storage and disposal of hazardous wastes, and the International Council of Cruise Lines (2005) has adopted standards that require cruise lines to properly treat and dispose of hazardous wastes. However, Canadian law does not require full disclosure from ships on their generation and disposal of hazardous wastes, and Nowell and Kwan (2001) contend that illegal dumping may still be an issue.

5. Solid waste:
   Solid waste includes plastic, paper, wood, cardboard, food waste, cans, and glass. It has been estimated that a typical one-week cruise can generate as much as fifty tons of garbage (Nowell and Kwan 2001). Canadian law prohibits the dumping of garbage in all waters south of the 60th parallel of north latitude, and the *Oceans Act* also prohibits dumping in specified fishing zones (Nowell and Kwan 2001).

6. Air pollution:
   Air pollution from cruise ships is produced by on-board combustion and incineration, and emissions include CO_2, polycyclic aromatic hydrocarbons (PAHs), nitrogen oxide, and sulphur dioxide. In the year 2000, cruise ships emitted almost 300 000 tons of greenhouse gases, and this figure does not include the emissions from incineration (Haggarty *et al.* 2003). Canadian law prohibits the discharge of emissions beyond a maximum level (20% black space – a density measurement), and the unnecessary discharge of soot within 1 000m of land (Nowell and Kwan 2001). They also require that ships report annually the sulphur contents and quantity of all fuel deliveries for any fuel used while operating in Canadian waters (Transport Canada 2005).

7. Ballast water:
   Ballast water is taken on by ships for stability and constitutes a major pathway for introduced species. To deal with these organisms, ballast water is often treated with chemicals, many of which may create chlorine residues (Haggarty *et al.* 2003). Ballast water may also contain oil and chemicals. Canadian law requires that ballast water taken on outside Canadian jurisdiction not be discharged in waters under Canadian jurisdiction unless specific management options have been performed (personal communication, I. Wade, MCTS, Canadian Coast Guard, 2006).

8. Vessel coating:
   Cruise ship hulls are painted with antifouling compounds to prevent them from being colonized by marine life (see section 4.2.2). The most common antifouling coating on cruise ships is copper-based, and copper and zinc are the most common leachates (Haggarty *et al.* 2003).

Regulations regarding pollution from cruise ships tend to be more stringently enforced in US than in Canada (Nowell and Kwan 2001). Haggarty *et al.* (Haggarty *et al.* 2003) suggest the possibility that strict US laws may render Canadian waters more vulnerable to intentional discharge, in that ships may choose to rid themselves of their waste load in waters in which they are less likely to be caught and prosecuted.

The port of Prince Rupert is the major destination and stopover point for cruise ships in the north coast. The new Northland cruise terminal has the capacity to berth cruise ships up to 330 metres in length, while the smaller Atlin cruise terminal can handle vessels up to 100 metres in length (http://www.rupertport.com/facilities.htm). The Northland terminal attracted 50 cruise ships and 90 000 passengers in 2005, a 50% increase over the figures from 2004 (http://www.rupertport.com/whatsnew.php). The preliminary schedule for 2006 (valid as of March 20) shows that the port expects 60 cruise ships, 48 of which will call at the Northland terminal and 12 at the Atlin terminal http://www.rupertport.com/pdf/2006PrelimCruiseSched.pdf). It is partially due to the growing popularity of Seattle as a starting point for Alaskan cruises that the port at Prince Rupert has seen its rates of visitation increase: the 1886 US Passenger Services Act states that vessels not owned by US citizens, built at US shipyards, and crewed by US citizens cannot transport passengers between US ports. This means that since most cruise ships are foreign flagged and owned, cruises from US to Alaska must stop somewhere in BC (Fisheries and Oceans Canada 2005).

3.4 Whale Watching

Whale watching in BC is increasing steadily in popularity. An estimated 200,000 to 300,000 commercial whale watching tours are undertaken annually along BC's coast, and the number of people taking these tours each year is estimated to have surpassed one million (Lien 2005). It has been suggested that this industry has the potential to degrade cetacean habitat due the noise of vessels and their sheer numbers around whale pods. Several researchers have documented behavioural changes in killer whales in the presence of commercial whale watching vessels, ranging from changes in swimming speed to reductions in sleep and rest time (Lien 2005). Increased interest in whale watching means that there are more boats on the water, and besides the noise they produce, they create contaminant issues, such as leaching of antifouling compounds and fuel residues.

3.5 Synthesis

Tourism in British Columbia appears to be expanding in scope, as visitors discover less traditional means of experiencing the Pacific Northwest. BC's north coast and the port of Prince Rupert in particular are becoming increasingly popular as cruise ship destinations. This means that the environmental concerns surrounding the cruise ship industry must be taken seriously. Other forms of tourism, including whale watching and visits to remote fishing lodges, are also increasing in popularity. While these sectors are generally seen to pose less of an environmental threat than large scale tourism such as the cruise ship industry, their expansion may cause them to become a more significant issue.

4 Ports

4.1 Shipping

Shipping refers to the movement of cargo (Fisheries and Oceans Canada 2005) by vessels such as oil tankers, container and cargo ships, and barges (Haggarty *et al.* 2003). The north coast sees a significant amount of shipping traffic, especially in and around the large ports at Kitimat and Prince Rupert (Figure 3.1), with more expected as a result of upgrades to both ports. Many of the contaminant issues which have been discussed previously with respect to tourism and transportation are also an issue for shipping vessels. These include chronic oiling, air pollution, ballast water, and vessel coatings. Many of these issues become concentrated around ports, harbours and marinas due to increased vessel density, residence time, and dry-dock activities.

4.2 Major Ports

Ports, harbours, and marinas face numerous contamination challenges. Although large tankers avoid the PNCIMA where they can due to a voluntary tanker exclusion zone (VTEZ) extending 50 nautical miles off the coast, there are still a significant number of ships bound for major ports at Prince Rupert and Kitimat. Fishing vessel density is high at northern ports throughout the year as fish are brought in for processing and vessels are refuelled, serviced, or moored (Fisheries and Oceans Canada 2005), although fishing vessel traffic has decreased in the north coast in recent years (Table 3.1). Recreational vehicles are also regular users of north coast ports, harbours, and marinas, which are all subject to contamination from wood preservatives and anti-sapstains, antifouling compounds, and persistent pollutants such as PAHs and pentachlorophenol (PCP).

4.2.1 Wood Preservatives and anti-sapstains

Preservatives such as creosote and chromated copper arsenate (CCA) are used to prolong the life of wooden structures. While creosote is the most common wood preservative used in BC (in 1999 in comprised 66.4% of total pesticide sales and use in the province), none was sold or used in the north coast region in 1999 (ENKON Environmental Limited 2001). The only wood preservative with documented use on the north coast in 1999 was CCA (ENKON Environmental Limited 2001). This chemical is a concern because copper, chromium, and arsenic are all heavy metals, and the synergistic toxicity of copper and chromium is thought to make CCA more toxic than the sum of its components (Cox 1991). In the north coast, the main source of this pesticide is its use on docks, pilings, bulkheads, and piers (Cox 1991; Johannessen and Ross 2002).

Anti-sapstains are applied by lumber mills to freshly cut wood in order to protect it from fungal growth (Verrin *et al.* 2004). The anti-sapstains used on the north coast are didecyl dimethyl ammonium chloride (DDAC) and disodium octaborate tetrahydrate (ENKON Environmental Limited 2001). These chemicals have been shown to be highly toxic to fish (Fraser River Action Plan 1998) and, until recently, were stored outside and exposed to the elements, leading to substantial amounts of runoff in a rain event. However, mills now store treated lumber in covered areas and build catchment basins in order to prevent runoff from entering watersheds (Fraser River Action Plan 1998).

4.2.2 Antifouling compounds

Harbours and marinas have been identified as the sites with the greatest contamination by antifouling paints containing organotin compounds (Haggarty *et al.* 2003). These paints are used to prevent colonization by marine organisms on the hulls of boats, ships, and wooden structures (such as pilings and docks), thereby compromsing their structural integrity. One of the most common organotin compounds, tributlytin (TBT), has been used since the 1970s in Canada and around the world (Haggarty *et al.* 2003). Stewart and Thompson (1994) called it "the most toxic substance ever deliberately introduced into natural waters". In areas such as the Vancouver Harbour, effects have been observed on reproduction in molluscs by way of imposex (the development in females of masculine reproductive traits), which has resulted in population declines to the point of complete extirpation (Pierce *et al.* 1998 as cited in; Haggarty *et al.* 2003). For reasons such as this, TBT has been banned in Canada and other countries for vessels less than 25m in length (except aluminum-hulled boats) since 1989 (Haggarty *et al.* 2003). Ferries, cruise ships, and increasingly the Canadian Navy now use copper-based antifouling paints rather than

TBT (Science Advisory Panel 2002; Haggarty *et al.* 2003) (see Table A1 for possible effects of copper on the marine environment).

Despite the ban, TBT levels in industrial harbours such as the one at Prince Rupert, which frequently host boats greater than 25m in length, have not decreased (Pierce *et al.* 1998 as cited in; Haggarty *et al.* 2003). Besides its use on boats over 25m in length, other inputs of TBT also exist. These include leaching from old paint chips and the illegal use of remaining stocks of paints containing TBT on smaller boats (Stewart and Thompson 1997), and it has been suggested that despite the 1989 ban, TBT contamination is still widespread (Stewart and Thompson 1994).

4.2.3 Other Sources of Contamination

Sediment samples at harbours and marinas have been shown to be contaminated with high levels of pollutants such as PAHs and PCP (Haggarty *et al.* 2003). PAHs, a known carcinogen, are frequently discharged at marinas with fuel docks, and were found to be up to 260 times higher at harbour sites than non-harbour sites (Kay 1989). Harbours may also have increased levels of dioxins and furans, resulting from nearby wood treatment facilities and combustion (Yunker and Cretney 1996). Finally, the discharge of materials such as ballast water and sewage into the marine environment may be of concern in the north coast. Ballast water constitutes a major pathway for the introduction of exotic species. Although Canadian law states that ballast water taken on outside Canadian waters must not be discharged in waters under Canadian jurisdiction unless specific management practices are undertaken (personal communication, I. Wade, MCTS, Canadian Coast Guard, 2006), illegal discharge of ballast water by container ships can be very difficult to monitor (Fisheries and Oceans Canada 2005). In terms of sewage, there are no regulated 'no-discharge' zones in the north coast that would prevent it from being dumped (Haggarty *et al.* 2003).

4.2.4 Prince Rupert Port

While the port at Prince Rupert is currently the largest and busiest port on BC's north coast, the years 2002 and 2003 saw the lowest shipping volumes in decades (Fisheries and Oceans Canada 2005). Partly for that reason, a new cruise ship dock was completed in 2004. In 2005, the Fairview terminal was demolished and in its place is being constructed a high volume container terminal to accommodate the increasing import of goods from Asia. The environmental review for this new facility was approved by the Government of Canada on January 24, 2006 (**http://www.rupertport.com/**). The terminal will be constructed in two phases: the first will involve the creation of a 400m long berth out into deep water (minimum depth 16m) and will cover approximately 58 acres. The second phase will extend the dock to 800m and will increase the dock area to 165 acres (Figures 4.1 and 4.2). The new terminal is expected to be fully operational by 2007 (Fisheries and Oceans Canada 2005). Such a significant expansion will greatly increase not only the presence of treated and preserved wood and other construction materials in the marine environment, but the intensity of ship traffic in and around the north coast. As such, chronic oiling and inputs of compounds like CCA and anti-sapstains will continue to be of concern at the Prince Rupert port. Also, because the majority of ships visiting the new terminal will be over 25m in length, inputs of TBT will continue and likely increase at the port.

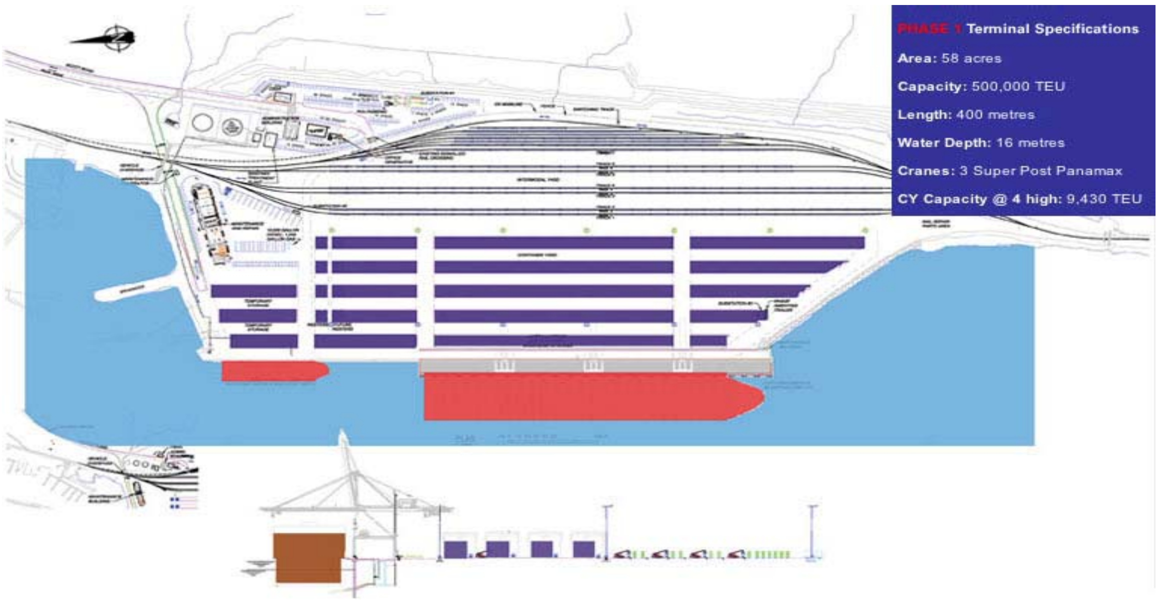

Figure 4.1 Phase 1 of the new Fairview high volume container terminal (figure from http://www.rupertport.com/container.php).

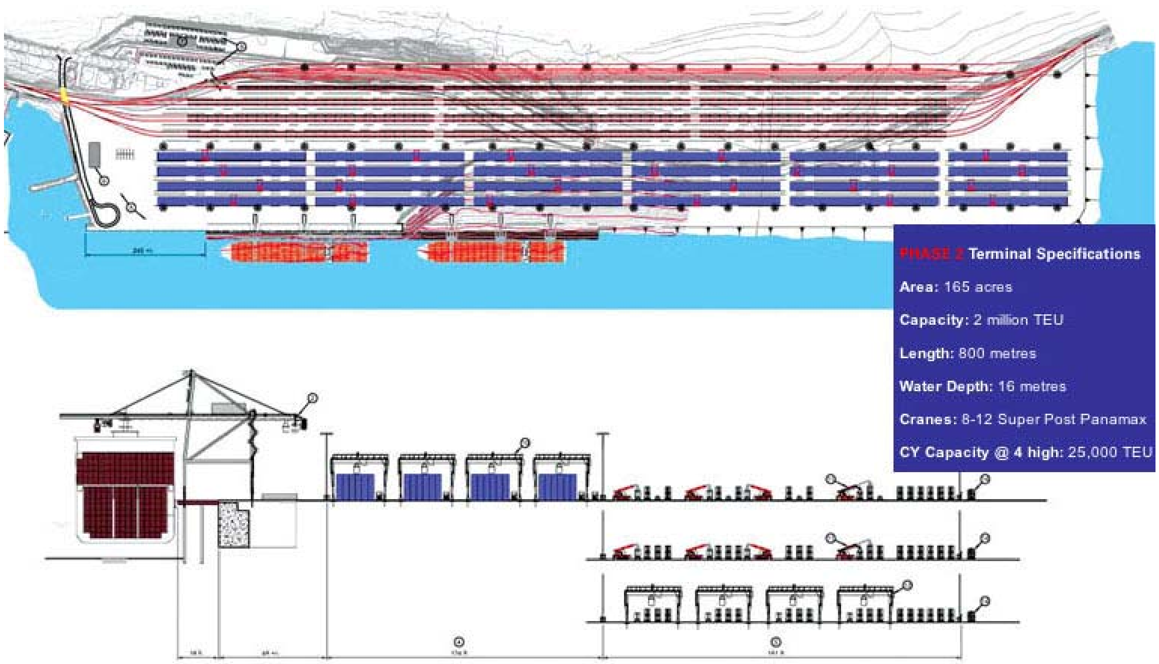

Figure 4.2 Phase 2 of the new Fairview high volume container terminal (figure from http://www.rupertport.com/container.php).

4.2.5 Kitimat Port

Two smaller ports comprise the main Kitimat Port: one serves industrial sites and the other is a small craft harbour (Fisheries and Oceans Canada 2005). Small craft harbours and their associated contaminant issues are addressed in the following section (4.3). The industrial port at Kitimat is the self-proclaimed first private container port in Canada, with no federal port authority (http://www.chamber-of-shipping.com/index/portsnorth, http://www.nwcorridor.com/bc/kitimat.html). It is the deepest and widest of the north coast ports (http://www.chamber-of-shipping.com/index/portsnorth) and serves the Alcan aluminum smelter, the Eurocan paper mill, and the Methanex methanol plant which is currently closed, although plans are in place to use the port for future methanol and condensate imports. Alcan sees the arrival and departure of several barges each month, while Eurocan expects about eight vessels a month (Fisheries and Oceans Canada 2005).

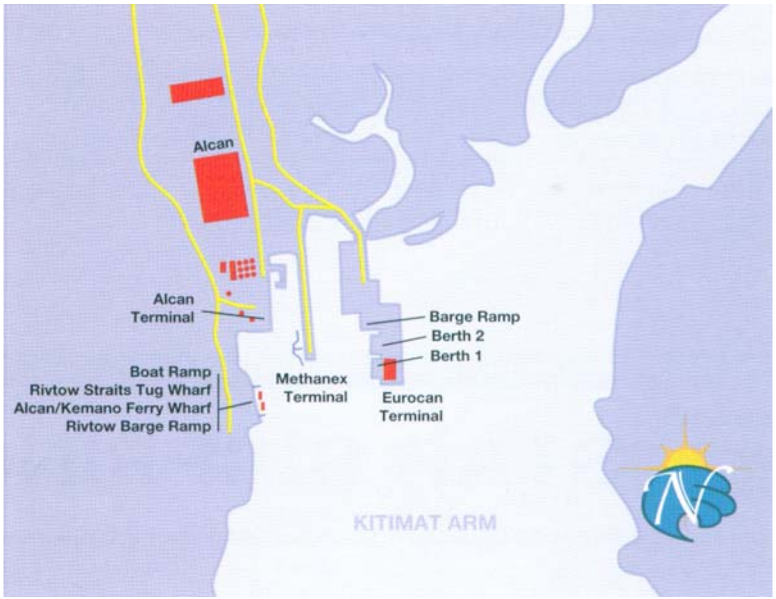

Figure 4.3 Layout of the existing industrial port at Kitimat (Fisheries and Oceans Canada 2005)

Enbridge Inc., operator of the world's longest liquid crude pipeline system, has entered a proposal to build a pipeline that would make Kitimat the destination for the export of crude oil and the import of condensate (Fisheries and Oceans Canada 2005). While this project may be four to eight years away, its potential impact on marine environmental quality in the north coast should not be overlooked. A second company is also looking into setting up operations in the Kitimat area. Galveston LNG, a company backed by European and U.S. investors, is proposing to build a liquefied natural gas (LNG) receiving, regasification, and send-out terminal in Emsley Cove, 15 km south of Kitimat. Construction is slated to begin in 2006 and the terminal is expected to be operational in 2008 (Fisheries and Oceans Canada 2005). Despite the apparent inconvenience, the company has proposed to build its terminal at some distance from Kitimat itself. This is in order to avoid opposition historically faced by LNG ports, stemming from a huge explosion at a port in Cleveland in 1941 which saw LNG banned from the United States for the next 20 years (Fisheries and Oceans Canada 2005).

4.2.6 Stewart

In addition to the large ports at Prince Rupert and Kitimat, there is a smaller port located close to the Alaska border at Stewart. It is the northern-most deep water port in BC and has limited facilities. However, it is capable of handling deep sea traffic year round and has ferry service via the Alaska Marine Highway (http://www.chamber-of-shipping.com/index/portsnorth). Possible contaminant issues would likely be very localized at this smaller port.

4.3 Small Craft Harbours and Marinas

There are a total of 19 small craft harbours throughout the north coast area. In recent years, the Department of Fisheries and Oceans (DFO) has been in the process of divesting itself of many of its small craft harbours, transferring ownership and/or management to local harbour authorities. Currently, seven small craft harbours on the north coast are still managed by DFO, and 12 are managed by local harbour authorities (Figure 4.4). The effect of divestiture on the quality and efficacy of environmental monitoring has not yet been determined.

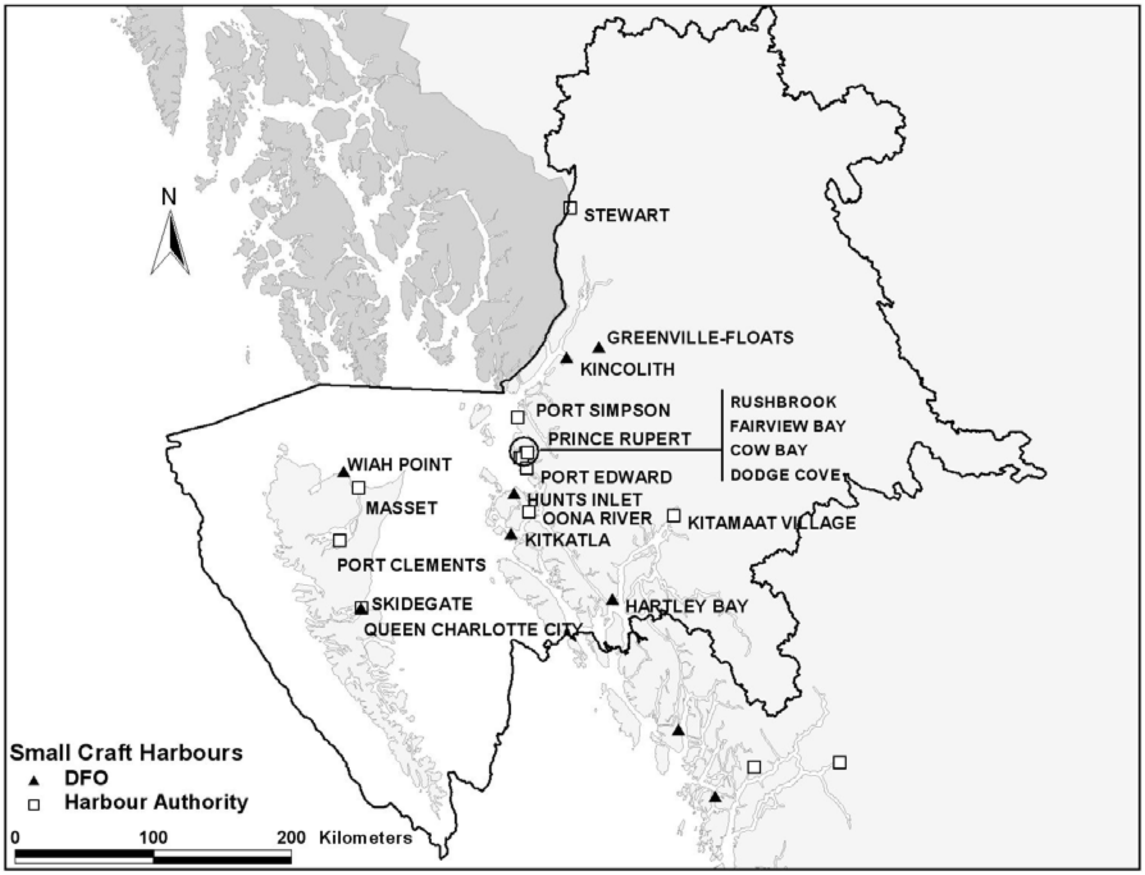

Figure 4.4 Locations and names of small craft harbours on BC's north coast (data from the BC Ministry of Sustainable Resource Management)

At harbours managed by the Small Craft Harbours division of DFO, several initiatives are underway with the goal of lessening their impact on the marine environment. While both washrooms and pump out stations exist at many harbours, washrooms are now preferentially installed over pump out stations to in order to reduce organic contaminants released into the water. There is also a major capital project underway in Prince Rupert that will use interception sites to achieve zero discharge of storm water from boat repair sites. The Small Craft Harbours division is also actively discouraging boat grids for hull maintenance and instead are suggesting that work be carried out in boat yards, where spilled and excess chemicals and wastes can be more easily kept out of the marine environment. Where boat grids are required, they have been modified in design to catch the run-off that results from maintenance. Finally, DFO is encouraging floating concrete to reduce the use of creosote in dock structures (Personal communication, A. Rowland, Small Craft Harbours, Department of Fisheries and Oceans, 2006).

In addition to the small craft harbours, there are numerous anchorages, boat launches, and marinas in the north coast area (Figure 4.5). For the most part, these small operations are not likely to have broad scale impacts except where many of them are clustered in one area. This tends to occur in populous areas, such as Prince Rupert and Kitimat, which also have large ports.

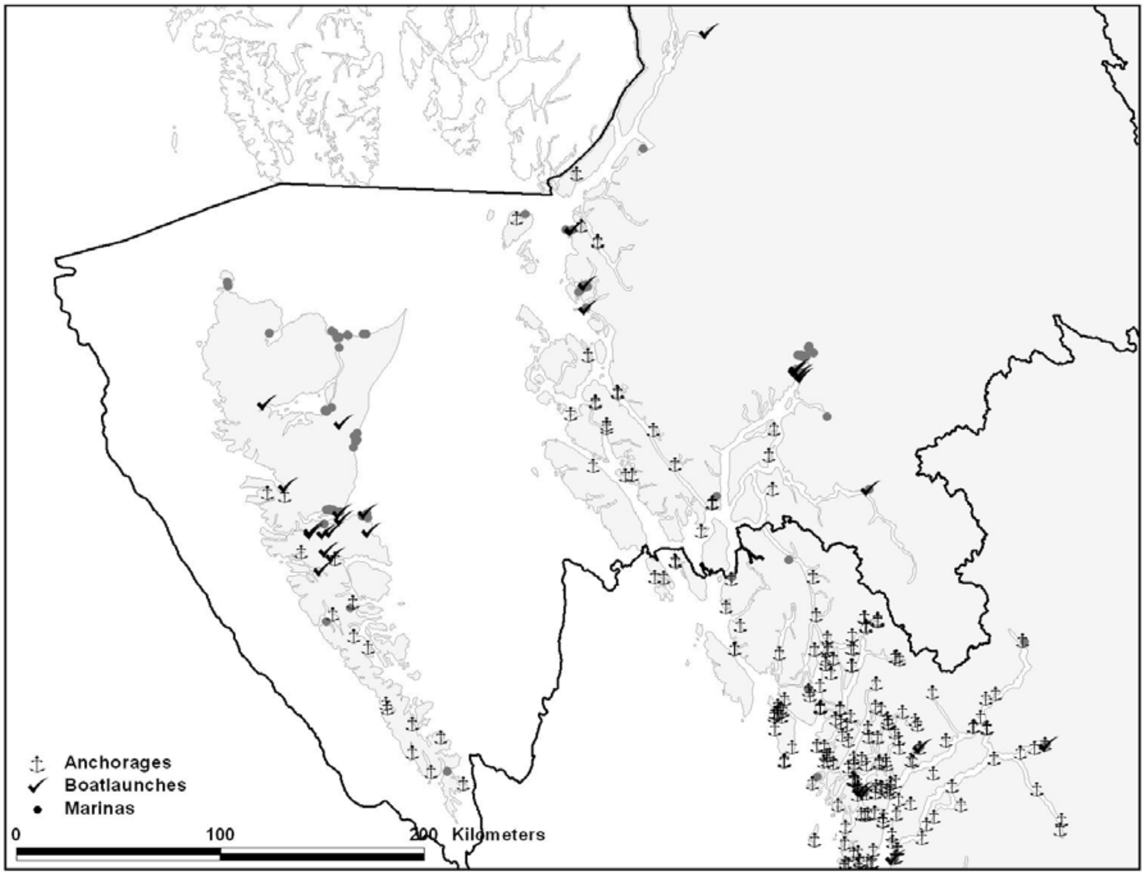

Figure 4.5 Locations of anchorages, boat launches, and marinas on BC's north coast (data from the BC Ministry of Sustainable Resource Management).

4.4 Synthesis

While vessel traffic, with the exception of ferries, has declined in the waters of BC's north coast in recent years, projects such as the high volume container terminal slated for Prince Rupert and possible development of the Kitimat port by industry suggest that this trend may change. In addition to chronic oiling, environmental concerns associated with the shipping include the chemicals used to maintain the structural integrity of both wood structures and the ships themselves. Wood preservatives and anti-sapstains have been shown to be toxic to marine life and antifouling paints containing toxic organotin compounds, though banned in Canada since 1989, persist at many ports and harbours. Persistent contaminants such as PAHs and PCP have also been detected at high levels at ports, harbours, and marinas.

Small craft harbours still managed by DFO are working to lessen their impact on the north coast marine environment and thus are not expected to pose a major contamination issue for the north coast. Whether the same can be said for harbours under private management and/or ownership is not yet clear.

5 Forestry

Forestry has traditionally played a significant part in the north coast economy. Aside from pulp mill activity, which is discussed in section 6, three main pollution concerns are associated with forestry activities: pesticide application; fire control chemical use; and the production of toxic leachates from woody debris. Significant portions of watersheds on both the north coast and the Queen Charlotte Islands contain tree farms, highlighting the importance of forestry activities in the area (Figure 5.1).

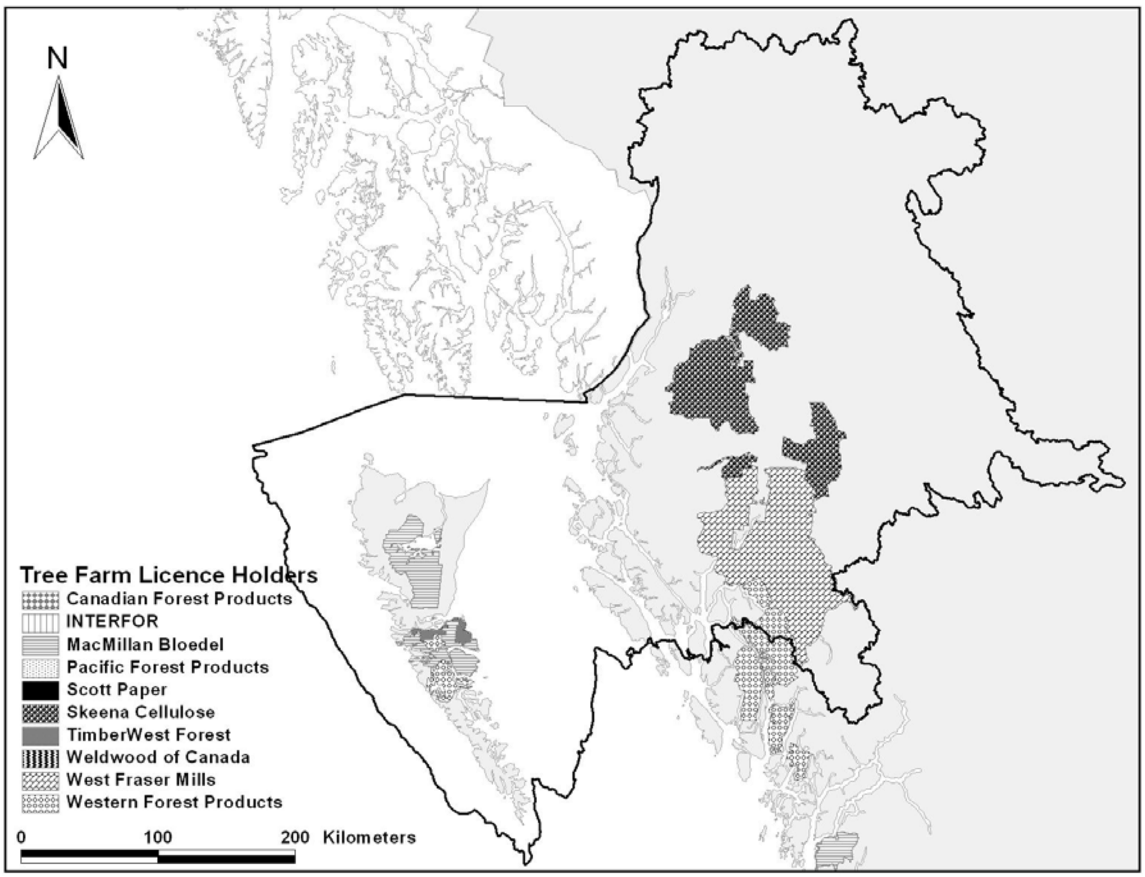

Figure 5.1 Location and ownership of tree farm licences on the northern coast of BC (data from the BC Ministry of Forests).

Pesticides are used in the forestry industry to battle destructive pests (insecticides) and to inhibit the growth of undesired plants (herbicides). In BC, the use of most pesticides has decreased over the last 20 years with the notable exception of two herbicides: glyphosate and triclopyr (data from the National Forestry Database Program: http://nfdp.ccfm.org). Glyphosate use has been variable but significant over the last decade and a half, accounting for approximately 90% of forest pesticide use (Verrin *et al.* 2004). It was also the only pesticide reported as sold in the North Coast region in 1999 (ENKON

Environmental Limited 2001). Glyphosate has a relatively short half-life in soil, and is considered slightly toxic to aquatic organisms and to have a low bioaccumulation potential (EXTOXNET 2003). Use of triclopyr has been increasing steadily in BC since the early 1990s. The triclopyr parent compound and amine salt are considered relatively non-toxic to fish, but the ester form, which is used in many herbicide formulations, is significantly more toxic (Wan *et al.* 1987). Triclopyr is only licensed for ground application in BC (rather than aerial spraying), which significantly reduces the chance of stream overspray and over-application. It was reported for use in the North Coast region for the first time in 1999 (Verrin *et al.* 2004). Considering the level of regulation and best practices development for pesticide application in the forest industry, pesticide use is not expected to be a significant marine environmental quality issue in the study area.

In the process of fighting forest fires, fire suppressant foams and fire retardant chemical salts are sometimes applied (Johannessen and Ross 2002). The fire retardant foams are of concern due to the surfactants they contain, which are used to strengthen the bubbles in the foam (Gaikowski *et al.* 1996). These surfactants can be acutely toxic and can also have sub-lethal effects at very low concentrations, as seen in other persistent organic pollutants (Section 10). The chemical salts are generally non-toxic; however, to inhibit corrosion of fire fighting equipment by the salts, sodium ferrocyanide is often added to the formulation. Upon exposure to sunlight, this substance can produce cyanide, which is highly toxic to fish (Burdick and Lipschuetz 1950; Norris *et al.* 1983; Little and Calfee 2000). However, since forest fires are relatively infrequent in BC's coastal rainforests, forest fire fighting activities are not predicted to significantly affect water quality in the study area.

Log dumping, booming, and storage are common activities in coastal waters and estuaries, and cause physical impacts including the compaction of seafloor sediments and smothering of benthic organisms by woody debris (Waldichuk 1979; Williamson *et al.* 2000; Conlan and Ellis 1979; Kathman *et al.* 1984b). The degradation of woody debris can also have chemical effects. On the sea floor, microbial activity uses up oxygen, potentially leading to anoxic conditions and toxic levels of hydrogen sulphide (Waldichuk 1979; Anderson and O'Connell 1977). Woody debris decomposing on land produces a concentrated leachate from the naturally occurring chemicals in the wood which can be toxic to aquatic life (Frankowski and Hall 1999). However, these hazards are recognized and work is being done to develop best practices to reduce impacts (White 2001).

6 Pulp and Paper Mills

There are two operational pulp and paper mills in the north coast area: Skeena Cellulose Inc. in Prince Rupert and Eurocan Pulp and Paper Co. Ltd. in Kitimat (Figure 6.1). In the earliest operation of pulp mills, the most significant effects reported were the introduction of fine solids (reported as total suspended solids or TSS) and biochemical oxygen demand (BOD). The oxygen demand of effluents resulted in very low dissolved oxygen in some rivers and estuaries, which resulted in mass mortalities of fish and other biota (Waldichuk 1961; Waldichuk 1963; Packman and Bradshaw 1977; Beak Consultants 1970; Beak Consultants 1974; Packman 1977). More recently, it was discovered that significant amounts of chlorinated organic compounds were being released into the environment, particularly dioxins and furans, as a result of the chlorine bleaching process (Harding and Pomeroy 1990; Servos *et al.* 1996; Yunker and Cretney 1995; Yunker *et al.* 2002; Colodey *et al.* 1990; Yunker and Cretney 2000b; Yunker and Cretney 2000a). Many of these substances are toxic, persistent, and tend to bioaccumulate in biota and biomagnify in higher trophic levels.

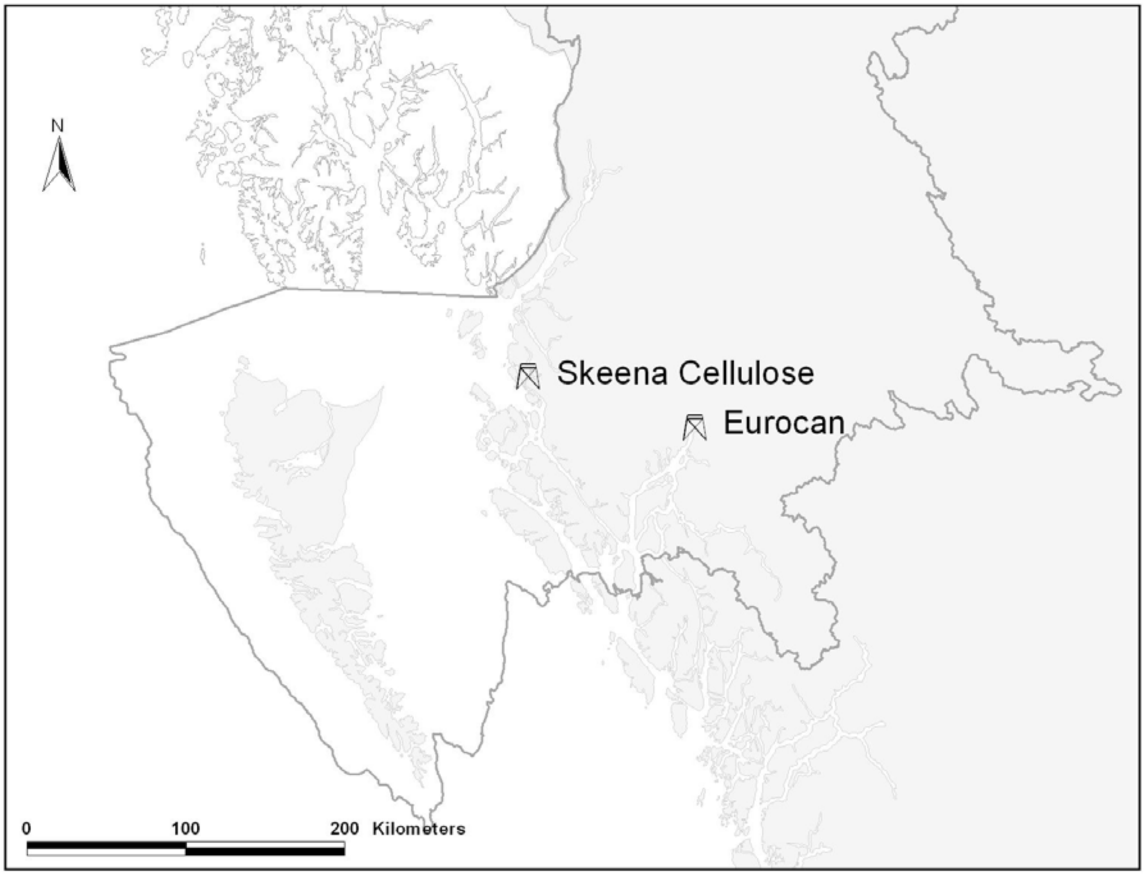

Figure 6.1 Location of the two currently active pulp and paper mills on BC's north coast

All BC pulp mills fall under federal legislation which prohibits the release of acutely toxic effluent and more recently, has severely restricted allowable dioxin and furan releases. By 1993, with the exception of Scott Paper, all BC pulp and paper mills had full secondary effluent treatment, involving bacterial decomposition of organic matter (Grant and Ross 2002). This effluent treatment and changes in chlorine use (largely a switch from Cl to ClO_2), have resulted in significant reductions in the toxicity of pulp and paper mill effluent. The improvements observed in BC pulp mill effluent since 1990 are summarized below (McGreer and Belzer 1999):

- The average acute toxicity of the effluent improved from 50% fish survival in 65% effluent solution concentration to 100% survival in 100% effluent concentration over 96-hour exposures.
- The number of days toxic effluent was discharged decreased by 99%.
- BOD decreased by 88% and is below allowable limits.
- TSS decreased 34% and is well below allowable limits.

- A 1996 study showed a 98.4% compliance with requirements of the Chlorinated Dioxins and Furans Regulations of the federal Canadian Environmental Protection Act (CEPA). This has resulted in a decline of over 99% in the discharge of dioxins and furans. For BC coastal pulp mills, Hagen *et al.* (1997) note a decrease of 97% between 1989 and 1994.

The effect of these changes on environmental loadings can be seen in Figure 6.2, which shows averaged data for Canadian pulp mills from 1990 to 2003. As dioxin and furan concentrations in mill effluent decreased, so have concentrations in sediments and in the tissues of benthic organisms such as crabs.

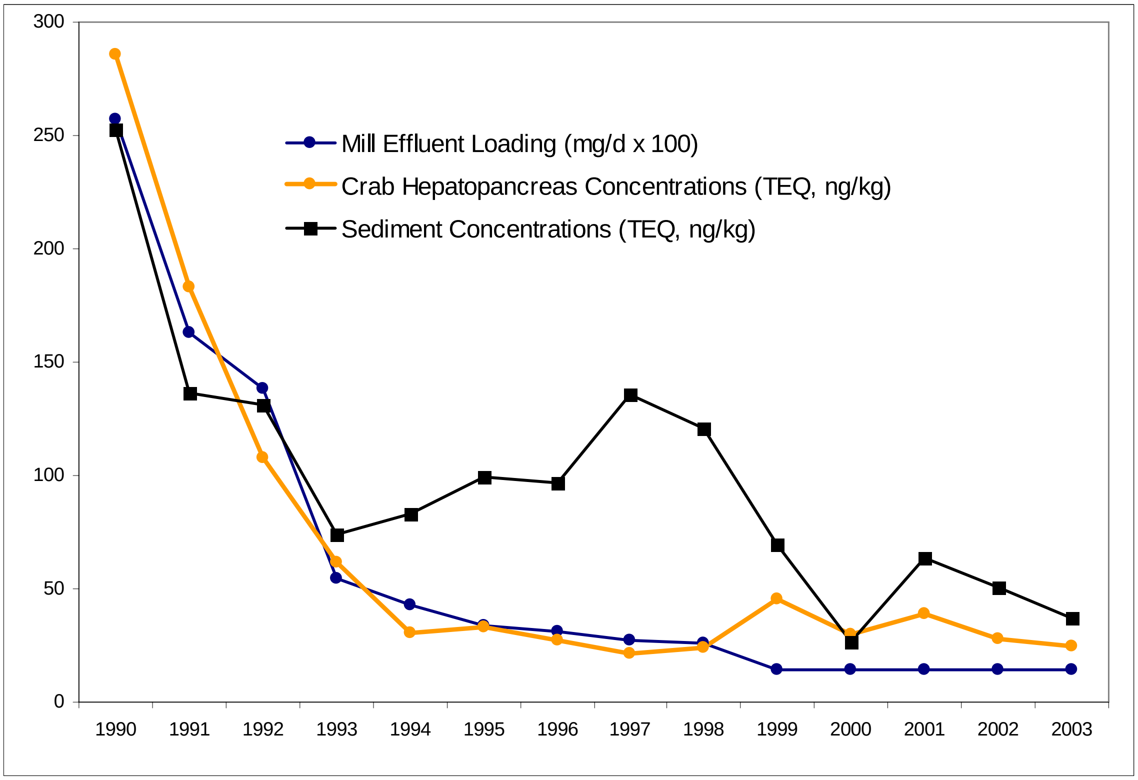

Figure 6.2 Change in dioxin and furan loadings in pulp mill effluents and concentrations in crab hepatopancreas and sediments near the outfall for 1990-2003 (graph from BC Ministry of Environment et al. 2006)

Current regulations require extensive environmental effects monitoring and reporting for all pulp mills (Colodey *et al.* 1999). Recent studies done for Eurocan (Norecol Dames & Moore 1997) and Skeena Cellulose (Dwernychuk and Hatfield Consultants Ltd. 1989; Hatfield Consultants Ltd. 1994; Hatfield Consultants Ltd. 1997; Hatfield Consultants Ltd. 2000) are readily available and provide a thorough review of monitoring efforts, which include toxicity (lethal and sublethal) testing, sediment testing, biological surveys, and tissue analysis.

Despite these improvements, there are still concerns about contaminants in pulp mill effluent. Sublethal effects are poorly understood and testing biota for chronic exposure to chemical mixtures presents both experimental and interpretive difficulties. Furthermore, while the changes have improved a number of water quality parameters and reduced the discharge of a number of known contaminants, there are a large number of contaminants of more recent concern which are poorly understood and not easily detected. Endocrine disruption is one of the major sublethal effects of pulp mill effluent and may result from combinations of endocrine disrupting compounds (EDCs) in the effluent, such as natural plant hormones, heavy metals, chlorinated compounds, and surfactants such as the alkylphenol ethoxylates (Hewitt and Servos 2001; Fox 2001; Yang and Randall 1996; Hodson *et al.* 1992; Kiparissis *et al.* 2001). Research has demonstrated a decline in the concentrations of a large number of EDCs after secondary treatment of the pulp mill effluent (Janz *et al.* 2001). However, the study did not analyse for the degradates of the chemicals tested, which raises the possibility that while secondary treatment reduces the concentration of parent compounds, the concentration of degradates, which may have an equal or greater endocrine disrupting effect, may increase.

7 Mining and Smelting

Mining is one of the few major active industries on BC's north coast. A large number of decommissioned and active mines exist in the watersheds of this area (Figure 7.1). Of these, some have directly impacted the marine environment either through discharge of tailings to coastal waters, or through an increase in local acid rock drainage (which usually includes heavy metals mobilized by the low pH). The latter is not clearly documented, but a study in the provincial report Environmental Trends in British Columbia 2002 (Ministry of Water Land and Air Protection 2002) identifies sites thought to be a risk for acid rock drainage and/or metal leaching, including the former Tasu and Jedway mines on Haida Gwaii, the Anyox slag heap and Kitsault mine near Observatory Inlet, and a few inland sites in the Skeena and Nass river watersheds (Figure 7.2). Little information was available on these interior sites. However, acute toxicity tests of mine tailings done for the Noranda (Bell) and Granisle copper mines located in the upper reaches of the Skeena watershed found no mortality in salmon after 96 hours of exposure to undiluted tailings effluent (Hoos and Holman 1973).

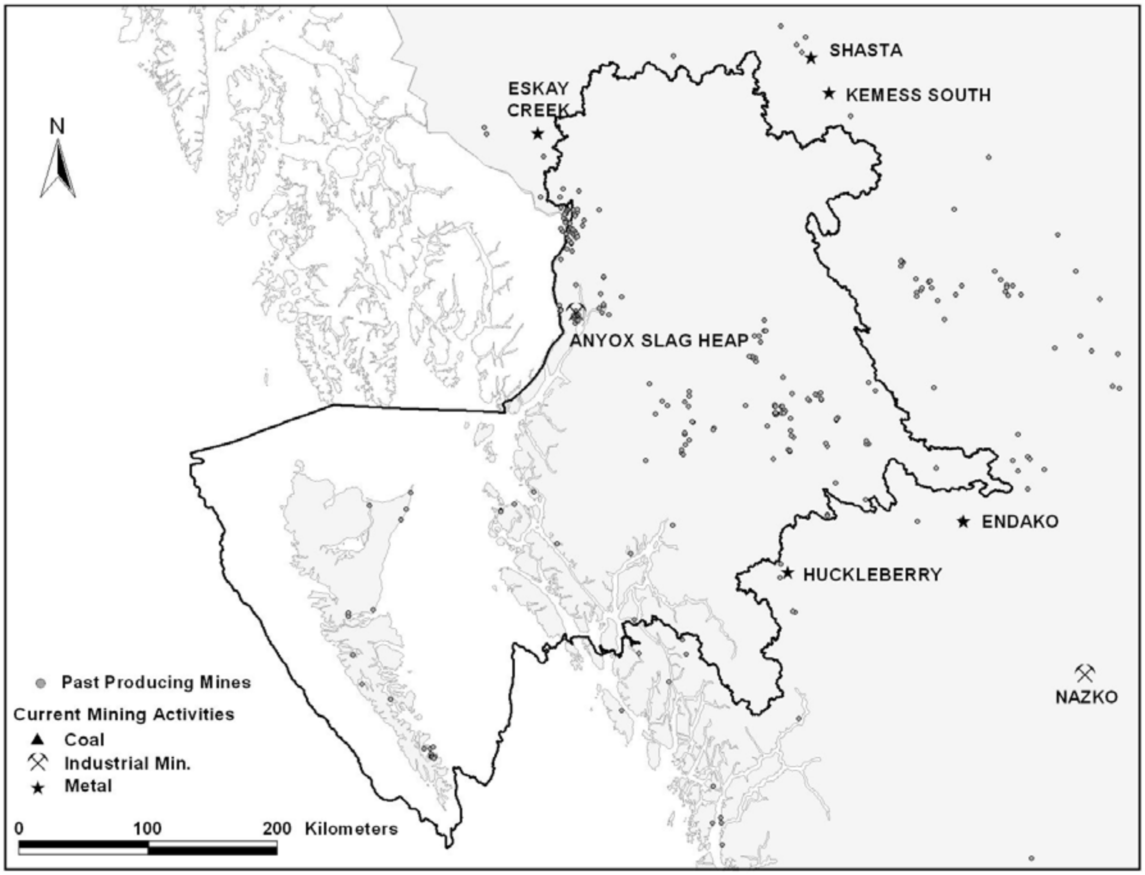

Figure 7.1 Location and type of active mines in and around the study area and locations of historically active mine sites (data from the BC Ministry of Energy and Mines).

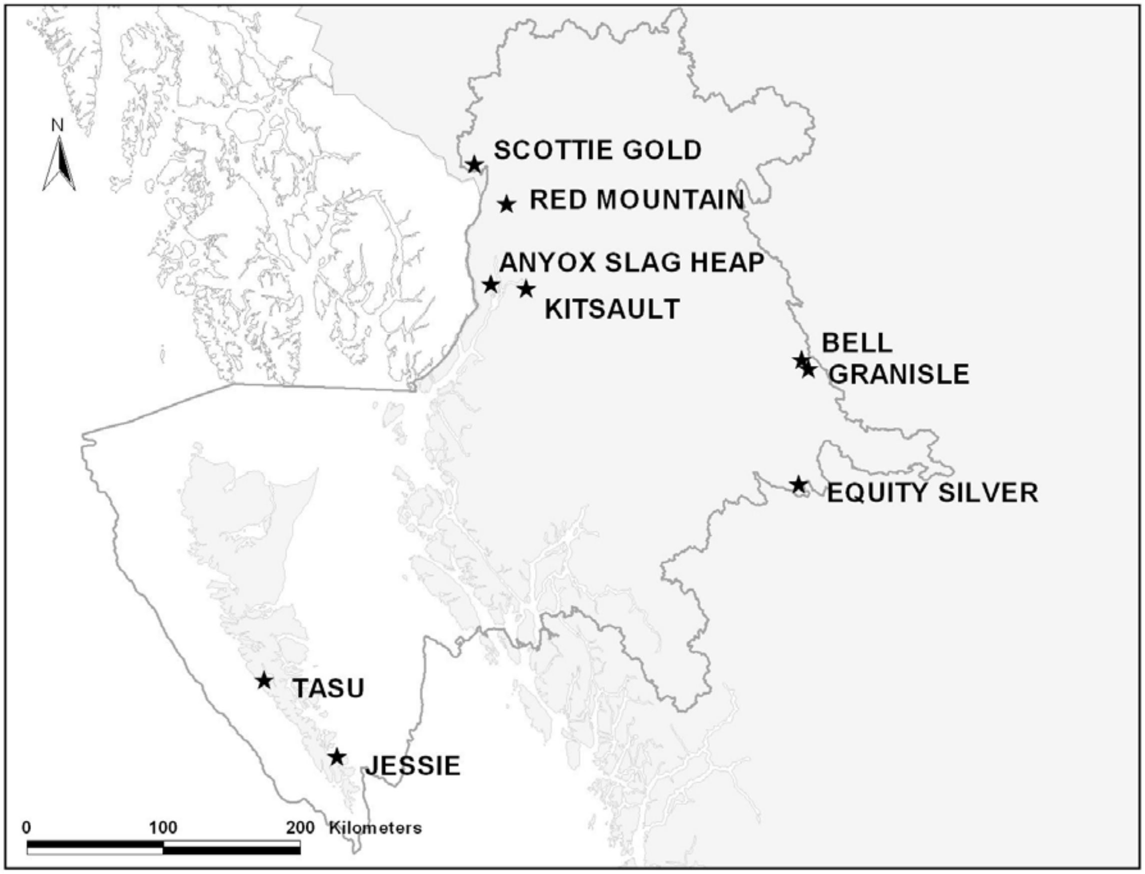

Figure 7.2 Location of mines and advanced exploration sites (both active and decommissioned) which are thought to present a risk of acid rock drainage and associated heavy metal leaching (data from Ministry of Water Land and Air Protection 2002)

7.1 Mining and Smelting in the Alice Arm/Observatory Inlet area

The area around Alice Arm has been the site of numerous mining ventures and is estimated to have provided approximately 388 000 tons of copper, lead molybdenum, gold, and silver between 1911 and 1972 from nine regional mines (Littlepage 1978). Extraction occurred primarily at the Anyox and Kitsault mines, with contributions from other Alice Arm area mines, such as the Torbrit, Dolly Varden, and Esperanza mines. Heavy metal contamination has been attributed to the Anyox, Kitsault, and Dolly Varden operations. Brief summaries of these three operations and the research into their effects are provided here.

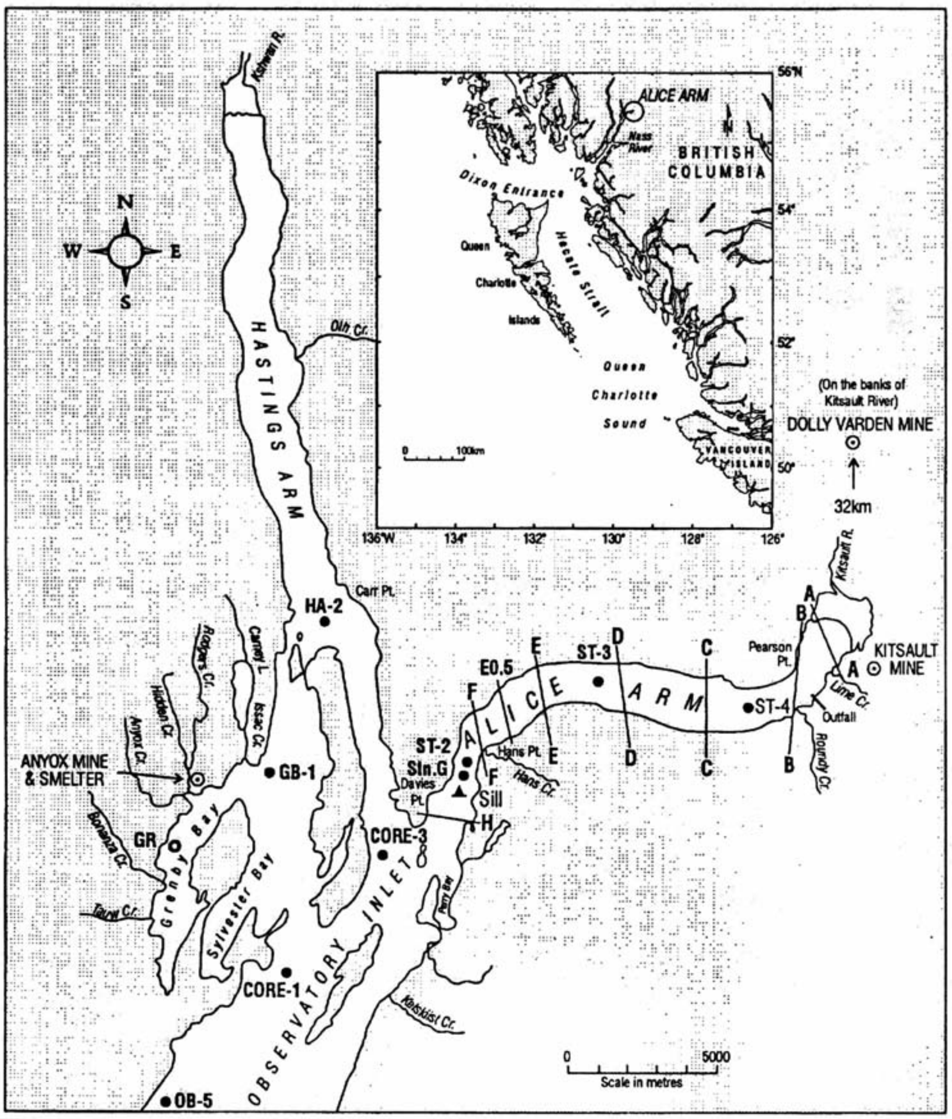

Figure 7.3 Map of Observatory Inlet area showing the location of the Kitsault, Dolly Varden, and Anyox mine sites as well as sediment core and surface sediment sampling transects (figure from Odhiambo et al. 1996)

7.1.1 Anyox Slag Heap History and Literature

Copper deposits in the area of Granby Bay (Figure 7.3) were found in the late 1890s and mined by Granby Consolidated Mining, Smelting and Power Company beginning in 1914. The mine smelted its own ore and later shipped out concentrate. The pyretic copper smelter at Anyox operated from 1914 to 1936 and was one of the largest in the British Empire (Goyette and Christie 1982b; Pinsent and Pardoe 2003). The smelter was also used to process ore from other deposits along the coast of BC and southeastern Alaska.

Slag from the smelter was dumped on shore and in the intertidal zone of Granby Bay. The slag pile eventually covered 51 acres and weighed several million tons (Goyette and Christie 1982b). Tailings from the copper mining were disposed of in small tailings ponds behind the smelter and adjacent to Hidden Creek. It is suspected that leaks from these tailings ponds entered Hidden Creek, causing a very low pH (2.2 – 2.6) and high iron (134-4770 mg/L), copper (2.6 – 294 mg/L), and zinc (2.9 – 73 mg/L) concentrations (BC Research Council 1973 as cited in Goyette and Christie 1982b).

The ongoing erosion of slag deposits are thought to be the cause of elevated levels of copper, zinc, cadmium and iron in local marine sediments 42 years after mine abandonment. 1978 sediment cores obtained near Anyox show a copper content averaging 650 mg/kg. Background concentrations were estimated at 30-50 mg/kg. Samples from other industrial sites in BC revealed copper concentrations of 256 mg/kg (Victoria Harbour), 70-190,000 mg/kg (Vancouver Harbour) and 199-700 mg/kg (Rupert-Holberg inlets). Zinc concentrations near Anyox ranged from 2000 to 2385 mg/kg. Background zinc concentrations in the Alice Arm area ranged from 91 to 135 mg/kg, while concentrations at other industrial sites were measured at 246 mg/kg (Victoria Harbour) and 9910 mg/kg (Vancouver Harbour). Cadmium concentrations near Anyox ranged from 24 to 29 mg/kg. Background cadmium concentrations for the area ranged from 1 to 2 mg/kg, and other industrial sites generally ranged from 1 to 5 mg/kg with a few exceptions, such as Vancouver Harbour, where concentrations were measured at 31 mg/kg (Garrett 1981 as cited in Goyette and Christie 1982b).

Elevated concentrations of copper and zinc were detected in mussels and alga sampled near Anyox. It is unclear whether these values resulted from drainage water from the tailings ponds, dissolution of metals from the weathering of the slag, or uptake of particulates from the slag (Goyette and Christie 1982b).

Currently, the slag heap is being mined by Tru-Grit Abrasives for the silica used in sandblasting abrasives and asphalt shingles. The Anyox area has not been as well studied as the adjacent Alice Arm (see below) and it is not known if mining of the slag is affecting the rate at which metals are entering the marine environment. However, it is clear from previous studies that both the slag heap and the tailings ponds associated with the Anyox mine are adding significant quantities of heavy metals to the local environment. Indeed, elevated metal concentrations in sediment core samples from as far away as Hastings Arm, Observatory Inlet, and Granby Bay have been attributed to Anyox. There is even evidence that when Anyox was active, impacts of its operation were observable in Alice Arm. It is estimated that copper and zinc contaminant loads in sediment, with half-lives of between 75 and 100 years, are only gradually decreasing (Odhiambo *et al.* 1996). Although the Anyox site is clearly contaminating the environment, information regarding potential biological effects of this contamination was unavailable.

7.1.2 Alice Arm – Amax/Kitsault mine tailings: history and literature

The Kitsault mine was operated by B.C. Molybdenum from 1967 to 1972. During this time, mine tailings were discharged directly into Lime Creek, which flows into Alice Arm. Estimates of total tailings discharge range from 9.3 million tons (AMAX of Canada 1991; Burd *et al.* 2000) to 12 million tons (6 000 tons of ore per day) (Goyette and Christie 1982b). The property was subsequently acquired by Amax of Canada Ltd. (formerly Climax Molybdenum Corporation of British Columbia Limited) and production continued from April 1981 to October 1982 (Littlepage 1978; Goyette and Christie 1982b; Burd *et al.* 2000). During this operational period, approximately 4.1 million tons (12 000 tons per day) of tailings were discharged directly into Alice Arm through a submarine disposal pipe at 50m depth (AMAX of Canada 1991; Burd *et al.* 2000).

The Dolly Varden silver mine, located roughly 32 km up the Kitsault River from Alice Arm, operated between 1948 and 1959. Barium rich tailings were discharged into the Kitsault River and washed down into Alice Arm (Burd *et al.* 2000; Odhiambo *et al.* 1996). High concentrations of cadmium, lead, and zinc in sediment cores are correlated with high barium concentrations, which suggests that these values are related to buried tailings from the Dolly Varden operation (Odhiambo *et al.* 1996).

A significant research program at the Amax site was commissioned by Climax Molybdenum Corporation of British Columbia Limited. It ran from1974 to 1977 and was headed by J. L. Littlepage with assistance from Dobrocky SEATECH Ltd. The results of the program were published in 35 technical reports covering physical, chemical, and biological oceanography as well as biological and hydrological studies (complete list in Appendix I of Littlepage 1978). A number of the studies looked at heavy metal content in sediments, water, and biological tissues (Goddard 1974b; Dempsey and Ernst 1975; Lea 1976; Dempsey and Ernst 1976; Goddard 1974a). The program continued to analyze metal contamination of marine and suspended sediments and biological tissues into the 1980s (Yunker *et al.* 1981; Smyth 1982; Erasmus and Yunker 1983; Yunker and Erasmus 1983; Yunker *et al.* 1983). After the second phase of operation of the mine, Amax produced annual reports of the Environmental Monitoring Program (e.g. AMAX of Canada 1991).

Fisheries and Oceans Canada commissioned a technical assessment of the tailings discharge to Alice Arm in the early 1980s (Burling *et al.* 1981; Burling *et al.* 1983). DFO also published a number of reports relating to the tailings issues in Alice Arm, which included ocean chemistry and sediment trap data (MacDonald *et al.* 1984a; MacDonald *et al.* 1984b; MacDonald *et al.* 1984c; O'Brien and MacDonald 1995), benthic infaunal survey data (Kathman *et al.* 1983; Kathman *et al.* 1984a; Brinkhurst *et al.* 1987; Burd and Brinkhurst 1990), data on heavy metal concentrations in various biological tissues (Futer and Nassichuk 1983; Farrell and Nassichuk 1984; Brand *et al.* 1984; Byers *et al.* 1984; Thompson *et al.* 1986), and studies on the effect of the tailings on zooplankton (Mackas and Anderson 1983; Anderson 1986). The data from these studies supported a number of journal articles on topics such as sediment and benthos (Odhiambo *et al.* 1996; Burd *et al.* 2000; MacDonald and O'Brien 1996), zooplankton (Anderson and Mackas 1986), the biogeochemistry of arsenic (Reimer and Thompson 1988), and the merits of submarine tailings disposal (Pedersen *et al.* 1995).

Environment Canada also produced a number of reports related to the Alice Arm submarine tailings disposal which focused on sediment and tissue metal contamination and water transmissometry and chemistry. These reports include studies carried out prior to the 1981 resumption of disposal (Sullivan and Brothers 1979; Goyette and Christie 1982b), studies conducted during mine operation (Goyette and Christie 1982a; Hinder and Goyette 1982; Goyette *et al.* 1985), and a tailings bioaccumulation experiment (Guthrie 1985).

These studies suggest that effects generated by the discharge of tailings have been largely restricted to Alice Arm. Earlier operation of the Dolly Varden and Kitsault mines did result in detectable metal concentrations in Alice Arm sediments but these are largely buried, suggesting that contributions from these tailings may have decreased since operations ceased. Tailings disposed of as a result of more recent operation of the Kitsault mine are believed to have remained within Alice Arm. Both metal concentration analysis (Odhiambo *et al.* 1996, Figure 7.4) and sediment trap data (MacDonald and O'Brien 1996, Figure 7.5) support this conclusion. Metal contamination is estimated to have measurably affected about half the area of Alice Arm (approximately 14 km^2) and significantly impacted about 7 km^2 (Figure 7.4).

The majority of the tailings (approximately 96%, Burling *et al.* 1981) either settled out immediately below the outfall or were carried as a turbidity current into the deep central trench of Alice Arm (Figure 7.5). Roughly 4% of the tailings formed a mid-water depth plume with an upper edge at 65-125m depth. This plume was thought to pose a potential threat to zooplankton, but studies on lethal and sublethal effects failed to find any physiological changes in zooplankton exposed to tailings at the concentrations detected in the field (Anderson and Mackas 1986). The study did not investigate possible long term effects such as bioaccumulation.

Studies of metal concentrations in biological tissues found no evidence of bioaccumulation over time (AMAX of Canada 1991). Indeed, concentrations detected in higher trophic level species such as yellowfin sole, eulachon, and Tanner and King crabs, suggest that foodweb biomagnification is not an issue in Alice Arm (AMAX of Canada 1991; Futer and Nassichuk 1983). Overall these findings suggest that metals in the Alice Arm tailings are not making their way into the biological foodweb in significant amounts. One exception to this finding is the elevated metal concentrations detected in deposit feeding clams (*Yolida* spp.). The concentrations mimic those found in the tailings themselves and it has been argued that rather than reflecting contaminated tissues, this is an indication of contamination of the clams by undigested tailings particles (AMAX of Canada 1991). This argument is not universally accepted (Burd *et al.* 2000).

The only clear effect of the submarine tailings disposal in Alice Arm is the physical smothering of benthic infauna. This was expected, and organisms were expected to re-colonize the affected area after mine closure as the tailings became buried by natural sedimentation. Indeed, considerable recovery was noted three years after mine closure, although only by some species. Large taxa showed much slower recovery (Burd *et al.* 2000). Unexpected results of the tailings disposal were observed after mine closure as a result of slumps and tailings re-suspension. These events caused new defaunation events and presence of exposed tailings at the sediment surface (Burd *et al.* 2000). Such events must be taken into account when estimating environmental recovery.

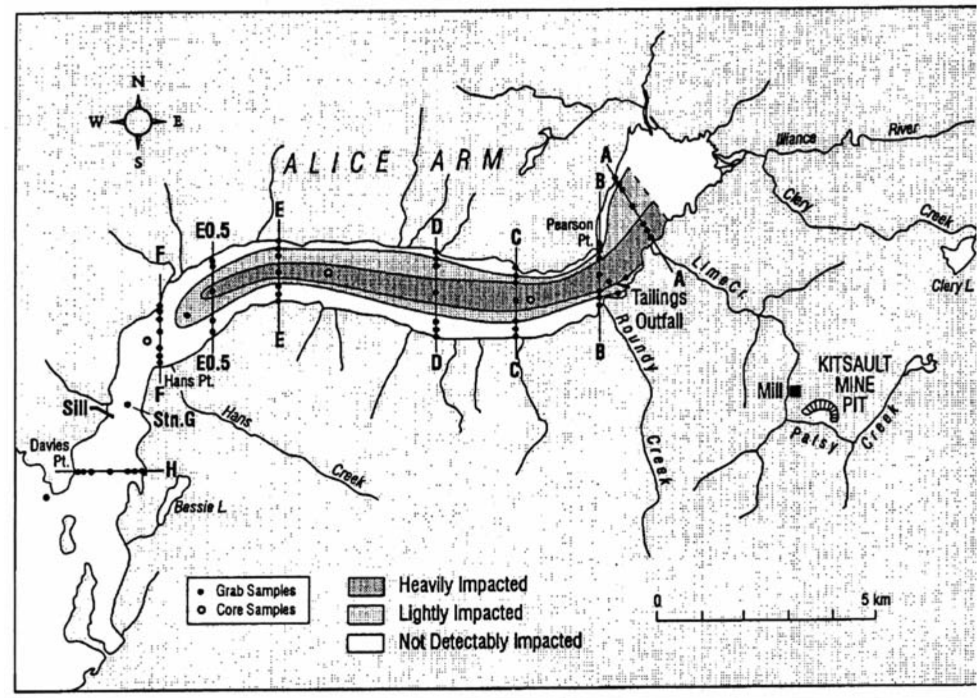

Figure 7.4 Map of tailings dispersal in Alice Arm as indicated by sediment metal concentrations. Contours are based on Principal Component Analysis of sediment metal data, with the lighter shading in the area readily distinguishable from background and darker shading indicating samples more than two standard deviations above this (figure from Odhiambo et al. 1996)

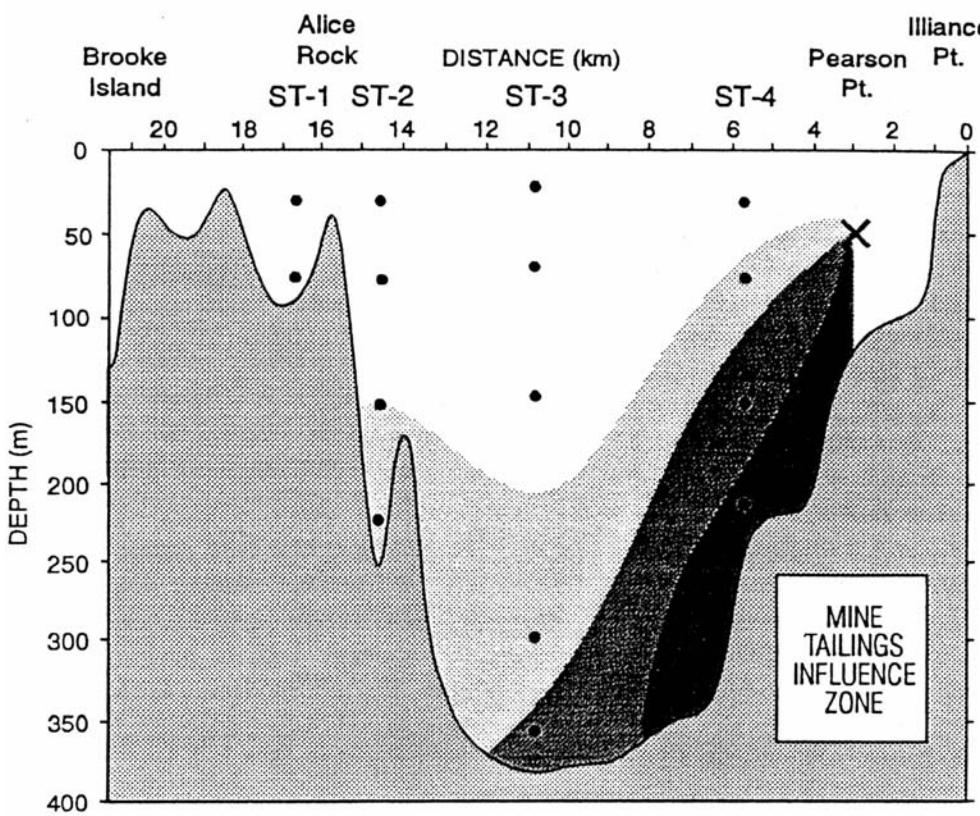

Figure 7.5 Diagram of submarine tailings transport from Kitsault mine based on sediment trap data. Dark black area illustrates the region overwhelmed by tailings, medium black shows the area where tailings dominate relative to natural sediment flux, and light shading indicates area where tailings are detected intermittently or at low levels. Tailings were not detected in the unshaded areas (figure from MacDonald and O'Brien 1996)

7.2 Submarine Tailings Disposal at Tasu Sound, Queen Charlotte Islands

Tasu Sound is located on the west coast of Moresby Island. Wesfrob Mines Limited discharged mine tailings directly into Tasu Sound from its iron-copper dressing plant beginning in 1967 (Brothers 1978). The mine closed in 1983 due to the exhaustion of economic reserves.

Environment Canada completed an environmental assessment on the effects of the discharge in 1977. The assessment determined that the mine tailing discharge into Tasu Sound had limited and localized effects that were "*…not considered to pose a serious threat to the marine ecosystem of the area*" (Brothers 1978). The study did not delineate the full extent of copper and iron contamination in sediments because of an insufficient sampling grid size. Concentrations elevated above background levels were found to extend 2.3 km north and northeast of the foreshore outfall site. Elevated zinc values were confined to within 1 km of the tailings delta. Lead, cadmium and mercury concentrations were not found to be higher than background concentrations in the sediments, nor were they elevated in fish and algae tissue samples. Reduced water column transmissibility, phytoplankton productivity, and the bioconcentration of heavy metals in fish and algae tissues all appeared to be confined to the immediate vicinity of the tailings outfall. A test of the acute toxicity of the mine effluent found no mortality in salmon after a 96 hour exposure to undiluted tailings effluent (Hoos and Holman 1973).

As the mine has been closed for more than 20 years, environmental effects should be considerably reduced relative to those detected at the time of these early studies, but no further research was found to confirm this.

7.3 Aluminum Smelting at Kitimat

Western Canada's only aluminum smelter, owned and operated by Alcan, is located in Kitimat. Initial contaminant concerns focussed on the dispersion of fluoride into terrestrial and marine ecosystems and biota (Brewer *et al.* 1979; Hocking *et al.* 1980; Bell and Kallman 1976); however, changes in smelter processes and additional emission controls reduced fluoride emissions. Of more recent and ongoing concern is the release of polycyclic aromatic hydrocarbons (PAHs) in air emissions and water effluent via two main routes: contamination by the pyrolysis and volatilization of the pitch/tar anode binder from the Söderberg electrode, and by the offloading and handling of pitch and coke on-site (Simpson *et al.* 1998b). PAHs include a wide range of compounds and can have both lethal and sublethal effects. PAHs include substances that are carcinogenic, and have been listed by the USEPA as having the third highest risk for contaminating sediments (United States Environmental Protection Agency 1996).

Numerous studies have shown that PAHs are present in highly elevated concentrations in biota and marine sediments around Kitimat Arm in patterns which clearly implicate the Alcan smelter as the source (Erickson *et al.* 1979; Simpson *et al.* 1998a; Paine *et al.* 1996; Simpson *et al.* 1996; Eickhoff *et al.* 2003a; Eickhoff *et al.* 2003b). However, despite their known presence in the environment, no studies have shown a clear link between PAH contamination and health effects in biota (Erickson *et al.* 1979). Some have proposed that this indicates low PAH bioavailability (Paine *et al.* 1996). Regardless, the area around the Kitimat smelter is considered significantly contaminated by PAHs.

7.4 Heavy Metals in the Environment

Very little information exists on the presence of naturally occurring or anthropogenically derived heavy metals in the broader marine environment of BC's north coast. A summary of shelf sediment geochemical knowledge was produced by Macdonald and Pedersen (1991), and some trace metal work was done on Hecate Strait marine sediments in 1979 (Sneddon and Holman 1982). Information on heavy metals in the water column is even more sparse and is generally related to methods development (Lu *et al.* 1986; Stukas *et al.* 1999). Some work has been done on fish, shrimp, and prawns, which showed slightly elevated levels of cadmium and lead (Harding and Goyette 1989). Work on seabirds and scoters (sea ducks) detected elevated cadmium levels, particularly around the Queen Charlotte Islands (Barjaktarovic *et al.* 2002; Elliott and Scheuhammer 1997), but studies of mercury in bald eagles did not detect significant values in the north coast area (Weech *et al.* 2003). Finally, elevated levels of cadmium in oysters and scallops have been detected all along the BC coast (Kruzynski 2004; Kruzynski *et al.* 2002; Kruzynski 2000). Specific sources of this contamination are not identified.

8 Aquaculture

8.1 Finfish Aquaculture

While salmon aquaculture constitutes a major source of employment and revenue for much of coastal British Columbia (Figure 8.1), no finfish aquaculture is occurring on the north coast at this time (Thomson, A.J.L., personal communication, Figure 8.2). At present, it is unclear as to whether finfish aquaculture development will take place on the north coast (Ministry of Employment & Investment (Economics Branch) *et al.* 2000). This section summarizes and updates the issues addressed in Haggarty *et al.* (2003), and provides background information should aquaculture operations occur.

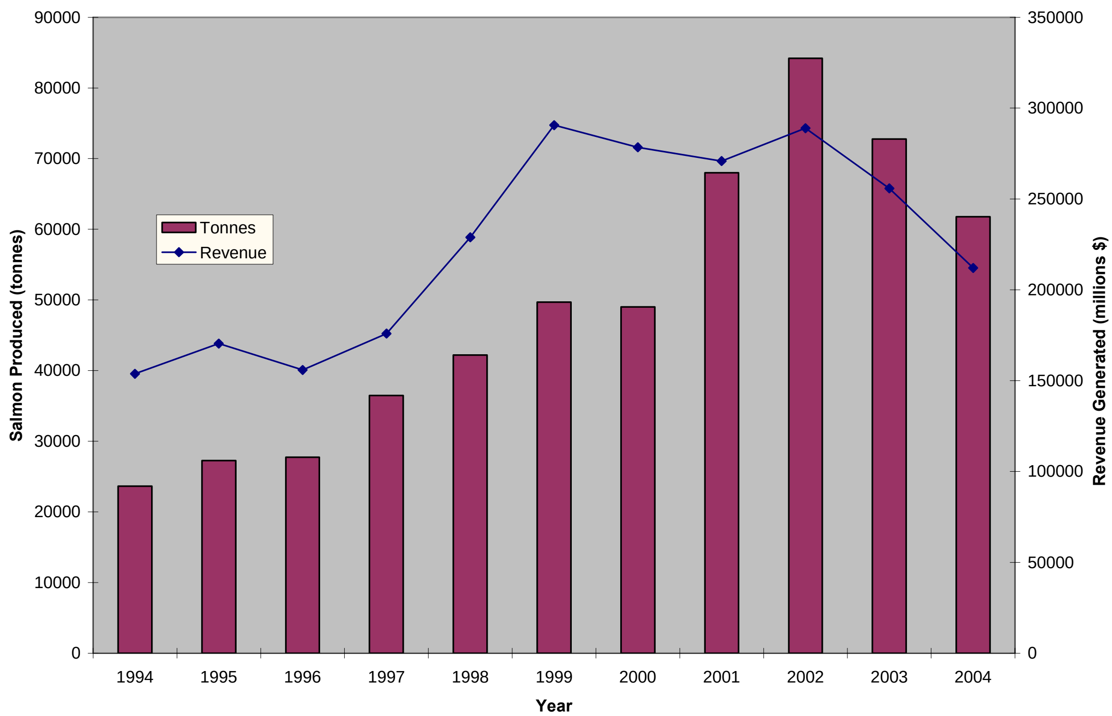

Figure 8.1 Amount of salmon produced and revenue generated by BC's salmon farming industry (data from http://www.dfo-mpo.gc.ca/communic/statistics/aqua/index_e.htm).

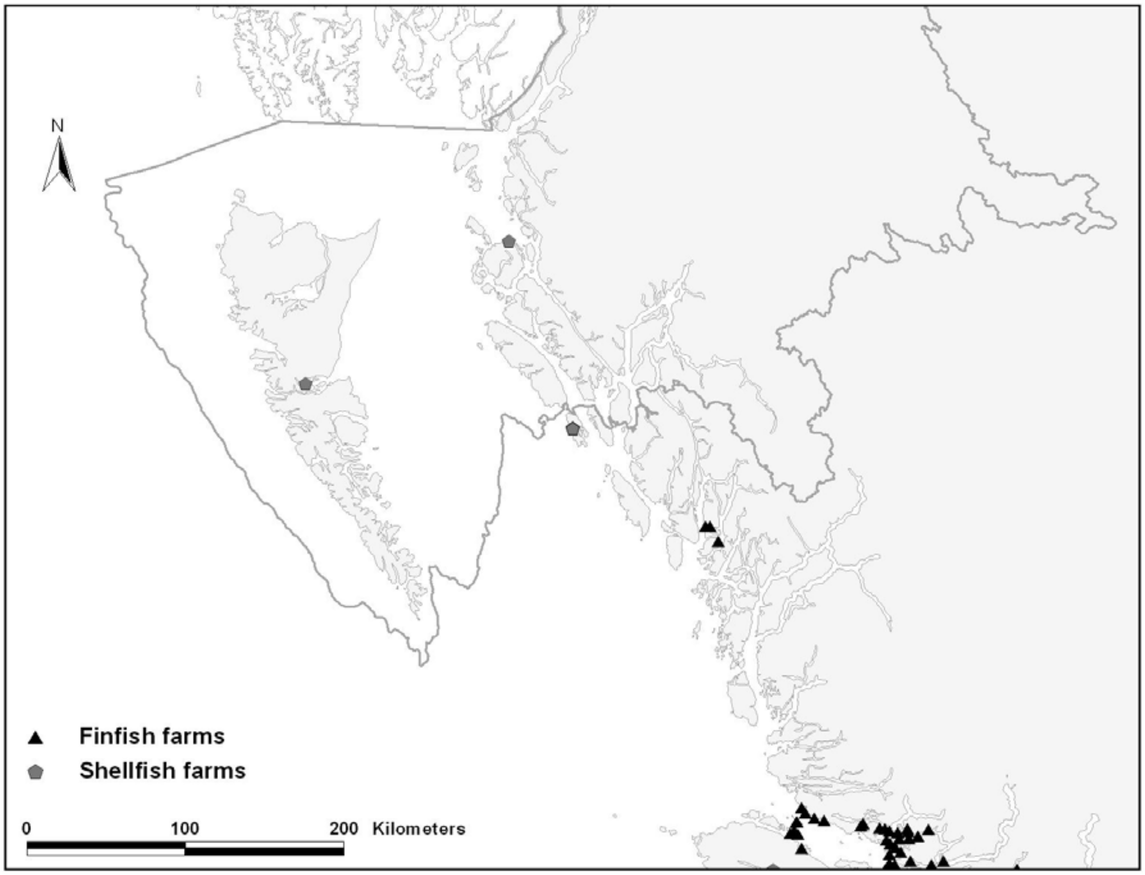

Figure 8.2 Location of finfish and shellfish aquaculture tenures on BC's north coast as of 2003 (data from the BC Ministry of Food and Fisheries).

There are currently 126 active finfish aquaculture sites in BC (for a complete list, see http://www.agf.gov.bc.ca/fisheries/licences/MFF_Sites_Current.htm). Although some measures have been taken in an attempt to lessen the environmental impact of finfish aquaculture, environmental concerns surrounding this industry remain. Finfish aquaculture creates both organic and chemical contamination. Biological contamination in the form of disease and parasite transfer between farmed and wild salmon, introduction of non-native species and diseases through the escape of Atlantic salmon (Gardner and Peterson 2003), and noise pollution associated with anti-predator devices (Morton and Symonds 2002; Hargrave 2003) are also concerns surrounding salmon aquaculture in BC.

8.1.1 Organic wastes

One of the most prevalent concerns with respect to salmon aquaculture is the production of organic wastes. Sources include excess feed, 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). Conflicting conclusions have been reached with regard to the scope and impact of this issue, highlighting the need for further research.

It has been estimated that approximately 5% of food goes uneaten and that 4% is ejected into the water column as feces (Nash 2000), resulting in higher concentrations of suspended particulate at aquaculture sites than in the surrounding environment

(Sutherland *et al.* 2001). Some researchers estimate that approximately 30g of nitrogen and 6.7g of phosphorus are discharged for every kilogram of Atlantic salmon produced (Nash 2000). As nitrogen is a limiting resource for marine phytoplankton, excess nitrogen can lead to increased levels of primary production and eutrophication (Haggarty *et al.* 2003). While phosphorus is not considered limiting in marine systems, it may be limiting in brackish and freshwater systems. Increased levels of these nutrients may also lead to toxic algal blooms (Haggarty *et al.* 2003). While for many aquaculture sites on the BC coast, tidal currents may be considered strong enough to dissipate and mix nutrients so that they will not reach harmful concentrations (Nash 2000), some localized sites may be vulnerable to enrichment and/or contamination. An effort to construct models and use tracers is underway to understand far-field effects and improve siting criteria for aquaculture facilities (Chamberlain *et al* 2005; Sutherland *et al.* 2001).

Sediment enrichment is another effect associated with organic wastes. Suspended organic particulate settles to the ocean floor, enriching the sediment with compounds such as nitrates, phosphates, ammonia, and ammonium. The effects of this deposition on benthic biogeochemical processes is well documented (Chamberlain *et al.* 2005; Wildish and Pohle 2005). Enriched sediments can smother benthic habitat, stimulate the growth of phytoplankton and attached algae, and reduce dissolved oxygen concentration, which can stress native organisms as well as farmed fish (Hargrave 2003). As a further complication, enriched sediments are degraded by microbial activity, which creates organic matter as a by-product. An increase in organic matter stimulates sulphur reduction, resulting in the production of sulphides, which can accumulate to levels that are toxic to benthic fauna (Holmer *et al.* 2001), and have the potential to change the composition of macro- and meiobenthic communities (Heilskov and Holmer 2001; Pohle *et al.* 2001). Sulphides can also interact with other elements to exacerbate hypoxia and anoxia, and can influence the bioavailability of metals such as cadmium, copper, and nickel (Levings *et al.* 2002). Excess organic content in sediments may also lead to the production of toxic gases such as ammonia and methane (Wu 1995). It may be possible to partially mitigate these effects by locating farms in dispersive and well swept areas and through good husbandry practices (e.g. minimal waste feed rates).

The effects of organic wastes seem to be generally agreed upon in the literature; however, the extent to which they occur is not. Haggarty *et al.* (Haggarty *et al.* 2003) states that organic wastes tend to lead to localized impacts, limited to the area immediately surrounding salmon net pens. This assertion is supported by Hargrave (2003), who points out that most studies have shown that the alteration of benthic communities is limited to less than 50 m from the aquaculture site. However, a study by Strain (2005) suggests that the organic wastes produced by finfish aquaculture can cause eutrophication on scales of kilometres to tens of kilometres, thereby changing the structure and function not only of the surrounding area, but of the ecosystem as a whole. A third, somewhat intermediate view comes from a study carried out in southwest New Brunswick by Wong *et al.* (1999, as cited in; Hargrave 2003), who found that localized enrichment effects (within 30 m of cages) occurred at newly established farm sites. However, as the farm became more established, measurable effects could be detected farther away. After about 5 years, changes could be detected more than 200 m from cage sites and at a site that had been active for 12 years, significant declines in diversity had occurred throughout the entire inlet system.

8.1.2 Chemical Contamination

Chemical use is widespread at finfish aquaculture sites in Canada and can be divided into two categories: chemicals that are used intentionally, and those that enter the environment unintentionally. Those used intentionally include feed additives, chemotherapeutants, disinfectants, and pesticides (Haggarty *et al.* 2003). Some unintentionally introduced chemicals can be found in feed and include persistent chemicals and heavy metals, while others, such as plastics, paints, metals, antifouling chemicals, and wood preservatives, are used in construction materials (Haya *et al.* 2001).

Intentionally Introduced Chemicals

As farmed salmon are unable to forage for themselves due to spatial constraints, the feed provided by farmers must contain all the required nutrients. Some common additives include zinc, colour additives, vitamins, and antibiotics.

Zinc is used to prevent cataracts in juvenile fish (Sutherland *et al.* 2001). Toxic effects of zinc have proved difficult to determine, though Brooks *et al*. (2003) suggest that as long as chemical remediation is completed before the next period of production begins, zinc should not accumulate in sediments. However, further research into the effect of numerous net pens in one area is required (Haggarty *et al.* 2003).

In the wild, salmon attain their red flesh colour by ingesting crustaceans such as euphausiids, which supply them with small amounts of dietary carotenoids such as astaxanthin. To attain this flesh colour in farmed salmon, feed pellets are usually supplemented with astaxanthin or a related carotenoid called canthaxanthin (Nash 2000). Zitko (1994, as cited in; Burridge 2003) suggests that these compounds are unlikely to affect non-target organisms.

Vitamins, including Biotin and Vitamin B_{12}, are also included in fish feed (Haggarty *et al.* 2003). While there appears to be little published information on the environmental effects of vitamin use in salmon aquaculture, they are thought to be safe (Nash 2000).

There are several chemotherapeutants used in the finfish aquaculture industry, administered either in feed or as a bath (Burridge 2003). Chemotherapeutants such as oxytetracycline (OTC), tribrissen (composed of trimethoprim and sulphadiazine), Romet ® 30 (composed of sulfadimethioxine and ormetoprim), and florfenicol are administered to salmon in their feed upon diagnosis of ailments such as vibrosis, furunculosis, and bacterial kidney disease (Haggarty *et al.* 2003)(see Table A1 for a summary of potential effects on the aquatic environment). Chemotherapeutants may create drug resistance in native microbial populations given that traces of these drugs may be observed up to 100m from aquaculture sites in measurable concentrations for up to 18 months (Hargrave *et al.* 2003). In addition, other species may be attracted to the farm for food and protection from predators, thereby risking exposure to chemotherapeutants (Hargrave 2003).

Emamectin benzoate (Slice ®) is administered to treat sea lice infestation. Teflubenzuron is also registered for use to treat sea lice infestation, but is rarely, if ever, used (Personal communication, L. Burridge, Biological Toxicologist, Saint Andrews Biological Station, Fisheries & Oceans Canada, 2007). Baths are not presently used in BC, but have been used elsewhere in Canada. To administer a bath, infected fish are isolated in a tarpaulin and pesticides are added to the water to the desired concentration. Baths typically last between 30 and 60 minutes, after which the tarpaulin is removed and the pesticide is released into the environment (Haya *et al.* 2001). Studies to determine the environmental effects of emamectin benzoate around finfish farms in Scotland found low concentrations of the compound and concluded that there was no evidence of toxic impacts on organisms in the water column or sediments (Wildish and Pohle 2005), however, further research is needed to determine possible sub-lethal, synergistic (multiple compounds together causing higher toxicity), and/or cumulative effects of the aforementioned chemotherapeutants on the marine ecosystem. Antifouling chemicals, which prevent the colonization of underwater structures by sedentary biota, are also commonly used in finfish aquaculture. Left unchecked, colonization can weigh down nets and restrict water flow through net pens and other structures. Hulls of boats must also be protected against biological fouling, usually with an antifouling paint. Tributyltin (TBT) was once a commonly used as an antifouling paint in British Columbia but was banned in 1988 due to its environmental toxicity (Haggarty *et al.* 2003). Today, copper compounds are the most common antifouling treatment. The cupric ion (Cu^{2+}) is toxic to marine organisms at moderately low levels (Brooks 2001). There are currently two copper-based antifouling products approved for use in Canada on aquaculture net pens: Flexgard VI (15.3% cuprous oxide) and Flexgard XI (26.5% cuprous oxide) (Parker *et al.* 2003) (see Table A1 for more detailed information on potential effects of these pesticides on the aquatic environment). It is unclear as to whether such products will produce significant impacts in the local biota.

Unintentional Chemicals

Some chemicals detected at salmon aquaculture sites were introduced unintentionally. For example, one avenue for the unintentional introduction of chemicals is through construction materials. For example, pentachlorophenol (PCP) is a persistent chemical used as a wood preservative for structures at aquaculture sites (Levings 1994 as cited in; Haggarty *et al.* 2003). Although this may not lead to contamination of food webs, PCP may present a threat to some species.

In addition, it has been found that commercial fish feeds, particularly those containing ingredients originating in Europe, may contain persistent chemicals such as dioxins and polychlorinated biphenyls (PCBs) (Nash 2000) (Table A1). As reported in Haggarty *et al*. (2003), the inadvertent introduction of persistent organic chemicals to fish farms by means of feed and construction materials poses a threat to native ecosystems. These chemicals are likely to enter local food webs and, because of their tendency to bioaccumulate and biomagnify, could represent health risks to higher trophic levels. Indeed, there have been reports of predation on farmed salmon by birds and marine mammals (Nash 2000).

8.1.3 Research Needs

Several authors have highlighted the need for further research in almost all areas of salmon aquaculture (Hargrave 2003; Burridge 2003; Parker *et al.* 2003; Rice 2005; Bright and Dionne 2004 and others). Due to the current lack of conclusive data, assertions about environmental risks or the lack thereof are difficult to make.

Perhaps one of the most contentious issues surrounding salmon aquaculture is the use of chemicals. Further research on the chronic toxicity and sub-lethal effects of these chemicals using non-target, native species from several trophic levels must be carried out in order to understand the challenges posed to these species by continued finfish aquaculture (Burridge 2003). There is currently considerable uncertainty as to the degree of exposure to which non-target organisms are subjected (Bright and Dionne 2004). Tests should be carried out in the field (Bright and Dionne 2004), and the methods of testing must realistically reflect the exposure pathway (feeding behaviour, food preferences, etc.) (Burridge 2003). While research is needed to determine lethal and sublethal endpoints for individual chemicals, it is also important that chemicals not be regarded as single entities. They do not exist in isolation in the aquatic environment, and as such, we must understand cumulative as well as individual effects (Burridge 2003).

Organic waste is of significant concern in areas immediately surrounding active salmon aquaculture, and may have more far reaching effects. Rice (2005) suggests that a better understanding of rates of feed wastage would be useful, followed by research into the biogeochemical processing of these wastes in order to come up with models that would allow for prediction of chemical and biological effects. Further, both Rice (2005) and Hargrave (2003) recommend research into the likelihood of resuspension of organic particles from feed waste and fecal materials. Aquaculture sites are not located above identical benthic environments, and for this reason, Wildish *et al.*(2004) advocate an examination of the effect of enrichment on different substrate types.

Physical processes occurring around salmon aquaculture sites are also poorly understood. General circulation models are required in order to understand the effects of tide, wind, mixing, exchange, and freshwater input on the dissipation, mixing, and exchange of contaminants, as well as a better understanding of changes to the water column around fish farms (Hargrave 2003).

8.1.4 Synthesis

There are many issues of environmental concern surrounding salmon aquaculture, and while advances have been made, there is much research to be done before confident assertions can be made as to the environmental effects of this industry.

There is disagreement in the literature regarding the extent to which organic and chemical contaminants produced by salmon aquaculture affect ecosystems. While data continues to be generated on the effects of individual chemicals, a more comprehensive understanding of cumulative impacts has yet to be attained. Organic compounds can cause sediment enrichment, and while it has been determined that this has detrimental effects to communities immediately adjacent to and below active aquaculture sites, the total area that will be affected over time is not yet clear. A number of other chemicals are used in salmon aquaculture, including antibiotics and pesticides. The risks to non-target organisms in terms of acute toxicity, sub-lethal and chronic effects, and possible pathogen resistance remain poorly understood.

Finally, the unintended introduction of persistent organic chemicals to fish farms by means of feed poses a threat to native ecosystems. Like other chemicals used in finfish aquaculture, they are likely to enter local food webs and this, coupled with their well documented tendencies to bioaccumulate and biomagnify, could pose health risks to non-target organisms at all trophic levels.

Should finfish aquaculture expand to the north coast, issues such as these will need to be addressed in terms of marine planning and marine environmental quality.

8.2 Shellfish Aquaculture

Commercial shellfish aquaculture has been occurring on the BC coast since the early 1900s (Jamieson *et al.* 2001). As of August 2005, there were 467 licensed shellfish aquaculture sites in BC, almost half of which are operated by private individuals (http://www.agf.gov.bc.ca/fisheries/licenses/SF_Sites_Current.htm). There is limited active shellfish aquaculture currently occurring on BC's north coast (Figure 8.2). In November 1998, the BC Ministry of Agriculture and Lands (Fisheries and Aquaculture Branch) introduced the Shellfish Development Initiative, with the stated goal of doubling the amount of Crown land available for shellfish aquaculture to 4,230 hectares within 10 years (http://www.agf.gov.bc.ca/fisheries/Shellfish/shellfish_dev.htm). As part of this initiative, shellfish pilot projects are underway at 15 sites on the north coast and Queen Charlotte Islands. The most commonly cultured species are clams and oysters, although farming techniques for scallops, mussels, and abalone are being developed (Haggarty *et al.* 2003). Environmental concerns surrounding shellfish aquaculture seem to be fewer than those about finfish aquaculture; however, those that do exist are less thoroughly researched.

8.2.1 Environmental Concerns

The shellfish aquaculture industry does not require the use of chemicals to the degree seen in the finfish aquaculture industry. No pesticides are used in shellfish aquaculture (Jamieson *et al.* 2001). The only consistent chemical source appears to be occasional use of antifouling agents, and given that the species causing the problem may be a secondary set of the species being farmed, application must be strictly monitored in order to protect the farmed population.

One of the major concerns about shellfish aquaculture is the risk of infection (Bower and McGladdery 2003). Farms provide a convenient reservoir for infectious agents, regardless of their carrier, because of the ease and potential severity of infection due to limited water exchange, high stocking densities, artificial feeding regimes, and accumulation of dead and/or dying larvae. Antibiotics commonly used in aquaculture have been shown to be unreliable in open water, resulting in suppression rather than eradication, which can lead to rapid development of drug resistance in pathogenic bacteria (Boyd 1999). This raises an issue discussed previously in relation to finfish aquaculture; namely, the risk that these antibiotics will create host resistance in organisms living in close proximity to the aquaculture site. This issue as it relates to shellfish aquaculture is perhaps less pressing than in finfish aquaculture in that the shellfish aquaculture industry does not use antibiotics to the same extent; however, it should not be discounted. Bower and McGladdery (2003) suggest that although it will be challenging, there must eventually be a shift from 'quick fixes' like the administration of chemotherapeutants to alternate methods of husbandry.

Also of concern is the ability of shellfish to control suspended particulate matter in their environment. Cranford *et al.* (2003) suggest that through grazing, bivalves may be able to affect entire coastal ecosystems by reducing phytoplankton biomass. While this theory has been supported by lab and field observations, it has not been proven.

Another issue related to shellfish aquaculture that is poorly understood includes the physical and biological disturbance of the subtidal area. Activities include the use of antipredator netting over extensive areas, and modification of the sediments through the introduction of cobble material that is suitable to aquaculture species. By altering the natural ecosystem to suit the needs of the aquaculture species in question, this may also restrict the natural diversity of the area.

8.2.2 Research needs

Issues such as habitat loss, methods of predator control, and the introduction of non-native species (and their non-native pathogens) are not yet fully understood in terms of their effects on the marine environment. Research is needed into the diseases to which 'new' shellfish species coming into culture are susceptible, thereby allowing researchers to distinguish between 'opportunistic infections' and 'primary pathogens' (Bower and McGladdery 2003). Opportunistic infections can be managed relatively easily by changing the conditions to which the farmed species is subjected, while primary pathogens require more stringent management (Bower and McGladdery 2003). They point out that we must also be more aware of the risks posed by fouling and 'hitch-hiking' organisms that may be introduced via pathways such as ballast water and suggest that understanding of disease susceptibility where non-native species are concerned is lacking, given that conditions on Canada's west coast may differ from the original habitats of these species. From a physical perspective, Cranford *et al.* (2003) advocate a better understanding of the effects of shellfish aquaculture on nutrient concentrations and elemental ratios, as well as further study of the consequences of altered nutrient dynamics for phytoplankton communities and blooms, including harmful algal blooms.

8.2.3 Synthesis

Commercial shellfish aquaculture is a relatively new industry on British Columbia's north coast. On the surface, it appears to have a lesser environmental impact than finfish aquaculture, due in large part to the fact that fewer chemicals are used. However, concerns do exist regarding issues such as the spread of infection and the control by bivalves of suspended particulate matter in the ecosystem, and these are just two among several issues which have yet to be thoroughly addressed. Given that this industry continues to expand, further research into these areas is advisable.

9 Coast Guard/Military Activities

The Canadian Coast Guard (CCG) maintains two stations in the north coast area, located at Sandspit and Prince Rupert (Fisheries and Oceans Canada 2005), which provide lighthouses, search and rescue, and navigational aides. Coast Guard ships likely contribute ship-based pollutants, as discussed in sections 3 and 4 and in Haggarty *et al.* (2003). In addition, historical contaminant sources may have included mercury that was used at, and transported to, lighthouse stations; cadmium and mercury in batteries from lighthouses; and navigational aides that were discarded overboard (Haggarty *et al.* 2003).

The Coast Guard has been involved in a process to recover batteries that were discarded overboard (Kruzynski 2000). While the CCG may at one time have represented a potential source of marine contaminants on British Columbia's north coast, it has since recognized this issue and is working to rectify it.

Currently, there are no active Canadian forces bases on the north coast. There are three military sites on the north coast which were used primarily during World War II and were subsequently 'stood down' by the Canadian military: CFS Masset, RCAF Alliford Bay, and RCAF Prince Rupert (http://www.rcaf.com/stations/). 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* designed to protect fish habitat. For example, since 1965, lead weights, lithium batteries, and other substances have been deposited into the ocean at Canadian Forces Maritime Experimental and Test Ranges off the coast of BC 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).

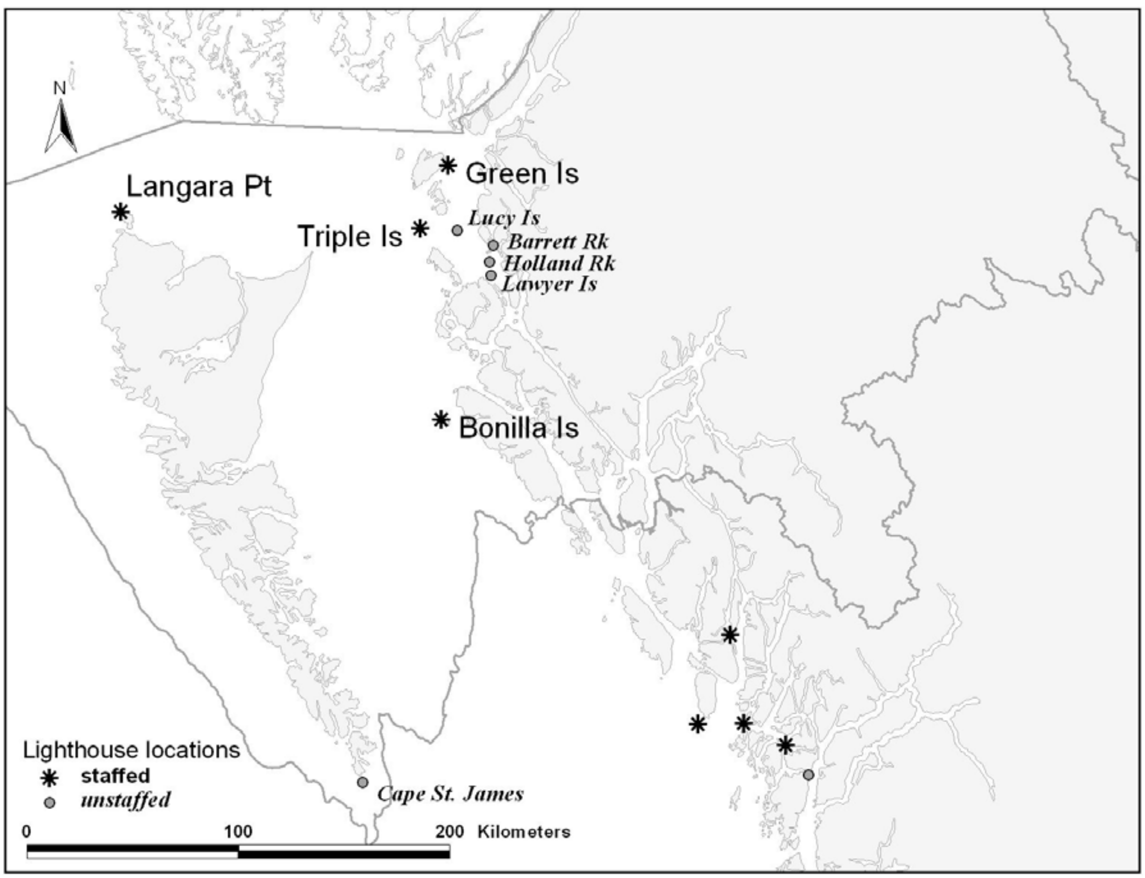

Figure 9.1 Location and name of staffed and unstaffed lighthouses on the northern BC coast (data from http://www.fogwhistle.ca/bclights/index.php).

10 Global Pollutants

Since World War II, the discovery and application of new chemical compounds in industrial and domestic settings has increased steadily. Today they are found in everything from the plastic cases of electronics and the coatings on frying pans to the multitude of products used in the home and the garden. However, in recent years, and with increasing frequency, some of these compounds are being found to have significant environmental effects. Of particular concern are the so-called Persistent Organic Pollutants (POPs). Some, such as DDT and PCBs, have been banned in many countries but remain an issue due to their persistence in the environment. POPs are lipophilic, which means they can partition into fatty tissues and accumulate in an organism over its lifetime (bioaccumulation) (Paasivirta 1998). When these organisms are consumed by others at higher trophic levels within the food web, the contaminant exposure of the consumer increases (biomagnification), resulting in greater risk of adverse health effects. POPs have also been shown to cause sublethal effects, including endocrine disruption, immunosuppression, and developmental effects, at relatively low concentrations.

Legacy POPs still present at detectable levels in the environment include 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). Since the 1970s, these organochlorine compounds have been banned by many nations, and they are now covered by the international Stockholm POPs Treaty. While concentrations of many of these pollutants in the environment have decreased, they can be transported to, and deposited in, places far removed from their source by both physical and biological mechanisms (Macdonald *et al.* 2002a; Blais *et al.* 1998; Campbell *et al.* 2000; Ewald *et al.* 1998; O'Neill *et al.* 1998; Wilkening 2001). Recent work on herons (Harris *et al.* 2003), oolichan (Chan *et al.* 2003), and marine mammals (Addison and Ross 2001; Cullon *et al.* 2005; Ross *et al.* 2004; Ross *et al.* 2000) demonstrates the continued presence of legacy POPs in BC wildlife.

While many problematic chemicals have since been regulated, some are currently used and may be considered as emerging threats to MEQ in remote areas. Brominated flame retardants such as polybrominated diphenyl ethers (PBDEs) are used in a wide variety of common materials and are increasing in the environment at an exponential rate, even in remote areas (Ikonomou *et al.* 2002; Betts 2002b; Betts 2002a). These chemicals are used as flame retardants in consumer products, but are also considered to be endocrine disruptors (Darnerud *et al.* 2007; Darnerud 2003).

Alkylphenol ethoxylates are surfactants widely used in detergents, pesticides, shampoos, and pulp mill processing. Few of these compounds have been studied, but a number are known endocrine disruptors.

Fluorinated organic compounds (FOCs) are also used as surfactants in products such as emulsifying agents, water repellents, fire retardants, wax, carpet cleaners, and non-stick coating. Some voluntary reductions in use appear to have resulted in a decrease in concentrations detected in Arctic seals (CBC.ca News 2006a). Other FOCs are in the process of being banned or restricted (CBC.ca News 2006b). Phthalate esters are a group of compounds used as softeners in plastics and are also found in personal care products, pesticides, and lubricants. Some of these compounds are confirmed or suspected endocrine disruptors at very low concentrations (Jobling *et al.* 1995; Myers 2002).

Currently-used pesticides are used in agricultural, forestry and urban applications. In many cases, these can be toxic to salmonids (Scholz *et al.* 2000; Tierney *et al.* 2006), and can lead to population-level declines (Fairchild *et al.* 1999).

Global contaminant threats to MEQ in the North Coast and Queen Charlotte Islands include:

- the 'legacy' from PCBs, as evidenced by the relatively high PCB concentrations in northern resident killer whales (categorized under SARA as 'threatened');
- the 'legacy' of other POPs arriving through atmospheric transport and by migrating animals, such as salmon;
- persistent, bioaccumulative and toxic (PBT) compounds that are not yet regulated, including the flame retardant PBDEs;
- non-PBT compounds, such as currently-used pesticides, and their additives, that may affect salmon and their prey in natal streams and coastal areas;
- Mercury (Hg), a natural metal that bioaccumulates in aquatic food webs, and is increasing in the global environment as a result of human activities including coal combustion.

While the remote nature of this area reduces the likelihood of major contaminant threats, it is evident that persistent and non-persistent chemicals being used in other parts of the world can be rapidly delivered to the North Coast and Queen Charlotte Islands. The high levels of PCBs found in northern resident killer whales are testimony to the vulnerability of remote areas. Regulations at a national level, stakeholder participation at a regional scale, and treaties and negotiations on an international scale, are all needed to adequately protect MEQ.

11 Oil and Gas Development

Issues related to offshore oil and gas development were discussed in Haggarty *et al.* (2003), and will be summarized briefly here. In the late 1960s, interest grew in the oil and gas potential of sedimentary rocks in the Queen Charlotte Basin, which underlie the continental shelf of central and northern BC (Figure 11.1). Fourteen exploratory wells were dug and a number of seismic lines were run to investigate the potential. As the results appeared promising, a number of environmental impact reviews were completed in the 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). However, two subsequent coastal oil spills, the *Nestucca* (1988, 227 000 gallons) off Gray's Harbour, Washington and the *Exxon Valdez* (1989, 11 000 000 gallons) in Prince William Sound, Alaska, caused public concern, and moratoria on further oil and gas exploration in the area were put in place by both the provincial and federal governments.

Recent re-consideration of the moratoria has resulted in another series of environmental reviews (Birtwell and McAllister 2002; Strong *et al.* 2002b; Jacques Whitford Environment Limited 2001; Jamieson and Davies 2003; Crawford *et al.* 2002; Cretney *et al.* 2002b; Cretney *et al.* 2002c; Cretney *et al.* 2002d; Cretney *et al.* 2002a; Hall *et al.* 2004; Simon Fraser University 2000; Whiticar 2000; Whiticar 2001). Two of the reviews concluded that the moratoria could be lifted provided that several scientific knowledge gaps be filled prior to exploration and development activities (Hall *et al.* 2004; Strong *et al.* 2002a).

Two of the main contaminant concerns related to offshore oil and gas activity, oil spills and increased shipping traffic, have been discussed in Haggarty *et al.* (2003) and elsewhere in this report. In addition to these issues, the exploration, development, and production of offshore oil and gas would involve potential noise pollution (e.g. from seismic activity and drilling) and the release of drilling mud and produced water to the marine environment. Drilling mud is a lubricant solution used in drilling which is generally low in toxicity but has a high density, which may lead to a smothering of benthic organisms. In addition, a number of optional additives, such as biocides, can increase its toxicity significantly. Produced water is water that is extracted along with the oil and gas. It is a mixture of naturally occurring water from the geological formation, and water that has been added during the drilling process. This water makes up the majority of the waste from oil and gas production and can contain a number of environmentally harmful compounds such as heavy metals, radionuclides, organic chemicals including petroleum hydrocarbons, and treating chemicals.

The federal moratorium remains in place, although it is currently under review, and the provincial moratorium has been lifted. Whether or not the federal moratorium is lifted, the presence of oil and gas in the area may be an ongoing pollution concern. During the process of exploration, seeps of oil, tar, or gas have been found both on land (Hamilton and Cameron 1989) and in offshore areas (Barrie 1988), and undiscovered seeps undoubtedly exist. The effect of this natural source of hydrocarbons to the environment is not currently known.

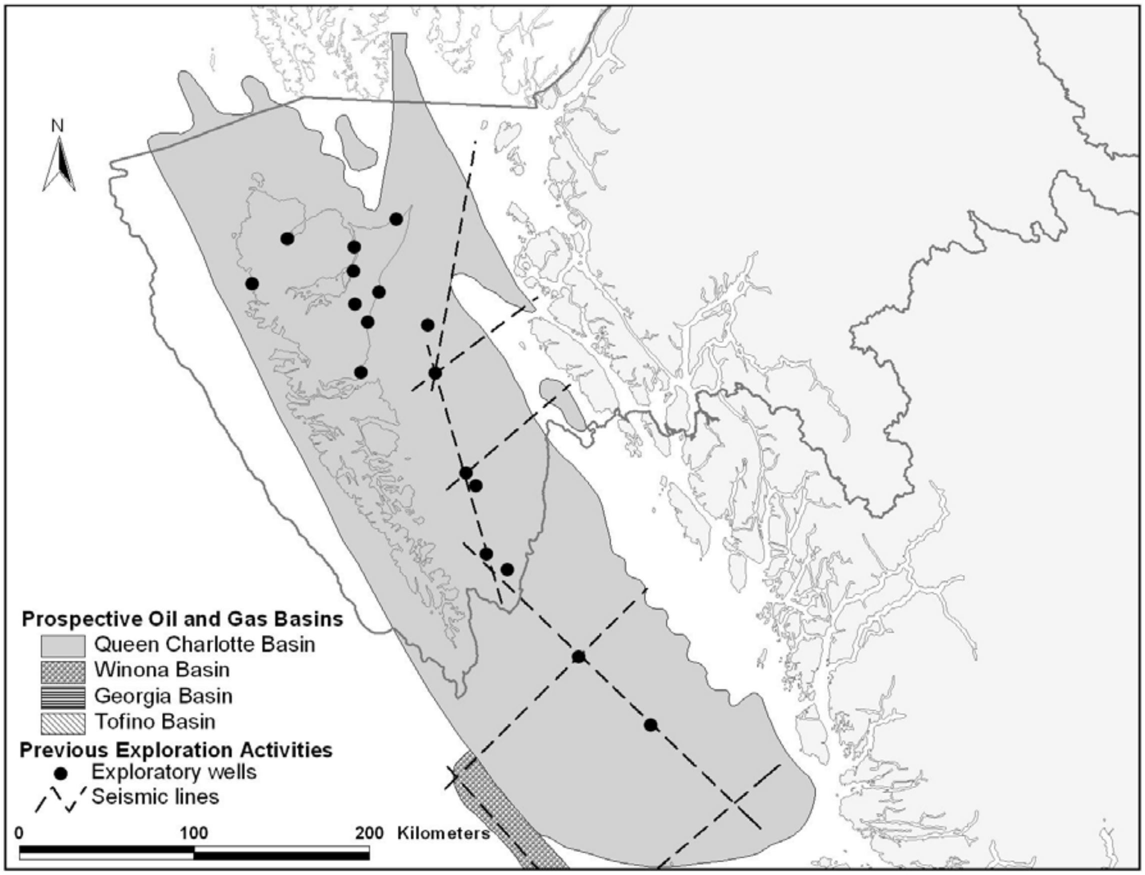

Figure 11.1 Location of the relevant land-based and offshore oil exploration wells and seismic lines from the 1960s exploration of the Queen Charlotte Basin (data from the BC Offshore Oil and Gas Team, Ministry of Energy and Mines). Nearly two-thirds of this highly prospective basin lies within the study area.

12 Ocean Dumping

In 1975, Canadian parliament passed the Ocean Dumping Control Act in partial fulfillment of Canada's international obligations under the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (also known as the London Convention) (Environment Canada 2003). The act governed the use of Canadian seas and Canadian ships and aircraft in disposing of waste material. In 1988 the Ocean Dumping Control Act was incorporated into the Canadian Environmental Protection Act (CEPA) as part VI. CEPA VI does not apply to discharges resulting from offshore mineral exploration and development, from the normal operation of ships and other craft, or from land-based sources such as effluent pipelines, which are covered by separate legislation (Environment Canada and Pacific and Yukon Region 2003). It does, however, apply to the disposal of all other materials at sea, including dredged material, inert, inorganic geological material, fish waste, uncontaminated organic material of natural origin, 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). Mine tailings are also routinely disposed of at sea (Section 7). The act also applies to the loading of wastes on ships, aircraft, platforms or other artificial structures for disposal at sea (Environment Canada 2003).

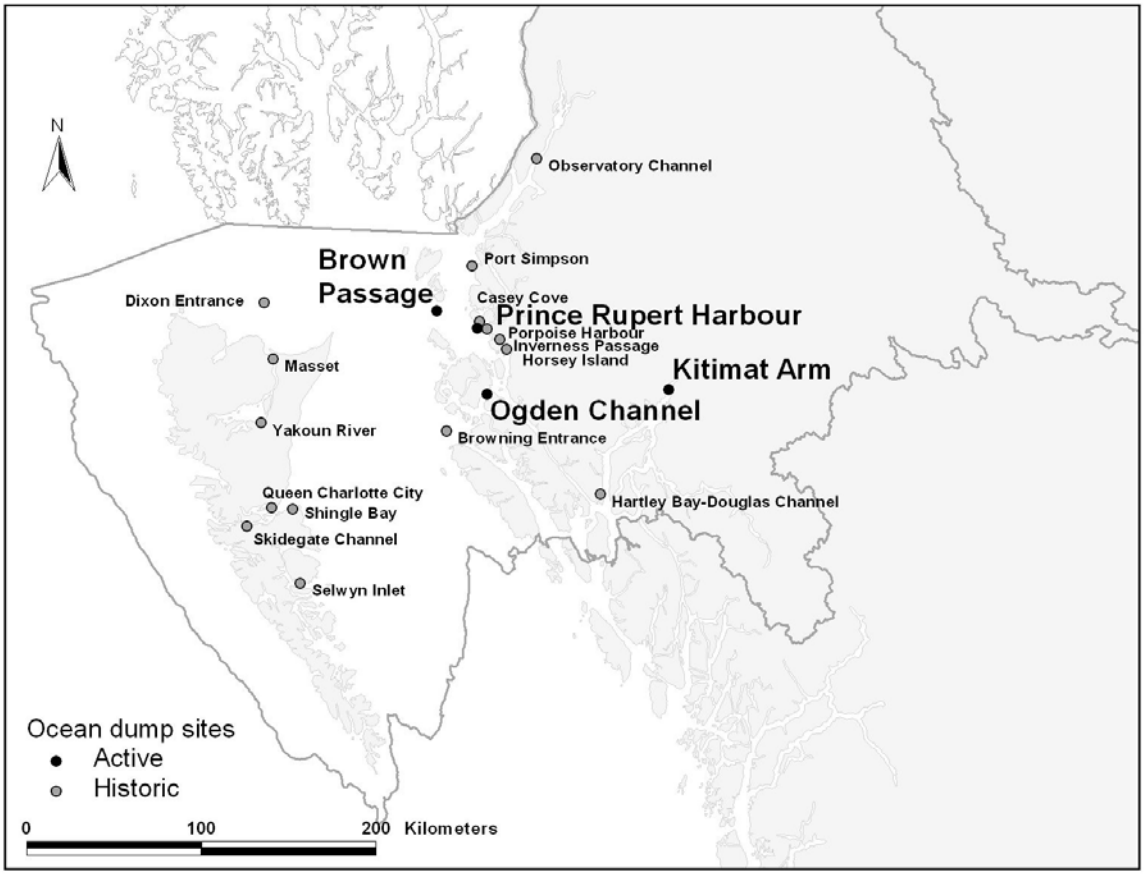

Figure 12.1 Locations and names of active and historic dump sites on the northern BC coast (data from Environment Canada, specific sources listed in Table A2).

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 such as mercury and cadmium may be approved for dumping and for this reason, some ocean dumpsites have elevated levels of mercury, cadmium, lead, zinc, and copper (Haggarty *et al.* 2003).

There are four active dump sites on the north coast of British Columbia (Figure 12.1): Brown Passage, Kitimat Arm, Prince Rupert Harbour, and Ogden Channel, although in recent years, there has not been significant dumping activity in this area (Personal communication, D. Sullivan, Environmental Protection Branch, Environment Canada, 2006). There are also several inactive sites in the region (Table A2).

The forest products industry frequently uses ocean dumps to dispose of wood wastes, and a significant amount of material is also generated through maintenance by dredging of channels, harbours, marinas, bridges, wharves, ferry terminals, and berthing areas to acceptable depths (Sullivan 1987). In the forest products industry, dredging is frequently required at log storage and sorting areas in order to maintain depth (Ward and Sullivan 1980). The dredgeate is, for the most part, wood waste and as such is high in organic content and is sometimes found in conjunction with other pollutants such as heavy metals

(Hoos 1977). Dredgeate generated through maintenance of waterways may also be high in organic content, heavy metals, and other pollutants. Often this type of dredgeate is not suitable for construction purposes; however, the rugged topography of the west coast can make land disposal sites difficult to reach. When flat land is available, it is often at the head of an estuary, which is not an appropriate location for land dumping due to a high organic content and the possibility of toxic leachates. For these reasons, there is significant interest in the ocean as a dumping ground (Hoos 1977).

The main impact of ocean dumping is its effect on the abundance and species composition of benthic communities (Hoos 1977). Wood particles differ from inorganic sediment in porosity, permeability, and stability, and as such have a significant effect on the benthic environment. They also increase the organic load in the water column by leaching carbohydrates, resins, tannins, and lignins, and the degradation of wood particles may exert measurable oxygen demands and create toxic levels of hydrogen sulphide (Anderson and O'Connell 1977). Deposited wood debris may discourage larval settlement and the combination of particulate matter, decreased oxygen, and increased hydrogen sulphide can be lethal for suspension feeders, especially bivalves (Anderson and O'Connell 1977). O'Clair and Freese (1985) found that crabs avoid bark deposits when given a choice, but when forced to inhabit them are less fecund and have lower feeding rates and decreased survivorship (Williamson *et al.* 2000). They also found that a Dungeness crab population living at a log dump in Alaska had less than half the number of ovigerous females as their control population and that the ovigerous females that were present were less than half as fecund (O'Clair and Freese 1988). It was also found that community structural alterations increased with the amount of wood waste. In an area with approximately 15 cm of waste, the fauna was limited to wood-inhabiting organisms such as shipworms and small polychaetes to the exclusion of all other organisms (Anderson and O'Connell 1977). The organic content in polluted dredgeate seems to have a greater effect on benthic communities than the metal content, but metal contamination in benthic organisms can still occur by way of ingestion of polluted food items (Haywood *et al.* 1983).

13 Other activities

This report is not exhaustive and a number of other activities may present a threat to MEQ in the study area. One of these is agriculture. The major threat posed by agriculture to the marine environment is runoff polluted by organic compounds and pesticides. This is a very real concern in areas such as the Strait of Georgia, where agricultural pesticide use is widespread. However, agriculture is not a major industry in the North Coast area. In fact, the North Coast has the lowest occurrence of agricultural activity in the province, with only 0.1% of its total area farmed (13 000 of 11.9 million hectares) (Verrin *et al.* 2004). Further, a report by ENKON Environmental (2001) states that no reportable agricultural pesticides were sold in this area in 1999. For these reasons, agriculture is not expected to pose a threat to marine environmental quality in the north coast area.

Another threat to MEQ is related to tourism activities not captured by vessel traffic including cruise ships (covered earlier in this report). In this regard, the growing popularity of fishing lodges in remote areas may represent a local source of certain contaminants. Remote lodges tend to be, at least at present, a relatively minor and localized issue. In tourism advertising campaigns, BC's north coast emphasizes its abundant opportunities for sport fishing and wildlife viewing. As such, sport fishing lodges can be found up and down the coast in many mainland and Queen Charlotte Island inlets and bays (Fisheries and Oceans Canada 2005). Aside from the comparatively small vessels used by lodges for fishing, there are few reports of contamination concerns associated with these lodges. One possible issue however, is that many lodges use septic systems, which provide approximately a primary level of treatment. This consists of the removal of solids and the skimming off of floating materials, and the discharge of liquid waste. This treatment level removes approximately 40 to 50% of total suspended solids, 50% of metals, and a small proportion of organic contaminants (Haggarty *et al.* 2003). These systems have the potential to leak, and have been shown to contaminate shorelines (Macdonald *et al.* 2002b).

14 Conclusions

An accurate assessment of the risk posed by contaminants in the north coast area based on existing scientific literature is difficult for a number of reasons. Information on past contaminant issues is often lacking or outdated. Current or expected changes in human activities in the area create situations that have not yet been assessed in the literature. Modern analytical techniques have revealed a number of contaminant concerns in other areas, but these techniques have rarely been applied to this portion of the BC coast.

Given these difficulties, this report provides a qualitative assessment of contaminant risks in the area and should serve to highlight areas where more information is required. Based on available information, a number of issues or activities present a reasonable risk of significantly affecting marine environmental quality:

- 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, vessel traffic, and related contaminant issues.
- Increasing cruise ship size has resulted in ever increasing numbers of people travelling up and down the BC coast. The various waste products and effluents from this mobile population are likely to affect marine ecosystems.
- ALCAN currently operates an aluminum smelter in Kitimat. The immediate environment around this smelter has been shown to be significantly contaminated by PAHs. The smelter has been implicated as the main source of this pollution.
- Mining was a significant activity in the area in the early part of the 20^{th} Century. Much of this activity had ceased by the late-middle of the century. A number of these former mine sites 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.
- Mine tailings have been disposed of into deep coastal basins at Alice Arm and Tasu Sound. Both sites underwent significant monitoring and tailings disposal is thought to have had little environmental effect beyond the initial smothering of benthic organisms in the immediate area.

- 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.
- Persistent organic pollutants (POPs) have been found in marine organisms around the world, both in industrialized and remote environments. Many 'legacy' POPs have had their use and production reduced or banned in most industrialized nations, but their persistence 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. Very limited data exist for North Coast biota and environmental compartments.
- Aquaculture is currently limited in the north coast but may expand in the future. Multiple operations in restricted waters are the most likely conditions to produce significant risk of environmental contamination.
- Offshore oil and gas exploration and development are not currently permitted in the area but existing federal and provincial moratoria are under review and could at some future date be lifted. Rising prices for oil and gas increase the pressure to lift these restrictions.
- Forestry is significant but there are limited contaminant issues related to this activity. This industry's pesticide use is fairly low, and is decreasing in BC overall. Forest fire fighting has the potential to contaminate streams, but significant effects from this have not been noted in the area to date and the use of chemicals in fire fighting is well 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 significant problem and, assuming modern 'best practices' are used, it is unlikely to become more significant in the future.
- Ocean dumping is an activity which requires a permit and the 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.

Available information suggests that the following issues and activities currently present a low risk of significantly affecting marine environmental quality:

- Agriculture is not a prevalent activity in the 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.

This assessment could be improved upon 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. There are three major documented contaminant issues on the north coast: elevated concentrations of heavy metals from mining, PAHs from smelting, and POPs in killer whales. Further research is needed to ascertain the extent of associated impacts.

- A study of the environment around 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, movements, effects, and mitigation strategies specific to this area is needed.
- Information is needed on the environmental effects of various 'new' pollutants such as pharmaceuticals, personal care products, hormones (artificial and natural), and flame retardants.
- Levels of cadmium and mercury are known to be high is some organisms along the BC coast. Some of the sources of this contamination are natural (upwellings, geology), but this has become a trade issue as exports to certain markets have been constrained by Cd exceedances. More work is needed to characterize source and fate of these metals in the area.
- Two pulp and paper mills operate in the area. Operational changes in the 1990s vastly reduced dioxin and furan emissions. However, the process of paper making produces or releases many chemicals such as plant hormones. Investigations into the effects of these chemicals are ongoing.

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Table A1 A summary of chemical compounds used in the Canadian aquaculture industry**(modified from Hargrave 2003)

Chemical	Use	Persistence in Sediment	Bioaccumulation	Potential Effects
Oxytetracycline	Antibiotic	Persistent for long periods depending on environmental factors (Björklund *et al.* 1990; Samuelsen 1994; Hektoen *et al.* 1995; Capone *et al.* 1996); half-life of 419 days under stagnant, anoxic conditions (Björklund *et al.* 1990)	Uptake by oysters and crabs either in the laboratory or in close proximity to salmon cage sites (Department of Fisheries and Oceans 1997); concentration in tissues of rock crabs over US FDA limit (Capone *et al.* 1996)	Resistance to oxytetracycline may occur in fish, non-target organisms and bacterial community near aquaculture sites (Björklund *et al.* 1991; Hansen *et al.* 1993; Hirvelä-Koski *et al.* 1994)
Tribrissen	Antibiotic	Estimated half-life of 90 days at 6-7 cm depth (Hektoen *et al.* 1995)		
Romet 30	Antibiotic		Uptake by oysters (Jones 1990; LeBris *et al.* 1995; Capone *et al.* 1996; Cross, unpublished work, in Hargrave 2003)	
Florfenicol	Antibiotic	Estimated half-life of 4.5 days (Hektoen *et al.* 1995)		
* **Hydrogen peroxide**		Not expected to persist, miscible in water, degrades quickly to oxygen and water (MSDS sheet)	Non-bioaccumulative (MSDS sheet)	In some cases, sea lice (*Lepeophtheirus salmonis*) have developed resistance (Bright and Dionne 2004)
* **Teflubenzuron**	Sea lice control	Solubility 19 $\mu g \cdot L^{-1}$ with a log K_{ow}^{a} of 4.3, indicating a potential to persist (Tomlin 1997); persisted >6 months in area <100 m from treated cage (Scottish Environmental Protection Agency (SEPA) 1999)		Chitin formation inhibitor; juvenile lobster mortalities reported (Scottish Environmental Protection Agency (SEPA) 1999); mitigation possible by depuration prior to molting (McHenery 1997; Scottish Environmental Protection Agency (SEPA) 1999)

Chemical	Use	Persistence in Sediment	Bioaccumulation	Potential Effects
* **Emamectin benzoate (Slice®)**	Sea lice control, recommended by BC MAFF (Bright and Dionne 2004)	Solubility 5.5 mg·L^{-1}, log K_{ow} of 5, indicating potential to persist (Scottish Environmental Protection Agency (SEPA) 1999); however, Bright and Dionne (2004) suggest that due to its large molecular size it may not bioconcentrate	Withdrawal period of 25 days prior to marketing salmon; administered to *Salmo salar,* residues were high in kidney (1.4-3.0mg/kg) and liver (1.0-2.3mg/kg): European Economic Community acceptable maximum residue levels are 0.1mg/kg (Kim-Kang *et al.* 2004; as cited in Bright and Dionne 2004)	Chloride ion movement disruptor (Roy *et al.* 2000); lethal to lobsters at 735 µg·kg^{-1} of food (Burridge *et al.* 2002); induces molting in lobsters (Waddy *et al.* 2002); not approved for general sale in Canada but it IS authorized for sale to vets on case-by-case basis (http://www.hc-sc.gc.ca/)
Ivermectin	Drug; In-feed 'off-label' treatment for sea lice control, seen as more toxic than emamectin benzoate and has not been used in Canada since late 1990s (Bright and Dionne 2004)	Solubility of 4 mg·L^{-1} (Tomlin 1997); could persist for 28 days (Wislocki *et al.* 1989; Roth *et al.* 1993)	Withdrawal period of 180 days prior to marketing; accumulated in lobster tissue over 10 days (Burridge, Haya, and Zitko, unpublished data in Hargrave 2003)	Chloride ion movement disruptor (Roy *et al.* 2000); cumulative 80% Atlantic salmon mortality to 0.2 mg·kg^{-1} for 27 days (Johnson *et al.* 1993); 96-h LC50 at 8.5 mg·kg^{-1} food for shrimp; NOEC[b] was 2.6 mg·kg^{-1} food (Burridge and Haya 1993)

Chemical	Use	Persistence in Sediment	Bioaccumulation	Potential Effects
Copper-based antifouling paints	Antifoulant; reduces fouling biota on nets	Elevated copper (Cu) reported in sediments (Burridge *et al.* 1999), surveys have shown that [Cu] in sediment around aquaculture sites often exceeds Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guideline (ISQG) (18.7µg/g dry weight) and occasionally exceeds the Probable Effects Limit (PEL) of 108 µg/g) (Parker *et al.* 2003)	May accumulate in aquatic biota	100-150 mg(Cu)·kg^{-1} in sediment may affect benthic fauna diversity (Debourg *et al.* 1993); most sample locations >ISQG[c] of 18.7 mg·kg^{-1}, lethal to amphipods and echinoids (Burridge *et al.* 1999), other observed effects include decreased benthic community diversity, reduced abundance, increased mortality, biological uptake, lowered reproductive success, and behavioural changes (Canadian Council of Ministers of the Environment (CCME) 1999; Ray *et al.* 1981; Deniseger and Kwong 1996; Eriksson and Weeks 1994 as cited in ; Parker *et al.* 2003)
Iodophors	Disinfecting equipment	Not expected (Zitko 1994)		Formulations may contain compounds harmful or toxic to aquatic biota (Zitko 1994; Madsen *et al.* 1997; Ashfield *et al.* 1998)
Chlorine/Hypo-chlorite	Disinfectant; net cleaning			Toxic to aquatic organisms (Zitko 1994)
PCBs, PAHs, p,p'-DDE, organochlorine pesticides, mercury, dioxins	Found in fish feed (Zitko 1994; Nash 2000)	PCBs not detectable at 0.05 - 0.10 µg·g^{-1} dry wt (Burridge *et al.* 1999); p,p'-DDE detected at DL=1 ng·g^{-1}, dry wt (Hellou *et al.* 2000)	Changing lipid profiles in wild fish (Zitko 1994); known to bioaccumulate; relatively high levels found in farmed fish (although limited number tested) (Easton *et al.* 2002)	

Chemical	Use	Persistence in Sediment	Bioaccumulation	Potential Effects
Cadmium, Lead, Copper, Zinc, Mercury	From cage structures; fish feed	Copper >2, zinc 1-2 times higher in sediments below cages than in fish feed (Chou *et al.* 2002); Cadmium exceeded 0.7 $\mu g \cdot g^{-1}$ (Burridge *et al.* 1999)	May be toxic and/or accumulate in aquatic biota	
Polystyrene beads	Styrofoam floats	Source of low molecular weight contaminants (Zitko 1994)		Benthic fauna altered by altering pore water gas exchange, by ingestion or by providing habitat for opportunistic organisms (Goldberg 1997)

** The table includes only compounds known to be used (or registered for use) in Canada. Other compounds are used routinely in other jurisdictions and may be introduced to Canada in the future. There exists variation in the use of these different chemicals across Canada that is not captured in this Table.

* Chemicals currently or provisionally registered for use in Canada for sea lice control (updated from Bright and Dionne 2004)

a - log K_{ow} = logarithm of the octanol-water paritioning coefficient. It is internationally accepted that log $K_{ow} \geq$ to 3 indicates a potential to bioaccumulate. The*Canadian Environmental Protection Act* recognizes log $K_{ow} \geq 5$ as indicative of potential to persist and/or bioaccumulate (Beek *et al.* 2000).]

b - NOEC = No Observed Effect Concentration

c - ISQG = Interim Sediment Quality Guidelines

Table A2 Active and historical dumpsites in the North Coast Management Area (source: Environment Canada unless otherwise specified)

SITE NUMBER	SITE NAME	LOCATION dd lat	dd long	DEPTH (m)	USE/DUMPED MATERIAL	STATUS
NORTH COAST:						
100	Brown Passage	54.307	-130.75	180	Used in 1946 for disposal of ammunition and scrap metal, used in 1950's for fish offal from processing plants (Sullivan 1987), 563 tonnes in 1996 + 295 393 m3 since 1976 (Schnider and Sullivan 1996), used 1982 and 1985 for dredgeate from Prince Rupert grain terminal (Kim and Sullivan 1993), 234 200m^3 dredged material dumped in 1989 (Kim and Sullivan 1993), permit pending for material from new Fairview container terminal at Prince Rupert port (Sullivan,D., personal communication)	Active
141	Browning Entrance	53.7	-130.6	40	Disposal of 164 000L of sewage sludge from Kitkatla Indian Reserve (Sullivan 1987)	Historical
99	Casey Cove (Digby Island)	54.26756667	-130.3668667	20	1000 – 1500 m^3 log storage waste	Historical
102	Dixon Entrance	54.28353333	-132.2671667	208	no information on use	Historical
142	Hartley Bay-Douglas Channel	53.41866667	-129.2373333	250	127 279 m^3 - dredgeate from small craft harbour construction at head of Hartley Bay (Sullivan 1987)	Historical
95	Horsey Island	54.13353333	-130.1166667	7.2	575 000 m^3 in 1953	Historical
96	Inverness Passage	54.18333333	-130.1838333	>11	190 000 m^3 in 1953-54, 1-2 000 m^3 annually until 1970's (Ward and Sullivan 1980)	Historical

SITE NUMBER	SITE NAME	LOCATION dd lat	dd long	DEPTH (m)	USE/DUMPED MATERIAL	STATUS
93	Kitimat Arm	53.96666667	-128.6883333	176	1 175 145 m^3 from 1966 to 1975 (Ward and Sullivan 1980), 63 555 m^3 since 1976, 100 m^3 in 1996 (Schnider and Sullivan 1996)	Active
103	Masset	54	-132.15	36	By Public Works Canada to dump dredged material (Kim and Sullivan 1993)	Historical
110	Observatory Channel	55.11666667	-129.95	420	Disposal of dredged material from barge ramp sites at Kinahan Island (Sullivan 1987), designated 1988 for Public Works Canada (Kim and Sullivan 1993)	Historical
94	Ogden Channel	53.9	-130.2666667	267 - 388	30 962 m^3 dumped in 1977 (Ward and Sullivan 1980)	Active
97	Porpoise Harbour	54.23383333	-130.3004	24	By Cancel Mill for routine dredging, site of PCB spill resulting in contaminated sediments (McGreer *et al.* 1980), 5000 m^3 in 1976 (Ward and Sullivan 1980)	Historical
101	Port Simpson	off Cannery Island (Ward and Sullivan 1980), position estimated in Figure 12.1.		36	80 000 m^3 in 1967-68	Historical
98	Prince Rupert Harbour	south of Digby Island (Ward and Sullivan 1980), position estimated in Figure 12.1		53	Disposal of material >5000 m^3 (Kim and Sullivan 1993)	Active
104	Queen Charlotte City	53.23963333	-132.0502	36	17 500 m^3 in 1967-68, 765 m^3 + 909 tonnes in 1974 (Ward and Sullivan 1980)	Historical
106	Selwyn Inlet	52.86686667	-131.7505	183	765 m^3 dumped 1978 (Ward and Sullivan 1980)	Historical
174	Shingle Bay, Q.C.I.	53.24283333	-131.8676667	51	179 600 m^3 in 1996 from construction of small craft harbour (Sandspit Harbour) (Schnider and Sullivan 1996)	Historical
105	Skidegate Channel	53.13423333	-132.2503		700 m^3 dumped 1978 (Ward and Sullivan 1980)	Historical

SITE NUMBER	SITE NAME	LOCATION dd lat	dd long	DEPTH (m)	USE/DUMPED MATERIAL	STATUS
143	Yakoun River	53.66666667	-132.2	not >1m	application of 3 400 kg of fertilizer at intertidal area to enhance productivity, thereby increasing food availability for juvenile salmonids (Sullivan 1987)	Historical
CENTRAL COAST ACTIVE:						
116	Cape Mudge	49.957	-125.0833333	200	162 973 m^3 dumped from 1976-1999 (Schnider and Sullivan 1996) (http://www.pyr.ec.gc..ca)	Active
120	Johnstone Strait (Hanson Island)	50.555	-126.8	350	176 556 m^3 dumped since 1976, 6 000 m^3 dumped in 1996 (Schnider and Sullivan 1996), 26 100 m^3 dumped from 1997-1999 (http://www.pyr.ec.gc.ca/disposal_at_sea/), was closed in 1985 out of concern for marine life, reopened in 1988 for material from Beaver Cove forest industry (Kim and Sullivan 1993)	Active
119	Johnstone Strait (Hickey Point)	50.458	-126.0746667	270	154 188 m^3 dumped since 1976, 3 600 m^3 dumped in 1996 (Schnider and Sullivan 1996),9 250 m^3 dumped from 1997-1999 (http://www.pyr.ec.gc.ca)	Active
75	Kingcome Inlet	50.91666667	-126.2166667	125	44 349 m^3 dumped as of 1993, used on an extremely infrequent basis (1977, 1984, 1992) (Kim and Sullivan 1993)	Active
121	Malcolm Island	50.7	-127.1	180	102 960 m^3 dumped as of 1993 (Kim and Sullivan 1993)	Active
165	Neroutsos Inlet	50.457	-127.5333333	180	5 700 m^3 dumped as of 1993, closed in 1992 to disposal of wood wastes and organics (Kim and Sullivan 1993)	Active

SITE NUMBER	SITE NAME	LOCATION dd lat	 dd long	DEPTH (m)	USE/DUMPED MATERIAL	STATUS
79	Port Alice	50.37366667	-127.4393333	50	49 500 m^3 dumped as of 1993, closed in 1992 to disposal of wood wastes and organics due to impact on dissolved oxygen and fisheries (Kim and Sullivan 1993)	Active
140	Queen Charlotte Strait	50.77066667	-127.3726667	390	8 613 m^3 dumped as of 1993 (Kim and Sullivan 1993)	Active
CENTRAL COAST HISTORICAL:						
69	Duncan Bay, Discovery Passage	50.08333333	-125.2670667	95	22 900 m^3 dredgeate from Elk Falls dumped in 1975 (Ward and Sullivan 1980)	Historical
70	Menzies Bay, Discovery Passage	50.11696667	-125.3338333	99	Log boom debris, wood chips, mud (Ward and Sullivan 1980)	Historical
71	Kelsey Bay, Johnstone Strait	50.41666667	-125.95	36	2 610 645 m^3 of mud, sediment, and log storage debris dumped in 1950's and 1960's (Ward and Sullivan 1980)	Historical
72	Beaver Cove, Johnstone Strait	50.5525	-127.8508	153	Used for dumping wood waste, bark, and other debris (Ward and Sullivan 1980)	Historical
73	Port McNeill, Johnstone Strait	50.58413333	-127.0358333	40	Used for dredged sediment, rock, and wood wastes (Ward and Sullivan 1980)	Historical
74	Alert Bay, Johnstone Strait	50.56676667	-126.9002	36	30 500 m^3 from Alert Bay harbour dumped in 1970; this site has been replaced by dumpsites at Hanson Island and Hickey Point(Ward and Sullivan 1980)	Historical
77	Kains Island	50.4507	-128.1170667	91	110 000 m^3 of spend sulphite liquor dumped in 1976 (Ward and Sullivan 1980)	Historical
78	Quatsino Sound	50.46716667	-127.8333333	99	Used for dumping wood wastes (Ward and Sullivan 1980)	Historical

SITE NUMBER	SITE NAME	LOCATION dd lat	dd long	DEPTH (m)	USE/DUMPED MATERIAL	STATUS
80	Holberg Inlet	50.58333333	-127.5833333	73	Used for dumping sand, gravel, and wood wastes (Ward and Sullivan 1980)	Historical
81	Holberg Inlet	50.63403333	-127.9833333	55	Used for dumping wood wastes (Ward and Sullivan 1980)	Historical
91	Ocean Falls, Cousins Inlet	50.3501	-127.7007	55	Used by the Ocean Falls Corporation to dispose of fibre, silt, wood wastes in the 1970's (Ward and Sullivan 1980)	Historical
178	Maud Island	50.13333333	-125.2413333	32	2 400 tonnes dumped in 1996 (Schnider and Sullivan 1996), was used for disposal of a vessel as a SCUBA diving attraction and has seen no disposal activities since	Historical